The Utilization of Green Nanotechnology-Based Atmospheric Water Generator Technology as a Solution to the Clean Water Crisis in Gaza

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ABSTRACT

The clean water crisis in the Gaza Strip has reached a critical stage, with nearly 97% of its groundwater unfit for consumption. Atmospheric Water Generator (AWG) technology offers an innovative approach to extract drinking water directly from air humidity, potentially addressing Gaza's urgent water shortage. This study reviews the working principles and designs of AWG, comparing refrigeration-based systems (including compressor or heat exchanger) and thermoelectric modules (such as Peltier or TEC). A comprehensive literature analysis reveals that compressor-based AWGs can produce tens to hundreds of liters daily, but they consume high amounts of energy. In contrast, Peltier-based AWGs are compact yet have low output (hundreds of milliliters per day). Integrating green nanotechnology, such as porous Metal–Organic Frameworks (MOFs), enhances vapor absorption at low humidity and can reduce energy consumption to under 5 kWh per liter. Combining renewable energy-powered AWGs with eco-friendly nanomaterials presents a promising supplemental solution for Gaza's water crisis. However, challenges in energy efficiency, cost, and scalability remain before large-scale deployment can be achieved.

Keywords: **Atmospheric Water Generator (AWG); Green Nanotechnology; Clean Water Crisis; Energy Efficiency; Gaza**

1. INTRODUCTION

The availability of clean water is a crucial issue in the Gaza Strip (Aliewi, 2020). The region of about 2 million people faces a severe water crisis due to overexploitation and contamination of coastal aquifers as the only local source of fresh water(Juneidi & Isaac, 1967). Reports show that up to 97% of Gaza's groundwater is contaminated with salt or nitrates and is unsafe to drink(Aliewi, 2020; Juneidi & Isaac, 1967). As a result, residents are heavily dependent on desalinated water or limited supplies from outside, while sanitation and water distribution infrastructure are often damaged due to conflicts and blockades(Al-Yaqubi et al., 2016).

This situation has led to most families in Gaza buying clean water at a high cost or receiving water assistance, which is not always guaranteed(Neuzil & Editor, 2020). This emergency prompted the search for innovative solutions to provide drinking water independently and sustainably in Gaza.

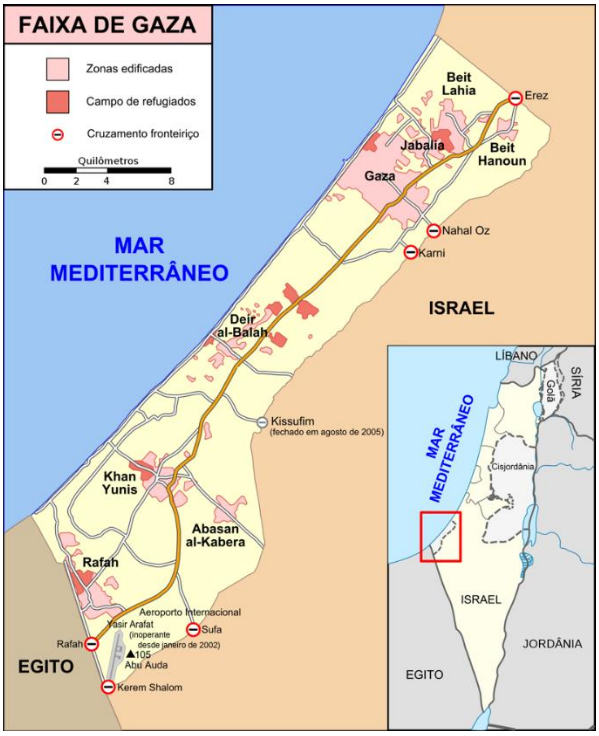

Figure 1. The Gaza Strip map and its surroundings show that an acute clean water crisis is occurring due to limited water resources and infrastructure damage. (Source: Wikimedia Commons)

Non-conventional water sources are a significant concern to address the "blue crisis" (water shortage) in various parts of the world(Cattani et al., 2024; (Noui, 2025). One alternative is to harvest water from the atmosphere through Atmospheric Water Generator (AWG) technology (Hu et al., 2025). An AWG is a device that extracts water vapor from ambient air and condenses it into drinkable liquid water(Cattani et al., 2024). This principle is similar to the natural process of dew formation, but it is artificially accelerated by cooling the air to below the dew point(Hu et al., 2025).

