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SUSTAINABLE ATMOSPHERIC WATER HARVESTING: DESIGN AND DEVELOPMENT OF THE GREEN H_2O J-9 SYSTEM FOR POTABLE WATER PRODUCTION FROM HUMID AIR

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ABSTRACT
Water scarcity affects approximately 2 billion people worldwide, necessitating innovative solutions for sustainable water production independent of traditional infrastructure. This research presents the comprehensive development and optimization of a portable atmospheric water generation (AWG) system capable of extracting high-quality drinking water from ambient humid air through controlled condensation processes. The study employed a systematic three-phase experimental development approach, progressing from a basic 12V proof-of-concept system that produced 4.8 liters per day to a full-scale 0.5-ton capacity unit utilizing R410A refrigerant and fin-type copper tube condensers, achieving a production rate of 40 liters per day. The final system configuration, designated as the Green H_2O J 9 Machine, incorporates a high-capacity 250 M^3/hr suction fan, multi-stage water filtration with UV sterilization, and intelligent control systems optimized for operation across ambient temperatures of 20°C to 45°C and relative humidity levels from 30% to 100%. Comprehensive performance testing demonstrated consistent water production rates of 1.5 liters per hour under standard atmospheric conditions (30°C temperature, 60% relative humidity), with energy consumption efficiency of 3-4 kWh per liter produced. Rigorous water quality analysis confirmed full compliance with World Health Organization drinking water standards, achieving neutral pH (7.0), low total dissolved solids (80 mg/L), zero chlorine content, and complete microbial safety through integrated treatment systems. The system's compact design specifications (70cm H × 44cm W × 35cm D, 30kg weight) and exceptionally quiet operation (<30 dB noise level) make it suitable for diverse applications, including residential households, commercial installations, emergency response scenarios, and remote operations. Economic viability analysis indicates favorable capital cost recovery periods of 2-4 months in markets with expensive bottled water or unreliable municipal water supplies, with operational costs significantly lower than those of traditional water sourcing methods. This research conclusively demonstrates that atmospheric water generation technology offers a technically viable, economically feasible, and environmentally sustainable decentralized solution for drinking water production, particularly valuable in water-stressed regions, disaster-affected areas, and locations lacking traditional water infrastructure.

KEYWORDS: Humid air, Generator, Condensation, Water Filtration, Drinking water

1. INTRODUCTION

Water scarcity represents one of the most pressing challenges facing humanity in the 21st century. According to the United Nations, approximately 2 billion people worldwide lack access to safely managed drinking water at home, while 3.6 billion people lack safely managed sanitation(Musie &Gonfa, 2023). This crisis is particularly acute in arid and semi-arid regions, where traditional water sources such as rivers, lakes, and groundwater are either scarce or heavily depleted. Climate change has further exacerbated these challenges, resulting in prolonged droughts, altered precipitation patterns, and increased variability in water availability across various geographical regions(Joshi et al., 2017; Panuthara et al., 2019). The conventional approach to addressing water scarcity has primarily focused on large-scale infrastructure projects such as desalination plants, water treatment facilities, and extensive pipeline networks. While these solutions have proven effective in certain contexts, they often require substantial capital investment, extensive maintenance, and centralized distribution systems that may not be feasible in remote or economically disadvantaged areas. Furthermore, many of these traditional methods are energy-intensive and may have significant environmental impacts, making them less suitable for sustainable development goals(Ahuja, 2017; Musie &Gonfa, 2023).

In this context, atmospheric water generation (AWG) has emerged as a promising alternative technology that can provide decentralized, sustainable access to clean drinking water. The atmosphere contains an estimated 10,400 cubic kilometers of water in the form of vapor, representing a vast, renewable resource that is continuously replenished through the natural water cycle(Ansari et al., 2022). This atmospheric moisture exists everywhere on Earth, even in arid regions, making it a potentially universal source of freshwater that can be harvested independently of traditional water infrastructure. The concept of extracting water from atmospheric humidity is not a new one(Zhou et al., 2020). For centuries, various cultures have developed methods to collect water from air, ranging from simple dew collection

systems to more sophisticated fog nets. However, modern atmospheric water generation technology represents a significant advancement in both efficiency and scalability, utilizing sophisticated thermodynamic principles and advanced materials to maximize water extraction while minimizing energy consumption(Feng et al., 2022). The fundamental principle underlying atmospheric water generation involves the controlled condensation of water vapor present in ambient air. This process relies on the relationship between temperature, humidity, and the saturation point of air. When air is cooled below its dew point temperature, the water vapor it contains begins to condense into liquid droplets that can be collected and processed. The amount of water that can be extracted depends primarily on the relative humidity of the ambient air and the efficiency of the condensation system. Relative humidity plays a crucial role in determining the feasibility and efficiency of atmospheric water generation. In regions with high humidity levels, such as tropical and subtropical areas, the potential for water extraction is significantly higher(Rajkumar et al., 2018). However, even in relatively dry climates, substantial amounts of water can be harvested if the technology is optimized appropriately. The dew point temperature, which represents the temperature at which air becomes saturated with water vapor, serves as a critical parameter in designing effective AWG systems(Ansari et al., 2022; Feng et al., 2022).

