



Water security -A need of 21st century

Ragini, Dr. Shalini Saxena*

Department of Botany, Lab of Cytogenetics and Environmental Science, Bareilly College, Bareilly, Uttar Pradesh, India

Abstract

Water security has emerged as a critical global challenge in the 21st century, encompassing the availability, accessibility, and sustainable management of water resources. This paper examines the multifaceted aspects of water security, including its definition, key drivers, and impacts on various sectors. Through a comprehensive analysis of current literature and global data, we explore the interconnections between water security, climate change, population growth, and socio-economic development. The study highlights the urgent need for integrated water resource management strategies, technological innovations, and policy interventions to address water security challenges. Our findings emphasize the importance of collaborative efforts at local, national, and international levels to ensure sustainable water security for present and future generations.

Keywords: Water security, Climate change, Sustainable development, Water resource management, Global water crisis

Introduction

Water is an indispensable resource for life, economic development, and environmental sustainability. As the global population continues to grow and climate change intensifies, ensuring water security has become one of the most pressing challenges of the 21st century (United Nations, 2021). Water security encompasses the availability of sufficient quantity and quality of water for human needs, economic activities, and ecosystem functions, while also addressing water-related risks such as floods, droughts, and pollution (Grey & Sadoff, 2007) ^[8]. The concept of water security has gained significant attention in recent years due to the increasing recognition of its critical role in achieving sustainable development goals and maintaining global stability. The United Nations has identified clean water and sanitation as one of the 17 Sustainable Development Goals (SDGs), emphasizing the urgent need to address water-related challenges worldwide (United Nations, 2015).

This research paper aims to provide a comprehensive analysis of water security in the context of the 21st century, exploring its various dimensions, challenges, and potential solutions. By examining the current state of water resources, emerging threats, and innovative approaches to water management, we seek to contribute to the ongoing discourse on water security and inform policy decisions at local, national, and international levels.

Water Security

Water security is a multidimensional concept that encompasses various aspects of water availability, accessibility, and management. The United Nations defines water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water, 2013).

This definition highlights several key components of water security:

- **Availability:** Ensuring sufficient water resources to meet human and ecosystem needs.
- **Accessibility:** Providing equitable access to water for all segments of the population.
- **Quality:** Maintaining water quality standards for various uses, including drinking, agriculture, and industry.
- **Sustainability:** Managing water resources in a way that preserves them for future generations.
- **Resilience:** Building capacity to cope with water-related risks and disasters.
- **Governance:** Implementing effective policies and institutions for water management. Understanding these components is crucial for developing comprehensive strategies to address water security challenges in the 21st century.

Global Water Resources and Scarcity

Distribution of Global Water Resources

The Earth's water resources are unevenly distributed across the planet, with some regions experiencing abundance while others face severe scarcity. Approximately 97.5% of the Earth's water is saltwater, leaving only 2.5% as freshwater. Of this freshwater, about 68.7% is locked in ice caps and glaciers, 30.1% exists as groundwater, and only 1.2% is readily available as surface water in rivers, lakes, and streams (Shiklomanov, 1993) ^[16].

Water Scarcity and Stress

Water scarcity occurs when the demand for water exceeds the available supply, while water stress refers to the ability to meet human and ecological demands for water. According to the United Nations, water scarcity affects more than 40% of the global population and is projected to rise (United Nations, 2021). The World Resources Institute's Aqueduct Water Risk Atlas provides a comprehensive assessment of water stress levels worldwide (World Resources Institute, 2019).

Presents the top 10 countries facing extremely high-water stress:

Table 1

Rank	Country	Water Stress Level
1	Qatar	Extremely High
2	Israel	Extremely High
3	Lebanon	Extremely High
4	Iran	Extremely High
5	Jordan	Extremely High
6	Libya	Extremely High
7	Kuwait	Extremely High
8	Saudi Arabia	Extremely High
9	Eritrea	Extremely High
10	UAE	Extremely High

Source: World Resources Institute (2019)

These countries face significant challenges in meeting their water demands, highlighting the urgent need for sustainable water management strategies and international cooperation.