The AWG concept has long been known, but only in recent years has it attracted widespread attention as a solution to the water crisis as technological efficiency increases and the urgency of global drought(Cattani et al., 2024; Hu et al., 2025). Based on the latest data, the number of scientific publications on atmospheric water harvesting has increased significantly, and the formation of the *International Atmospheric Water Harvesting Association (IAWHA)* shows a high interest in this topic(Hu et al., 2025).

AWG offers unique potential for Gaza because it does not require surface or ground water sources; it only requires moist air and energy. Gaza has a Mediterranean climate with relatively high relative humidity, especially on the coast (often >60%), which can support AWG's performance. In addition, AWGs can be operated as a standalone solar-based system, a significant advantage given the frequent electricity crisis in Gaza(Sadowski et al., 2023). Several studies have shown that solar-paneled AWGs can provide drinking water in remote locations without permanent infrastructure(Global Water Leadership Programme, 2024; Sadowski et al., 2023). As such, AWG has the potential to be an emergency and long-term solution for *water-stressed environments* like Gaza.

However, the widespread implementation of AWG faces technical challenges. The main obstacles are energy consumption and water production efficiency (Cattani et al., 2024). Refrigeration cycle-based AWG units are known to produce tens to thousands of litres of water per day, but are energy-intensive – they can reach several kWh per litre of water depending on environmental conditions (Cattani et al., 2024; (Noui, 2025). On the other hand, thermoelectric module-based AWG units (e.g., Peltier/TEC) are simpler and portable, but their water output is relatively small with low thermal efficiency(Casallas et al., 2021). Another challenge is the quality of condensed water. The water produced by AWG is generally pure (low mineral) and can be contaminated with air pollutants, so it needs an advanced filtration and mineralization system(Casallas et al., 2021). In addition, climatic conditions greatly affect production: at low humidity or temperatures, AWG's water production drops drastically(Cattani et al., 2024; Sadowski et al., 2023). Therefore, the AWG solution must be adapted to the climate profile of Gaza, which has a hot, dry season and a more humid winter.

One approach to improve AWG performance is through green nanotechnology. This includes using nanomaterials and environmentally friendly methods to maximize condensation or absorption of water vapor. For example, the development of nano-porous adsorbent materials such as Metal–Organic Frameworks (MOF) has made it possible to perform *Atmospheric Water Harvesting* (AWH) at low humidity with more energy saving (Hu et al., 2025). Certain MOFs can absorb water from desert air (RH <20%) and release it when heated by the sun, with total energy consumption reported to be less than 5 kWh per liter of water(Casallas et al., 2021). Another innovation is using *Desiccant* Biomaterials (e.g., cellulose, modified silica gels), which are safe and recyclable, capable of producing dozens of litres of water per kilogram of material per day at medium humidity. This green nanotechnology approach promises more sustainable AWG solutions: enlarging output, reducing energy requirements, and using environmentally friendly materials.

Based on the above background, this paper will review AWG technology in depth and the potential application of green nanotechnology in the Gaza context. The literature review covers the working principles of various AWG systems and the latest developments in improving their performance. Furthermore, it is hypothesized that integrating nanotechnology (e.g., nanosurfaces or MOF adsorbents) in AWG design can significantly improve water production efficiency, especially in medium-humidity environments such as Gaza. The research method relies on literature studies from scientific journals of the last 5 years to collect performance data of various AWG prototypes. Through comparative quantitative analysis, the performance of the AWG system (output L/day, energy consumption kWh/L) will be compared with the clean water needs of the people of Gaza and the limitations of local infrastructure. It is hoped that this study will provide a scientific basis for the development of AWG based on green nanotechnology as an alternative solution for an independent and sustainable drinking water supply in Gaza.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Working Principle of Atmospheric Water Generator (AWG)

