Unbottled Drinking Water

Quality Standards in the Kingdom of Saudi Arabia

In partnership with Metyis

الهيئة السعودية للمياه
Saudi Water Authority

Table of contents

Executive
Summary

The “Unbottled Drinking Water Quality Standards” report outlines the current state and challenges of water quality management in Saudi Arabia. It aligns with international benchmarks and Saudi Vision 2030, emphasizing the strategic importance of sustainable and high-quality water resources for public health and environmental protection.

The report identifies a number of major challenges that have an impact on the water quality, including industrial and agricultural pollution, municipal waste, and the effects of climate change. Each of these factors contributes to the complexity of managing water resources in a manner that ensures accessibility and sustainability for all residents.

Safe drinking water plays an important role in sustaining life and promoting public health, highlighting the necessity of accessible, safe water for all. The strategic importance of water quality in KSA within the context of Vision 2030 and the National Water Strategy 2030 is examined, emphasizing sustainability, efficiency, and high-quality service delivery.

Water quality’s impact on public health involves the role of consumers in maintaining water quality and the effects of industrial, agricultural, and municipal activities on water pollution. The significance of consumer behavior, proper handling, and storage practices in ensuring safe drinking water is crucial.

The Ministry of Environment, Water, and Agriculture (MEWA) and the Saudi Water Authority (SWA) in responsibility for developing and implementing drinking water rules and guidelines in order to maintain the highest standards integrated with the water entities across the value chain, and protect the environment and public health. Therefore, the Kingdom of Saudi Arabia (KSA) follows the World Health Organization’s (WHO) guidelines for drinking water quality.

It is obvious that careful water management is required at every level, and it is essential to define best practices for monitoring and maintaining water quality to ensure safe consumption. Important global water quality issues, such industrial pollution and climate change, require future directions for international standards to be presented, with a focus on the importance of human development in effective monitoring and management of water quality.

Important conclusions and suggestions emphasize the need for strong national frameworks and standards, proactive consumer involvement, and an integrated strategy to managing water quality. In order to effectively address the complex problems of water quality, advanced technology, sustained financing, and global collaboration are essential.

01

INTRODUCTION

Overview of Unbottled Drinking Water Quality: Challenges and Concerns

Water is crucial for sustaining life, and everyone should have access to a safe and adequate water supply. Access to safe water is a fundamental right and is essential for public health. International policymakers and experts have continuously highlighted the importance of water, sanitation, and hygiene for the health risk and development of modern societies (WHO, 2022).

Improving access to safe drinking water has a significant impact on people's health. Every effort should be made to ensure that drinking water meets safe standards. While access to safe drinking water is essential for human activity, pollution and associated costs can also be detrimental. Contaminated water contains harmful bacteria, viruses, and parasites, leading to respiratory issues, gastrointestinal infections, and skin conditions. Exposure to water pollutants such as chemicals and heavy metals can result in neurological damage, cancer, and reproductive problems. Communities with contaminated water sources face heightened health risks (Yadav, 2024).

01
Overview of Unbottled Drinking Water Quality: Challenges and Concerns

The global focus has largely been on water quantity, water-use efficiency, and allocation concerns. However, the poor management of wastewater and agricultural drainage has led to significant water quality issues in many areas, exacerbating the water crisis. This is a critical issue because water scarcity is not only due to the physical lack of the resource but also to the progressive deterioration of water quality, reducing the amount of safe water available for consumption (Mateo-Sagasta et al., 2018).

To address these water quality issues, it is crucial for the global community, including both public and private sectors, to come together to safeguard and enhance the quality of water resources. This demands a stronger commitment to prevent water pollution in the future through effective treatment and restoration of contaminated waters, as well as the protection of the health of our rivers, lakes, aquifers, wetlands, and estuaries. Through the adoption of sustainable practices, we can ensure that these crucial ecosystems can meet the diverse needs of both humans and the environment (Souza & Souza, 2019). According to the UNICEF and the WHO, through their Joint Monitoring Program (2023), 142 countries had estimates for safely managed drinking water (Figure 1).

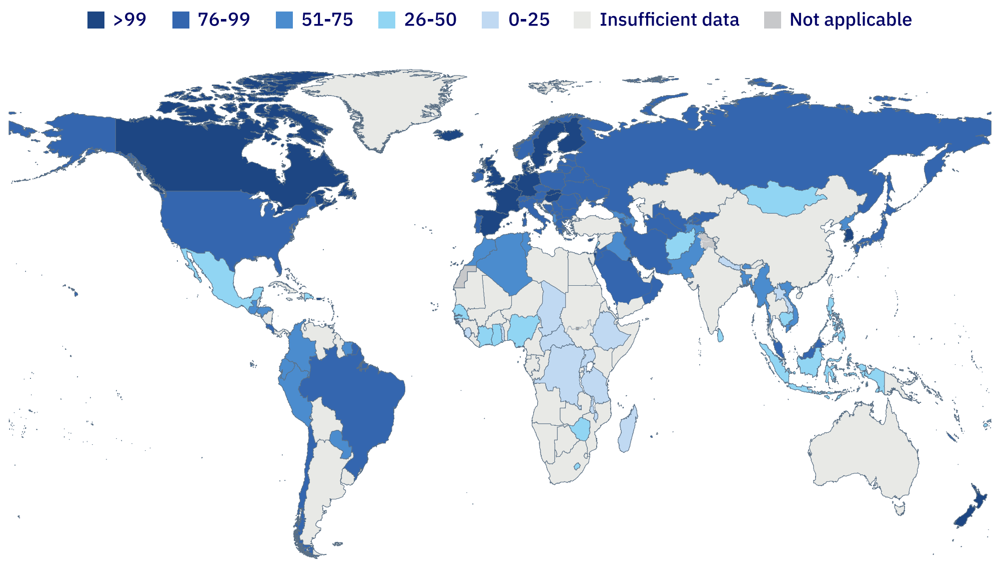

Figure 1. The proportion of the population using safely managed drinking water services, 2022 (%). Source: UNICEF & WHO, 2023.

01
Overview of Unbottled Drinking Water Quality: Challenges and Concerns

1.5 billion
With only basic services

292 million
With limited services

296 million
Using unimproved sources

115 million
Relying on surface water

Since 2015, global coverage of safely managed drinking water has improved from 69% to 73%. In rural areas, coverage has increased from 56% to 62%, and in urban areas, it has gone up from 80% to 81%. As of 2022, 32 countries were on track to achieve universal access by 2030. However, 78 countries were lagging behind, and 16 saw a decline. Despite progress, 2.2 billion people still lack safely managed drinking water. This includes 1.5 billion with only basic services, 292 million with limited services, 296 million using unimproved sources, and 115 million relying on surface water (UNICEF & WHO, 2023).

International Water Quality Standards: Human Health and Environmental Protection

Access to clean water is identified as a fundamental human right by the United Nations. This right allows everyone to sufficient, safe, acceptable, physically accessible, and affordable water for individual and domestic use. The importance of clean water in ensuring human health, dignity, and well-being is underscored by this recognition (UN-Water, n.d.).

To ensure the safety of drinking water, it is essential to establish a comprehensive framework for safe drinking water standards. This framework must be evidence-based and adopt a proactive, risk-informed approach to regulating water quality. It should include measurable health-based objectives set by a recognized health authority and requires reliable and well-managed systems, including robust infrastructure, ongoing monitoring, and effective planning and management processes (WHO, 2022).

01
International Water Quality Standards: Human Health and Environmental Protection

Guidelines specify the minimum requirements for high-quality drinking water, both aesthetically and in terms of public health. Water suppliers should use a preventive risk management approach, as outlined in the Guidelines, to ensure that water is supplied at the highest possible standard. The guideline values should never be interpreted as permission to reduce the quality of a drinking water supply to that level (NHMRC, 2011).

Furthermore, international guidelines are best implemented through an integrated preventive management framework for safety that extends from catchment to consumer. These guidelines provide a scientific basis for national authorities to develop appropriate drinking water regulations and standards. When creating standards and regulations, it is important to ensure that resources are used efficiently and focus on substances that are significant for public health. Following these guidelines should lead to easily enforceable national standards and regulations that protect public health (WHO, 2022). Moreover, KSA's standards are based on the parameters set by the WHO, although an even more stringent internal set of standards for produced water quality has been implemented, aimed at ensuring reliability and efficiency. This comprehensive monitoring program encompasses a wide range of variables, which are meticulously tracked to maintain and enhance water quality across the Kingdom (Al-Hamzah & Fellows, 2024).

International guidelines and frameworks are crucial for water management as they provide a comprehensive framework for ensuring environmental and human health safety. Governments and water providers can use these guidelines to control water quality and prevent waterborne diseases. Additionally, water utilities can efficiently manage drinking water quality and prevent waterborne diseases by taking a proactive, risk-informed approach and using evidence-based guidelines. Maintaining public trust in the water supply system depends on the continues improvements in the water supply infrastructure and the high quality of water services.

02 REPORT’S OBJECTIVES

The objective of this report is to present a comprehensive examination of the guidelines for the unbottled drinking water quality of the Kingdom of Saudi Arabia. These guidelines will align with the international standards and the strategic goals outlined in the KSA Vision 2030. The report seeks to assess the current state of water quality management in KSA, including the effectiveness of existing water management practices and regulatory frameworks.

The report will address the implementation of sustainable practices and improved management of industrial, urban, and agricultural activities. Specifically, it will address the impact of fertilizers and pesticides on contamination and groundwater quality. Additionally, the report will outline the necessity for climate resilience strategies in water resource management to mitigate the impacts of climate change on water quality and availability.

Moreover, the report aims to provide practical recommendations for enhancing water quality management in KSA, addressing global challenges related to water quality, such as pollution, climate change, and urbanization. It will emphasize the importance of enhancing monitoring systems using advanced technologies and introducing stricter regulations and advanced treatment technologies to reduce pollutants from human sources.

Ultimately, this report aims to contribute to the broader discussion on water quality management by offering insights and strategies that can be applied not only in KSA but also in other regions facing similar challenges. Through promoting best practices and encouraging international cooperation, the report strives to support the global effort to ensure safe and reliable water supply for all.

03

STRATEGIC IMPORTANCE OF WATER QUALITY IN KSA AND ALIGNMENT WITH THE VISION 2030

Under the visionary leadership of King Salman bin Abdulaziz and Crown Prince Mohammed bin Salman, the Kingdom of Saudi Arabia has placed a significant emphasis on revolutionizing its water sector. This initiative is a core component of the Saudi Vision 2030, which aims to improve the sustainability and efficiency of water resources.

Established in 2024, the Saudi Water Authority (SWA) plays a pivotal role in this transformation, overseeing the regulation and monitoring of water sector businesses and services to ensure they align with national goals. The strategic focus until 2030 is to optimize water use through increased efficiency, reduced waste, and the promotion of sustainable practices.

In sync with the National Water Strategy 2030, this approach not only supports Saudi Arabia's long-term environmental and economic objectives but also parallels global efforts to tackle climate change—a critical concern for arid regions. By adopting such forward-thinking policies, the Kingdom not only aims to safeguard its own water resources but also sets a benchmark for global water management standards. This strategic direction reflects a broader commitment to sustainable development and environmental stewardship, ensuring a prosperous future for the nation and its people.