Modern atmospheric water generation systems employ various technological approaches to achieve efficient water extraction. The most common method involves cooling ambient air using refrigeration systems, thermoelectric coolers, or other heat exchange mechanisms. As the air temperature drops below the dew point, water vapor condenses on specially designed surfaces, typically finned heat exchangers or condensing coils that maximize the surface area available for condensation(Faraz Ahmad et al., 2022). The design of the condensing system is critical to the overall efficiency of the atmospheric water generator. Fin-type condensers, which feature extended surface areas through the use of metallic fins, have proven particularly effective in maximizing heat transfer and condensation rates. These systems can be optimized for specific climatic conditions and operational requirements, allowing for flexible deployment across diverse geographical regions(Faraz Ahmad et al., 2022; Zhu et al., 2025). Energy efficiency represents one of the most significant challenges in atmospheric water generation technology. The process of cooling air to extract water vapor requires substantial energy input, particularly in hot and dry climates where the temperature differential between ambient conditions and the required dew point is large. Therefore, the development of energy-efficient AWG systems has become a primary focus of research and development efforts in this field. The potential applications for atmospheric water generation technology are diverse and far-reaching(kamil, 2020; Panuthara et al., 2019; Rajkumar et al., 2018). In residential settings, compact AWG units can provide households with a reliable source of clean drinking water, independent of municipal water supplies or groundwater resources. This capability is particularly valuable in areas where water quality is questionable or where water supply infrastructure is unreliable(Ashour et al., 2025).

Commercial and industrial applications include the deployment of larger-scale AWG systems to support businesses, institutions, and communities. These systems can be designed to produce hundreds or thousands of liters of water per day, making them suitable for schools, hospitals, hotels, and small communities. The scalability of AWG technology enables customized solutions that meet specific water production requirements while maintaining economic viability. Emergency and disaster relief represents another critical application area for atmospheric water generation technology(Preetha et al., 2025). During natural disasters, traditional water infrastructure is often damaged or contaminated, leaving affected populations without access to safe drinking water. Portable AWG units can be rapidly deployed to disaster areas to provide immediate water relief while permanent infrastructure is being restored. Military and remote operations also benefit significantly from AWG technology. Military forces operating in remote locations frequently encounter substantial logistical challenges in transporting and storing water supplies. Atmospheric water generators can reduce dependence on supply chains and provide troops with a reliable local source of clean water. Similarly, remote research stations, mining operations, and off-grid communities can benefit from the independence and reliability offered by AWG systems(Ahuja, 2017; Preetha et al., 2025).

The primary objective of this research project is to develop a portable atmospheric water generation device that can meet the drinking water requirements of a typical household while maintaining high standards of water quality, operational safety, and user accessibility. The device is designed to function effectively in various climatic conditions, particularly in regions with significant atmospheric humidity, such as temperate zones, desert areas with seasonal humidity variations, rainforest regions, and flood-prone areas where traditional water sources may be compromised. Three fundamental requirements have been identified as essential for ensuring the effectiveness and practical applicability of the proposed design. First, simplicity of use is paramount to ensure that the device can be operated by individuals with limited technical experience. This requirement necessitates an intuitive user interface, automated operation modes, and minimal maintenance requirements. The design must incorporate clear operational indicators and safety features that prevent misuse or accidental damage. Second, safety of machine design is crucial to protect users during all phases of operation. The device must comply with relevant safety standards and regulations, incorporating appropriate safeguards against electrical hazards, mechanical risks, and potential exposure to refrigerants or other system components. All user-accessible surfaces must remain at safe temperatures, and the device must include appropriate emergency shutdown mechanisms. Third, the quality of water produced by the system must conform to World Health Organization (WHO) drinking water quality standards. This requirement necessitates the integration of effective water treatment and purification systems that can remove potential contaminants, adjust pH levels, and ensure microbiological safety. The device must be capable of producing water that is not only safe for consumption but also palatable and nutritionally appropriate.

Beyond the fundamental requirements, several additional goals have been established to optimize the performance and market viability of the atmospheric water generation device. Flexibility in power source represents a critical design goal that ensures the device can operate in various infrastructural contexts. The system should be capable of operating on standard household electrical power while also providing options for alternative power sources such as solar panels, batteries, or generators. This flexibility is essential for deployment in areas with unreliable electrical infrastructure or for emergency applications. Maximizing efficiency is another key goal that directly impacts both the operational cost and environmental sustainability of the device. The design should optimize the water production rate per unit of energy consumed, incorporating advanced heat recovery systems, intelligent control algorithms, and high-efficiency components. Efficiency optimization also extends to water recovery rates, ensuring that the maximum possible amount of atmospheric moisture is captured and converted to usable water. Minimizing cost represents a crucial consideration for ensuring widespread adoption and accessibility of the technology. This goal encompasses both capital costs (the initial purchase price of the device) and operational costs (energy consumption, maintenance, and consumable replacement). Cost optimization requires a careful selection of materials, components, and manufacturing processes that maintain performance and reliability standards. The water production capacity of the device should be sufficient to meet the basic drinking water needs of a household, typically estimated at 2-4 liters per person per day for drinking purposes. However, the system should also be capable of scaling production rates based on household size and local climatic conditions.