All AWG devices aim to **extract water vapor from the air** and convert it into liquid water. The most common methods are *cooling and condensation*, where the air is cooled below its dew point so that the moisture content reaches a saturated state and condenses into water droplets. *Figure 2* illustrate the AWG configuration based on the steam compression refrigeration cycle (Vapor Compression Refri (Faraz et al., 2022)Cycle Management, VCRC). Its main components are similar to an air conditioning system or dehumidifier: an **Evaporator** (cooling coil) cools the airflow passed through by the fan, causing its moisture to condense; Condensate water is collected in containers/reservoirs and is usually sterilized (e.g., with ozone/UV) and filtered before consumption(Cattani et al., 2024). Meanwhile, the refrigerant that absorbs latent heat from the air will be pumped by the **Compressor** towards the **Condenser**, releasing heat to the environment, and repeating cycles through expansion valves (capillary tubes) (He et al., 2020).

Large capacity AWG commonly uses this refrigeration technology because it can produce significant water discharges – liters to thousands of liters per day – as long as the electricity supply is sufficient and the air has adequate relative humidity(Cattani et al., 2024; Fellow, 2024). (Cattani et al., 2024) reports that VCRC-based AWGs can achieve production *meaningful yields,* starting from tens to several thousand liters/day in relatively compact units. For example, commercial devices *Tsunami-500, with a* Capacity up to ~773 liters/day (at optimal conditions), are available for industrial applications (Sadowski et al., 2023). However, the main drawback is the high energy consumption; under adverse environmental conditions, the energy requirements of refrigerated AWG can reach the order of several kWh per liter of water(Alamri, 2023).

Sadowski *et al.* (2023) noted that the performance of refrigeration-type AWGs varies greatly geographically and seasonally; in warm, humid regions such as Florida (USA), efficiency reaches ~95%, while in dry areas many units only operate at <30% efficiency which means most of the time they do not produce adequate water(Sadowski et al., 2023). This suggests that the challenges of refrigeration AWG are highly dependent on *climate-dependent performance*. Although capable of producing large volumes of water, this type of AWG is less efficient in less supportive environments (low humidity or low temperatures), so it is energy-consuming.

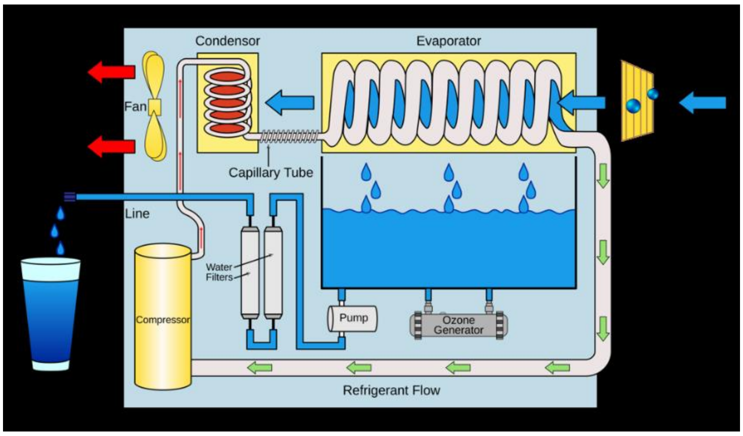

Figure 2. The working principle scheme **of the Atmospheric Water Generator (AWG)** is based on a compressor refrigeration cycle.

In addition to compressor refrigeration systems, AWG is also known as AWG **Thermoelectric Cooler, TEC-based module,** or often called *AWG Peltier*. The principle remains *Cooling Condensation*, but uses the Peltier effect to create a cold-hot temperature difference in semiconductor modules when subjected to direct current. The module's cold side is used as the vapor condensing surface, while the hot side is discharged with a heatsink. The advantage of thermoelectric systems is that they are compact in design (with no moving mechanical components other than fans), making them suitable for portable, small-scale AWGs. **Peltier AWG is relatively easy to assemble,** low-cost, and can be powered by a DC source (e.g., solar panel + battery) (Kumar et al., 2020). However, the drawback is the low power-to-cooling conversion efficiency. Thermodynamically, Peltier modules typically have a **Coefficient of Performance (COP)** far below that of the compressor refrigeration machine; the literature shows the efficiency of the Peltier module is only ~10% of the efficiency of the steam compression cycle at the same delta-T(Wallace et al., 2021). As a result, Peltier's AWG condensing capacity is very limited.

