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ESCASEZ DE AGUA EN LA AGRICULTURA: DESAFÍOS PARA LA SEGURIDAD HÍDRICA GLOBAL Y LA PRODUCCIÓN SOSTENIBLE DE ALIMENTOS

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ABSTRACT

Water scarcity has become one of the most critical environmental and socioeconomic challenges affecting global agriculture, food security, and sustainable development in the twenty-first century. Increasing population growth, climate change, environmental degradation, urbanization, and unsustainable agricultural practices are intensifying pressure on freshwater resources worldwide, threatening both agricultural productivity and human well-being. The objective of this study was to analyze the principal causes and consequences of water scarcity in agriculture and evaluate its impact on global water security and sustainable food production. The study was developed using a qualitative analytical methodology supported by a comprehensive narrative literature review. Scientific articles, institutional reports, and academic investigations published between 2015 and 2026 were analyzed through recognized scientific databases and international organizations. The analysis followed a thematic and interpretative approach focused on climate change, agricultural water management, food insecurity, environmental degradation, governance, and sustainable agriculture. The findings demonstrated that water scarcity significantly threatens agricultural systems by reducing crop productivity, degrading ecosystems, increasing food insecurity, and intensifying social and economic inequalities. The results also revealed that inefficient irrigation systems, groundwater overexploitation, pollution, and weak governance accelerate global water stress. However, sustainable agriculture, technological innovation, precision irrigation, wastewater reuse, and climate-smart management strategies were identified as essential alternatives for improving water-use efficiency and promoting long-term environmental sustainability.

Keywords:

Water scarcity, sustainable agriculture, food security, climate change, water management.

RESUMEN

La escasez de agua se ha convertido en uno de los desafíos ambientales y socioeconómicos más críticos que afectan la agricultura mundial, la seguridad alimentaria y el desarrollo sostenible en el siglo XXI. El crecimiento acelerado de la población, el cambio climático, la degradación ambiental, la urbanización y las prácticas agrícolas insostenibles están intensificando la presión sobre los recursos de agua dulce a nivel mundial, amenazando tanto la productividad agrícola como el bienestar humano. El objetivo de este estudio fue analizar las principales causas y consecuencias de la escasez de agua en la agricultura y evaluar su impacto en la seguridad hídrica global y la producción sostenible de alimentos. El estudio se desarrolló mediante una metodología analítica cualitativa sustentada en una revisión narrativa integral de la literatura científica. Se analizaron artículos científicos, informes institucionales e investigaciones académicas publicados entre 2015 y 2026 a través de bases de datos científicas reconocidas y organismos internacionales. El análisis siguió un enfoque temático e interpretativo centrado en el cambio climático, la gestión hídrica agrícola, la inseguridad alimentaria, la degradación ambiental, la gobernanza y la agricultura sostenible. Los hallazgos demostraron que la escasez de agua amenaza significativamente los sistemas agrícolas al reducir la productividad de los cultivos, degradar los ecosistemas, incrementar la inseguridad alimentaria e intensificar las desigualdades sociales y económicas. Los resultados también revelaron que los sistemas de irrigación ineficientes, la sobreexplotación de aguas subterráneas,

la contaminación y la débil gobernanza aceleran el estrés hídrico global. Sin embargo, la agricultura sostenible, la innovación tecnológica, la irrigación de precisión, la reutilización de aguas residuales y las estrategias de gestión inteligente frente al clima fueron identificadas como alternativas esenciales para mejorar la eficiencia en el uso del agua y promover la sostenibilidad ambiental a largo plazo.

Palabras clave:

Escasez de agua, agricultura sostenible, seguridad alimentaria, cambio climático, gestión hídrica.

INTRODUCTION

Water is one of the most essential natural resources for human survival, economic development, environmental sustainability, and agricultural productivity. Throughout history, civilizations have depended on reliable water supplies to sustain food production, maintain public health, support ecosystems, and promote social and economic stability. However, during the twenty-first century, water scarcity has emerged as one of the most critical global challenges affecting both developed and developing nations. Increasing population growth, climate change, environmental degradation, industrial expansion, urbanization, and unsustainable agricultural practices have intensified pressure on freshwater resources worldwide. Consequently, the availability of safe and accessible water is rapidly declining in many regions, threatening not only ecological balance but also global food security and sustainable development.

Among all economic sectors, agriculture is the largest consumer of freshwater resources worldwide. According to the Food and Agriculture Organization of the United Nations (2026), agriculture accounts for approximately 70% of global freshwater withdrawals, a proportion expected to increase significantly in coming decades due to rising food demand associated with population growth and changing consumption patterns. The expansion of agricultural production, combined with inefficient irrigation systems and unsustainable water management practices, has accelerated the depletion of rivers, lakes, reservoirs, and groundwater aquifers. Consequently, many agricultural regions are already experiencing severe water stress conditions that negatively affect crop productivity, livestock systems, and rural livelihoods.