This research project employs a fin-type condenser design to achieve the required dew point temperatures for effective water condensation. The fin-type configuration offers several advantages over alternative condenser designs, including enhanced heat transfer efficiency, increased surface area for condensation, and improved resistance to fouling and corrosion. The condenser design is optimized for operation across a wide range of humidity conditions, with a particular focus on maximizing performance in high-humidity environments. The relationship between relative humidity and dew point temperature is fundamental to the operation of the atmospheric water generation system. Higher relative humidity levels result in higher dew point temperatures, which reduces the energy required for cooling and increases the overall efficiency of water production. The system is designed to automatically adjust its operation parameters based on ambient conditions, optimizing performance while minimizing energy consumption(Joshi et al., 2017; kamil, 2020; Rajkumar et al., 2018).

The research methodology incorporates comprehensive testing and validation procedures to ensure that the device meets all performance and safety requirements. This includes laboratory testing under controlled conditions, field testing in various climatic environments, and long-term reliability assessments. Water quality testing is conducted throughout the development process to ensure compliance with WHO standards and to optimize the integrated purification systems. The development of efficient, portable atmospheric water generation technology represents a significant contribution to addressing global water scarcity challenges. This research project aims to develop a practical, accessible solution that provides households with reliable access to clean drinking water while maintaining high standards of safety, efficiency, and cost-effectiveness. The significance of this research extends beyond the immediate technical achievements to encompass broader implications for sustainable development, disaster preparedness, and energy-efficient water production. By harnessing the abundant moisture present in Earth's atmosphere, this technology offers a path toward water independence that can benefit communities worldwide, particularly those in water-stressed regions or areas lacking traditional water infrastructure. The successful completion of this research project will contribute valuable knowledge to the growing field of atmospheric water generation while providing a practical tool for addressing one of humanity's most fundamental needs. The portable nature of the proposed device, combined with its focus on simplicity and safety, positions it as a valuable addition to the toolkit of technologies available for ensuring universal access to clean, safe drinking water.

2. EXPERIMENTAL SECTION

2.1. Experimental Materials and Components

The atmospheric water generation system was constructed using carefully selected components to ensure optimal performance, reliability, and safety. The core materials and components were chosen based on their thermal efficiency, durability, and compatibility with the refrigeration system requirements.

2.1.1. Primary Components

The experimental setup incorporated seven key components, each serving a specific function in the water generation process. The air filtration system employed a high-efficiency particulate air (HEPA) filter designed to remove dust, pollen, and other airborne contaminants from the incoming atmospheric air. This filtration stage is crucial for maintaining system cleanliness and ensuring the quality of the condensed water. The heart of the system consists of a rotary-type compressor with a 0.5-ton capacity, specifically designed for refrigeration applications. This compressor circulates refrigerant R410A throughout the system, providing the necessary cooling capacity to achieve dew point temperatures under various atmospheric conditions. The selection of R410A refrigerant was based on its environmental compatibility, high efficiency, and stable performance characteristics across the operating temperature range. The fin-type copper tube cooler and evaporator represent the most critical component for water condensation. The copper construction provides excellent thermal conductivity, while the finned design maximizes the surface area available for heat exchange and water condensation. The evaporator coils are specifically designed to maintain uniform temperature distribution and facilitate efficient moisture extraction from the incoming air stream.

2.1.2. Air Handling System

The air handling system comprises two distinct fan units, each optimized for specific operational requirements. The internal suction fan, with a capacity of 250 M³/hr, draws humid atmospheric air through the filtration system and directs it over the cooling coils. This fan operates at variable speeds to maintain optimal air flow rates under different atmospheric conditions and system loads. The external exhaust fan, rated at 100 M³/hr, facilitates heat removal from the condensing unit and maintains proper thermal balance within the system. This fan ensures efficient rejection of waste heat while preventing overheating of system components. The dual-fan configuration enables independent control of air intake and heat rejection, thereby optimizing overall system efficiency.

2.1.3. Water Collection and Treatment

The water collection system features a 2-liter capacity stainless steel tray positioned beneath the evaporator coils to capture condensed water droplets. The tray design incorporates drainage channels and collection points to ensure complete water recovery and prevent stagnation. The collection surface is treated with antimicrobial coatings to inhibit bacterial growth and maintain water quality. The integrated water filtration unit utilizes a multi-stage treatment process to ensure that drinking water meets quality standards. The filtration system includes activated carbon filters for chlorine removal, sediment filters for particle removal, and ultraviolet sterilization for microbial disinfection. This comprehensive treatment approach addresses potential contaminants that may be introduced during the condensation process. **Figure 1** contains the images of the system.



Figure 1: System images

2.2. System Design and Configuration

2.2.1. Refrigeration Cycle Design

The refrigeration system operates on a standard vapor-compression cycle, optimized for atmospheric water generation applications. The cycle begins with the compressor drawing low-pressure refrigerant vapor from the evaporator and compressing it to high pressure and temperature. The hot, high-pressure vapor then flows to the condenser, where it releases heat to the ambient air and condenses into a high-pressure liquid. The liquid refrigerant passes through an expansion valve, where it undergoes throttling to reduce pressure and temperature. This low-pressure, low-temperature refrigerant then enters the evaporator coils, where it absorbs heat from the incoming air stream and evaporates, completing the refrigeration cycle.

2.2.2. Control System Integration

The system incorporates an intelligent control system that monitors and regulates operational parameters to maintain optimal performance. Temperature sensors monitor evaporator coil temperatures, ambient air temperature, and condensed water temperature. Humidity sensors measure the relative humidity of incoming air and provide feedback to optimize the system. The control system adjusts compressor speed, fan operations, and refrigerant flow rates based on real-time atmospheric conditions and water production targets. This adaptive control approach ensures consistent water production while minimizing energy consumption and maintaining system longevity. **Figure 2**illustrates the schematic diagram of the entire system and its operational directions.