Drivers of Water Insecurity

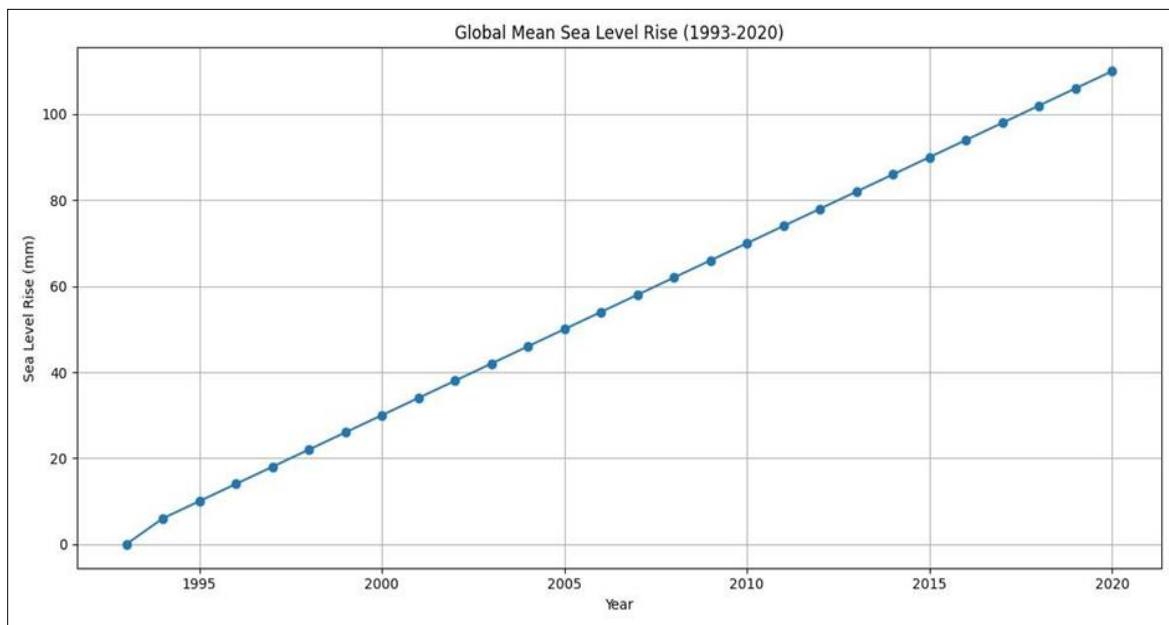
Several interconnected factors contribute to the growing water insecurity in the 21st century. Understanding these drivers is crucial for developing effective solutions and policies to address water-related challenges.

Climate Change

Climate change is one of the most significant drivers of water insecurity, affecting water availability, quality, and distribution patterns worldwide (Jiménez Cisneros *et al.*, 2014) [10]. The impacts of climate change on water resources include:

- **Altered precipitation patterns:** Changes in rainfall frequency, intensity, and distribution affect water availability and increase the risk of floods and droughts.
- **Melting glaciers and snow cover:** Accelerated melting of glaciers and reduced snow cover affect water storage and seasonal water availability in many regions.
- **Sea-level rise:** Rising sea levels lead to saltwater intrusion in coastal aquifers, reducing freshwater availability in coastal areas.
- **Increased evaporation:** Higher temperatures increase evaporation rates, reducing surface water availability and increasing irrigation demands.

To visualize the impact of climate change on global water resources, we can create a line plot showing the trend in global mean sea level rise:



Graph (1)

This graph illustrates the steady increase in global mean sea level, which has significant implications for coastal water resources and communities.

Population Growth and Urbanization

The world's population is projected to reach 9.7 billion by 2050, with most of this growth occurring in developing countries (United Nations, 2019). This rapid population growth, coupled with increasing urbanization, puts enormous pressure on water resources. The impacts include:

- **Increased water demand:** Growing populations require more water for domestic, industrial, and agricultural use.
- **Urban water stress:** Rapid urbanization strains existing water infrastructure and increases the risk of water scarcity in cities.

- **Water pollution:** Higher population densities and industrial activities lead to increased water pollution, affecting water quality and availability.

Agricultural Expansion and Intensification

Agriculture is the largest consumer of freshwater globally, accounting for approximately 70% of all water withdrawals (FAO, 2017). The expansion and intensification of agriculture to meet growing food demands contribute to water insecurity through:

- **Increased water withdrawals:** Expanding irrigated agriculture leads to higher water consumption.
- **Water pollution:** Intensive use of fertilizers and pesticides contributes to water pollution and eutrophication.

