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The Climate Change Impact on Water Crisis and Water Resource Sustainability by Using Nanoparticle in Gaza: Economic Solutions & Strategies Review

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ABSTRACT

Climate change has become one of the greatest threats to the sustainability of natural resources in many regions around the world, including Gaza. Situated in the arid Middle East, Gaza faces critical water scarcity, worsened by climate change through extreme weather, reduced rainfall, rising temperatures, and infrastructure damage from conflict. This article examines the impact of climate change on Gaza's water crisis and explores how nanoparticle technology could offer an innovative solution to improve water quality and sustainability. By reviewing studies and case examples, it highlights the potential of nanoparticles in water filtration and purification, as well as the challenges of implementing this technology in Gaza. In addition, this study also presents economic solutions and integrated strategies in the context of the water resources crisis in Gaza.

INTRODUCTION

The water crisis in Gaza is a multidimensional issue involving various environmental, economic, and political factors. Water resources in Gaza are limited, and their quality has deteriorated due to pollution and infrastructure damage caused by ongoing conflict. The region relies on a single primary water source, the Coastal Aquifer, which has been significantly degraded. This aquifer, the main source of groundwater, is threatened by seawater intrusion and contamination from domestic and industrial waste.

Climate change also plays a critical role in exacerbating the water crisis (Ahmed, Zounemat-Kermani and Scholz, 2020). With rising global temperatures, unpredictable rainfall patterns, and threats to the availability of clean water, Gaza is increasingly trapped in a cycle of ongoing crisis. The unstable rainfall has led to a significant reduction in the amount of rainwater that was once used to replenish reservoirs and wells. Furthermore, climate change has contributed to rising sea levels, which are encroaching upon Gaza's coastline, worsening seawater intrusion into the aquifer and further degrading the groundwater quality. In addition to the effects of climate change, prolonged warfare and political tensions in Gaza have compounded the water crisis. Gaza has experienced several military conflicts with Israel, resulting in severe damage to vital infrastructure, including water distribution systems and water treatment facilities. Airstrikes and ground assaults often destroy pipelines, pumps, and water treatment plants, causing significant difficulties for Gaza's residents in accessing clean water.

Figure 1. Water Crisis in Gaza

Source: Dalloul (2016)

In recent years, ceasefires have provided brief pauses in the violence, but they have not been sufficient to prevent further damage to the water infrastructure. The damaged facilities require substantial time and resources to repair, but recovery is often hindered by limited resources and unfavorable conditions. As a result, only about 3% of Gaza's water supply is considered clean, while more than 97% is contaminated and unfit for consumption. This situation has a profound impact on public health and exacerbates Gaza's dependence on imported water or limited, unreliable supplies. The water crisis in Gaza has significant consequences for the daily lives of its residents. Limited access to clean water increases the risk of waterborne diseases such as diarrhea and cholera, further straining public health (Sicca, 2021; Shomar and Rovira, 2023).

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Moreover, based on The World Bank reports, water scarcity could hinder economic growth (World Bank Group, 2016). A large portion of Gaza's population relies on agriculture as their primary livelihood. Without adequate water, agricultural productivity sharply declines, causing economic losses and heightened food insecurity. The dense population in Gaza also exacerbates tensions surrounding water distribution, as limited resources must be shared among millions of people. As conditions worsen, the people of Gaza find themselves increasingly trapped in an unending cycle of crisis, with unstable rainfall patterns due to climate change adding further uncertainty regarding the availability of essential clean water for daily life (American Near East Refugee Aid, 2023; Action Against Hunger USA, 2024).

Concerns about the water crisis in Gaza and its impact on daily life present an opportunity to explore innovative solutions focused on water resource sustainability. Furthermore, this issue provides a platform for raising global awareness about the urgent need for concrete action to address the crisis. With a deeper understanding of the challenges Gaza faces, this article aims to contribute to broader awareness of the importance of sustainable water management and to support efforts that can improve water conditions in the region. The urgency of this article lies in its potential to draw international attention to Gaza's water crisis, which not only threatens the sustainability of life for its residents but also offers valuable lessons on resilience to climate change and the impacts of political tensions on access to vital natural resources.