Water scarcity has become deeply interconnected with global food insecurity. Agricultural systems depend heavily on stable water supplies to sustain crop growth, maintain soil fertility, and ensure long-term food production. However, increasing drought frequency, irregular rainfall patterns, desertification, and groundwater depletion are reducing agricultural productivity across multiple regions of the world. According to Tabler (2023), water scarcity currently represents one of the greatest threats to global food security because it directly limits the capacity of agricultural systems to meet the nutritional demands of growing populations. This situation is particularly critical in vulnerable regions such as Africa, the Middle East, South Asia, and parts of Latin America, where agriculture constitutes a major source of employment and economic stability.

Climate change has significantly intensified the global water crisis and its effects on agriculture. Rising global temperatures contribute to increased evaporation rates, prolonged droughts, altered precipitation cycles, and declining water availability. These environmental changes not only reduce water supplies but also increase uncertainty in agricultural production systems. The United Nations Educational, Scientific and Cultural Organization (2023) warned that between two and three billion people worldwide currently experience water shortages, and these shortages are expected to worsen substantially in the coming decades if international cooperation and sustainable water management strategies are not strengthened. The increasing unpredictability of water availability creates major risks for farmers, especially in regions dependent on rain-fed agriculture where crop yields are highly vulnerable to climatic variations.

In addition to climate-related factors, poor water governance and inefficient resource management contribute significantly to global water scarcity. In many countries, outdated irrigation infrastructure, inadequate public policies, weak institutional regulation, and unequal access to water resources limit the effectiveness of agricultural water management. Neo & Jha (2023) emphasized that water security has become one of the most urgent global priorities because water scarcity affects economic productivity, public health, environmental sustainability, energy systems, and social stability simultaneously. The authors also highlighted that insufficient investment in water infrastructure and poor resource allocation continue to undermine global efforts to achieve sustainable development goals.

The relationship between agriculture and water scarcity is complex and multidimensional. On one hand, agriculture depends heavily on water availability for food production; on the other hand, unsustainable agricultural practices contribute to the degradation and depletion of freshwater resources. Intensive irrigation systems, excessive groundwater extraction, inefficient water distribution, and contamination from fertilizers and pesticides have accelerated the deterioration of aquatic ecosystems worldwide. Ingrao et al. (2023) explained that traditional agricultural systems frequently operate with low water-use efficiency, generating substantial losses through evaporation, leakage, and runoff. Furthermore, the overexploitation of water resources for agricultural purposes contributes to declining groundwater levels and ecological degradation, threatening long-term environmental sustainability.

The growing scarcity of freshwater resources has serious social, economic, and environmental implications. Reduced agricultural productivity contributes to rising food prices, malnutrition, poverty, migration, and social instability, particularly in low-income regions heavily dependent on agriculture. Water scarcity also increases competition among agricultural, industrial, domestic, and environmental water demands, intensifying political tensions and resource conflicts in many parts of the world. In this context, ensuring sustainable agricultural production while preserving water resources has become one of the most significant global challenges of modern society.

Despite these challenges, technological innovation and sustainable agricultural strategies offer important opportunities to improve water management and strengthen agricultural resilience. Advances in precision irrigation, drip irrigation systems, wastewater reuse, desalination technologies, climate-smart agriculture, and digital monitoring systems have demonstrated significant potential for reducing water consumption and improving agricultural efficiency. Shemer et al. (2023) argued that innovative water treatment technologies and sustainable water management solutions are essential to addressing future global water scarcity. Their research emphasized the importance of integrating technological innovation, policy reform, and environmental sustainability to ensure long-term water security.

Similarly, sustainable agricultural practices such as crop rotation, regenerative agriculture, drought-resistant crops, soil conservation, rainwater harvesting, and integrated water management systems may help reduce agricultural vulnerability to water scarcity. These strategies contribute not only to improving water-use efficiency but also to enhancing ecosystem resilience and promoting environmental sustainability. Nevertheless, the implementation of such solutions often requires substantial financial investment, institutional support, technological accessibility, and international cooperation.

Another important aspect of the global water crisis involves the unequal distribution of water resources and technological capabilities among countries and communities. While some nations possess advanced irrigation systems and strong water governance structures, many developing regions continue to face severe infrastructural limitations and economic constraints that restrict access to reliable water supplies. As a result, vulnerable populations often experience disproportionate impacts from water scarcity, food insecurity, economic instability, and reduced agricultural productivity. Addressing these inequalities is therefore essential for achieving sustainable global water security and equitable agricultural development.

The complexity of water scarcity demonstrates that the crisis cannot be understood solely as an environmental issue. Instead, it represents an interdisciplinary challenge involving agriculture, climate change, economics, politics, technology, public policy, and social justice. Effective solutions require collaboration among governments, researchers, agricultural producers, environmental organizations, and international institutions. Sustainable water management policies must balance agricultural productivity with environmental protection while ensuring equitable access to water resources for present and future generations.