National Water Strategy 2030 and the Vision 2030

The National Water Strategy 2030 aims to establish a sustainable water sector that effectively manages water resources, ensures a safe water supply, and provides high-quality and efficient services to support economic and social development. In Saudi Arabia, the water sector framework is designed to align with Vision 2030 objectives and focuses on five strategic goals to ensure the sustainable management of water resources (MEWA, 2018):

03
National Water Strategy 2030 and the Vision 2030

01 Ensure continuous access to enough safe water in normal situations and in emergencies.

02 Improve water demand management for all uses.

03 Provide high-quality and cost-saving water services at affordable prices.

04 Conserve water resources and the local environment for the current and future interests of Saudi society.

05 Ensure the competitiveness of the water sector and its positive contribution to the national economy through effective governance, private sector participation, integration of capacities, and innovation.

The Kingdom's Commitment to Preserving the Present for Future Generations

Preserving Saudi Arabia's environment and natural resources is important for fulfilling Islamic, human, and moral obligations. To ensure a high quality of life for current and future generations, KSA is focusing on improving waste management efficiency, implementing recycling initiatives, reducing pollution, and combating desertification to protect the environment. The goal is to use water more efficiently by utilizing treated and renewable water and reducing consumption. The commitment is also to preserve and restore beaches, reserves, and islands while ensuring universal access for all (Vision 2030, n.d.).

03
The Kingdom's Commitment to Preserving the Present for Future Generations

Saudi Arabia has demonstrated its commitment to sustainability and the well-being of its residents by keeping a focus on water conservation and environmental protection. The strategic initiatives outlined in Vision 2030 and the National Water Strategy 2030 aim not only to preserve natural resources but also to drive economic growth and social development. Efforts to improve water efficiency, minimize waste, and encourage innovative water management practices are crucial steps toward securing a resilient and sustainable future. By leveraging advanced technologies and fostering public-private partnerships, Saudi Arabia seeks to establish a model of water stewardship that can serve as a global inspiration. Ultimately, the dedication to preserving water resources reflects a responsibility to future generations, ensuring a world where water is safe, plentiful, and managed sustainably.

04

GOVERNANCE IN KSA'S WATER SECTOR

The governance structure in Saudi Arabia's water sector (Figure 2) is a collaborative effort aimed at ensuring the efficient management of this vital resource. The water sector effectively manages water resources to ensure a reliable supply of clean water by leveraging the strengths and expertise of various organizations.

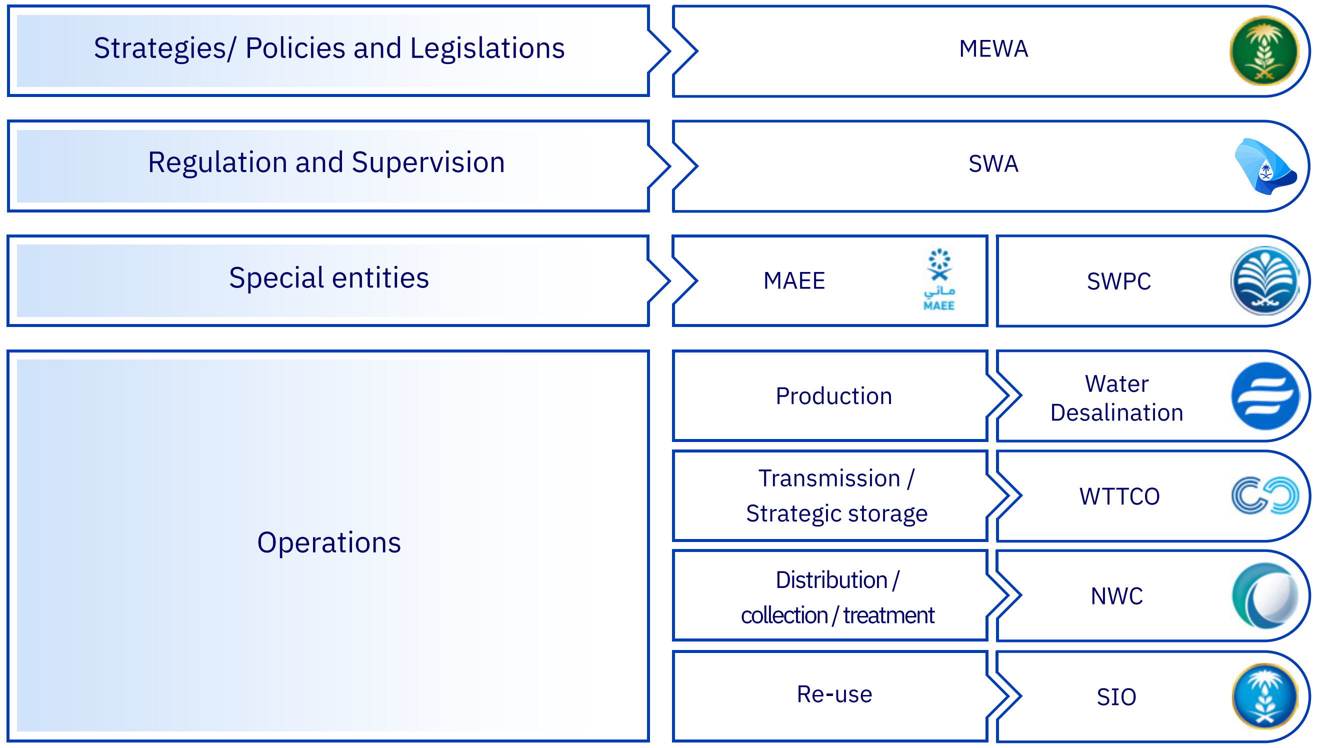

Figure 2. Water Sector Governance in KSA.

04
Governance in KSA's Water Sector

The water quality standards in the Kingdom of Saudi Arabia (KSA) are influenced by these key entities, each playing a vital role in ensuring the safety, efficiency, and sustainability of water resources, as can be seen in Table 1. These organizations collaborate to set, regulate, and enforce water quality standards, manage water production and transmission, and promote water conservation.

Entity	Impact on Water Quality Standards
Ministry of Environment Water and Agriculture	Sets legislation and specifications; oversees implementation of national policies related to water, agriculture, and environmental protection.
Saudi Water Authority	Regulates and monitors water sector businesses and services; ensures adherence to water quality standards and enhances water sustainability.
Saudi Water Partnership Company	Develops the water sector through privatization and public-private partnerships; enhances efficiency and sustainability in water projects.
Water Desalination	The primary producer of desalinated water. By using a cutting-edge desalination technology to ensure excellent water quality.
Water Transmission and Technologies Company	Manages water transmission, storage, and dispatch systems; innovates in water technology to maintain quality during transmission.
National Water Company	Provides water and sanitation services adhering to international standards; focuses on connecting consumers to water networks and conserving natural resources.
Saudi Irrigation Organization	Manages irrigation activities to prevent agricultural runoff contamination; ensures efficient use of water resources in agriculture.
National Water Efficiency and Conservation Center	Promotes water efficiency and conservation practices; provides consultancy and technical services to various sectors for sustainable water use.

Table 1. Impact of water entities on water quality standards in KSA

Legislative

A strong legislative framework is essential for effective governance in Saudi Arabia's water sector. This framework, led by the Ministry of Environment, Water, and Agriculture (MEWA), is crucial in developing and implementing policies to ensure sustainable water management and high-water quality standards. At the core of this framework is the Water Law, which establishes clear responsibilities and rigorous standards to protect general health and the environment while also aiming to achieve water and food security.

Ministry of Environment Water and Agriculture

The Ministry is leading efforts to ensure the sustainability of all the natural resources and environment in the Kingdom. MEWA is responsible for developing and implementing policies that help achieve water and food security. This comprehensive approach integrates environmental stewardship with the nation's economic and social goals, ensuring that water resources are managed in a way that supports long-term sustainability and resilience.

Water law

The Water Law in Saudi Arabia provides the framework for regulating unbottled drinking water. It reflects the government's policy that the responsibility for water quality should be managed by those best equipped to do so. The law includes several critical components for water quality requirements, such as defining who is responsible for setting water quality standards and outlining the role of the SWA. This includes overseeing the licensing requirements of water producers, transmission and distribution entities, and other licensed bodies. The law mandates rigorous standards to ensure that water supplied to the public meet's health and safety requirements, thus safeguarding public health and the environment.

04
Legislative

MEWA leads the legislative framework that ensures Saudi Arabia's water resources are managed sustainably. MEWA's policies and the Water Law create a robust system for maintaining high water quality standards. This framework not only supports environmental stewardship and public health but also aligns with the nation's economic and social goals, ensuring a resilient and sustainable future for Saudi Arabia's water resources. By clearly defining responsibilities and setting stringent water quality requirements, the Water Law ensures that the Kingdom's water supply remains safe and reliable, protecting both its people and its environment.

Regulation and Supervision

The regulation and supervision are essential components of water sector governance in Saudi Arabia. These functions are primarily carried out by the Saudi Water Authority (SWA) playing a distinct yet complementary role. The coordinated efforts ensure that the strategic objectives of Vision 2030 are met, promoting a sustainable, efficient, and reliable water supply across the Kingdom.

Saudi Water Authority

The Saudi Water Authority (SWA) plays a crucial role in regulating and monitoring the water sector in Saudi Arabia to achieve water sustainability and meet Vision 2030 goals. The Authority ensures the enforcement of regulations that guarantee safe, clean, reliable, and high-quality water supplies at competitive prices while promoting fairness among consumers. SWA's goal is to secure equitable access to water for everyone, meeting their needs and safeguarding the rights of consumers, service providers, and the public interest. SWA's key responsibilities also include developing policies, implementing integrated planning, educating the public, and promoting innovation and capability building and education.

GOVERNANCE IN KSA'S WATER SECTOR

Execution

Ensuring reliable access to clean water in Saudi Arabia is crucial. This requires coordinated efforts from different institutions, each with a specific role in managing, operating, and innovating within the water supply chain. These organizations work together to achieve the strategic objectives of Vision 2030 and the National Water Strategy, thereby promoting sustainable water management and conservation.

Water Desalination (formerly SWCC)

SWA, through its operational arm, is responsible of desalinating most of the seawater in the Kingdom. It plays a critical role in addressing water scarcity issues by converting seawater into drinkable water, providing a vital resource to millions of residents, and contributing to the nation's water security.

Water Transmission and Technologies Company (WTTCO)

The Water Transmission and Technologies Company is tasked with managing, operating, and maintaining water transmission, storage, and dispatch systems across the Kingdom. In addition to these core functions, WTTCO leads innovation in water technology and research to ensure efficient and reliable transmission systems. The company serves various industries to meet the diverse water needs of the Kingdom through advanced technological solutions.

The National Water Company (NWC)

The NWC is authorized to provide water and sanitation services in accordance with international standards. NWC's dedicated efforts aim to connect all customers to the water and sanitation network. The company's mission includes conserving natural water resources, protecting the environment, and aligning its operations with sustainable practices and the nation's broader environmental goals.

04
Execution

Saudi Irrigation Organization (SIO)

The SIO is responsible for managing irrigation activities across the Kingdom. SIO operates and develops irrigation systems to efficiently meet agricultural water needs. The organization also handles the transfer and implementation of all irrigation-related tasks, supporting the agricultural sector and contributing to food security.