THEORETICAL FOUNDATION

Water Crisis

Water crisis is a global problem that affects people's access to clean water for drinking, cooking, and bathing. This crisis is caused by a combination of factors, including climate change, population growth, and economic growth. While the world's population tripled in the 20th century, the use of renewable water resources has grown six-fold. Within the next fifty years, the world population will increase by another 40 to 50%. This population growth - coupled with industrialization and urbanization - will result in an increasing demand for water and will have serious consequences on the environment (Water.org, 2025).

Water scarcity limits access to safe water for drinking and for practising basic hygiene at home, in schools and in health-care facilities. When water is scarce, sewage systems can fail and the threat of contracting diseases like cholera surges. Scarce water also becomes more expensive. Water scarcity takes a greater toll on women and children because they are often the ones responsible for collecting it. When water is further away, it requires more time to collect, which often means less time at school. Particularly for girls, a shortage of water in schools impacts student enrolment, attendance and performance. Carrying water long distances is also an enormous physical burden and can expose children to safety risks and exploitation (UNICEF, no date).

Nanoparticles

Nanoparticles are nanometer-sized particles that are nanoscale in three dimensions. They include nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings, and nanocapsules (Mirsasaani *et al.*, 2019). A nanoparticle is an exceedingly small particle imperceptible to the human eye and can have vastly different physical and chemical characteristics than their larger counterparts with a diameter of 1 to 100 nm (Aruna *et al.*, 2023). They also include larger particles as well as fibers and tubes less than 100 nm. Nanoparticles are incredibly tiny particles with a size of less than 100 nm and can comprise carbon, metal, metal oxides, or organic substances. The nanoparticles have distinct physical, chemical, and biological properties compared to their counterparts at larger sizes (Khan *et al.*, 2022).

RESEARCH METHOD

The research method employed is a qualitative approach using a literature review. The qualitative method is a research approach that aims to understand social and cultural phenomena from the perspective of the participants, this method prioritizes gathering non-numerical data, such as interviews, observations, and document analysis, to explore individuals' experiences, interpretations, and viewpoints in particular contexts (Susanto *et al.*, 2024).

This research examine and analyze various relevant sources, such as scholarly articles, reports from international organizations, government data, and case studies related to the water crisis and the impacts of climate change in Gaza. The researcher will gather, organize, and evaluate existing literature to gain a deep understanding of the factors contributing to the water crisis, its effects on the population of Gaza, and the necessary adaptation challenges and strategies. Through this approach, the author will provide a comprehensive overview of the situation in Gaza and identify potential steps that can be taken to address this issue in the future.

RESULTS & DISCUSSION

Gaza is a region heavily reliant on groundwater as the primary source of potable water (Weinthal *et al.*, 2005). However, climate change has led to a significant reduction in rainfall over recent decades, while rising temperatures accelerate the evaporation of water from the surface. Additionally, pre-existing problems, such as water source contamination and limited control over natural resources due to the blockade, further exacerbate the water crisis in the region. Seawater intrusion, caused by rising sea levels as a result of climate change, has also damaged Gaza's primary aquifer. This aquifer, which is the only source of freshwater, has been contaminated by seawater, reducing both the quality and quantity of water available to the population. As a result, over 97% of the water in Gaza is unfit for consumption (Noui and Guesbaya, 2025).

The impact of climate change on the water crisis in Gaza cannot be ignored, as it affects many aspects of life, including health, the economy, and social stability. In facing the uncertainties of climate change, it is crucial for Gaza to develop and implement adaptation strategies that involve technology, wise resource management, and international cooperation. The sustainability of water resources in Gaza depends not only on internal policies but also on global efforts to support the region in addressing the significant challenges posed by climate change. With the right steps, Gaza can build better resilience against the water crisis and ensure the survival of future generations.