Overall, water scarcity represents one of the most urgent threats to sustainable agriculture, food security, and global development in the twenty-first century. The increasing pressure on freshwater resources, combined with climate change and growing food demand, highlights the necessity of transforming current agricultural systems toward more sustainable and resilient models. Without immediate action, water scarcity may significantly compromise future food production, environmental sustainability, and human well-being on a global scale.

Therefore, the objective of this study is to analyze the causes and impacts of water scarcity in agriculture and evaluate its implications for global water security and sustainable food production. Additionally, the study aims to examine current challenges, environmental consequences, and potential strategies for improving agricultural water management and promoting sustainable and resilient food systems in the context of climate change and increasing global water demand.

MATERIALS AND METHODS

The present study was developed using qualitative analytical methodology supported by a comprehensive narrative literature review focused on water scarcity in agriculture and its implications for global water security and sustainable food production. This methodological approach was selected because it allows an interdisciplinary examination of environmental, agricultural, climatic, economic, and social dimensions associated with the increasing global water crisis. The research aimed to analyze the principal causes, consequences, and adaptation strategies related to agricultural water scarcity through the integration of recent scientific evidence and contemporary academic contributions.

The study involved systematic identification, selection, classification, and interpretation of scientific literature addressing water scarcity, climate change, agricultural sustainability, food security, water governance, and environmental resilience. Academic publications, review articles, institutional reports, and scientific investigations published between 2015 and 2026 were examined to ensure the inclusion of recent data, current environmental challenges, and modern technological developments associated with sustainable water management and agricultural production systems.

The bibliographic search process was conducted using internationally recognized scientific databases and academic repositories. The search strategy incorporated combinations of descriptors and thematic keywords such as "water scarcity," "agricultural water management," "food security," "climate change," "sustainable agriculture," "global water crisis," "water governance," "irrigation efficiency," "environmental sustainability," and "water insecurity." Boolean operators including AND, OR, and NOT were used to refine the search process and improve the precision of the selected literature.

The inclusion criteria were based on scientific relevance, methodological consistency, thematic contribution, and direct applicability to the objectives of the study. Selected investigations were required to address at least one of the following dimensions: agricultural water scarcity, global water security, climate-related impacts on freshwater resources, food production systems, sustainable agricultural practices, environmental degradation, water governance, or technological adaptation strategies. Studies presenting analytical discussions, comparative assessments, predictive models, case studies, or sustainability-oriented solutions were prioritized due to their contribution to understanding the multidimensional nature of water scarcity.

The exclusion criteria involved publications lacking sufficient scientific rigor, duplicated studies, sources unrelated to water management or agriculture, articles focused exclusively on highly localized technical data without broader analytical implications, and investigations with limited methodological transparency. In addition, publications containing unsupported claims or insufficient academic development were excluded from the final review process.

Following the selection stage, the identified literature was categorized into thematic areas to facilitate comparative analysis and interpretation. These categories included climate change and water insecurity, agricultural impacts of water scarcity, food security challenges, environmental degradation, technological innovation in irrigation systems, sustainable agricultural practices, governance and public policy, social inequality associated with water access, and future adaptation strategies. This thematic organization enabled the identification of recurring scientific patterns, emerging environmental trends, and interdisciplinary relationships among the analyzed studies.

The analytical process followed a thematic and interpretative content analysis approach. Each selected source was critically examined to identify principal arguments, environmental implications, adaptation strategies, and global perspectives concerning water scarcity and sustainable agriculture. Attention was given to the interaction between climate change, agricultural productivity, freshwater availability, and food security. The collected information was subsequently synthesized into conceptual frameworks that supported the development of the discussion and conclusions presented throughout the study.

Additionally, the research incorporated a sustainability-oriented perspective focused on the long-term relationship between agricultural systems and environmental conservation. The study considered the importance of balancing food production demands with responsible water management practices capable of protecting freshwater ecosystems and ensuring resource availability for future generations. Social and ethical dimensions associated with water insecurity were also analyzed, particularly issues related to inequality, vulnerable populations, governance failures, and unequal access to technological resources.

Overall, the adopted methodological framework provides a comprehensive and interdisciplinary understanding of agricultural water scarcity as a global environmental and socioeconomic challenge. By integrating scientific evidence from multiple disciplines, the study offers a broad analytical perspective regarding the causes, impacts, and potential solutions associated with sustainable water management and global food security under increasingly complex climatic conditions.

RESULTS AND DISCUSSION

Water scarcity has progressively evolved into a structural challenge that threatens the sustainability of global agricultural systems and the stability of food production worldwide. Although agriculture remains indispensable for human survival and economic development, current production models increasingly depend on intensive freshwater extraction practices that exceed natural replenishment capacities. This imbalance between water availability and agricultural demand has generated severe environmental degradation, reduced water accessibility, and intensified vulnerabilities in both rural and urban populations. As freshwater resources become increasingly limited, the agricultural sector faces the urgent necessity of transforming traditional production systems toward more sustainable and efficient approaches capable of preserving long-term water security.