Specialized Entities

In order to ensure the efficiency and protection across the water supply chain, securing accountable and sustainable use of water resources, and the competency of the entities to work on the basis of commercial visibility the water sector has specialized entities which play crucial roles.

The National Water Efficiency and Conservation Center (MAEE)

The National Water Efficiency and Conservation Center plays a crucial role in achieving the objectives outlined in Saudi Vision 2030 and the National Water Strategy. MAEE focuses on water sustainability by providing consultancy and technical services to urban, agricultural, and industrial sectors. The center proposes initiatives to enhance efficiency and conservation across the water supply chain, ensuring responsible and sustainable use of water resources.

04
Specialized Entities

Water management strategies in Saudi Arabia are carried out by a network of specialized institutions, each contributing to the overall goal of sustainable water management and high-quality standards. These organizations, from water desalination, transmission and distribution to irrigation and conservation, play critical roles in efficiently and sustainably managing the Kingdom's water resources. By leveraging advanced technologies, adhering to international standards, and prioritizing innovation, these institutions collectively ensure the reliable supply of clean drinkable water, supporting both the population and the environment in line with Vision 2030 and the National Water Strategy.

Saudi Water Partnership Company

The SWPC is a government-owned entity responsible for developing the water sector in Saudi Arabia. SWPC plays a crucial role in implementing privatization and public-private partnership (PPP) initiatives within the country's water and wastewater projects. The company aims to enhance efficiency, promote sustainability, and increase private sector participation in the water industry. By fostering collaborations between the public and private sectors, SWPC seeks to drive innovation, improve service delivery, and ensure the long-term sustainability of water resources.

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UNBOTTLED DRINKING WATER QUALITY AND POLLUTION: A CRITICAL COMPONENT OF PUBLIC HEALTH

Water Quality and the Consumer

Water quality is important for public health because it impacts both residential and commercial usage, as well as public utilities like tree planting and public parks. Clean water is necessary for human existence and is used for drinking, cooking, and hygiene. Maintaining high standards of water quality is mandatory for community, and the stability of the economy.

Water used in households for drinking, food preparation, and hygiene is vital for human survival. Without water, life cannot last more than a few days (WHO, 2020). Vulnerable populations, such as children under 5 years of age and adults over 50 years of age, are particularly affected by environmental factors like poor water quality and inadequate sanitation (Prüss-Üstün et al., 2016). Water consumption and hygiene have direct health consequences related to physiological needs and the control of various infectious and non-infectious diseases. Productive water use also significantly impacts human health by supporting livelihoods and preventing poverty (WHO, 2020).

However, as industrialized society has expanded, the environment has deteriorated, leading to increased water pollution incidents. More and more drinking water sources have become contaminated, posing significant health threats to the population. This issue is particularly severe in rural areas, where drinking water safety is often compromised due to inadequate disinfection and treatment facilities (Tian et al., 2019).

Natural water is not entirely pure, as its chemical and physical properties continuously change when it interacts with the environment. Some of these changes can be beneficial, like water purification as it seeps into aquifers or the absorption of minerals that enhance its taste and value. However, other changes can result in water that, though safe to drink, may not meet consumer standards due to aesthetic concerns such as taste, smell, or color (UNICEF, 2008). Water can also become unsafe for human consumption due to contamination by naturally occurring chemicals like arsenic or pollution from human activities like pesticides (UNICEF, 2008).

Ensuring high-quality drinking water is critical for public health and requires addressing both the aesthetic and safety aspects to meet consumer standards and health requirements. Effective water quality management, especially in rural areas, is essential to safeguard health, support livelihoods, and prevent poverty. As industrialization and environmental changes continue to impact water sources, comprehensive measures must be taken to protect and improve drinking water quality for all populations.

Water Pollution: Industrial, Agricultural, and Municipal Activities

Water pollution has become a major concern for human health and the environment, with several factors contributing to its increasing prevalence. Industrial activities, agricultural runoff, and municipal waste have all become more significant as societies expand, and populations grow.

Industrial Activities

During the Industrial Revolution, technological advancements rapidly transformed the production and consumption of goods. As industries scaled up and manufacturing processes became more complex, environmental concerns began to arise. Before this era, small-scale industries primarily released smoke into the environment, but their limited number and operating hours kept pollution levels relatively low (Jahan & Singh, 2023).

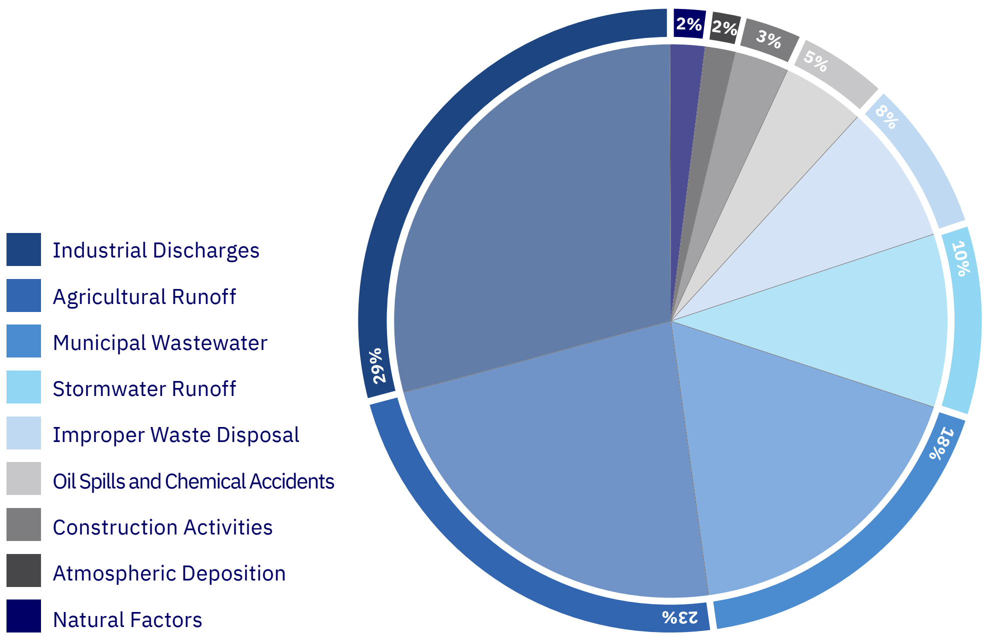

Figure 3: Factors causing water pollution. Source: Nallakaruppan et al., 2024

05
Industrial Activities

According to Nallakaruppan et al. (2024) and as seen in Figure 3, industrial discharge is the leading factor causing water pollution at a staggering 29% in smart cities around the globe. The addressing of these factors is crucial for protecting public health and ecosystems, ensuring sustainable development, and creating public awareness for pollution prevention (Nallakaruppan et al., 2024).

Furthermore, industrial operations are identified as sources of pollutants that can enter stormwater in two ways: by pollutant emissions into the atmosphere and subsequent wet and dry atmospheric deposition, or through direct surface runoff from industrial land. The contributions of industrial pollutants to stormwater are determined by the types of industrial operations, and these contributions will change as market needs and new technology for both industrial production and pollution control emerge (Müller et al., 2020).

Similarly, other pollutants that harm human health through, for example, air pollution can also contaminate waterways, adversely affecting aquatic ecosystems and, ultimately, human consumption. In this sense, the recent WHO air quality update shows that air pollution poses health risks at lower concentrations than previously thought. These guidelines include evidence-based recommendations for limiting values of various air pollutants, highlighting the need for stricter air quality standards to protect public health. Moreover, reducing important air pollutants will also help reduce climate change having a multilayered benefit. Therefore, industrial pollutants responsible for poisoning air, are also responsible for contaminating waterways and must be reduced to improve water quality. In Table 2, it is noted that the new limits for annual mean levels have been set for certain pollutants. These pollutants include Particulate Matter 2.5 (PM2.5), which now has a guideline value that is half of the previous one, PM10, which has undergone a 25% decrease, and nitrogen dioxide (NO_2), which now has a guideline that is four times lower than the previous one (WHO, 2022).

05
Industrial Activities

Pollutant	Interim target				AQG (2021)	AQG (2005)
	1	2	3	4		
$PM_{2.5}$	35	25	15	10	5	10
PM_{10}	70	50	30	20	15	20
NO_2	40	30	20		25	40

Table 2: WHO's air quality guidelines. Source: WHO, 2022

The changes in the permissible limits in these guidelines underscore the ongoing enhancement of standards that affect consumer health. The impact of industrial activities on water pollution is profound and multifaceted, necessitating comprehensive strategies to mitigate their effects. By understanding the sources and pathways of industrial pollutants, and implementing stringent regulations and innovative technologies, it is possible to significantly reduce water pollution caused by industrial activities. This will not only protect human health and ecosystems but also support sustainable development and climate change mitigation efforts.

Agricultural Runoff

Agricultural runoff poses a significant threat to groundwater quality in Saudi Arabia, given that the biggest consumer of groundwater irrigation, as it can be seen in Figure 4

05
Agricultural Runoff

Sectors	Year										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Municipal	2284	2423	2527	2731	2874	3025	3129	3150	3392	3493	3629
Industrial	753	800	843	890	930	977	1015	1000	1400	1400	1680
Agricultural	14,410	15,970	17,514	18,639	19,612	20,831	19,789	19,200	21,200	10,500	8500

Figure 4. Water consumption by sector in KSA in million m^3. Source: Pradipta et al., 2024

Agricultural activities can significantly impact water quality due to their scale, soil-disturbing nature, and the resulting consequences from silt, fertilizers (Figure 5), pesticides, and herbicides. The National Water Quality Assessment indicates that agricultural runoff is the leading cause of water quality issues in rivers and streams, the third major source for lakes, and the second largest source of impairments in wetlands. The effects of runoff vary widely based on the type of agricultural operation, landscape conditions, soils, climate, and farming practices. Elevated levels of nitrogen and phosphorus from fertilizers and manure can lead to algal blooms in lakes and rivers, creating hypoxic (low oxygen) conditions that endanger aquatic life (EPA, 2023).

05
Agricultural Runoff

Agriculture is the largest consumer of water resources, and both contribute to and suffer from water pollution. Being the predominant user of freshwater, agriculture impacts surface and groundwater quality through the release of chemical and organic pollutants. These pollutants adversely affect human health, biodiversity, and marine ecosystems, underscoring the critical need for sustainable agricultural practices (Drechsel et al., 2023). Studies evaluating groundwater quality in agricultural regions of Saudi Arabia have brought attention to several important issues (Ali & Negm, 2024). Research showed that the groundwater close to agricultural fields had been affected by human activity, leading to changes in the main bacterial groups present in the groundwater microbial communities. Furthermore, the majority of groundwater samples had total nitrogen concentrations that exceeded the safe limit of 15 mg/L for agricultural irrigation. As a result, it was concluded that the groundwater quality in Western Saudi Arabia was suboptimal. The findings suggest that improved agricultural management practices and groundwater treatment methods are necessary.