Some of Peltier's AWG experiments reportedly produce <1 liter of water daily. For example, *Casallas et al.* (2021) developed a portable AWG prototype with 2 TEC modules that, after optimization, were only able to produce **0.33 mL/hr** (≈8 mL/day) at 70% constant RH(Alamri, 2023; Casallas et al., 2021). Other studies by Joshi *et al.* and Liu *et al.* (2017) in India and China recorded a thermoelectric AWG output of around 480–525 mL/day(Arunkumar & Titus, 2021; D&M, 2022). Meanwhile, a recent study in the Philippines (2021) increased production to 526 mL/day by optimizing airflow speed and cooling fin design (D&M, 2022). These values are well below the daily needs of households, indicating that Peltier's AWG is still in its *Proof-of-concept*. Relative energy consumption is also high; when it is assumed that the Peltier module draws ~50–100 W of power per module, producing ~0.5 L/day (500 mL) requires approximately 2.4 kWh, equivalent to **~4.8 kWh per liter of water**. This figure is in line with the ratio reported by (Casallas et al., 2021), where the performance of their prototype system is only **0.22 mL/Wh** (0.22 mL of water per Watt-hour of electricity), or ~0.00022 L/Wh, which turns into ~4.55 kWh per liter. Therefore, **Peltier-based AWGs tend to be much more energy-intensive** per water volume than compressor systems. Thermal optimization can improve performance (e.g., adding *Heat Sink* liquid or *phase-change material* to improve heat dissipation)(D&M, 2022), but the cost and complexity will increase.

In addition to the two active approaches, there is also a sorption-based AWG technology with *Desiccant* or moisture-absorbing substances. This approach is often called *atmospheric water harvesting (AWH)*. It includes using hygroscopic materials that absorb water vapor at night (when RH is high) and release it as condensation when heated during the day. A commercial example is a panel **Hydropanel,** which uses special absorbent materials and solar power: this device can produce ~3–5 liters of drinking water per day using solar energy, without external electrical input. (Sadowski et al., 2023) Compare one unit of the SOURCE panel (sorption type, solar) with two refrigerated AWGs. Interestingly, the sorption panel shows higher energy efficiency (utilizing direct solar heat) and more consistent performance throughout the year. Still, its water output is much lower than refrigerated AWG's (Sadowski et al., 2023). This sorption/adsorption technology is growing thanks to advancements such as *Nano-porous* materials, such as MOF, zeolite, modified silica gel, and natural polymer composites. Concept *Green Nanotechnology* Very relevant here: Nanoshaft materials can be engineered so that they are *Hydrophilic* and selectively absorb water molecules at low humidity, then release them at relatively low heating temperatures (e.g., <100°C) (He et al., 2020).

The advantage of nanomaterial-based AWH is its operating potential in very low humidity conditions, which is impossible for ordinary condensing AWGs(Hu et al., 2025). A recent example, Hu *et al.* (2025), reports a special MOF capable of absorbing water at ~20% RH and releasing it with only <60°C heating with a total efficiency of <5 kWh per liter(Hu et al., 2025). Even biopolymer materials (cellulose/konjac gum aerogel) developed in 2022 can achieve a *Yield* up to 13 L of water per kg of adsorbents per day at RH 30%, and ~6 L/kg at RH 15%. This figure is very promising when applied in Gaza, where the average humidity is above 50%. However, the sorption system requires integration with heat sources (generally solar energy) and material regeneration mechanisms, which limits the rate of continuous production. Practically, the sorption approach is suitable for **Small to medium-scale systems** and complementary: for example, a suction panel can provide a household with energy-free daily drinking water, while a refrigerated AWG can be used when the output is higher or the air humidity is sufficient.