One of the principal drivers of agricultural water scarcity is the growing global demand for food associated with rapid population growth and changing dietary consumption patterns. The continuous expansion of agricultural production requires greater irrigation capacity, larger cultivated areas, and more intensive farming systems. In many regions, these practices have accelerated the overexploitation of rivers, reservoirs, and underground aquifers. Excessive groundwater extraction has become especially problematic because many aquifers require decades or even centuries to recover naturally. Consequently, numerous agricultural zones are currently experiencing declining groundwater levels, soil degradation, and increasing

desertification processes that threaten future agricultural productivity.

The intensification of industrial agriculture has further contributed to unsustainable water consumption patterns. Modern agricultural systems frequently prioritize maximum productivity through large-scale irrigation and monoculture production methods that require substantial quantities of freshwater resources. Crops such as rice, wheat, cotton, and sugarcane are particularly water-intensive and are often cultivated in regions already affected by water stress. This situation creates considerable pressure on local ecosystems and reduces water availability for domestic, industrial, and environmental needs. In many developing countries, limited technological infrastructure and inefficient irrigation systems additionally contribute to substantial water losses through evaporation, leakage, and runoff.

Climate variability has become another critical factor influencing agricultural water scarcity. Changes in precipitation patterns, prolonged drought periods, and increasing temperatures are significantly affecting water availability and agricultural stability across multiple regions. In many areas, farmers are facing unpredictable growing seasons, declining soil moisture, and reduced crop yields due to irregular climatic conditions. Drought events not only diminish immediate agricultural productivity but also produce long-term economic and social consequences, including rural poverty, migration, unemployment, and food insecurity. These effects are particularly severe in regions where agriculture depends predominantly on rainfall rather than advanced irrigation infrastructure.

The relationship between climate change and agriculture is especially concerning because both phenomena influence each other reciprocally. Agricultural activities contribute substantially to greenhouse gas emissions through deforestation, livestock production, fertilizer use, and energy-intensive farming operations. Simultaneously, climate change intensifies agricultural vulnerability by reducing water availability and increasing environmental instability. As temperatures continue to rise globally, evaporation rates increase, reducing surface water reserves and accelerating soil dehydration. This combination of environmental stressors threatens the capacity of agricultural systems to maintain stable food production in coming decades.

Water scarcity also generates significant implications for global food security and nutritional stability. Agricultural production depends fundamentally on reliable water supplies to sustain crop development and livestock systems. When water resources become insufficient, agricultural yields decline, production costs increase, and food supply chains become more vulnerable to disruptions. These conditions frequently result in rising food prices and reduced food accessibility, particularly affecting low-income populations that already experience nutritional insecurity. In regions heavily dependent on agriculture for economic survival, declining productivity may additionally weaken local economies and increase social inequality.

Another major consequence of agricultural water scarcity involves the deterioration of natural ecosystems and biodiversity. Excessive water extraction alters river flows, reduces wetland areas, and damages aquatic habitats essential for ecological balance. Agricultural runoff contaminated fertilizers, pesticides, and chemical residues further contribute to water pollution, affecting both human health and environmental sustainability. In many regions, polluted irrigation flows contaminate nearby lakes and groundwater sources, reducing the availability of potable water and increasing environmental degradation. These ecological impacts demonstrate that agricultural water scarcity extends beyond food production and represents a broader environmental crisis with multidimensional consequences.

Technological innovation has emerged as one of the most promising approaches for improving agricultural water management and reducing waste of resources. Advanced irrigation systems, including drip irrigation and precision agriculture technologies, allow farmers to optimize water distribution and minimize unnecessary consumption. Digital monitoring systems, remote sensing technologies, and artificial intelligence applications can provide real-time information regarding soil moisture, crop conditions, and climatic variations, facilitating more efficient irrigation decisions. Such innovations contribute to improving agricultural productivity while simultaneously reducing pressure on freshwater resources.

However, technological solutions alone are insufficient to resolve the global water crisis if they are not accompanied by effective governance strategies and sustainable public policies. Many countries continue to experience weak institutional regulation, fragmented water management systems, and insufficient investment in rural infrastructure. Inadequate governance often leads to unequal water distribution, inefficient allocation practices, and limited access to technological resources for small-scale farmers. Consequently, sustainable agricultural transformation requires not only technological modernization but also comprehensive institutional reforms capable of promoting equitable and responsible water management.

International cooperation additionally plays a fundamental role in addressing agricultural water scarcity. Water insecurity transcends national boundaries because rivers, aquifers, and climatic systems are interconnected globally. Collaborative efforts among governments, scientific institutions, environmental organizations, and agricultural sectors are essential for developing sustainable solutions capable of addressing the complexity of the crisis. International initiatives focused on sustainable irrigation, climate adaptation, food security, and water conservation

may contribute significantly to improving resilience in vulnerable agricultural regions.