Furthermore, algal blooms can impact recreational activities in local streams, reservoirs, and estuaries. Excessive sedimentation caused by erosion can overwhelm aquatic ecosystems, suffocate breeding areas, and degrade coastal and marine ecosystems, including coral reefs. Bacteria and nutrients in livestock and poultry manure can lead to the closure of beaches and shellfish beds, as well as contaminate drinking water sources. Pesticide runoff into streams can harm aquatic life, fish-eating wildlife, and drinking water supplies (EPA, 2023).

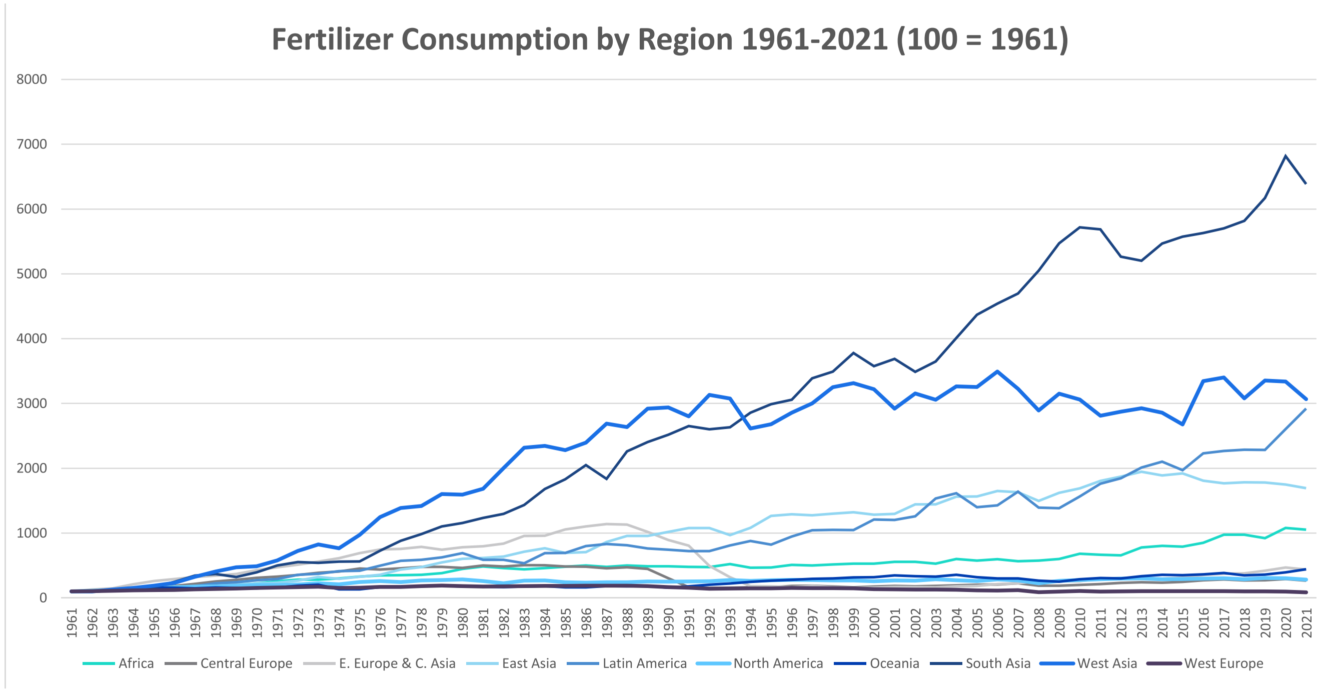

Figure 5: Fertilizer Consumption by Region, 2021–1961 Source: FASTAT, 2021

05
Agricultural Runoff

In 2021, global fertilizer usage surpassed 190 million metric tons, nearly six times the amount used 55 years ago. Developing countries have seen a 34-fold increase in fertilizer consumption, corresponding to the intensification of agriculture and significant growth in crop output observed during this period. For instance, global cereal output has more than tripled over the years. The use of nitrogenous fertilizer is associated with local air pollution, contributing to fine particulate matter and ground-level ozone, both of which can lead to cardiovascular and respiratory diseases. Fertilizer, in particular, ranks second only to cattle in terms of emitted ammonia, a type of nitrogen that significantly contributes to particulate matter formation.

05
Agricultural Runoff

Moreover, fertilizer application leads to a substantial increase in soil emissions of nitrous oxide, a greenhouse gas 300 times more harmful than carbon dioxide, thereby contributing to global climate change. When considering its energy-intensive manufacturing process, fertilizer's carbon footprint becomes even larger (World Bank, n.d). Another important fertilizer, nitrate, has the potential to pollute drinking water, whether through deep drainage or surface runoff into both groundwater and surface water. The concentration of nitrates in drinking water should not surpass 50 mg/L. To address this problem, it is essential to carefully manage the application of fertilizers, taking into account a comprehensive analysis of both plant and soil conditions to prevent the leaching of nitrates into freshwater systems (Ali & Negm, 2024).

Agricultural runoff is a primary source of water pollution, impacting various ecosystems and human health. Effective management strategies are crucial to minimize the adverse impact of agricultural activities on water quality. This involves adopting sustainable farming practices, improving fertilizer use efficiency, implementing buffer zones to intercept runoff, and enhancing wastewater treatment processes. Addressing agricultural runoff necessitates coordinated efforts from policymakers, farmers, and communities to safeguard water resources and ensure a sustainable future.

UNBOTTLED DRINKING WATER QUALITY AND POLLUTION: A CRITICAL COMPONENT OF PUBLIC HEALTH

Municipal Waste

Municipal waste, while constituting only about 10% of all trash produced, often accounts for more than one-third of public sector funding efforts aimed at reducing and managing pollution. The primary concerns related to municipal waste include the potential impact on public health and the environment, such as soil and water contamination, air quality degradation, climate impacts, land use changes, and landscape alterations (OECD, 2015).

Proper municipal waste management is essential for the well-being of urban infrastructure and the environment. Improper waste management can lead to significant environmental and health hazards. Contaminated water sources, polluted air, and degraded soil quality are just some of the adverse effects of inadequate waste disposal practices. These impacts can lead to serious health issues such as respiratory problems, infectious diseases, and increased cancer risks due to exposure to hazardous substances. As illustrated in Figure 6, it is projected that the world will produce 2.59 billion tonnes of waste annually by 2030 and 3.40 billion tonnes by 2050, representing a 31% increase in just 20 years.

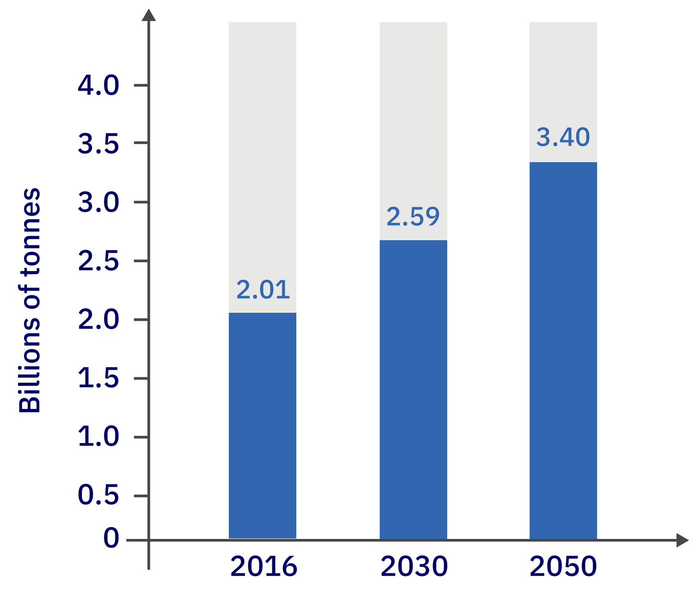

Figure 6 : Projected waste generation. Source: Kaza et al., 2018

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Municipal Waste

The world's rapid growth presents major environmental and social challenges. These include climate change, pollution, overburdened waste management systems, and rising economic costs. Recent data from 2021 (Figure 7) shows differences in waste generation across regions, with Asia and Europe being responsible for the majority of waste produced. This rapid growth poses significant environmental and social challenges, including climate change, pollution, overburdened waste management infrastructure, and escalating economic costs.

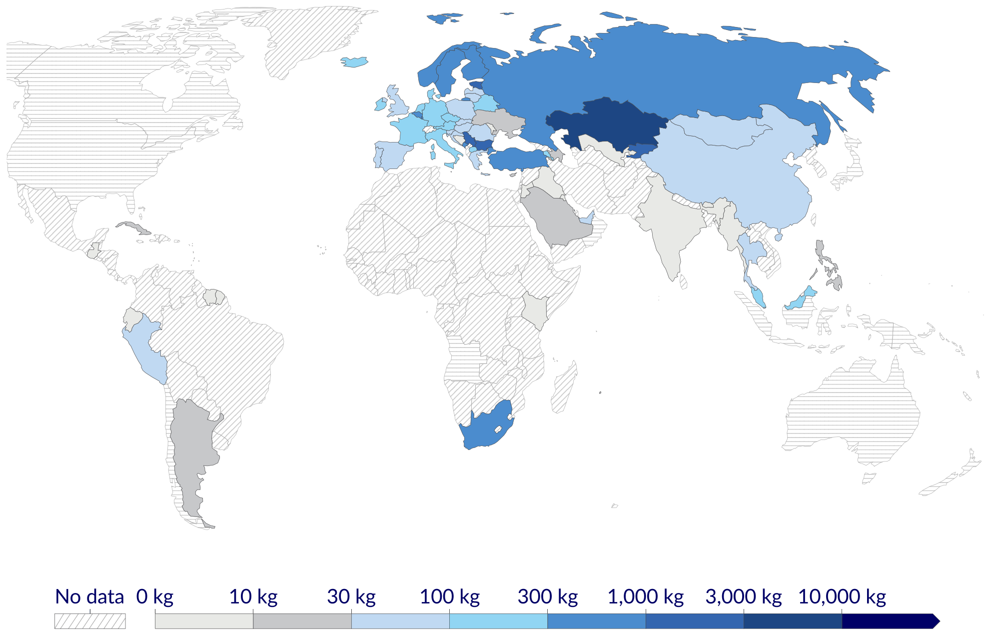

Figure 7: Hazardous waste generated per capita in 2021, Source: (Our world in data, 2023)

Managing municipal waste effectively is crucial for protecting human health and the environment. As global waste generation continues to increase, it's important to adopt sustainable waste management practices. By reducing waste generation, promoting recycling and upcycling, and ensuring proper disposal methods, we can tackle the environmental and social challenges posed by municipal waste. Collaborative efforts from governments, industries, and communities are essential to create a sustainable future and mitigate the impacts of waste on our planet.

UNBOTTLED DRINKING WATER QUALITY AND POLLUTION: A CRITICAL COMPONENT OF PUBLIC HEALTH

Climate Change and Water Scarcity

Climate change, caused by human activities such as the use of fossil fuels, deforestation, and industrial processes, is causing significant and long-term changes in global climate patterns. This has a broad impact on many aspects of our lives, including rising temperatures, sea levels, and extreme weather events. (Rawat et al., 2024).