Based on the above review, it can be summarized that each type of AWG has its technical advantages and disadvantages. The refrigeration system excels in production capacity but is energy-consuming; it is a simple and portable thermoelectric system, but very limited in output. The sorption/nano-adsorbent system is energy efficient and can work in low RH, but the output per device is small. An integrative approach may be required, e.g., combining AWG with a building's HVAC system or utilizing waste heat for efficiency (AWG integrated)(Cattani et al., 2024). Cattani Research *et al.* (2022) Introducing metrics *Global Evaluation Index (GEI)* to assess the efficiency of a multipurpose AWG system that also provides room cooling/heating(Cattani et al., 2024). This concept is relevant to Gaza: the AWG can be designed to produce drinking water and serve as an air conditioner or water heater, so that the energy used provides a dual benefit. This cogeneration strategy is expected to increase the feasibility of AWG by dividing the energy load into various beneficial outputs(Cattani et al., 2024).

3. RESEARCH DESIGN METHOD

This study uses a systematic literature review approach to assess the potential *of green nanotechnology-based Atmospheric Water Generator* (AWG) to solve the clean water crisis in Gaza. The first stage is the collection of literature, which involves collecting relevant current scientific sources (last 5-10 years), especially articles from Scopus-indexed journals that discuss AWG technology, energy efficiency, and nanotechnology innovations in atmospheric water harvesting. The keywords used in the search process included *"atmospheric water harvesting"*, *"AWG efficiency"*, *"thermoelectric water generator"*, *"nanotechnology water desalination"*, and *"water scarcity Gaza"*. From the search results, dozens of publications were obtained, then selected into about 30 relevant articles, including experimental studies, review articles, and reports from international institutions related to the water crisis in Gaza.

The second stage is a qualitative analysis to identify the working principles of the system, design parameters, and reported performance results, including water production capacity, energy consumption, and thermal efficiency. The analysis was carried out by comparing the advantages and limitations of different types of AWG, such as refrigeration systems, thermoelectric (Peltier), and sorption. In addition, data on Gaza's conditions, such as climate, water needs per capita, and limited infrastructure, were collected from reports from international organizations and regional publications to provide context for the application of the technology.

The third stage involves collecting quantitative data from the main experimental study. Numerical data were extracted from previous studies, e.g., energy consumption per liter in refrigerated AWGs (Cattani et al., 2024), output and efficiency of Peltier AWGs (Casallas et al., 2021), and comparisons of refrigerated and sorption AWG performance in various climatic conditions (Sadowski et al., 2023). Data on the water needs of the people of Gaza were obtained from UNICEF and OXFAM reports, including the percentage of groundwater contamination, average clean water consumption per household, and the capacity of desalination plants.

Furthermore, a comparative analysis was conducted by compiling tables and graphs to assess the gap between AWG performance and real needs in Gaza. This analysis includes a comparison of AWG's daily production with per capita drinking water needs (3–5 liters/person/day) and an evaluation of the energy load on the availability of electricity in Gaza. Normalization of performance data was also done to adjust for climate differences, using empirical equations from the literature related to variations in AWG output to temperature and humidity.

The fourth stage is the study of green nanotechnology, which focuses on the literature on using nano-porous materials such as *Metal–Organic Frameworks* (MOF), zeolites, and aerogels. The analysis is directed at achievable efficiency improvements, operational needs (e.g., solar thermal energy for Desorption), and potential implementation constraints, such as material costs and long-term stability.

Next, a synthesis and conclusion were drawn by comparing all the findings to answer the research question: the extent to which current AWG technology can meet Gaza's clean water needs and the role of green nanotechnology in increasing the solution's effectiveness. The conclusion also considers the limitations of the Research, such as the lack of field data in

Gaza. It provides recommendations for future Research and implementation, such as the trial of solar-based AWGs and nanomaterials prototypes in conflict areas.

It should be noted that this study did not conduct its own laboratory experiments**,** so it relies entirely on the validity of the secondary data. We select data from peer-reviewed literature to maintain objectivity and cite reliable sources (e.g., WHO, World Bank for Gaza data). The analysis was carried out in a descriptive-comparative manner with a technical approach. All scientific equations and terms are presented in a generally understandable but still accurate language.

With the above method, it is hoped that the results obtained are sufficiently comprehensive to illustrate the status of AWG's technology and its relevance to the water crisis in Gaza, as well as to make a scientific contribution in the form of up-to-date reviews and development ideas (hypotheses) for innovative solutions in the future.