- **Groundwater depletion:** Overexploitation of groundwater resources for irrigation leads to aquifer depletion and land subsidence.

Industrial Development

Industrial growth, while essential for economic development, often comes at the cost of increased water consumption and pollution. Key issues include:

- **High water demand:** Many industries require large volumes of water for production processes.
- **Water pollution:** Industrial effluents can contaminate water sources, reducing water quality and availability for other uses.
- **Competing water demands:** Industrial water use often competes with agricultural and domestic water needs.

Energy Production

The water-energy nexus is a critical aspect of water security, as energy production requires significant water resources, and water management often depends on energy-intensive processes. Key challenges include:

- **Thermoelectric cooling:** Power plants require large volumes of water for cooling, competing with other water uses.
- **Hydropower:** While a renewable energy source, hydropower can alter river flows and affect downstream water availability.
- **Biofuel production:** Expanding biofuel crops can increase water demand and compete with food production.

Understanding these drivers of water insecurity is crucial for developing integrated approaches to water resource management and ensuring water security in the 21st century.

Impacts of Water Insecurity

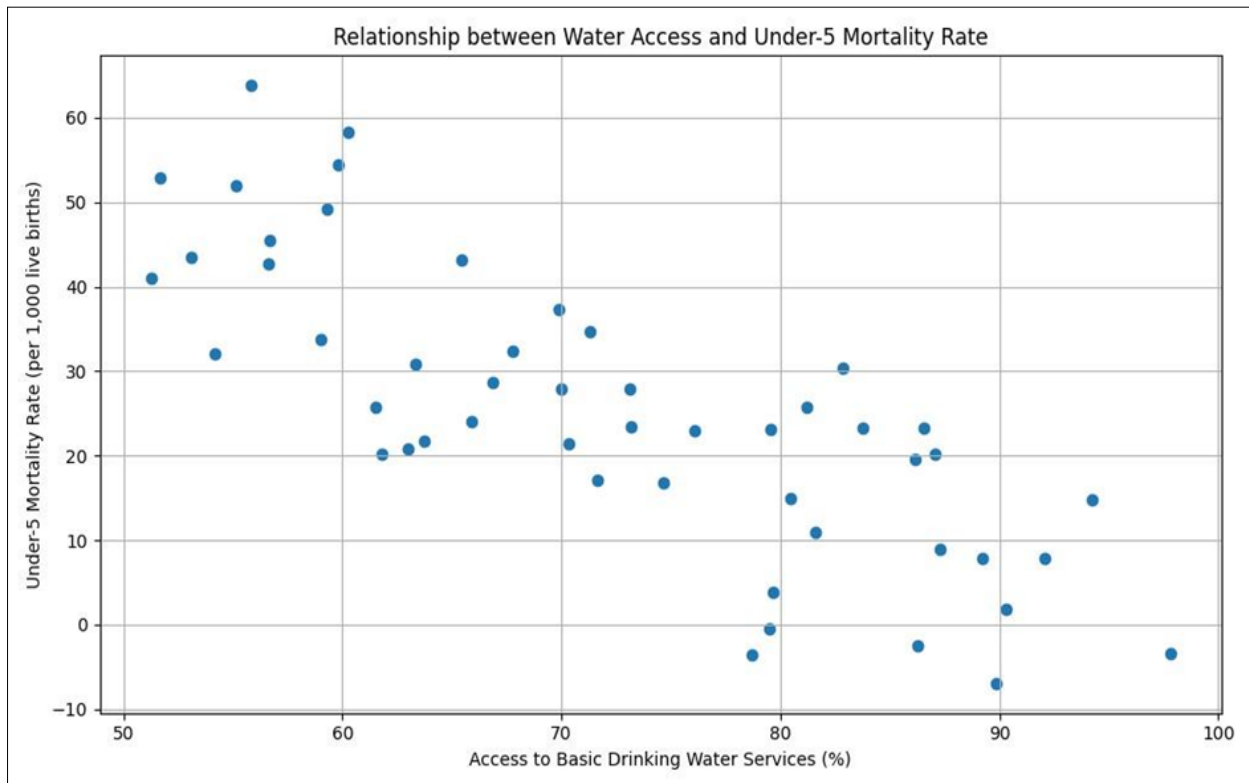
Water insecurity has far-reaching consequences that affect various aspects of human life, economic development, and environmental sustainability. This section explores the major impacts of water insecurity on different sectors and systems.