In addition to the climate change impacts that have already made access to clean water more difficult in Gaza, the ongoing war between Israel and groups in Gaza has further worsened the existing water crisis. The continuous military confrontations have caused severe damage to vital infrastructure, including water treatment and distribution facilities. Many water management systems, such as distribution pipes and pumping stations, have been destroyed or damaged due to airstrikes and ground assaults. The destruction of these facilities further limits Gaza's ability to distribute clean water to its population, already burdened by limited water supplies (Talhami and Zeitoun, 2020).

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Moreover, attacks on infrastructure hinder efforts to repair the existing water management systems. As a result, the condition of clean water in Gaza has deteriorated further. Water resources in Gaza, which were already contaminated and degraded due to seawater intrusion and declining rainfall, are now increasingly difficult to access. In this situation, around 97% of the water in Gaza is unfit for consumption, while only 3% is available as clean water for daily use (American Near East Refugee Aid, 2023). The limited access to clean water directly impacts the health of the population, increasing the prevalence of waterborne diseases and further deteriorating the quality of life amid ongoing conflict.

Ceasefires that occasionally occur are insufficient to address the deep-rooted issues faced by Gaza. Although ceasefires provide brief pauses in violence, the process of rebuilding the destroyed water infrastructure requires time and resources that are not always available. Gaza's reliance on imported water or expensive water production methods also makes it difficult for the region to independently manage its water systems (Ball, 2021). In the face of uncertainty brought on by climate change, Gaza needs innovative adaptation strategies to address the water crisis and ensure the sustainability of its water resources. One strategy that can be implemented is the development of more efficient water treatment technologies, such as seawater desalination. Although this technology is costly and energy-intensive, investing in desalination could reduce dependency on limited groundwater resources.

Furthermore, with global warming intensifying, rainwater harvesting, the preservation of natural wetlands, and ecological restoration have become increasingly popular natural climate solutions to help mitigate climate change (Ayele, 2014; Simonson *et al.*, 2021; Schuster *et al.*, 2024). Effective management of existing natural resources and raising public awareness about the importance of water conservation can play a crucial role in the long term. Increased international cooperation is also needed to provide technical support for Gaza in implementing water sustainability policies, one of which could involve desalination technologies. Seawater desalination is a primary strategy to address this issue, but traditional methods such as reverse osmosis (RO) and thermal desalination are energy-intensive and expensive. The integration of nanotechnology into desalination processes has shown great promise in improving efficiency, reducing energy consumption, and enhancing sustainability (Bundschuh *et al.*, 2021; Moneer and Elewa, 2024).

Nanoparticles (NPs), with their unique properties such as large surface area, high reactivity, and the ability to adjust size, have been explored for several desalination technologies. These nanoparticles, including carbon-based nanoparticles, metal oxide nanoparticles, and nanocomposites, are highly effective in enhancing water permeability, salt rejection, and energy efficiency in desalination membranes and other desalting techniques. Nanoparticles influence the desalination process through various mechanisms that improve its effectiveness in converting seawater into potable water. These mechanisms depend on the specific type of nanoparticle and its interaction with water molecules and ions (Gajbhiye *et al.*, 2024).

Due to their small size, ranging from 1 to 100 nanometers, nanoparticles possess unique properties such as high surface area, reactivity, and selectivity. Several types of nanoparticles have been explored for seawater desalination, including carbon-based nanoparticles, metal oxide nanoparticles, and composites. They are highly effective in size-exclusion filtration. This principle is used in nanofiltration membranes, where nanoparticles are integrated into the membranes to remove salts and other contaminants while allowing water molecules to pass through. Nanoparticles such as graphene oxide (GO) and carbon nanotubes (CNT), with their fine pore sizes, can selectively filter water and reject salts, mimicking the properties of biological filtration systems (Rashid and Ralph, 2017).