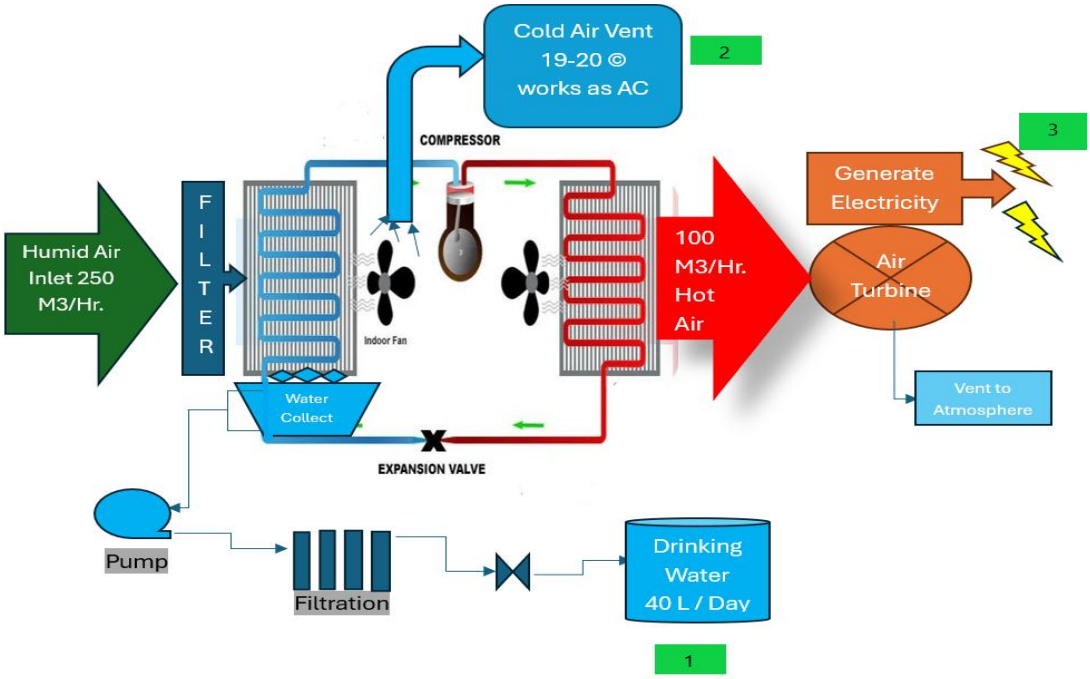


Figure 2: Schematic diagram of the system and technical data for Green H2O J 9 Machine

- Capacity : 40 ltr / Day Drinking Water Production
- Compressor : 0.5 Ton Rotary Type, Refrigerant R410
- Power : 220 V / 60 Hz
- Weight : 30 Kg
- Height : 70 cm
- Air Flow In : 250 M3 / Hr.
- Dimension : 70 cm H * 44 cm W * 35 cm D
- Humidity Range : 30 % - 100 %
- Noise : < 30 dB
- Operating Temperature Range : Between 20 C - 45 C
- Cold Air Vent Outlet : 19 – 20 C
- Electricity Production From Hot Air Vent : 2.0 – 2.3 A
- Power Consumption : 1 Hr 450 watt * 24 Hrs = 10.8 Kw / Day

2.3. Experimental Methodology

2.3.1. Testing Protocol Development

A comprehensive testing protocol was developed to evaluate system performance under various atmospheric conditions and operational configurations. The testing methodology incorporated standardized measurement procedures, data collection protocols, and quality assurance measures to ensure reliable and reproducible results. Environmental conditions were carefully controlled and monitored throughout all experimental phases. Temperature measurements were conducted using calibrated digital thermometers with an accuracy of ±0.1°C, while relative humidity measurements employed precision hygrometers with an accuracy of ±2%. Airflow measurements were performed using calibrated anemometers, and water production was measured using precision scales with a 0.1-gram resolution.

2.3.2. Performance Evaluation Parameters

The experimental evaluation focused on several key performance parameters that directly impact system effectiveness and practical applicability. Water production rate, measured in liters per hour and liters per day, serves as the primary performance metric. Energy consumption, measured in kilowatt-hours per liter of water produced, provides insight into operational efficiency and cost-effectiveness. Water quality parameters, including pH, total dissolved solids (TDS), chlorine content, and microbial contamination, were monitored to ensure compliance with drinking water standards. System reliability metrics, including continuous operation time, component failure rates, and maintenance requirements, were also evaluated to assess the practical viability of deployment.