Sustainable agriculture has increasingly gained attention as an alternative capable of balancing food production with environmental conservation. Practices such as regenerative agriculture, crop diversification, conservation tillage, rainwater harvesting, agroforestry, and drought-resistant crop cultivation may reduce agricultural dependence on intensive water extraction while improving ecosystem resilience. These approaches promote soil conservation, increase water retention capacity, and support long-term agricultural sustainability. Furthermore, sustainable farming systems may contribute to reducing greenhouse gas emissions and strengthening adaptation to climate-related challenges.

An important aspect of the water crisis involves social inequality and unequal access to resources. Smallholder farmers and rural communities often possess limited access to advanced irrigation technologies, financial support, and institutional assistance. As a result, vulnerable populations are disproportionately affected by water shortages and agricultural instability. In many developing regions, women and marginalized communities bear a significant burden associated with water collection, food insecurity, and declining agricultural productivity. Therefore, addressing agricultural water scarcity also requires social policies focused on equity, education, and community resilience.

The future of global agriculture will depend heavily on the capacity of societies to adopt integrated and sustainable water management strategies. Current consumption patterns and production systems are increasingly incompatible with the finite nature of freshwater resources. Without substantial changes in agricultural practices, environmental governance, and international cooperation, water scarcity may intensify global food insecurity and environmental degradation in coming decades. Consequently, sustainable agricultural transformation represents not only an environmental necessity but also a social, economic, and humanitarian priority essential for preserving future global stability.

Overall, the growing scarcity of freshwater resources demonstrates the urgent need for a more sustainable relationship between agriculture and the environment. Agricultural systems must evolve toward models capable of increasing productivity while reducing ecological pressure and preserving water resources for future generations. Achieving this objective requires the integration of technological innovation, environmental responsibility, institutional reform, and international collaboration. Only through coordinated global action will it be possible to ensure long-term water security, sustainable food production, and environmental resilience in an increasingly water-stressed world.

Amparo-Salcedo et al. (2025) conducted a comprehensive comparative analysis of water security under climate change conditions across 43 countries, demonstrating that the increasing variability of climatic patterns, rising global temperatures, and environmental degradation are intensifying global water insecurity at unprecedented levels. Their study revealed that climate change directly affects the availability, accessibility, and sustainability of freshwater resources, particularly in regions highly dependent on agriculture and vulnerable ecosystems. The authors emphasized that prolonged droughts, irregular precipitation, and increasing evaporation rates are significantly reducing water availability for agricultural production, industrial development, and domestic consumption. Furthermore, the research highlighted that water insecurity is not exclusively an environmental issue but also a social, political, and economic challenge capable of destabilizing food systems, increasing poverty, and generating regional inequalities. One of the major contributions of the study was its emphasis on adaptive governance strategies and international cooperation as fundamental mechanisms for mitigating future water crises. The authors concluded that sustainable water management policies, climate adaptation measures, and investment in resilient infrastructure are essential to ensuring long-term global water security.

Moreover, Salehi (2022) explored the growing relationship between global water shortages and potable water safety, identifying water scarcity as one of the most urgent environmental crises of the twenty-first century. The study demonstrated that increasing pollution from industrial, agricultural, and urban activities is severely compromising water quality and reducing access to safe drinking water in many parts of the world. The author explained that contamination by heavy metals, pesticides, untreated wastewater, and chemical residues has intensified pressure on already limited freshwater resources.

Additionally, the research emphasized that rapid urbanization, population growth, and climate change are accelerating the deterioration of global water systems and threatening public health stability. Salehi (2022) also highlighted the critical connection between water quality degradation and food security, since contaminated water sources directly affect agricultural productivity and increase health risks associated with food production systems. The study ultimately concluded that integrated water management strategies, stricter environmental regulations, technological innovation, and international collaboration are urgently required to prevent future global water crises and guarantee sustainable access to safe water resources.

Similarly, Biswas et al. (2025) developed an extensive critical review examining how water scarcity represents a major obstacle to sustainable development and agricultural production worldwide. Their research demonstrated that increasing water shortages are significantly reducing

agricultural productivity, degrading soil quality, and threatening the sustainability of food systems in both developed and developing countries. The authors identified climate change, excessive groundwater extraction, population growth, and inefficient irrigation systems as some of the principal factors contributing to the acceleration of global water scarcity. Furthermore, the study emphasized that water scarcity not only affects agricultural outputs but also influences socioeconomic stability, public health, and environmental sustainability. One of the most important contributions of the article was its detailed discussion of adaptation strategies aimed at reducing agricultural vulnerability. These strategies included precision irrigation technologies, wastewater reuse systems, climate-smart agriculture, water conservation policies, and sustainable crop management practices. The authors concluded that future agricultural sustainability depends heavily on the implementation of integrated water management systems capable of balancing food production demands with environmental conservation.