Human Health and Well-being

Water insecurity directly affects human health and well-being through multiple pathways:

- **Waterborne diseases:** Lack of access to clean water and sanitation facilities increases the risk of waterborne diseases such as cholera, typhoid, and diarrheal diseases (Prüss-Ustün *et al.*, 2014) ^[13].
- **Malnutrition:** Water scarcity affects food production and can lead to malnutrition, particularly in vulnerable populations.
- **Mental health:** Water insecurity can cause stress, anxiety, and other mental health issues, especially in regions where water collection is time-consuming and physically demanding (Wutich & Ragsdale, 2008) ^[28].

To illustrate the relationship between water access and health outcomes, we can create a scatter plot showing the correlation between access to basic drinking water services and under-5 mortality rates:



Graph (1.1)

This visualization demonstrates the inverse relationship between access to basic drinking water services and under-5 mortality rates, highlighting the crucial role of water security in public health.

Food Security

Water insecurity poses significant challenges to food security, affecting agricultural productivity and food availability:

- Crop yield reduction: Water scarcity and droughts can lead to reduced crop yields and crop failures.
- Livestock impacts: Insufficient water affects livestock health and productivity.
- Fisheries decline: Changes in water availability and quality can negatively impact freshwater and marine fisheries.

The Food and Agriculture Organization (FAO) estimates that by 2050, agricultural production will need to increase by 60% to meet global food demand (FAO, 2017). Achieving this goal while ensuring water security will require significant improvements in water use efficiency and agricultural practices.

Economic Impacts

Water insecurity has substantial economic implications, affecting various sectors and overall economic growth:

- Agricultural losses: Reduced crop yields and livestock productivity due to water scarcity result in economic losses for farmers and the agricultural sector.
- Industrial disruptions: Water shortages can disrupt industrial processes, leading to production losses and economic downturns.
- Energy sector impacts: Water scarcity affects energy production, particularly in regions reliant on hydropower or thermoelectric plants.
- Infrastructure costs: Addressing water scarcity and improving water infrastructure require significant investments, straining national budgets.

A World Bank study estimates that water scarcity, exacerbated by climate change, could cost some regions up to 6% of their GDP by 2050 (World Bank, 2016).

Environmental Degradation

Water insecurity contributes to various forms of environmental degradation:

- Ecosystem damage: Overexploitation of water resources and changes in water flows can harm aquatic ecosystems and biodiversity.
- Soil degradation: Water scarcity and poor irrigation practices can lead to soil salinization and erosion.
- Groundwater depletion: Unsustainable extraction of groundwater can lead to aquifer depletion and land subsidence.
- Water pollution: Inadequate wastewater treatment and agricultural runoff contribute to water pollution, affecting both human and ecological health.

Social and Political Instability

Water insecurity can exacerbate social tensions and contribute to political instability:

- Water conflicts: Competition for scarce water resources can lead to conflicts at local, national, and international levels.
- Migration: Water scarcity and related environmental degradation can force people to migrate, potentially leading to social and political tensions in receiving areas.
- Gender inequality: In many regions, women and girls bear the primary responsibility for water collection, which can limit their opportunities for education and economic participation (Sorenson *et al.*, 2011) ^[17].

Understanding these multifaceted impacts of water insecurity is crucial for developing comprehensive strategies to address the challenge and ensure sustainable water security in the 21st century.

Strategies for Enhancing Water Security

Addressing water security challenges in the 21st century requires a multifaceted approach that combines technological innovations, policy interventions, and behavioral changes. This section explores key strategies for enhancing water security at various levels.

Integrated Water Resources Management (IWRM)

Integrated Water Resources Management (IWRM) is a holistic approach to water management that considers the interconnections between water, land, and related resources (Global Water Partnership, 2000). Key components of IWRM include:

- Basin-wide planning: Managing water resources at the river basin level to ensure equitable and sustainable use.
- Stakeholder participation: Involving all relevant stakeholders in water management decisions.
- Water allocation: Developing fair and efficient systems for allocating water among competing uses.
- Environmental flow requirements: Ensuring sufficient water flows to maintain ecosystem health.