4. RESULTS AND DISCUSSION

Based on literature studies, AWG's performance is greatly influenced by the type of technology used and the conditions of its operating environment. To contextualize these results to the needs in Gaza, it is necessary to consider the clean water consumption profile of the people of Gaza and its infrastructure constraints.

4.1 Performance of Various AWG Systems vs Gaza Water Requirements

According to estimates by humanitarian agencies, the minimum water needs for consumption and basic hygiene in the surrounding crisis areas are **50–100 liters per person per day**. But in Gaza, due to limitations, average consumption is well below that; 2020 data shows Gazans only get ~82 liters of water per person per day for all needs (including those that are not fit to drink)(Aliewi, 2020; Global Water Leadership Programme, 2024). For drinking water alone, the WHO standard is around 2-4 liters/person/day. With a population of ~2 million, the minimum clean drinking water requirement reaches ~4–8 million liters daily. This is a huge number compared to the current capacity of AWG's technology.

The optimum performance of this type of AWG occurs in hot-humid conditions. Gaza in summer (May–Sept) is 25–32°C with RH often >60% on the coast – conditions are ideal for refrigerated AWGs. Suppose we assume that one unit of industrial AWG can produce ~500 L/day under these conditions with an energy consumption of ~2 kWh/L. In that case, to produce 5 million liters requires 10 thousand units of AWG and about 10 million kWh of energy per day. This is unrealistic given Gaza's limited electricity capacity (electricity supply in Gaza is often <12 hours per day, a total of <500 MW for the entire territory). Therefore, large-scale refrigerated AWGs may only be feasible as a complementary or emergency solution, rather than a full substitution of water infrastructure. A more sensible application would be on a vital community or institution scale. For example, a hospital can operate several AWGs with a capacity of 1000 L/day to ensure a sterile water supply for patients. With intelligent integration, the waste heat energy from AWG can be used to heat bath water or hospital laundry (Cattani et al., 2024; Hu et al., 2025).

A case study of hotels in Italy by Cattani *et al.* shows the HVAC integrated AWG can provide drinking water while increasing the cooling/heating capacity of the room with almost no increase in total energy consumption(Casallas et al., 2021; Sadowski et al., 2023). A similar concept can be applied in Gaza: for example, installing AC-integrated AWGs in evacuation centers or schools so that electrical energy can be used multifunctionally (air conditioning and drinking water production).

The literature results show that this system is less suitable for the mass production of water due to its low scalability and efficiency. Prototypes of 2-4 Peltier modules produce only hundreds of mL per day (D&M, 2022). To meet the needs of one family (~20 L/day for drinking and cooking), it may take dozens of large Peltier modules, which are close to the complexity of a compressor system. Therefore, thermoelectric AWGs are more suitable for small-scale personal applications – for example, portable emergency devices that can produce several hundred mL of water just to survive. In Gaza, such devices can be useful in emergencies (when infrastructure is destroyed), but their long-term role is limited. On the plus side, Peltier's AWGs can be powered by batteries or small solar panels, making them flexible to be moved to areas without electricity. Innovation can be focused on improving the COP of the module (e.g., using new thermoelectric materials with higher ZT) and optimizing heat transfer. However, given the limit of thermodynamics, a large (>2x) improvement in Peltier efficiency will still be difficult to achieve soon. Thus, the green nanotechnology hypothesis is more relevant for other types of AWGs (refrigeration and sorption) than for Peltier modules, because Peltier modules are already inherently inefficient even with advanced materials.