Saudi Arabia, along with its neighboring countries, is extremely vulnerable to the repercussions of climate change, which pose significant challenges to its environment, society, and governmental institutions. The rising temperatures are particularly concerning, with the region having already experienced heatwaves surpassing 50 degrees Celsius in 2021. Climatologists are warning that the region could see a temperature increase of 4 degrees by 2050, well exceeding the critical threshold of 1.5 degrees necessary to prevent widespread ecological collapse (Dargin, 2023).

Temperature and precipitation patterns can change dramatically, putting food security in jeopardy. Changes in ocean chemistry due to increasing CO2 levels impact marine ecosystems and fisheries, providing vital food and livelihoods for millions of people. Climate change guides to more frequent and severe natural disasters, like floods and storms, which have catastrophic consequences for human settlements and communities (Rawat et al., 2024). These events highlight the critical need for effective and sustainable water management practices to ensure everyone can access clean water (Kumar et al., 2023).

In response to the challenges posed by climate change, Saudi Arabia's Vision 2030 incorporates various programs and initiatives aimed at mitigating the negative impacts of climate change. Examples include the Green Kingdom and Green Riyadh initiatives, among others.

05
Climate Change and Water Scarcity

Climate change worsens water scarcity by altering precipitation patterns, resulting in prolonged droughts in many areas. This directly impacts the availability of freshwater resources, making it essential to invest in sustainable water treatment and conservation practices. It is essential to maintain public health and support agricultural and industrial activities that rely on water resources by ensuring access to clean water.

It is crucial to take proactive steps to reduce the impacts of climate change. This includes investing in strong infrastructure, raising awareness about the consequences of climate change, and implementing measures to reduce disaster risks. By taking these actions, we can mitigate the risks connected with natural disasters and their impact on human societies (Rawat et al., 2024). Additionally, transitioning to renewable energy sources and enhancing carbon sequestration efforts are critical in reducing greenhouse gas emissions and mitigating global warming.

in 2020, Figure 8 represents the global carbon dioxide (CO_2) emissions map in 2020, which revealed the presence of millions of kilotons of CO_2. That, as it is widely known, is a natural gas formed through photosynthesis and released as a result of activities such as fossil fuels combustion, biomass burning, changes in land use, and industrial processes. This gas is the primary human-produced greenhouse gas responsible for impacting the Earth's radiative balance. Since the industrial revolution, the use of carbon-based fuels has led to a rapid increase in atmospheric CO_2 concentrations, expediting global warming and contributing to human-induced climate change. Additionally, CO_2 contributes to ocean acidification when it dissolves in water to form carbonic acid (World Bank Open Data, 2022).

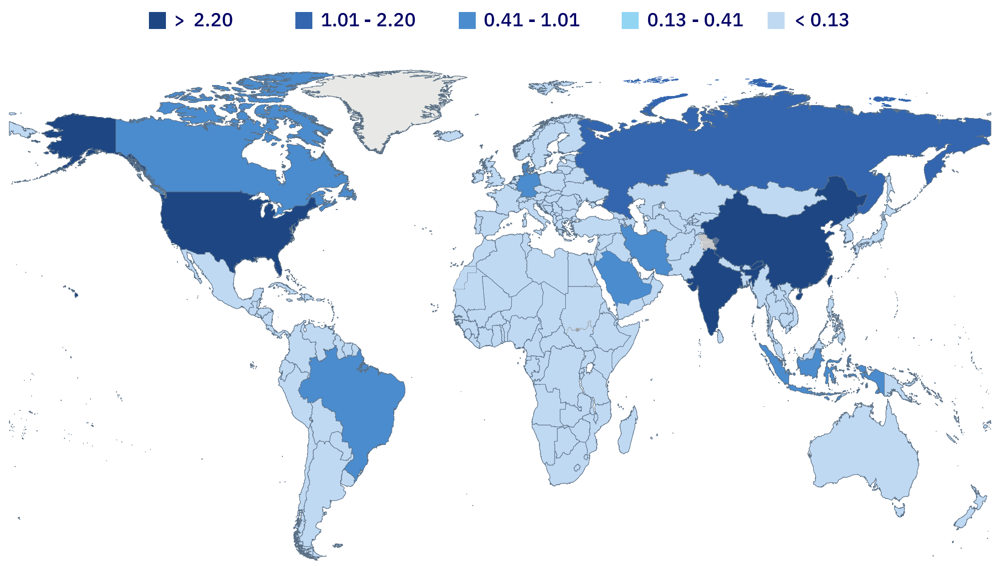

Figure 8: Climate Watch Historical CO2 emissions (kilotons) in 2020. Source: World Bank Open Data, 2022

05
Climate Change and Water Scarcity

The impact of climate change on drinking water quality and environmental health is significant and has many dimensions. It's crucial to implement effective strategies for both mitigation and adaptation to address these challenges. This includes improving infrastructure resilience, promoting sustainable water management practices, and reducing greenhouse gas emissions by adopting clean energy technologies. Taking proactive measures will help us protect water resources, preserve ecosystems, and ensure a sustainable future for generations to come.

06

STANDARDS AND GUIDELINES: A FRAMEWORK FOR QUALITY

World Health Organization (WHO) Water Quality Guidelines Values for Drinking Water

The World Health Organization’s Water Quality Guidelines for drinking water provide a comprehensive framework to ensure the safety and quality of drinking water worldwide. These guidelines are based on three essential components (WHO, 2024):

01 Developing Regulations and Standards:

These include setting health-based targets such as water quality targets that ensure the safety of drinking water.

02 Undertaking Water Safety Planning:

This involves a comprehensive and proactive risk assessment and risk management approach, covering all steps in the water supply chain from catchment to consumer.

03 Carrying Out Independent Surveillance:

Independent surveillance ensures that risk management practices are effective and that health-based targets are being met.

The WHO Guidelines are designed to help develop and implement risk management strategies that ensure the safety of drinking water supplies by controlling hazardous water constituents. These strategies may encompass standards that are set at a national or regional level based on the scientific evidence presented in the Guidelines. Consequently, the Guidelines describe reasonable minimum safe practice requirements to protect consumer health and derive numerical “guideline values” for water constituents or water quality indicators.

When establishing mandatory limits, it is preferable to take into account the guidelines within the local or national mental, social, economic, and cultural context. Moreover, the Guidelines should be part of a larger health-protection strategy that includes sanitation and other measures, such as managing food contamination. This strategy would also typically be integrated into a legislative and regulatory framework that aligns with the Guidelines (WHO, 2022).

06
World Health Organization (WHO) Water Quality Guidelines Values for Drinking Water

In developing national drinking-water standards based on these Guidelines, it is essential to consider a variety of environmental, social, cultural, economic, dietary, and other factors that influence potential exposure. Consequently, national standards may differ significantly from the Guidelines in both scope and risk targets. A program that sets modest but realistic goals—including fewer, high-priority health parameters at achievable levels—can provide a reasonable degree of public health protection by reducing disease risks within the population. This approach is often more effective than an overambitious one, especially when targets are periodically upgraded (WHO, 2022).

For the Kingdom of Saudi Arabia, creating unbottled drinking water quality standards means refers back to key international standards and global and regional bodies for example WHO and GSO, however In the absence of specific specifications in the first two references, reference was made to the guidelines and directives of other international bodies such as the World Bank, the European Union, the US Environmental Protection Agency, the Australian and New Zealand Guide to Freshwater Quality and the Canadian Water Quality Standards, especially since the World Health Organization avoids setting maximum permissible values for any of the standards that have not been proven to exist in water at concentrations higher than those that may affect human health.

06
World Health Organization (WHO) Water Quality Guidelines Values for Drinking Water

The WHO Water Quality Guidelines provide a robust framework for ensuring the safety and quality of drinking water. By incorporating scientific evidence and comprehensive risk management strategies, these guidelines help countries develop effective water quality standards tailored to their specific needs and circumstances. Implementing these guidelines within a broader health protection strategy, including sanitation and food safety measures, ensures a holistic approach to public health. Tailoring national standards to local conditions while setting realistic and achievable targets can significantly enhance public health protection and water safety.

Drinking Water Standards in the Kingdom of Saudi Arabia

Ensuring the safety and quality of drinking water in Saudi Arabia involves a comprehensive framework of regulations, standards, and monitoring, overseen by several key institutions. This framework is designed to enhance water sustainability and protect public health by ensuring that water sources and supply systems meet stringent quality standards.

The management of water quality is primarily overseen by two main entities: MEWA and SWA. The Ministry is responsible for establishing legislation and specifications concerning water sources, while the Water Authority is tasked with regulating and monitoring water sector businesses and services to improve water sustainability.

The Role of the Ministry of Environment Water and Agriculture

The MEWA is responsible for implementing national policies regarding water, agriculture, and environmental protection. MEWA sets legislation and specifications for water quality and manages water sources. This involves aligning water quality requirements with the Water Law, which provides the framework for regulating unbottled drinking water. The Water Law mandates that those best equipped to manage water quality should assume responsibility for it.

MEWA establishes water quality standards for Prescribed Concentration or Value (PCV) to ensure that water supplied to the public is safe and meets health standards. Licensees, such as entities involved in water production, transmission, and distribution, are responsible for ensuring compliance with the latest standards issued by the Ministry.

The critical values for water quality in KSA are defined and approved by the Ministry, following the current World Health Organization guidelines. Additionally, the SWA enforces a more stringent internal set of standards to ensure the reliability of the transmission system. The monitoring program includes tracking variables as detailed by Al-Hamzah & Fellows (2024):

01 Basic physical and chemical analysis:

pH, TDS, electrical conductivity, total alkalinity, residual chlorine, chloride, sodium, potassium, calcium, magnesium, bicarbonate, and sulfate.

02 Nutrients for microbial organisms:

ammonia, nitrate, nitrite, phosphate, and silica.

03 Inorganic elements:

arsenic, selenium, mercury, lead, chromium, cadmium, iron, copper, manganese, nickel, cobalt, aluminum, uranium, zinc, barium, vanadium, beryllium, molybdenum, etc.

04 Organic materials:

qualitative and quantitative estimation of organic compounds likely to be present in water.

05 Disinfection by-products:

trihalomethanes, haloaceticacids, bromate, chlorate, chlorite.

06 Biological (microbial) analysis.

07 Radioactive isotopes.

Within these variables, the Ministry sets stringent limits for various parameters to guarantee the safety and quality of drinking water in Saudi Arabia. As it can be read in Table 3, these standards cover a broad range of physical, chemical, and biological characteristics that are critical for public health.