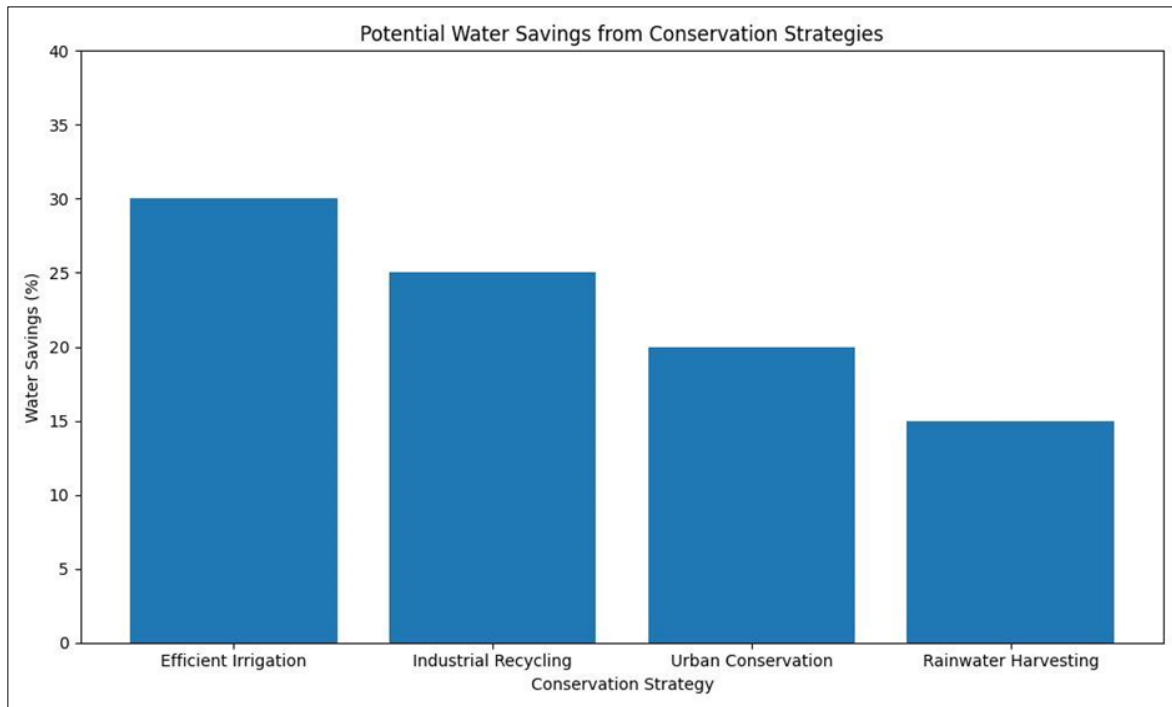
Implementing IWRM can help balance various water demands while promoting sustainable use and conservation of water resources.

Water Use Efficiency and Conservation

Improving water use efficiency across all sectors is crucial for enhancing water security. Strategies include:

- Agricultural water management: Implementing precision irrigation techniques, drought-resistant crops, and water-efficient farming practices.
- Industrial water recycling: Promoting water reuse and recycling in industrial processes to reduce freshwater demand.
- Urban water conservation: Encouraging water-saving behaviors, implementing water efficient appliances, and reducing water losses in distribution systems.
- Rainwater harvesting: Promoting the collection and use of rainwater for non-potable purposes.

To illustrate the potential impact of water conservation measures, we can create a bar chart showing water savings from different conservation strategies:



Graph (1.2)

This visualization highlights the significant potential for water savings through various conservation strategies.

Water Infrastructure Development and Maintenance

Investing in water infrastructure is essential for improving water security. Key areas include:

- Water storage: Developing and maintaining reservoirs, dams, and other water storage facilities.
- Water treatment: Improving and expanding water treatment facilities to ensure safe drinking water.
- Wastewater management: Enhancing wastewater treatment and reuse capabilities.
- Distribution systems: Upgrading water distribution networks to reduce losses and improve efficiency.