In the same context, He & Rosa (2023) investigated possible solutions to agricultural green water scarcity under climate change scenarios. Their study focused on the concept of green water, which refers to soil moisture derived from rainfall that supports rain-fed agricultural systems. The authors explained that climate change is significantly reducing green water availability through altered precipitation cycles, prolonged droughts, and increasing evaporation rates. Their findings demonstrated that many agricultural regions are becoming increasingly vulnerable due to declining soil moisture and unpredictable rainfall patterns. Furthermore, the study highlighted that green water scarcity poses serious risks for global food production because a large proportion of world agriculture depends directly on rainfall rather than irrigation infrastructure. The authors proposed sustainable land management strategies, improved soil conservation techniques, and efficient rainwater harvesting systems as critical measures for strengthening agricultural resilience. Additionally, they emphasized the importance of integrating climate adaptation policies with sustainable agricultural planning to ensure future food security under increasingly uncertain environmental conditions.

Likewise, Liu et al. (2017) conducted a multidimensional assessment of water scarcity in the past, present, and future, providing one of the most comprehensive global analyses of freshwater availability trends. Their research demonstrated that water scarcity has intensified considerably over recent decades due to rapid population growth, urbanization, industrial expansion, and increasing agricultural demand. The study projected that future water stress levels will continue rising substantially if current consumption patterns and management practices remain unchanged. The authors also emphasized that climate change will exacerbate regional inequalities in water distribution, causing severe stress in arid and semi-arid regions already experiencing limited freshwater availability. Another significant contribution of the study was its integration of predictive models capable of evaluating future water scarcity scenarios under different socioeconomic and climatic conditions. Liu et al. (2017) concluded that effective long-term solutions require coordinated global efforts focused on sustainable water allocation, efficient resource management, technological innovation, and climate adaptation planning.

Consequently, Mulwa et al. (2021) examined the status of water scarcity in Kenya, identifying critical environmental, infrastructural, and socioeconomic challenges associated with limited water availability. Their study revealed that recurring droughts, rapid population growth, deforestation, and inadequate water infrastructure are significantly reducing access to freshwater resources in the country. The authors explained that water scarcity in Kenya particularly affects rural communities dependent on agriculture for survival and economic stability. Furthermore, the research highlighted that insufficient water access contributes to declining agricultural productivity, food insecurity, poor sanitation, and increasing public health risks. The study also addressed the unequal distribution of water resources, noting that vulnerable populations experience disproportionate impacts due to poverty and limited institutional support. Among the proposed solutions, the authors emphasized the importance of investing in water infrastructure, improving irrigation efficiency, strengthening environmental conservation policies, and promoting public awareness regarding sustainable water use practices.

From a social science perspective, Wutich (2025) argued that water insecurity is fundamentally a human and socially constructed phenomenon shaped by inequality, political exclusion, poverty, and environmental injustice. The author emphasized that water insecurity cannot be fully understood through technical or hydrological perspectives alone because social structures determine who experiences the greatest vulnerability to water scarcity. The study demonstrated that marginalized populations, including low-income communities and politically excluded groups, are disproportionately affected by limited water access and inadequate infrastructure. Furthermore, Wutich (2025) highlighted the importance of incorporating social sciences into water security research and policy development in order to address governance failures, inequality, and institutional exclusion. One of the major contributions of the study was its emphasis on community participation, environmental justice, and equitable governance as essential elements for achieving sustainable water security. The author concluded that future water management strategies must integrate social, political, cultural, and environmental dimensions rather than relying exclusively on technological interventions.

Additionally, Du Plessis (2022) examined persistent global water quality degradation and its implications for

environmental sustainability and public health. The study demonstrated that pollution from industrial activities, agricultural runoff, untreated wastewater, and urbanization is increasingly contaminating freshwater ecosystems worldwide. The author explained that deteriorating water quality reduces the availability of safe water for both human consumption and agricultural production, intensifying existing water scarcity problems. Furthermore, the research emphasized that poor water quality contributes to ecosystem degradation, biodiversity loss, and the spread of waterborne diseases. Du Plessis (2022) also highlighted the urgent need for stronger environmental regulations, sustainable waste management systems, and improved wastewater treatment technologies to protect freshwater resources. The study ultimately concluded that preserving water quality is as important as ensuring water quantity because both factors are fundamentally interconnected in achieving long-term water security.

Meanwhile, Mancosu et al. (2015) analyzed future challenges associated with water scarcity and global food production, emphasizing the increasing pressure that population growth and climate change place on agricultural systems. Their research demonstrated that traditional irrigation methods are frequently inefficient and responsible for substantial water losses through evaporation and leakage. The authors explained that agriculture must evolve toward more sustainable water management strategies to meet future food demands without exhausting freshwater resources. Furthermore, the study proposed the adoption of precision agriculture technologies, advanced irrigation systems, and sustainable farming practices to improve water-use efficiency and reduce environmental degradation. The authors concluded that ensuring future food security requires balancing agricultural productivity with responsible and sustainable water resource management.