06
The Role of the Ministry of Environment Water and Agriculture

Category	Rationale
1. Physical Parameters	Physical standards ensure that water is safe for consumption in terms of aesthetic qualities such as color, taste, and clarity. These parameters are essential for maintaining acceptable drinking water quality and include limits on impurities and other physical characteristics that affect the overall acceptability of the water.
2. Inorganic Chemical Parameters	Inorganic chemical standards specify the maximum allowable concentrations of various inorganic substances, including metals and salts, in drinking water. These standards are designed to ensure that these substances do not pose a health risk to consumers. Examples include limits on substances such as nitrates and chloride.
3. Trace Elements and Heavy Metals parameters	This category lists the permissible levels of trace elements and heavy metals, such as lead, mercury, and arsenic, in drinking water. These standards are crucial for preventing toxic exposure and protecting public health, particularly in vulnerable populations.
4. Organic and Hydrocarbon Miscellaneous organic parameters (industrial chemicals, pesticides and herbicides)	Various organic standards include limits for industrial chemicals, pesticides, and herbicides. These standards ensure that the levels of these organic compounds in water are safe for consumption, protecting consumers from potential health risks associated with chemical contamination.
5. Various organic and hydrocarbon compounds parameters	This category specifies the limits for various organic compounds and hydrocarbons. By regulating these substances, the standards help prevent contamination that could negatively impact health, including compounds such as benzene, toluene, and xylene.
6. Chemicals resulting from water purification processes and by-products parameters	These standards list the acceptable levels of chemicals and by-products resulting from water treatment and disinfection processes. This includes substances and disinfection by-products ensuring they remain within safe limits.
7. Radioactive Parameters	Radioactive standards set the limits for radioactive substances in drinking water. These standards ensure that radiation levels remain below harmful thresholds, protecting consumers from potential radiation exposure.
8. Radionuclides Parameters	This category outlines the allowable concentrations of specific radioactive isotopes, ensuring that drinking water is free from harmful levels of radiation. This is crucial for protecting public health from the long-term effects of radiation exposure.
9. Microbial parameters	Microbial standards specify acceptable levels of microorganisms in drinking water. These standards ensure that the water does not contain harmful bacteria, viruses, and other pathogens, thus preventing waterborne diseases and safeguarding public health.

Table 3. Unbottled Drinking Water Quality Parameters. Source: MEWA, 2024

06
The Role of the Ministry of Environment Water and Agriculture

Monitoring and preserving ideal water quality parameters are crucial for safeguarding human health and protecting assets. Corrosion can cause harm to pipes, equipment, and result in the release of harmful substances into the water supply, posing a threat to public health. To prevent corrosion, water utilities should regularly monitor key parameters such as pH levels, total dissolved solids (TDS), chloride levels. By doing so, they can ensure the integrity of their assets, protect public health, and provide a safe and reliable supply of water.

For these parameters and standards to be effective, they must be accompanied by limits and thresholds that benefit human health. These limits ensure that the unbottled drinking water quality in KSA is of an excellent standard, often surpassing European or American criteria. Due to this, in some cases, KSA's water quality outperforms its Western counterparts (Al-Hamzah & Fellows, 2024). Appendix A provides the latest parameters and standards authorized by the Ministry.

The Saudi Water Authority Role

The Saudi Water Authority is responsible for regulating and monitoring water sector businesses and services to enhance water sustainability. The regulatory functions of SWA include ensuring that water sector entities comply with national standards and regulations, thereby maintaining the quality and sustainability of water resources.

The regulatory functions play a critical role in enforcing adherence to the water quality standards defined by MEWA. This includes overseeing the licensing requirements of water producers, transmission and distribution entities, and other licensed bodies. The Saudi Water Authority ensures that all entities involved in the water supply chain meet the standards set for producing, transmitting, storing, distributing, and sewage water.

06
The Saudi Water Authority Role

Saudi Water Authority responsibilities Around Water Quality:

01 Supply of Wholesome Water:

Ensuring that all water supplied to consumers is safe and meets established health standards.

02 Relaxation of Requirements:

Providing provisions for any additional requirements necessary to ensure the provision of wholesome drinking water to consumers.

03 Monitoring of Water Supplies:

Conducting regular monitoring to ensure ongoing compliance with water quality standards.

04 Records and Information:

Maintaining comprehensive records and information related to water quality and compliance.

05 Enforcement:

Taking enforcement actions to address any non-compliance with water quality standards.

The drinking water standards in Saudi Arabia are managed by MEWA and enforced by SWA. This framework aims to guarantee the safety and quality of the nation's water supply. By establishing strict standards, conducting regular monitoring, and ensuring compliance, these organizations collaborate to protect public health and promote water sustainability. This comprehensive approach holds all parties in the water supply chain responsible for upholding high water quality standards, which ultimately ensures the delivery of safe and clean drinking water to all consumers.

07

WATER QUALITY: ACROSS THE VALUE CHAIN

The management of water is crucial at all stages of the water cycle (Figure 9), from extracting freshwater to treating, Transmission, distributing, consuming, collecting, treating wastewater, and returning it to the environment. The global increase in population, rapid urbanization, and economic development is leading to more wastewater production and increased pollution (UN, 2018).

High water quality requires careful management at every stage of the water cycle. This includes extracting freshwater, treating it, distributing it, using it, collecting it, treating wastewater, and returning it to the environment. Each stage is essential for maintaining the safety and integrity of the water supply, which is crucial for public health and the environment.

The growing global population, rapid urbanization, and economic development are significantly increasing the amount of wastewater produced and its overall pollution, according to the United Nations (2018). These factors add complexities to managing water quality throughout the entire process. Effective water management strategies need to adapt to these changes to ensure sustainable water usage and reduce environmental impacts.

Managing water quality throughout the entire process is essential for ensuring a sustainable and safe water supply. Each stage, from extraction to consumption and back to the environment, requires careful oversight and innovative solutions to address challenges brought by urbanization, population growth, and economic development. Through comprehensive water management practices, we can protect public health, conserve essential water resources, and promote environmental sustainability.

Figure 9. Unbottled Drinking Water Value Chain

Water Quality Management in Production and Transmission

Humanity has historically benefited from extracting freshwater from saltwater and other saline sources by desalination, which entails eliminating salts and minerals from the feedwater. Desalination is becoming increasingly popular in coastal places across the world as a means of obtaining drinking water and diversifying water supplies. However, water quality during manufacturing plays a crucial role. Water quality control is critical to the effective operation and optimal performance of desalination facilities. Effective water quality management in desalination requires continual monitoring, modern control systems, stringent compliance testing, and efficient byproduct disposal. This assures the generation of high-quality freshwater while increasing operating efficiency and reducing environmental impact.

07
Water Quality: Across the Value Chain

Ensuring that water stays safe and clean during its transfer from treatment facilities to end users is known as water quality management in transmission. Strict adherence to regulations, regular infrastructure maintenance, cutting-edge monitoring technologies.

Ensuring the quality of produced desalinated water and its transportation involves a meticulous monitoring program established by the Water Authority through the laboratories of its innovation branch, by implementing ISO/IEC 17025 which is the international standard for testing and calibration laboratories, ensuring their competence, impartiality, and consistent operation to maintain the accuracy and reliability of results.

The water quality monitoring program includes the following steps (internal data, 2020):

01 Collecting water samples:

Produced water samples shall be collected after treatment from the furthest point in the main line before the water is exported from the plant to the consumer.

02 Daily follow-up:

From the central laboratories to receive water samples sent from production systems (desalination plants), transportation systems, and purification stations in dams.

03 Request for chemical, physical, and biological tests and analysis:

The analysis request form for the water quality monitoring program from the desalination plants.

07
Water Quality: Across the Value Chain

04 Chemical, physical, and biological tests and analysis:

The tests and analysis are carried out in the laboratories by specialists which prepare reports on the results reviewed and approved by the Director of Laboratories.

05 Preparing the final report:

The project manager prepares a periodic reports on the water quality. moreover, the responsibility of project manager is developing the water quality monitoring program, contacts the relevant parties in the production and transmission systems to discuss the issues and find solutions.

Monitoring During Storage and Distribution

Ensuring the quality of water during storage and distribution is crucial for maintaining public health and safety. Many local authorities have comprehensive water quality monitoring programs for their source water and treatment processes. However, water quality can change once it leaves the treatment facility, so it’s essential to monitor water quality throughout the storage and distribution system and respond promptly to any changes.

The National Water Company (NWC) ensures the quality of unbottled drinking water by applying strict standards and specifications adopted by the Ministry of Environment, Water, and Agriculture. Additionally, NWC adheres to the Unbottled Drinking Water Quality Monitoring Guide. this (NWC, 2024).

07
Monitoring During Storage and Distribution

Water Quality Monitoring Methodology: the monitoring process begins with the collection of samples from various sources, followed by analysis in accredited laboratories, and finally, comparison of the results with specified standards.

01 Identifying Sampling Points:

Sampling points for unbottled drinking water are chosen based on the Unbottled Drinking Water Monitoring Guide from SWA, taking into account water source types like production facilities, intake points, and distribution networks. This process adheres to global standards such as ISO 5667.

02 Sample Collection:

Samples are collected according to annual plans prepared by the company's laboratories and submitted to SWA for approval and implementation. Samples are transported to laboratories following specific procedures and the requirements of ISO/IEC 17025:2017 to preserve their characteristics until analysis.

03 Sample Analysis:

Analyses are performed and repeated according to the requirements Guide and the standards specified in the Unbottled Drinking Water Standards and Specifications issued by MEWA, categorized based on the water source type

04 Results and Evaluation:

Analysis results are recorded and compared with the approved standards and specifications for water quality by the ministry using the LIMS system and displayed on the water quality monitoring dashboard.

WATER QUALITY: ACROSS THE VALUE CHAIN

07
Water Quality Monitoring Methodology:

05 Use of Modern Technology:

The company employs advanced technologies for water analysis, utilizing sophisticated analytical devices to ensure accurate and timely results. Geographic Information Systems (GIS) are used to visualize sampling point locations, associated information, recent sampling activities, and latest results. Additionally, all NWC laboratories are equipped with the LIMS (Laboratory Information Management System), a comprehensive global system for monitoring and quality control.

06 Internal and External Audits:

Periodic internal audits are conducted for NWC's drinking water quality monitoring laboratories to ensure continuous compliance with ISO/IEC 17025:2017 requirements. External audits are conducted on internationally recognized company laboratories, currently numbering 14 central laboratories, by the Saudi Accreditation Center to ensure compliance with ISO/IEC 17025:2017 standards and provide necessary improvements.

It is crucial to actively monitor drinking water during storage and distribution to ensure its safety and quality. Regular inspections, strict cleaning protocols, and advanced monitoring technologies are essential for maintaining water quality. By following recommended sampling frequencies and monitoring critical parameters, municipalities can effectively manage water quality, prevent contamination, and ensure that consumers receive safe and reliable water.

Consumer Awareness: Best Practices in Household Water Management

Customers are involved in every step of the water practices through collection, treatment, and storage. Their behavior can affect other people's access to clean water in addition to ensuring the safety of their own water usage. In order to preserve and enhance the quality of the water in their homes and communities, users must implement best practices.

In Saudi Arabia, consumers play a crucial role in efficiently managing household water usage. Best practices include:

- Ensuring that any leaks are promptly identified and repaired to prevent any further damage or inconvenience.
- Installing water-efficient fixtures, such as low-flow toilets, aerated faucets, and water-saving showerheads, to conserve water and reduce water utility costs.
- Practicing mindful water use, such as turning off taps while brushing teeth and using buckets instead of hoses for washing cars.

Educational campaigns like the Qatrah program, part of the National Transformation Program and Vision 2030, promote these practices by raising awareness and encouraging the public to pledge to reduce water consumption. Such efforts aim to optimize water use and contribute to the country's sustainability initiatives. Implementing these practices not only conserves water but also aligns with broader environmental and resource management strategies pivotal for the long-term objectives set by the Kingdom (Almulhim & Abubakar, 2024).