Technological Innovations

Leveraging technological advancements can significantly contribute to water security:

- Desalination: Improving the efficiency and reducing the costs of seawater desalination technologies.
- Smart water systems: Implementing IoT-based solutions for real-time monitoring and management of water resources.
- Water-efficient technologies: Developing and promoting water-saving technologies in agriculture, industry, and domestic use.
- Remote sensing and GIS: Utilizing satellite imagery and geographic information systems for better water resource mapping and management.

Climate Change Adaptation and Mitigation

Addressing the impacts of climate change on water resources is crucial for long-term water security:

- Climate-resilient infrastructure: Designing and upgrading water infrastructure to withstand climate change impacts.

- Ecosystem-based adaptation: Protecting and restoring natural ecosystems that provide water-related services.
- Drought and flood management: Developing comprehensive strategies for managing extreme water-related events.
- Climate-smart agriculture: Promoting agricultural practices that are resilient to climate change and water-efficient.

Policy and Governance

Effective water governance and policy frameworks are essential for achieving water security:

- Water pricing: Implementing appropriate water pricing mechanisms to encourage conservation and efficient use.
- Transboundary water management: Developing cooperative agreements for managing shared water resources.
- Water quality regulations: Enforcing and strengthening water quality standards and pollution control measures.
- Capacity building: Enhancing institutional and human capacity for water management at all levels.

Public Awareness and Education

Raising public awareness about water issues and promoting water-conscious behaviors is crucial:

- Water education programs: Incorporating water education into school curricula and public outreach campaigns.
- Stakeholder engagement: Involving communities in water management decisions and conservation efforts.
- Behavior change campaigns: Promoting water-saving habits and sustainable water use practices.

Implementing these strategies in a coordinated and context-specific manner can significantly enhance water security and contribute to sustainable development in the 21st century.

Case Studies: Successful Water Security Initiatives

Examining successful water security initiatives from around the world can provide valuable insights and lessons for addressing water challenges. This section presents three case studies that highlight innovative approaches to enhancing water security.

Singapore's Integrated Water Management

Singapore, a small island nation with limited natural water resources, has achieved remarkable success in ensuring water security through its integrated water management approach (Tortajada, 2006) ^[19].

Key strategies

- Four National Taps: Diversifying water sources through local catchment water, imported water, high-grade reclaimed water (NEWater), and desalinated water.
- Water demand management: Implementing water conservation measures and public education programs.
- Technological innovation: Developing advanced water treatment technologies and smart water management systems.

Results

We have reduced water imports from 80% in the 1960s to less than 40% in 2020 and achieved near 100% access to safe drinking water and sanitation. Similarly we have reduced per capita domestic water consumption from 165 liters per day in 2003 to 141 liters per day in 2019. At same time long-term planning and political commitment are required for water security and diversifying water sources enhances resilience to supply disruptions. Public engagement and education play a vital role in water conservation efforts. Israel's Water Management and Agricultural Innovation as a model system. Israel, located in a water-scarce region, has developed innovative approaches to water management and agricultural water use efficiency (Tal, 2006).

Key strategies

Drip irrigation: Widespread adoption of efficient irrigation technologies.

Water reuse: Treating and reusing wastewater for agriculture.

Desalination: Large-scale implementation of seawater desalination plants.

Water-efficient crop selection: Promoting drought-resistant and high-value crops are key strategies for water security. We have achieved increased agricultural output by 1600% between 1948 and 2001, while water consumption remained relatively stable and over 85% wastewater reuse for agriculture. Moreover we have reduced freshwater use in agriculture from 70% of total consumption in the 1980s to less than 50% in 2020. Technological innovation can significantly improve water use efficiency in agriculture and wastewater reuse can be a valuable strategy for augmenting water supplies in water-scarce regions. Combining water management with agricultural innovation can lead to substantial improvements in water productivity. Like the

Israel model the Murray-Darling Basin Plan is a comprehensive approach to managing water resources in Australia's largest river system, addressing long-standing water allocation and environmental issues (Australian Government, 2012) ^[2]. Sustainable diversion limits: Setting limits on water extraction to ensure environmental flows. Water trading: Implementing a water market to promote efficient water allocation. Environmental water management: Allocating water for environmental purposes and habitat restoration. Indigenous water rights are key strategies for recognizing and incorporating Indigenous water values and uses.