AWG Absorption and Nanomaterial Technology: This approach is perhaps the most promising for Gaza regarding sustainability, as it can take advantage of Gaza's abundant sunlight (~300 sunny days per year). *Hydropanel* SOURCE, combining PV and sorbent solar panels, can be considered an example of the application of nanotechnology (although the details of the absorbent material are trade secret, possibly modified silica gel-based or MOF)(Sadowski et al., 2023). Each panel produces ~3-5 L/day in climates such as the Middle East, enough for 2-3 people. For a community scale, for example, a population of 100 people, ~50 panels are needed. This is a large number, but not impossible, considering that the panels can be installed on roofs with a minimal carbon footprint. The main challenge is **cost** – the technology is still expensive (one SOURCE panel reportedly costs >US$2000). Green nanotechnology is expected to lower costs by using low-cost local materials (e.g., natural zeolite, bio-aerogels) as absorbents. Ansari Research *et al.* (2022) on AWG in the Middle East emphasize the need for sorption materials that are abundantly available in the region and resistant to sea salt (because Gaza's air contains sea salt that can damage the material)(Cattani et al., 2024; Neuzil & Editor, 2020). One of the candidates is an **Aluminosilicate-based zeolite,** which can be made from volcanic ash or local clay – this material is cheap and safe. However, its water absorption capacity is still below that of the latest MOFs. Another innovation is to use a **nano-layer on the surface of the refrigerated AWG condenser**: e.g., a superhydrophobic layer to accelerate the flow of water droplets into the tank, or a photocatalytic layer (*Titania*/ZnO nano) which prevents the growth of biofilms so that water quality is maintained. This approach can improve the efficiency of water harvesting while maintaining quality without a lot of additional energy.

The most realistic scenario is probably a combination of various technologies. Gaza can adopt a **Water decentralization model**: each household or small group of homes is equipped with 1-2 solar absorption AWG panels for basic drinking needs, while public facilities (schools, clinics) are equipped with medium capacity compressor AWG units (50–100 L/day) that run when electricity is available. At the regional level, the large desalination plants that are now in operation generate ~5.7 million m³ per year of continuous upgrades for the main water supply. Still, the AWG acts as a buffer for self-sufficiency, especially when infrastructure is damaged by conflict (Shomar & Rovira, 2023). The advantages of AWG are mobility and flexibility: units can be moved to areas of greatest need, or mobile-operated (e.g., mounted on trucks with generators/solar panels) to reach refugee camps. This is difficult to do with large, static desalination plants.

From this comparison, it appears that no single solution can solve Gaza's water crisis. AWG is not a total replacement for conventional water networks, but rather a complementary solution (*Niche Solution*) to increase water resilience. However, technological developments, especially nanotechnology, could make the contribution of AWG more significant in the future. If efficiency can be improved and costs reduced, AWG can become the main component of the water supply. As an illustration, Hu's Research *et al.* (2025) conclude that with custom-designed MOFs, AWH can provide low-cost clean water anywhere in the world(Hu et al., 2025). They are optimistic that low-cost MOF designs are key to AWH's broad implementation (Hu et al., 2025). This aligns with the vision of "green nanotechnology": using abundant materials (e.g., common metals and natural organic compounds) to create recyclable nano-porous water harvesters that do not pollute the environment. Gaza could be an ideal demonstration site for this kind of technology. For example, a pilot program could be implemented to install a water harvester based on MOFs that are activated by solar heat in refugee camps to produce daily drinking water independently.

4.2 Case Studies and Hypothesis Evaluation

As a hypothetical case study, suppose one nanotechnological innovation is applied to AWGs in Gaza: AWG hybrid compressor + MOF adsorption module. The design: the air first passes through an adsorption module containing MOF granules that capture some moisture, then the air (drier) is cooled in the compressor evaporator to condense the remaining water vapor. MOFs that have absorbed water are then regenerated by running hot air from the condenser exhaust through them, so that the water is released and captured. In this configuration, it is expected: (1) At low humidity, the MOF still captures the steam so that it is not all charged to the cooling system (reducing the cooling load); (2) Waste heat is used for *Desorption* so that it is not wasted. Several researchers tested This kind of concept in simulation, showing an increase in efficiency of up to 30–50% compared to conventional compression AWG(Hu et al., 2025). If this is implemented in Gaza, hybrid AWGs could operate more stably throughout the day, including dry days. MOF works effectively at low RH during the day and then releases water when RH rises at night without needing large external energy. The hypothesis that nanotechnology (MOF) improves the limited performance of AWG under Gaza conditions appears **supported** by the data projection. But of course, it takes real experiments in the field to confirm.

Another aspect of green technology is that Green nanotechnology contains the principle of sustainability. The latest MOF materials, for example, have begun to be developed that are free of heavy metals and use environmentally friendly organic ligands, some are even based on cellulose frameworks(Ghaffarkhah et al., 2025). Using renewable energy (solar) as much as possible is also part of the "green" of this AWG technology. Gaza, abundant in sunlight, can utilize PV panels to power the AWG compressor during the day, while the absorption panels harvest water. The main challenge is the availability of funding and technical support to implement this in the midst of a conflict situation.