07
Consumer Responsibilities: Best Practices in Household Water Management

In many other countries, households rely on domestic sources such as private wells and rainwater for their water needs. In households with non-piped water sources, proper measures must be taken for safe collection, storage, and treatment of drinking water. The following practices are essential:

01 Qualified Installation and Maintenance:

Qualified professionals should install and maintain household plumbing systems to prevent contamination due to cross-connections or backflow. Regular inspections play a crucial role in spotting and addressing potential issues to safeguard water quality before any harm is done.

02 Safe Collection Practices:

For households that collect water from sources such as wells or rainwater, using clean containers and maintaining proper hygiene during collection can significantly reduce the risk of contamination. Containers should be covered and stored in clean environments to prevent the ingress of pollutants.

03 Regular Cleaning of Storage Containers:

Implementing regular cleaning protocols for water storage tanks and containers is crucial. Containers should be cleaned at least once a year to prevent the accumulation of bacteria and other contaminants. This practice is particularly important in developing countries where water is often stored in tanks and jerry cans due to inconsistent water supply (Manga et al., 2021).

Various factors in water supply practices can impact water quality, potentially putting residential water at risk. However, by taking proactive measures, consumers can significantly reduce water consumption, mitigate the risk of waterborne diseases, and help maintain water quality. Regular maintenance of infrastructure and awareness of potential risks are critical to ensuring the safety of household water supplies. By adopting these best practices, consumers can help in maintaining water quality.

08

Global Challenges and Future Directions: A Call to Action

Overview of global challenges related to water quality

The quality of drinking water can be affected by various human and natural activities, impacting its biological, chemical, and physical characteristics. Human activities such as agriculture, industry, mining, waste disposal, population growth, urbanization, and climate change all play a role in contaminating and degrading water resources globally.

Agriculture has a significant impact on water quality due to the use of nutrients and pesticides, which can increase water salinity and result in excessive nutrient contamination. This is a widespread issue, with over two million tons of agrochemicals being used annually, leading to water pollution on a global scale (Da Silva Antunes De Souza & De Souza, 2019).

Industrial activities release around 300-400 million tons of heavy metals, solvents, toxic sludge, and other pollutants into the world's water systems each year, further exacerbating water quality issues (Da Silva Antunes De Souza & De Souza, 2019). Additionally, natural disasters such as floods, droughts, landslides, and land subsidence cause significant deaths, economic damage, and disruption to the water supply, while climate change, land use changes, urbanization, migration patterns, energy issues, and food production elevate these risks (Mishra et al., 2021).

Drought has both physical and social implications and can profoundly impact water resources and agricultural systems. Its effects vary among communities based on their resilience levels. Drought can create tension between human usage and environmental flow requirements, putting strain on competing water uses. It can also limit water usability in various societal contexts, such as energy production. Groundwater, crucial for drinking water, agriculture, and sustainable living, has been increasingly utilized over the past 50 years, especially during droughts (Mishra et al., 2021).

To effectively address these issues, it is crucial to conduct more research, adopt innovative science-based techniques, and embrace the principles of integrated water resources management (IWRM). IWRM entails the integrated planning, development, and sustainable management of water, land, and associated resources. and to optimize economic and social well-being while ensuring the sustainability of essential ecosystems:

08
Overview of global challenges related to water quality

- **Research and Innovation:**

  Emphasize the importance of scientific research and the development of new technologies to address water quality challenges.

- **Clean Water Sources:**

  Focus on developing clean water sources and efficiently managing wastewater.

- **Sanitation Facilities:**

  Establish basic sanitation facilities as crucial steps to address the water crisis and promote sustainability and human progress (Mishra et al., 2021).

According to Moe and Rheingans (2006), four universal barriers hinder progress in water and sanitation access, regardless of country-specific conditions:

01 Inadequate Investment:

Insufficient investment in water and sanitation infrastructure limits advancements.

02 Lack of Political Will:

In some regions, there is a noticeable lack of political will to address challenging issues.

03 Conservative Approaches:

A tendency to rely on conventional water and sanitation interventions, without community involvement, even when they are inappropriate for specific environments and community needs.

04 Lack of Evaluation:

Failure to conduct evaluations of water and sanitation interventions to determine their success and sustainability.

08
Overview of global challenges related to water quality

Addressing global water quality challenges requires a multifaceted approach that integrates scientific research, innovative technologies, and comprehensive management strategies. By understanding and mitigating the impacts of human activities on water resources, and overcoming barriers to advancement, we can ensure sustainable water use and improve public health worldwide. Governments, industries, and communities must work together to enhance water quality, manage water resources efficiently, and promote sustainability.

Future Directions for International Standards

The landscape of unbottled drinking water quality is changing rapidly due to technological advancements, increased regulatory scrutiny, and growing awareness of environmental and public health issues. To ensure the continued safety and reliability of unbottled drinking water, several future directions for international standards can be identified.

The success of water quality monitoring programs depends on several factors. These factors include human capacity, funding, and technical equipment availability to monitoring agencies, with a particular focus on specific uses such as drinking water, and regions like Africa, developing countries, and tropical areas (Kirschke et al., 2020).

One of the most promising directions for future water quality standards involves the adoption of advanced treatment technologies. Membrane filtration techniques, such nanofiltration, are gaining prominence for their ability to remove a wide range of contaminants with high efficiency. Additionally, other technological innovations are being explored for their effectiveness in breaking down organic pollutants and pathogens that conventional treatment methods may miss. These technologies represent a significant leap forward in ensuring the purity and safety of drinking water.

08
Future Directions for International Standards

Human capacity is crucial for the success of unbottled drinking water quality monitoring programs. The availability of skilled personnel, trained in water quality management, ensures that monitoring is conducted effectively. This requires investment in education and training to develop a knowledgeable workforce. Adequate funding is another essential factor, as it supports the acquisition and maintenance of technical equipment, regular assessments, and the implementation of corrective actions. Without sufficient financial resources, monitoring programs cannot function effectively. Furthermore, the availability and quality of technical equipment directly impact the accuracy and reliability of water quality monitoring. Advanced monitoring technologies and infrastructure, such as Artificial Intelligence or Internet of Things (IoT) applications, are essential for timely detection and resolution of water quality issues. The integration of IoT technologies and smart sensors is revolutionizing water quality monitoring. These tools enable real-time tracking of critical water quality parameters, including turbidity, pH, and contaminant levels. Coupled with big data analytics and AI, these systems can predict potential contamination events and optimize water treatment processes proactively. The future of water quality monitoring lies in the ability to respond swiftly to emerging threats, ensuring consistent water safety.

While the technological and regulatory side is critical, water quality monitoring research often overlooks the human development context within which it occurs. Human development indicators such as economic growth, education levels, and overall societal well-being play a crucial role in determining a state's ability to provide public services, including water quality monitoring (Kirschke et al., 2020). Economic growth influences the financial resources available for monitoring freshwater resources. Countries with robust economies can invest more in comprehensive water quality monitoring systems and infrastructure. Additionally, societies with higher education levels and a strong knowledge base have a greater availability of skilled personnel for monitoring. Education and training programs focused on water quality management can significantly enhance the effectiveness of monitoring efforts.

GLOBAL CHALLENGES AND FUTURE DIRECTIONS: A CALL TO ACTION

08
Future Directions for International Standards

Integrating human development considerations into water quality monitoring involves capacity building, securing sustainable funding, and leveraging advanced technologies. Investing in capacity-building initiatives to train and educate personnel in water quality monitoring techniques and best practices is crucial for the long-term success of monitoring programs. Securing sustainable funding sources, such as government budgets, international aid, and private sector investments, supports ongoing monitoring efforts. Utilizing advanced monitoring technologies improves the accuracy and efficiency of water quality assessments, making monitoring programs more effective.

Also, as scientific research uncovers new contaminants and health risks, there is a pressing need for regulatory frameworks to evolve accordingly. Future standards will likely involve regular updates to reflect the latest scientific knowledge and address emerging contaminants of concern. Cooperation among organizations and nations to harmonize national standards with international guidelines, such as those from the World Health Organization and the U.S. Environmental Protection Agency, will ensure a consistent global approach to water quality management.

The future success of international water quality monitoring standards depends on addressing the multifaceted challenges identified through research. By focusing on human capacity, investment in innovation and technology, and integrating human development considerations, we can enhance the effectiveness of monitoring programs globally. A holistic approach that includes capacity building, sustainable funding, and the use of advanced technologies will ensure that water quality monitoring efforts are robust, reliable, and capable of addressing the complex challenges posed by global water quality issues.

09

Conclusion and Recommendations

The report has conducted a comprehensive analysis of various aspects of water quality management including international standards, national regulations, consumer engagement, and the global environmental changes. Effective drinking water quality standards require a comprehensive approach that covers the entire water cycle, from freshwater extraction to post-treatment and return to the environment. This holistic strategy ensures the sustainability and safety of water resources in addressing both current and future challenges. National frameworks, such as those implemented by the Kingdom of Saudi Arabia, are critical in ensuring water quality. The Ministry of Environment, Water, and Agriculture and related entities like the Saudi Water Authority and the Water Value chain Organizations demonstrate how coordinated efforts and stringent regulations can uphold high water standards and safeguard public health.

Consumers play a significant role in maintaining water quality through responsible behavior and best practices in household water management. Proper collection, storage, and treatment of water, along with regular cleaning of storage containers and the use of filtration systems, are essential to prevent contamination and ensure safe drinking water. Global challenges such as climate change, industrial pollution, agricultural runoff, and population growth complicate water quality management. Addressing these issues requires innovative solutions, including advanced monitoring technologies, sustainable funding, and international cooperation. Integrating human development indicators, such as education and economic growth, into water management strategies is vital for overcoming these challenges.

The future of water quality monitoring and management depends on the continuous improvement of international standards. Research highlights the significance of human capacity, technical equipment, and financial resources in successful monitoring programs. Additionally, considering the broader context of human development enhances the effectiveness and sustainability of these programs. Proactive measures, including regular inspections, public awareness campaigns, and community involvement, are crucial for maintaining water quality. Education and training programs can empower individuals and communities to adopt best practices, ensuring the long-term success of water quality initiatives.

Embracing innovative, science-based standards, techniques and principles of integrated water resources management can significantly improve water quality. Developing clean water sources, managing wastewater efficiently, and establishing basic sanitation facilities are fundamental steps toward addressing the global water crisis and promoting sustainability. Water is a fundamental resource for life, and ensuring its quality is paramount for public health, environmental sustainability, and economic development. This report underscores the complexity of water quality management and emphasizes the need for a coordinated, multi-faceted approach involving governments, industries, and individuals. By integrating advanced technologies, robust policies, and proactive community engagement, we can overcome current challenges and secure a safe and sustainable water future for all.

In light of these findings, the following recommendations have been formulated to guide future efforts of stakeholders in enhancing water quality management. These recommendations are designed to address the identified challenges and leverage the opportunities presented by innovative practices and international cooperation:

Strengthen National Frameworks: Encourage governments to develop and enforce robust national frameworks for water quality management, ensuring coordination among various agencies.

Empower and Educate Consumers: Educate the public on responsible consumer practices in household water management, including reducing consumption, proper collection, storage, and treatment techniques.

Address Global Challenges: Develop innovative solutions through technology and cooperation to tackle global challenges such as climate change, industrial pollution, and agricultural runoff.