- Recovered over 2,100 gigalitres of water for the environment by 2020.
- Improved water use efficiency in agriculture through water trading and infrastructure upgrades.
- Enhanced protection of ecologically significant wetlands and river systems.
- Basin-wide planning and stakeholder engagement are essential for managing complex water systems.
- Market-based instruments can promote more efficient water allocation and use.
- Balancing environmental, economic, and social water needs requires ongoing adaptive management.

These case studies demonstrate that successful water security initiatives often involve a combination of technological innovation, policy reform, and stakeholder engagement. While each context presents unique challenges, the principles and approaches from these examples can inform water security efforts in other regions.

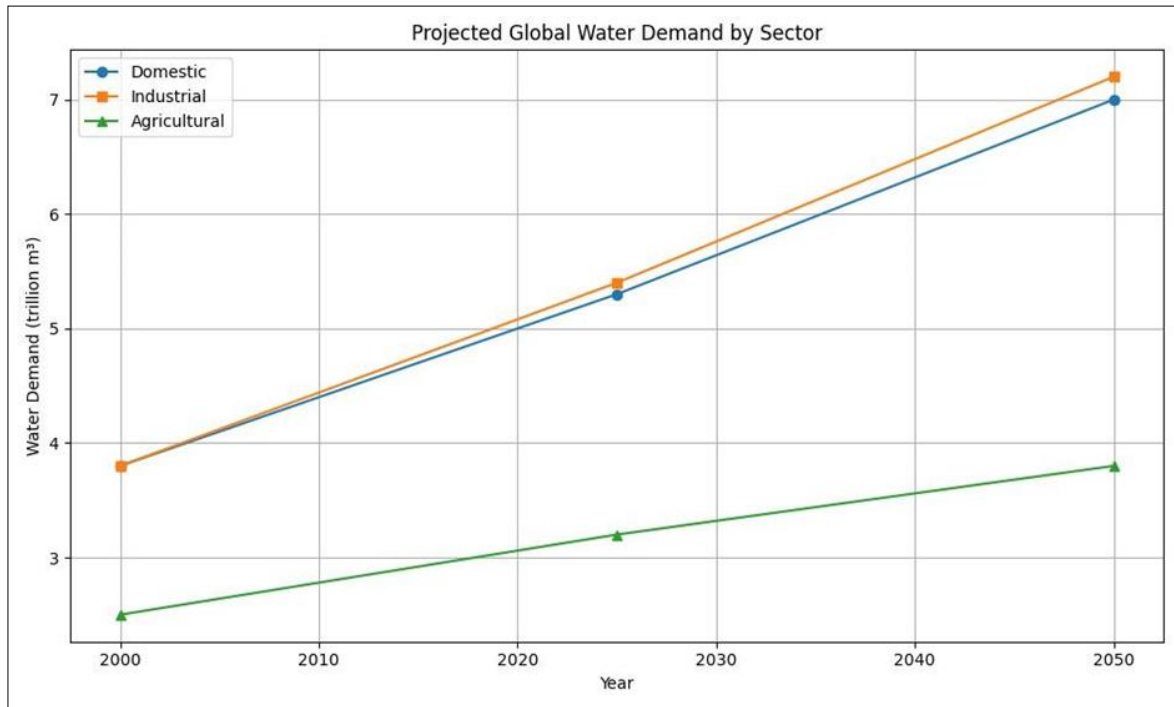
Future Challenges and Opportunities

As we progress further into the 21st century, water security will continue to be a critical global challenge. This section explores emerging challenges and opportunities in ensuring water security for future generations.

Emerging Challenges

- Climate change intensification: As climate change accelerates, its impacts on water resources are likely to become more severe and unpredictable (Jiménez Cisneros *et al.*, 2014) ^[10].
- Increasing water demand: Growing populations and economic development will continue to drive up water demand, particularly in developing countries (Boretti & Rosa, 2019) ^[3].
- Groundwater depletion: Unsustainable extraction of groundwater resources threatens long-term water security in many regions (Famiglietti, 2014) ^[5].
- Water quality degradation: Emerging contaminants, such as microplastics and pharmaceutical residues, pose new challenges to water quality management (Schwarzenbach *et al.*, 2010) ^[14].
- Transboundary water conflicts: As water becomes scarcer, the potential for conflicts over shared water resources may increase (Petersen-Perlman *et al.*, 2017) ^[12].