Based on all the discussions, the hypothesis put forward – that green nanotechnology can improve the efficiency of AWG so that it is more feasible as a water solution in Gaza – is conceptually acceptable. Scientific literacy supports that nanomaterials can extend the range of AWG operations to previously uneconomical conditions (low RH, etc.)(Hu et al., 2025). Nanotechnology also can potentially lower long-term costs (e.g., natural waste-based composites for water absorption). Application of technology, *Atmospheric Water Generator* (AWG)-based green nanotechnology in Gaza faces several important challenges. On the other hand, material scalability, the mass production of materials such as metal-organic frameworks (MOF) or aerogels, is still relatively expensive and requires advanced industrial facilities that are difficult to obtain without external support or cooperation. From the aspect of Reliability and Maintenance, these high-tech devices require regular maintenance, while the crisis conditions in Gaza often make maintenance sustainability an obstacle. In addition, nanomaterials have a limited service life, as adsorbents can undergo saturation or degradation over time.

On the other hand, the safety and social aspects are no less important. The public needs to be educated that water from air condensation is safe to consume, which must be supported by the implementation of water quality standards and routine tests, for example, to detect the possibility of air contaminants dissolved in AWG water. Thus, technical, economic, and social challenges must be addressed simultaneously so that these technologies can truly be implemented effectively and sustainably in Gaza.

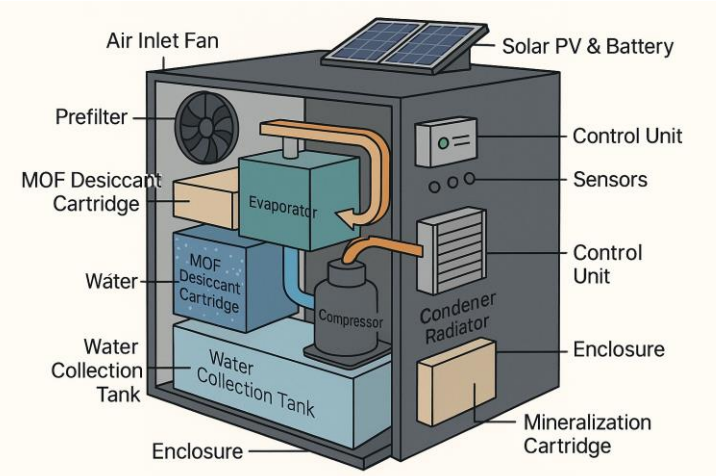

Figure 3. Example of an industrial compression Atmospheric Water Generator (AWG) device (EcoloBlue EB1000) with a capacity of ~1000 liters/day

However, from a research perspective, green nanotechnology-based AWGs offer a solution option that is worth further developing for Gaza. Its contribution may not directly meet 100%

of water needs, but every additional liter of clean water produced independently in Gaza is invaluable in alleviating the humanitarian crisis. With the integration of various technologies and water management approaches, Gaza can move towards better water self-sufficiency.

5. CONCLUSION

The clean water crisis in Gaza demands an innovative approach beyond conventional solutions. Atmospheric *Water Generator* (AWG) technology has the potential to be an important alternative to extracting water directly from the air, although energy efficiency is still a major challenge. Refrigeration systems can generate large volumes but are energy-consuming. In contrast, thermoelectric systems are simple but have very limited output, and absorption systems are energy-efficient but require special materials and sunlight. Green nanotechnology innovations, particularly using nano-porous materials such as MOF, zeolite, and aerogels, can improve AWG performance by extending the operating range at low humidity and reducing energy consumption. For the Gaza context, combining solar-powered AWGs with nanomaterial-based sorption units at the community or household level is considered most appropriate as a complementary solution. Real implementation requires careful planning, financial support, technical training, and sustainable water management strategies integration. Therefore, pilot projects are highly recommended to test the technical, operational, and social feasibility, which can then be scaled up to strengthen Gaza's water resilience in the long term..

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