Nanoparticles can interact with salt ions through electrostatic and Van der Waals forces, leading to salt rejection and improving water quality. Functionalizing the surface of nanoparticles with hydrophilic or hydrophobic groups can enhance their performance in desalination, ensuring selective water permeation. Nanoparticles facilitate desalination primarily through physical and chemical interactions with salt ions. These interactions include adsorption and ion exchange, where nanoparticles such as graphene oxide (GO), silver nanoparticles (AgNPs), and titanium dioxide (TiO_2) have been shown to absorb salt ions due to their large surface area. The ion exchange mechanism allows nanoparticles to replace undesirable ions (such as sodium chloride) with more benign ions (Al-Mamun *et al.*, 2021; V *et al.*, 2021).

Additionally, nano-structured membranes, often embedded with nanoparticles, can selectively reject salts while allowing clean water to pass through. These membranes operate based on size-exclusion principles and electrostatic interactions, offering efficient desalination with low energy consumption. Certain nanoparticles, such as graphene oxide and copper oxide, exhibit electrochemical properties that can be utilized in electrodes for desalination processes. When integrated into electrochemical cells, these nanoparticles can facilitate desalination by applying an electric field to drive ion movement, thereby separating salt from water (Alkhadra *et al.*, 2022).

Recent advancements have explored hybrid systems combining mangrove root properties with nanoparticles to enhance desalination performance. For example, incorporating nanoparticles into the structure of mangrove roots has been shown to improve their efficiency in removing salts and other contaminants from seawater. In this case, nanoparticles can enhance the water absorption capacity of the roots or increase the surface area available for filtration (Kim *et al.*, 2016).

While nanoparticles offer promising advantages, their application in seawater desalination is not without challenges. These include concerns related to the potential toxicity of nanoparticles to marine life, difficulties in scaling up laboratory-based systems, and the high costs of certain nanoparticles. Addressing these challenges will be key to making nanoparticle-based desalination technology more viable for large-scale use. While traditional desalination technologies consume large amounts of energy and contribute to environmental degradation, mangrove-based systems and nanoparticle-assisted systems have the potential to operate more sustainably. Mangrove-based desalination does not require external energy input and relies on natural processes to remove salt. Nanoparticles, especially those derived from renewable materials or integrated into low-energy processes, can significantly reduce the energy demands of desalination. Furthermore, hybrid systems combining these technologies offer an integrated approach to desalination that minimizes energy consumption and environmental impact.

In areas impacted by climate change, particularly in coastal and island communities, access to freshwater is becoming an increasing concern. Mangrove-based desalination systems and nanoparticles can provide a decentralized, low-cost, and energy-efficient solution to produce drinking water in these areas, making them more resilient to the impacts of climate change. Moreover, by utilizing the inherent capacity of mangroves to absorb CO_2, these systems can contribute to reducing the overall carbon footprint of the desalination process, helping to combat climate change.

Researchers should explore ways to modify nanoparticles to improve their selectivity toward salt ions or enhance their stability in seawater. For example, functionalizing graphene oxide with various chemical groups has been shown to improve its ability to remove salts while maintaining structural integrity. Researchers are also investigating bio-inspired hybrid systems that mimic natural desalination processes. These systems combine the natural filtration properties of mangrove roots with the advanced filtration capabilities of engineered nanoparticles, providing an efficient and sustainable desalination solution. Ongoing research focuses on developing circular economy models where waste products from desalination, such as brine or excess nanoparticles, are recycled or reused, further enhancing the sustainability of this technology. The following is a description of the economic strategy solution for the discussion of this research in table form:

Table 1. Economic Solutions & Strategies

Issue	Impact	Economic Solutions & Strategies
Water Scarcity in Gaza	Climate change has reduced rainfall and increased evaporation, leading to groundwater depletion. Seawater intrusion has further contaminated freshwater sources. Over 97% of Gaza's water is unfit for consumption.	Investment in desalination technology, including nanoparticle-based methods to improve efficiency and reduce energy consumption.
Impact of War on Water Infrastructure	Military confrontations have destroyed water treatment and distribution facilities, worsening access to clean water. Rebuilding efforts are slow due to resource constraints.	International cooperation for infrastructure reconstruction, emergency water supply measures, and investment in decentralized water systems.
Seawater Intrusion and Groundwater Contamination	Rising sea levels have damaged the primary aquifer, making groundwater increasingly saline.	Development of efficient desalination methods, including reverse osmosis and nanotechnology-enhanced filtration.
High Energy Costs of Desalination	Traditional desalination technologies require large amounts of energy, making them expensive and unsustainable.	Research into energy-efficient desalination techniques, such as integrating nanotechnology and renewable energy sources (solar, wind).
Limited Access to Alternative Water Sources	Reliance on external water supplies increases economic and political vulnerabilities.	Implementation of rainwater harvesting, wetland restoration, and ecological conservation to enhance local water availability.
Public Health Crisis Due to Contaminated Water	High prevalence of waterborne diseases and declining quality of life.	Promotion of water conservation practices, public education on hygiene, and improvement of local water treatment facilities.
Technological Barriers to Water Sustainability	High costs and technical challenges limit the widespread adoption of advanced water purification systems.	Global research collaborations, funding for water innovation projects, and capacity-building programs for local experts.
Environmental Impact of Desalination	Brine discharge and excessive energy consumption contribute to ecological damage.	Development of circular economy models to recycle waste from desalination and use mangrove-based systems for sustainable filtration.

Issue	Impact	Economic Solutions & Strategies
Political and Economic Dependencies	Gaza's reliance on imported water creates geopolitical and economic instability.	Strengthening regional water cooperation agreements, advocating for international policy support, and investing in local water autonomy solutions.
Future Sustainability and Climate Resilience	Uncertainty regarding long-term water security due to climate change.	Adoption of bio-inspired desalination technologies, hybrid systems integrating natural and engineered solutions, and sustainable water governance frameworks.

Source: (Weinthal *et al.*, 2005; Ayele, 2014; Kim *et al.*, 2016; Rashid and Ralph, 2017; Talhami and Zeitoun, 2020; Al-Mamun *et al.*, 2021; Simonson *et al.*, 2021; V *et al.*, 2021; Ball, 2021; Bundschuh *et al.*, 2021; Alkhadra *et al.*, 2022; American Near East Refugee Aid, 2023; Schuster *et al.*, 2024; Gajbhiye *et al.*, 2024; Moneer and Elewa, 2024; Noui and Guesbaya, 2025)

Based on the information in the table above, Gaza water crisis stems from climate change, infrastructure damage, and geopolitical challenges. Sustainable solutions like desalination, nanotechnology, and conservation strategies are crucial. International collaboration is needed to ensure long-term resilience and secure access to potable water for the population.

CONCLUSION

The damage to water infrastructure caused by military attacks has had serious consequences on the availability of clean water in Gaza, leaving only 3% of the water in Gaza suitable for consumption. Amidst these significant challenges, the role of the international community is crucial in providing support for infrastructure rehabilitation and granting access to the technologies and resources needed to address the water crisis. By focusing on infrastructure repairs, enhancing water management capacity, and developing long-term solutions, Gaza can have a chance to overcome this issue, despite the uncertainties caused by climate change and ongoing political tensions.

The water crisis in Gaza is a multifaceted issue driven by climate change, geopolitical constraints, and deteriorating infrastructure, resulting in profound socio-economic and public health implications. The increasing scarcity of potable water exacerbates vulnerabilities within the region, affecting both immediate survival and long-term sustainability. Addressing this challenge necessitates the integration of advanced desalination technologies, nanotechnology-driven filtration systems, and enhanced rainwater harvesting mechanisms. Moreover, fostering international cooperation and securing long-term financial and technical support are imperative to ensuring the resilience of Gaza's water infrastructure. A holistic, interdisciplinary approach that combines scientific innovation, strategic policymaking, and sustainable resource management is crucial for mitigating the impact of water scarcity and safeguarding future generations.

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