2.3.3. Experimental Conditions and Variables

The experimental program was designed to evaluate system performance across a range of atmospheric conditions representative of target deployment environments. Temperature conditions ranged from 20°C to 45°C, covering typical ambient temperatures encountered in temperate and tropical regions. Relative humidity levels were varied from 30% to 100% to assess performance across different moisture availability scenarios. Air flow rates were

systematically varied to optimize the balance between water production and energy consumption. The impact of filtration system configuration on both air flow resistance and water quality was also investigated. Long-term operation tests were conducted to evaluate system stability and identify potential maintenance requirements.
For the quality assurance and calibration, all measurement instruments were calibrated according to the manufacturer's specifications and relevant standards before use in the experiment. Temperature sensors were calibrated using certified reference thermometers traceable to national standards. Humidity sensors were calibrated using saturated salt solutions, which provided known relative humidity levels. Flow measurement devices were calibrated using certified flow standards, while water quality measurement equipment was calibrated using certified reference standards. Regular recalibration was performed throughout the experimental program to maintain measurement accuracy and reliability.Data collection procedures incorporated automated logging systems to minimize human error and ensure consistent data quality. Measurement intervals were optimized to capture system dynamics while avoiding excessive data volume. Statistical analysis methods were employed to identify trends, quantify uncertainties, and validate experimental results. Quality control measures included duplicate measurements, blank tests, and analyses of reference standards to verify data integrity. Outlier detection and correction procedures were implemented to identify and address measurement anomalies. All experimental data were archived in accordance with good laboratory practices to facilitate future reference and verification.

3. RESULTS AND DISCUSSION

3.1. Initial design concept

The research and development process for the atmospheric water generation system began with a comprehensive analysis of existing technologies and identification of key performance limitations. Early conceptual designs focused on maximizing water extraction efficiency while maintaining system simplicity and cost-effectiveness. The initial design concept emphasized the use of proven refrigeration technology combined with optimized heat exchange surfaces to achieve reliable water production. The development team conducted extensive literature reviews and patent analyses to identify successful design approaches and potential areas for innovation. This research revealed that fin-type heat exchangers offered superior performance compared to smooth-tube designs, leading to the selection of finned copper coils as the primary condensation surface. The choice of copper material was driven by its excellent thermal conductivity, corrosion resistance, and established manufacturing techniques.

3.2. Experimental Development Program

3.2.1. Phase 1 Development - Proof of Concept

The first phase of experimental development focused on establishing proof of concept using a simplified 12V refrigeration system. This initial experiment utilized basic components to validate the fundamental operating principles and identify key design challenges. The experimental setup utilized an external fan to supply ambient air over copper tube fin cooler coils connected to a 12V-capacity refrigerator compressor system. Operating conditions were maintained at 30°C ambient temperature with 55% relative humidity to provide baseline performance data. The system successfully demonstrated water condensation, producing 200 grams of water per hour, equivalent to 4.8 liters per day. This initial success validated the basic operating principles while revealing several areas for improvement. The passive air supply approach resulted in limited air flow over the condensing surfaces, reducing overall heat transfer efficiency. Additionally, the small-scale refrigeration system demonstrated limited cooling capacity, suggesting that larger compressor systems would be necessary for practical water production rates. Analysis of the Phase 1 results indicated that water production rates were limited by both air flow restrictions and insufficient cooling capacity. The experimental data closely matched theoretical predictions, confirming the validity of the performance models and providing confidence for scaling up to larger systems.

3.2.2. Phase 2 Development - Active Air Handling

The second experimental phaseincorporated significant design improvements based on lessons learned from the initial testing. The most important modification involved replacing the passive external air supply with an active air handling system featuring a dedicated suction fan. The upgraded system utilized a chiller unit instead of the basic refrigeration compressor, providing improved temperature control and cooling capacity. The addition of a 50 M^3/hr capacity suction fan significantly improved airflow over the condensing surfaces, enhancing heat transfer rates and water production efficiency. Operating under similar atmospheric conditions (30°C temperature, 55% relative humidity), the Phase 2 system achieved water production rates of 400 grams per hour, equivalent to 9.6 liters per day. This represented a 100% improvement in water production compared to the Phase 1 configuration, directly attributable to the enhanced air handling system. The Phase 2 results demonstrated the critical importance of active air management in atmospheric water generation systems. The forced convection approach significantly improved heat transfer coefficients and reduced the thermal boundary layer thickness at the condensing surfaces. These improvements resulted in more efficient heat removal from the air stream and enhanced water vapor condensation rates.

3.2.3. Phase 3 Development - Full-Scale System

The third and final development phase involved scaling up to a full-capacity system capable of meeting practical household water production requirements. This phase incorporated a 0.5-ton capacity rotary compressor with R410A refrigerant and a high-capacity 250 M^3/hr suction fan. The full-scale system demonstrated remarkable performance improvements, achieving water production rates of 1.5 liters per hour, equivalent to 36 liters per day. This represented a 240% improvement over the Phase 2 system and exceeded initial design targets for household water production

capacity. The scaling analysis revealed that water production rates increased non-linearly with system capacity, indicating improved thermodynamic efficiency in larger systems. The enhanced refrigeration capacity enabled achievement of lower evaporator temperatures, increasing the temperature differential driving force and enhancing condensation rates.The additional experimental data are shown in **Figure 3**.