Improve Human Capacity: Invest in education and training programs to enhance human capacity in water quality management, developing a knowledgeable workforce capable of effective monitoring and implementation.

Promote Proactive Measures: Implement regular inspections, public awareness campaigns, and community involvement initiatives to maintain water quality and encourage early detection of issues.

Leverage Advanced Technologies: Utilize advanced monitoring technologies to improve the accuracy and efficiency of water quality assessments.

Support International Cooperation: Foster international cooperation to share knowledge, resources, and best practices in water quality management.

By implementing these recommendations, stakeholders can enhance water quality management globally, ensuring a safe and sustainable water supply for future generations. This coordinated approach involves governments, industries, and individuals working together to overcome challenges and promote public health, environmental sustainability, and economic development.

List of Tables and Figures

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Appendix

Appendix A. Unbottled Drinking Water Quality Standards. Source: MEWA, 2024.

NO.	Standard	Unit	Specified Concentration or Value
1	Color	Platinum-Cobalt	Less than or equal to 15
2	Taste	-	Acceptable
3	Odor	-	Acceptable
4	Temperature	Celsius	Less than 40
5	pH	-	6.5 - 8.5
6	Turbidity	NTU	Less than or equal to 5
7	Free Chlorine	(Cl_2)	0.2 - 0.5
8	Chlorine Dioxide	(ClO_2)	0.2 - 0.7
9	Total Dissolved Solids (TDS)	mg/L	Min: 100, Max: 1000

Table (1) - Physical parameters

NO.	Standard	Chemical formula	Specified Concentration or Value
1	Ammonia	(NH_3)	0.5
2	Sodium	(Na)	200
3	Calcium Hardness	(Ca)	Greater than 30
4	Sulfates	(SO_4)	Less than or equal to 250
5	Chlorides	(Cl)	250
6	Nitrates	(NO_3)	50
7	Nitrites	(NO_2)	3.0
8	Total Hardness	(Total Hardness)	Less than 320

Table (2) - Inorganic Chemical parameters (mg/L)

NO.	Standard	Chemical formula	Specified Concentration or Value
1	Antimony (Sb)	(Sb)	0.02
2	Aluminum (Al)	(Al)	0.2
3	Barium (Ba)	(Ba)	1.3
4	Boron (B)	(B)	2.4
5	Copper (Cu)	(Cu)	2.0
6	Iron (Fe)	(Fe)	0.3
7	Lead (Pb)	(Pb)	0.01
8	Arsenic (As)	(As)	0.01
9	Zinc (Zn)	(Zn)	3.0
10	Mercury (Hg)	(Hg)	0.006
11	Cyanide (HCN)	(HCN)	0.07
12	Selenium (Se)	(Se)	0.04
13	Fluoride (F)	(F)	1.5
14	Cadmium (Cd)	(Cd)	0.003
15	Chromium (Cr)	(Cr)	0.05
16	Manganese (Mn)	(Mn)	0.4
17	Molybdenum (Mo)	(Mo)	0.07
18	Nickel (Ni)	(Ni)	0.07
19	Uranium (U)	(U)	0.03

Table (3) - Trace Elements and Heavy Metals parameters (mg/L)

NO.	Standard	Chemical formula	Specified Concentration or Value
1	Atrazine	$C_8H_{14}ClN_5$	0.1
2	Acrolein	$C_{14}H_{20}ClNO_2$	0.02
3	Aldrin and Dieldrin	$C_{12}H_8Cl_6$,$C_{12}H_8Cl_6O$	0.00003
4	Aldicarb	$C_7H_{14}N_2O_2S$	0.01
5	Epichlorohydrin	C_3H_5ClO	0.0004
6	Isoproturon	$C_{12}H_{12}N_2O$	0.009
7	Endrin	$C_{12}H_8Cl_6O$	0.0006
8	Pendimethalin	$C_{13}H_{19}N_3O_4$	0.02
9	Trifluralin	$C_{13}H_{16}F_3N_3O_4$	0.02
10	Terbuthylazine	$C_9H_{16}ClN_5$	0.007
11	Ethylenediaminetetraacetic Acid (EDTA)	$C_{10}H_{16}N_2O_8$	0.6
12	Dichloroprop / Dichloroprop-P (Dalapon)	$C_9H_8Cl_2O_3$	0.1
13	Dichlorodiphenyltrichloroethane (DDT)	$C_{14}H_9Cl_5$	0.0001
14	1,2 - Dibromo - 3 - chloropropane	$C_3H_5Br_2Cl$	0.001
15	1,2 - Dibromoethane	$C_2H_4Br_2$	0.0004
16	1,2 - Dichloropropane	$C_3H_6Cl_2$	0.04
17	2 - Methyl - 4 - chlorophenoxyacetic Acid (MCP)	$C_9H_9ClO_3$	0.002
18	1,3 - Dichloropropene	$C_3H_4Cl_2$	0.02
19	2,4 - Dichlorophenoxyacetic Acid (2,4 - D)	$C_8H_6Cl_2O_3$	0.03
20	2,4 - Dichlorophenoxybutyric Acid (2,4 - DB)	$C_{10}H_{10}Cl_2O_3$	0.09
21	2,4,5 - Trichlorophenoxyacetic Acid (2,4,5 - T)	$C_8H_5Cl_3O_3$	0.009
22	2,4,6 - Pentachlorophenol (PCP)	$C_6H_3Cl_3O$	0.2
23	Pentachlorophenol	C_6HCl_5O	0.009
24	Dimethoate	$C_5H_{12}NO_3PS_2$	0.006
25	Cyanazine	$C_9H_{13}ClN_6$	0.0006
26	Simazine	$C_7H_{12}ClN_5$	0.002
27	Fenoprop	$C_9H_7Cl_3O_3$	0.009
28	Carbofuran	$C_{12}H_{15}NO_3$	0.007
29	Chlorpyrifos	$C_9H_{11}Cl_3NO_3PS$	0.03
30	Chlorotoluron	$C_{10}H_{13}ClN_2O$	0.03
31	Chlordane	$C_{10}H_6Cl_8$	0.0002
32	Lindane	$C_6H_6Cl_6$	0.002
33	Molinate	$C_9H_{17}NOS$	0.006
34	Metolachlor	$C_{15}H_{22}ClNO_2$	0.01
35	Methoxychlor	$C_{16}H_{15}Cl_3O_2$	0.02
36	Mecoprop	$C_{10}H_{11}ClO_3$	0.01
37	Hydroxyatrazine	$C_8H_{15}N_5O$	0.2

Table (4) - Organic and Hydrocarbon Miscellaneous organic parameters (industrial chemicals, pesticides and herbicides) (mg/L)

NO.	Standard	Chemical formula	Specified Concentration or Value
1	Ethylbenzene	$C_6H_5C_2H_5$	0.3
2	Benzo(a)pyrene	$C_{20}H_{12}$	0.0007
3	Benzene	C_6H_6	0.01
4	1,4 - Dioxane	$C_4H_8O_2$	0.05
5	Toluene	C_7H_8	0.7
6	Di(2 - ethylhexyl) phthalate	$C_6H_4(CO_2C_8H_{17})_2$	0.008
7	Dichloromethane	CH_2Cl_2	0.02
8	1,2 - Dichloroethane	$C_2H_4Cl_2$	0.03
9	1,2 - Dichloroethene	$C_2H_2Cl_2$	0.05
10	1,2 - Dichlorobenzene	$C_6H_4Cl_2$	1.0
11	1,4 - Dichlorobenzene	$C_6H_4Cl_2$	0.3
12	1,1,1 - Trichloroethane	C_2HCl_3	0.02
13	Tetrachloroethene	C_2Cl_4	0.04
14	Xylene	C_8H_{10}	0.5
15	Styrene	C_8H_8	0.02
16	Hexachlorobutadiene	C_4Cl_6	0.0006
17	Chlorobenzene (Monochlorobenzene, MCB)	C_6H_5Cl	0.3
18	Vinyl chloride	C_2H_3Cl	0.0003
19	Microcystins (MCs)	$C_{49}H_{74}N_{10}O_{12}$	0.001
20	Nitrilotriacetic acid (NTA)	$C_6H_9NO_6$	0.2

Table (5) - Various organic and hydrocarbon compounds parameters (mg/L)

NO.	Standard	Chemical formula	Specified Concentration or Value
1	Monochloramine	NH_2Cl	3.0
2	Acrylamide	C_3H_5NO	0.0005
3	Bromate	BrO_3^-	0.01
4	Bromo-dichloromethane	$CHBrCl_2$	0.06
5	Bromoform	$CHBr_3$	0.1
6	Perchlorate	ClO_4^-	0.07
7	Total Trihalomethanes (THMs)*	-	Less than or equal to 1
8	Trichloroacetic acid	$C_2HCl_3O_2$	0.2
9	Dibromoacetonitrile	C_2HBr_2N	0.07
10	Dichloroacetonitrile	C_2HCl_2N	0.02
11	Dibromochloromethane	$CHBr_2Cl$	0.1
12	Sodium Dichloroisocyanurate	$C_3Cl_2N_3NaO_3$	50.0
13	Dimethylnitrosamine	$C_2H_6N_2O$	0.0001
14	Carbon Tetrachloride	CCl_4	0.004
15	Chlorate	ClO_3^-	0.7
16	Chloroacetic acid	$C_2H_3ClO_2$	0.06
17	Chloroform	$CHCl_3$	0.3
18	Chlorite	ClO_2^-	0.7
19	Cyanogen chloride	CNCl	0.07

Table (6) - Chemicals resulting from water purification processes and by-products parameters

Note: The sum of the concentrations of trihalomethanes (THMs) should not exceed 1, as follows:

1 ≥ (Concentration of Dichlorobromomethane / Maximum allowable limit for Dichlorobromomethane) + (Concentration of Bromodichloromethane / Maximum allowable limit for Bromodichloromethane) + (Concentration of Bromoform / Maximum allowable limit for Bromoform) = Total Trihalomethanes (THMs)

NO.	Standard	Specified concentration or Value
1	Gross Alpha Activity	0.5
2	Gross Beta Activity	1.0
3	Radioactivity (excluding Potassium - 40)	0.1

Table (7) - Radioactive parameters (Bq/L)

NO.	Standard	Specified concentration or Value
1	Strontium - 90	4.9
2	Plutonium - 239	0.56
3	Potassium - 40	22
4	Polonium - 210	0.1
5	Tritium	7,716
6	Thorium - 232	0.6
7	Thorium - 230	0.7
8	Thorium - 228	1.9
9	Radon - 222	300
10	Radium - 228	0.2
11	Radium - 226	0.5
12	Lead - 210	0.2
13	Cesium - 137	10.5
14	Cesium - 134	7.2
15	Carbon - 14	236
16	Iodine - 131	6.2
17	Uranium - 238	3.0
18	Uranium - 234	2.8

Table (8) - radionuclides parameters (isotopes) (Bq/L)

NO.	Standard	Unit	Specified concentration or Value
1	Enterococci	Number/100 ml	0
2	Escherichia coli	Number/100 ml	0
3	Total Coliforms (Bacteria)	Number/100 ml	0 in %95 of samples from large supplies

Table (9) - Microbial parameters