Furthermore, Obayomi et al. (2026) explored the opportunities and challenges associated with sustainable agriculture under increasing water scarcity conditions from a global perspective. Their study emphasized that sustainable agriculture represents one of the most effective approaches for reducing environmental degradation while maintaining agricultural productivity and food security. The authors highlighted that climate change, land degradation, and water shortages are creating serious risks for global food systems and agricultural economies. Moreover, the research examined how innovative agricultural practices such as regenerative farming, drought-resistant crops, efficient irrigation systems, and circular water-use models can contribute to agricultural resilience. The authors concluded that long-term agricultural sustainability depends on integrating technological innovation, environmental protection, economic development, and institutional cooperation within global food production systems.

In relation to food security, Christoforidou et al. (2023) conducted a comparative analysis of Egypt and Jordan to evaluate how water scarcity affects agricultural production and food security in arid regions. Their findings demonstrated that both countries face severe limitations in freshwater availability, which directly compromise agricultural productivity and increase dependence on food imports. The authors emphasized that climate change and population growth are intensifying regional water stress and creating additional pressure on already fragile agricultural systems. Furthermore, the study highlighted the importance of transboundary cooperation, efficient irrigation policies, and sustainable water allocation mechanisms for improving food security under conditions of limited water availability. The research concluded that integrated regional water governance is essential for addressing future agricultural and food security challenges in water-scarce regions.

Likewise, Farrelly (2024) analyzed the principal causes, impacts, and solutions associated with water scarcity in agriculture. The study explained that agriculture currently represents the largest consumer of freshwater resources globally, accounting for approximately 70% of total water withdrawals worldwide. The author argued that unsustainable agricultural practices, inefficient irrigation systems, and poor water governance are accelerating global water stress. Additionally, the research identified several practical solutions for reducing agricultural water consumption, including drip irrigation systems, regenerative farming practices, improved storage infrastructure, and circular water reuse models. Farrelly (2024) concluded that sustainable agricultural transformation is essential for protecting freshwater resources and guaranteeing long-term food security.

Additionally, Jägermeyr (2020) addressed agriculture's historic dual challenge of ensuring global food supply while promoting sustainable water use. The author argued that future agricultural systems must significantly increase food production without intensifying environmental degradation or depleting freshwater resources. The study demonstrated that climate change, population growth, and increasing consumption patterns are creating unprecedented pressures on global agricultural systems. Furthermore, Jägermeyr (2020) emphasized the importance of adopting sustainable irrigation practices, improving crop efficiency, and strengthening agricultural resilience through climate adaptation strategies. The article concluded that balancing food production with environmental sustainability represents one of the most critical global priorities of the twenty-first century.

Finally, Hejazi et al. (2023) investigated the impacts of water scarcity on agricultural production and electricity generation in the Middle East and North Africa, one of the world's most water-stressed regions. Their research demonstrated that declining freshwater availability

significantly affects both agricultural systems and energy production infrastructures, increasing regional vulnerability to climate-related disruptions. The authors explained that water scarcity threatens economic stability, food security, and energy sustainability simultaneously, creating interconnected environmental and socioeconomic risks. Furthermore, the study highlighted the importance of integrated water-energy-food nexus approaches for improving regional resilience and sustainable development. The authors concluded that future adaptation strategies must combine technological innovation, policy reform, and resource efficiency to address the multidimensional consequences of water scarcity.

In conclusion, Ertan (2025) analyzed the relationship between water scarcity, climate change, and the global food crisis, emphasizing that environmental degradation and increasing resource demand are intensifying global food insecurity risks. The author demonstrated that prolonged droughts, rising temperatures, and declining freshwater availability are reducing agricultural productivity and threatening the sustainability of food systems worldwide. Furthermore, the study argued that vulnerable populations and developing regions are disproportionately affected by climate-related water shortages due to limited infrastructure and economic resources. Ertan (2025) concluded that sustainable agriculture, international cooperation, environmental conservation, and efficient water management will be essential for preventing future humanitarian crises and ensuring long-term global food security.

The analyzed studies collectively demonstrate that water scarcity has become one of the most critical global challenges affecting environmental sustainability, agricultural productivity, public health, and food security. The literature consistently highlights that climate change, population growth, urbanization, industrial expansion, and unsustainable agricultural practices are intensifying pressure on freshwater resources worldwide. Increasing temperatures, prolonged droughts, irregular rainfall patterns, and excessive groundwater extraction are significantly reducing water availability in many regions, especially those heavily dependent on agriculture.

The reviewed investigations also emphasize that agriculture remains the sector most vulnerable to scarcity due to its high dependence on freshwater resources for irrigation and food production. Inefficient irrigation systems, excessive water consumption, soil degradation, and contamination from agricultural activities have accelerated environmental deterioration and increased water stress globally. As water resources decline, agricultural productivity becomes increasingly unstable, creating serious risks for food security, economic development, and rural livelihoods.