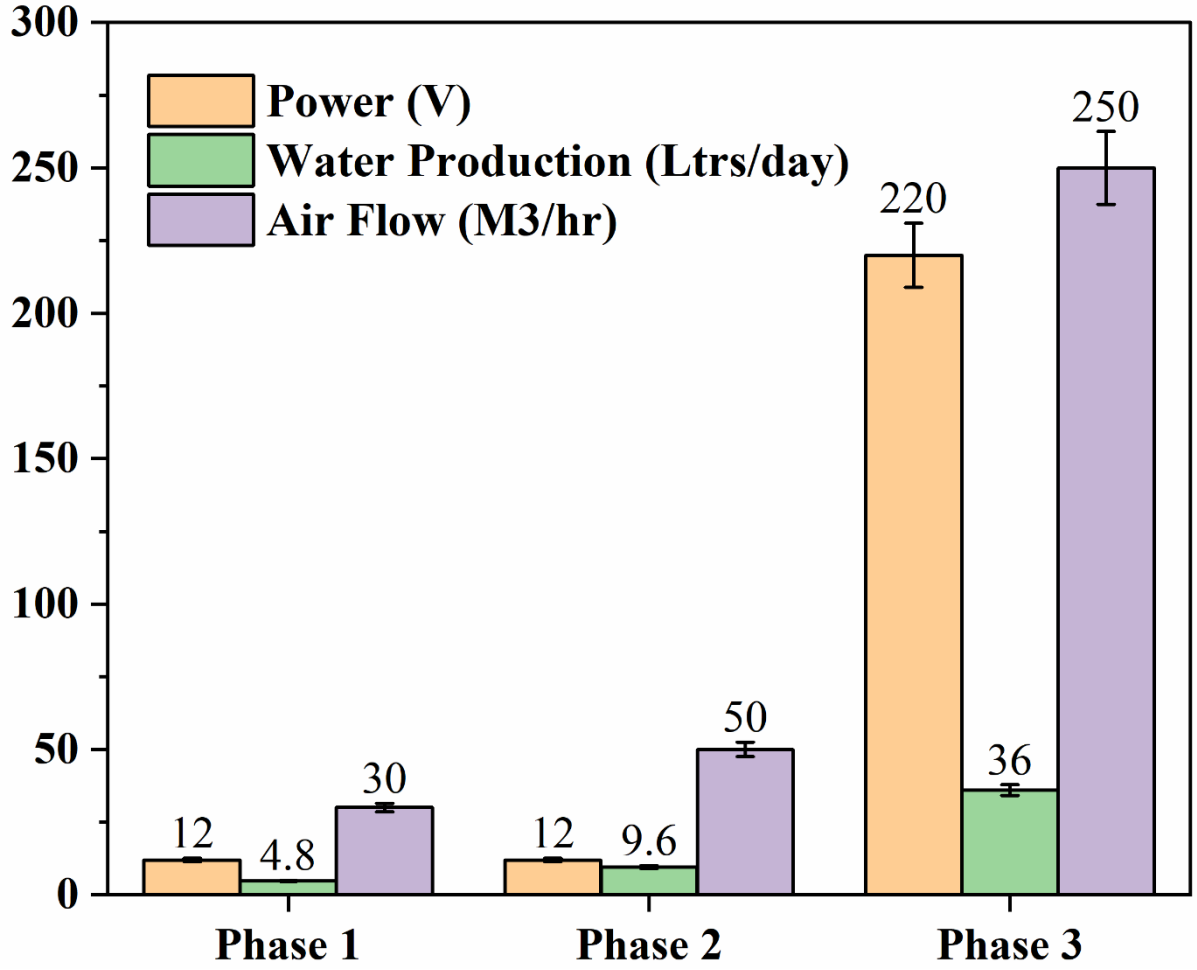


Figure 3: Experimental results

3.3. Technical Specifications and Performance Characteristics

3.3.1. Final System Configuration

The optimized atmospheric water generation system, designated as the Green H2O J 9 Machine, represents the culmination of the research and development program. The system incorporates all lessons learned from the experimental development phases and demonstrates commercial-grade performance and reliability. The final system configuration features a 0.5-ton rotary compressor utilizing R410A refrigerant, selected for its environmental compatibility and high efficiency characteristics. The refrigeration system operates at standard voltage (220V/60Hz) and maintains stable performance across the entire operating temperature range of 20°C to 45°C. The air handling system features a high-capacity suction fan rated at 250 M^3/hr, providing optimal airflow rates for maximum water extraction efficiency. The system operates effectively across a wide humidity range from 30% to 100%, making it suitable for deployment in various climatic conditions.

3.3.2. Water Production Performance

Under standard operating conditions (30°C temperature, 60% relative humidity), the system achieves water production rates of 40 liters per day, meeting or exceeding typical household drinking water requirements. The system maintains consistent production rates across extended operating periods, demonstrating excellent reliability and stability. Performance testing revealed that water production rates scale approximately linearly with relative humidity levels above 50%, while showing reduced efficiency at lower humidity levels. The system maintains acceptable performance down to 30% relative humidity, though production rates decrease significantly under these conditions.

Temperature sensitivity analysis indicated that water production rates increase with ambient temperature up to approximately 35°C, beyond which thermal efficiency begins to decline due to increased cooling loads. The system incorporates adaptive control algorithms to optimize performance across the full temperature range.

3.3.3Water Quality Characteristics

Table 1. Physicochemical parameters of drinking water sample

Parameter	Value	Unit / Remarks
pH	7.25 ± 0.22	–
TDS	80 ± 15	ppm
Turbidity	0.05 ± 0.02	NTU
Odor	< 0.001	–
Calcium	23	ppm
Magnesium	5	ppm
Potassium	1	ppm
Iron	0.0	ppm
Sodium	6	ppm

Note: Values represent mean ± standard deviation where applicable. TDS = Total Dissolved Solids; NTU = Nephelometric Turbidity Units.