To visualize the projected global water demand, we can create a line plot showing the expected increase in different sectors:



Graph (1.3)

This graph illustrates the projected increase in water demand across different sectors, highlighting the need for improved water management strategies.

Opportunities and Promising Solutions

Despite these challenges, several opportunities and promising solutions offer hope for enhancing water security in the future:

- Nature-based solutions: Implementing green infrastructure and ecosystem-based approaches to water management can provide multiple benefits, including improved water quality, flood mitigation, and biodiversity conservation (WWAP/UN-Water, 2018).
- Circular water economy: Adopting circular economy principles in water management can promote water reuse, resource recovery, and reduced water consumption (Voulvoulis, 2018).

Big data and artificial intelligence: Leveraging big data analytics and AI can improve water resource modeling, demand forecasting, and infrastructure management (Shafiee *et al.*, 2020).

- Decentralized water systems: Implementing decentralized water treatment and supply systems can enhance resilience and improve access in underserved areas (PeterVarbanets *et al.*, 2009) ^[11].
- Water-energy-food nexus approaches: Integrated management of water, energy, and food resources can lead to more efficient resource use and improved security across all three sectors (Hoff, 2011) ^[9].
- Citizen science and participatory monitoring: Engaging communities in water monitoring and management can improve data collection, raise awareness, and promote water stewardship (Buytaert *et al.*, 2014) ^[4].
- Innovative financing mechanisms: Developing new financing models, such as green bonds and blended finance, can help mobilize resources for water infrastructure and conservation projects (Alaerts, 2019) ^[1].

Research and Policy Priorities

To address future water security challenges and capitalize on emerging opportunities, the following research and policy priorities should be considered:

- Improving climate change projections and their integration into water management planning.
- Developing and scaling up water-efficient technologies for agriculture, industry, and domestic use.
- Enhancing water governance frameworks to promote integrated and adaptive management approaches.
- Strengthening transboundary water cooperation and conflict resolution mechanisms.
- Advancing water quality monitoring and treatment technologies for emerging contaminants.
- Promoting interdisciplinary research on the water-energy-food nexus and its implications for water security.
- Developing innovative financing mechanisms to support water infrastructure development and maintenance.
- Enhancing capacity building and knowledge sharing on water security issues at all levels.

By addressing these priorities and leveraging emerging opportunities, we can work towards achieving sustainable water security in the face of 21st-century challenges.

Key priorities include:

Strengthening water governance frameworks at local, national, and international levels.

- Investing in water infrastructure development and maintenance.
- Promoting water-efficient technologies and practices across all sectors.
- Enhancing climate change adaptation and mitigation efforts related to water resources.
- Fostering international cooperation on transboundary water management.

- Advancing research and innovation in water-related technologies and management approaches.
- Raising public awareness and promoting water conservation behaviours.

Conclusion

Water security has emerged as a critical global challenge in the 21st century, with far-reaching implications for human health, food security, economic development, and environmental sustainability. This comprehensive review has examined the multifaceted aspects of water security, including its definition, key drivers, impacts, and potential solutions.

The complex interplay of factors such as climate change, population growth, urbanization, and increasing water demand across sectors has exacerbated water security challenges worldwide. These challenges are particularly acute in water-stressed regions, where competition for limited water resources is intensifying and the risks of water-related conflicts are rising.

However, the review has also highlighted numerous strategies and innovative approaches for enhancing water security. These include integrated water resources management, improving water use efficiency, technological innovations, and nature-based solutions. Case studies from Singapore, Israel, and Australia demonstrate that successful water security initiatives often involve a combination of technological innovation, policy reform, and stakeholder engagement.

Looking to the future, emerging challenges such as climate change intensification and groundwater depletion will require continued attention and innovative solutions. Opportunities presented by advances in technology, such as big data analytics and artificial intelligence, offer promising avenues for improving water management and enhancing water security.

To address these challenges and capitalize on emerging opportunities, a concerted effort is needed from governments, international organizations, the private sector, and civil society. In conclusion, ensuring water security in the 21st century is a complex but essential task that requires integrated approaches, innovative solutions, and collaborative efforts at all levels. By addressing water security challenges proactively and holistically, we can work towards a more sustainable and water-secure future for all.

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