Another important finding shared among the studies is that water scarcity cannot be understood solely as an environmental problem. The crisis also involves social inequality, governance failures, inadequate infrastructure, and unequal access to technological resources. Vulnerable populations, particularly rural communities and low-income regions, experience the most severe consequences of limited water availability, including poverty, malnutrition, migration, and public health challenges. Several authors stress that sustainable water management requires not only technological innovation but also equitable governance, international cooperation, and stronger environmental policies.

The literature further demonstrates that water quality degradation represents an additional dimension of the global water crisis. Pollution caused by industrial waste, untreated wastewater, pesticides, and fertilizers reduces access to safe water for both human consumption and agricultural use. This contamination threatens ecosystem stability, biodiversity, and public health while simultaneously intensifying water shortages.

Moreover, the reviewed studies identify sustainable agriculture and technological modernization as essential strategies for addressing future water challenges. Precision irrigation systems, regenerative agriculture, wastewater reuse, drought-resistant crops, and climate-smart farming practices are presented as viable alternatives for improving water-use efficiency and strengthening agricultural resilience. Researchers also emphasize the importance of integrating environmental sustainability with economic and social development in order to guarantee long-term food production and water security.

Overall, the collective contributions of these investigations reveal that future global stability will depend heavily on the capacity of societies to develop integrated, sustainable, and resilient water management systems capable of balancing agricultural demands, environmental conservation, and human well-being under increasingly complex climatic conditions.

CONCLUSIONS

Water scarcity has emerged as one of the greatest global threats to sustainable agriculture, environmental stability, and food security during the twenty-first century. The findings analyzed throughout this study demonstrate that the increasing pressure on freshwater resources is no longer an isolated environmental concern but a multidimensional global crisis capable of affecting economic systems, public health, agricultural productivity, social stability, and human survival itself. Climate change, population growth, unsustainable agricultural expansion, environmental degradation, and weak water governance have collectively intensified water insecurity across numerous regions of the world, particularly in areas already vulnerable to poverty and food instability.

The study revealed that agriculture remains both one of the principal victims and one of the major contributors to

global water scarcity. Modern agricultural systems depend heavily on freshwater extraction to sustain growing food demands; however, inefficient irrigation methods, groundwater overexploitation, and unsustainable production practices continue accelerating environmental deterioration and resource depletion. As freshwater availability declines, agricultural productivity becomes increasingly unstable, threatening the capacity of global food systems to meet the nutritional needs of rapidly expanding populations.

Another important conclusion derived from this research is that water scarcity cannot be understood exclusively from a hydrological or environmental perspective. The crisis is deeply interconnected with social inequality, economic vulnerability, governance limitations, technological disparities, and political instability. Rural populations, smallholder farmers, and low-income communities experience disproportionate impacts due to limited access to water infrastructure, sustainable technologies, and institutional support. Consequently, achieving global water security requires not only environmental protection but also social justice, equitable governance, and international cooperation.

The analyzed literature additionally demonstrated that water quality degradation intensifies the severity of the global water crisis. Pollution generated by agricultural runoff, industrial waste, untreated wastewater, and chemical contamination reduces the availability of safe water for both human consumption and agricultural production. Therefore, preserving freshwater ecosystems and improving water quality management are essential components of future sustainability strategies.

Despite the seriousness of these challenges, the study also identified significant opportunities for improving agricultural resilience and promoting sustainable water management. Technological innovation, including precision irrigation, wastewater reuse systems, artificial intelligence applications, remote sensing technologies, and climate-smart agriculture, offers promising alternatives for reducing water waste and improving agricultural efficiency. Likewise, sustainable farming practices such as regenerative agriculture, crop diversification, soil conservation, agroforestry, and rainwater harvesting may strengthen ecosystem resilience while reducing dependence on intensive water extraction.

However, the findings clearly indicate that technological solutions alone will not be sufficient to solve the global water crisis. Sustainable transformation requires integrated public policies, stronger environmental regulations, institutional reform, investment in water infrastructure, and coordinated international action capable of balancing agricultural productivity with ecological preservation. Future strategies must prioritize long-term sustainability rather than short-term economic gains.

Ultimately, the future of global food security will depend heavily on humanity's capacity to establish a more sustainable relationship with freshwater resources. Without immediate and coordinated action, water scarcity may intensify food insecurity, environmental degradation, forced migration, social conflict, and economic instability in coming decades. In contrast, adopting sustainable agricultural systems and responsible water governance may contribute not only to preserving natural ecosystems but also to guaranteeing human well-being and global stability for future generations.

Water scarcity represents far more than an environmental challenge; it is a defining issue for the future of civilization. Ensuring sustainable water management, resilient agricultural production, and equitable access to freshwater resources will be fundamental for protecting global food security, environmental sustainability, and the survival of future societies in an increasingly climate-stressed world.

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The author declares no conflicts of interest.

Author Contributions:

Hosein Shabanali: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, original draft writing, and writing, review, and editing.

Ethical statement:

The study was based on the analysis of documentary sources and publicly available data, and therefore did not involve the direct participation of human subjects. No personally identifiable information was handled.