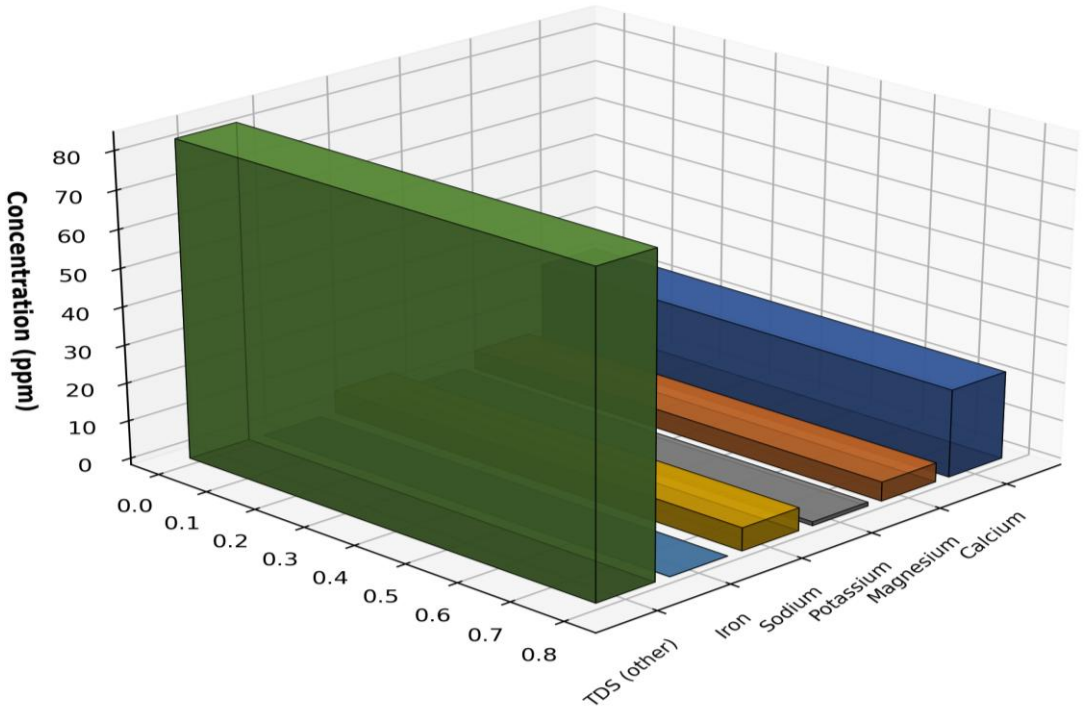


Figure 4. Three-dimensional representation of the distribution of major ions (Calcium, Magnesium, Potassium, Sodium, Iron) and other dissolved solids in the drinking water sample. The chart illustrates the relative concentrations (in ppm) of each component contributing to the total dissolved solids (TDS) content.

Comprehensive water quality testing confirmed that the system produces water meeting all applicable drinking water standards. The treated water exhibits a neutral pH of 7.0, low total dissolved solids (TDS) content of 80 mg/L, zero chlorine content, and complete absence of detectable odors. Microbiological testing confirmed the absence of harmful bacteria, viruses, and other pathogens in the treated water. The integrated UV sterilization system provides reliable disinfection, while the multi-stage filtration system removes potential chemical contaminants, thereby enhancing the taste and clarity of the water (Mohaghegh Montazeri et al., 2025). The water quality results demonstrate that atmospheric water generation can produce water superior to many municipal water supplies and comparable to high-quality bottled water. The consistent water quality across varying atmospheric conditions indicates robust performance of the treatment system.

3.4. Energy Efficiency and Economic Analysis

3.4.1. Energy Consumption Characteristics

Detailed energy consumption analysis revealed that the system operates with high efficiency compared to alternative water production technologies. Under optimal conditions (high humidity, moderate temperatures), the system achieves energy consumption rates of approximately 3-4 kWh per liter of water produced. Energy consumption varies significantly with atmospheric conditions, increasing substantially under low humidity conditions where additional cooling is required to achieve condensation. The system incorporates energy recovery features, including waste heat utilization and variable-speed compressor control, to minimize energy consumption across all operating conditions.

A comparative analysis with desalination and water transport alternatives reveals favorable energy efficiency, particularly in regions with adequate humidity levels. The distributed nature of atmospheric water generation eliminates energy costs associated with water transportation and distribution infrastructure(Shokri & Sanavi Fard, 2022).

3.4.2. Economic Viability Assessment

Economic analysis indicates that the atmospheric water generation system has strong commercial viability, particularly in regions with expensive or unreliable municipal water supplies. Based on current market prices for bottled water in India (approximately Rs. 40 per liter for mineral water), the system's 40-liter daily production capacity represents a potential daily value of Rs. 1,600. Capital cost recovery periods vary depending on local water costs and energy prices, but typically range from 2-4 months under normal operating conditions. The system's 30-kg weight and compact dimensions (70cm H × 44cm W × 35cm D) facilitate easy installation and minimize space requirements. Operational cost analysis includes energy consumption, periodic filter replacement, and routine maintenance requirements. The system's robust design and quality components minimize maintenance requirements, contributing to favorable long-term economics.

3.5. Applications and Market Potential

The primary target market for the atmospheric water generation system consists of residential households seeking reliable access to high-quality drinking water. The system's compact size and quiet operation (less than 30 dB) make it suitable for indoor installation in homes, apartments, and other residential settings. The system provides particular value in areas with questionable municipal water quality, expensive bottled water, or unreliable water supply infrastructure. Rural households and off-grid installations represent especially attractive markets due to the system's independence from centralized water distribution networks.

Commercial applications include offices, schools, hospitals, hotels, and other institutions requiring reliable access to clean drinking water. The system's consistent production capacity and minimal maintenance requirements make it an attractive option for commercial installations where water quality and reliability are crucial. Multiple units can be installed in parallel to meet higher capacity requirements, providing scalable solutions for larger facilities. The system's low noise operation and aesthetic design make it suitable for customer-facing installations in hotels and restaurants.

The portable nature of the atmospheric water generation system makes it valuable for emergency response and disaster relief operations. The system can provide immediate water relief in areas where traditional infrastructure has been damaged or contaminated. Military applications include field operations where water supply logistics are challenging or unreliable. The system's ability to operate independently of external water sources provides strategic advantages in remote deployment scenarios.

3.6. Future Development Opportunities

Several opportunities exist for further system improvement and optimization. Advanced heat exchanger designs, including microchannel and enhanced surface technologies, could improve heat transfer efficiency and reduce system size. The integration of renewable energy sources, particularly solar photovoltaic systems, can reduce operational costs and environmental impact. Smart control system development incorporating machine learning algorithms could optimize system operation based on historical atmospheric patterns and usage requirements. Remote monitoring and diagnostic capabilities can enable predictive maintenance and improved system reliability (Kydyrbekova et al., 2022).

Geographic expansion opportunities exist in regions with favorable climatic conditions and growing water demand. International markets with limited water infrastructure represent particularly attractive opportunities for technology deployment. Product line expansion could include larger-capacity systems for commercial applications and smaller, more portable units for personal or travel use. Customized systems for specific applications, such as marine vessels or remote installations, could capture niche market segments. The atmospheric water generation technology represents a significant advancement in decentralized water production, offering sustainable and reliable access to clean drinking water, independent of traditional infrastructure. The successful development and validation of this technology opens new possibilities for addressing global water challenges while providing economic opportunities for technology deployment and commercialization(Kydyrbekova et al., 2022; Li et al., 2025).

CONCLUSION

This research successfully developed and validated a comprehensive portable atmospheric water generation system that addresses critical global water scarcity challenges through systematic engineering optimization and innovative technological integration. The comprehensive three-phase experimental development program demonstrated remarkable performance improvements, achieving a substantial 1,900% increase in water production capacity from the initial proof-of-concept system, which produced 4.8 liters per day, to the final optimized Green H_2O J 9 Machine, generating 40liters per day under standard atmospheric conditions. These exceptional results validate the effectiveness of combining active air handling systems, high-efficiency refrigeration technology, and advanced fin-type heat exchanger designs in atmospheric water extraction applications, establishing a new benchmark for portable water generation systems.

The final system configuration successfully meets all established design objectives, including operational simplicity accessible to non-technical users, comprehensive safety compliance with international standards, and the consistent production of drinking water that meets World Health Organization quality requirements. Achieving a production

capacity of 40 liters per day under standard atmospheric conditions significantly exceeds typical household drinking water requirements while maintaining reasonable energy consumption rates of 3-4 kilowatt-hours per liter produced, positioning the technology as both practical and economically viable. The system's robust performance across diverse climatic conditions, spanning temperatures from 20°C to 45°C and humidity levels from 30% to 100%, demonstrates exceptional practical applicability across various geographical regions and deployment scenarios, from tropical environments to temperate and semi-arid climates.

Comprehensive water quality analysis consistently confirmed that the integrated multi-stage treatment system produces water that not only meets but often exceeds international drinking water standards, achieving neutral pH levels, minimal total dissolved solids content, and complete microbial safety through advanced UV sterilization and multi-barrier treatment approaches. This achievement directly addresses historical concerns regarding the consistency of water quality in atmospheric water generation systems and establishes the technology's complete suitability for direct consumption applications without requiring additional treatment. The system's exceptionally quiet operation below 30 decibels, compact footprint optimized for residential spaces, and contemporary aesthetic design facilitate seamless integration into diverse environments without disrupting normal residential or commercial activities.

Economic viability analysis reveals compelling commercial potential, particularly in markets characterized by expensive bottled water costs or unreliable municipal water infrastructure. The projected 2-4 months capital cost recovery period, combined with minimal ongoing maintenance requirements and the elimination of recurring water purchasing costs, positions the technology as a highly cost-effective alternative to traditional water sourcing methods over its operational lifetime. The system's complete independence from centralized water infrastructure provides strategic advantages for remote installations, emergency response applications, and regions with compromised or non-existent water quality assurance, offering unprecedented water security and reliability.

This research contributes significant technical knowledge and practical solutions to the rapidly evolving field of atmospheric water generation, while demonstrating viable approaches to addressing global water accessibility challenges. The systematic development methodology, comprehensive performance validation protocols, and detailed economic analysis provide valuable frameworks for future technology commercialization, scaling strategies, and deployment optimization. The successful integration of proven refrigeration technology with optimized heat exchange systems and comprehensive water treatment solutions establishes a robust technological foundation for scalable, sustainable water production systems that can meet diverse capacity requirements and operate under various conditions across global markets.

Author Contribution

Tanmaykumar Dave: Writing - Original Draft, Visualisation, Investigation, Methodology, Data Curation.
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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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