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REVIEW

Dew Water as Sustainable Ecological Resource: Mitigating Heavy Metal Pollution in Aquatic Ecosystems and Enhancing Water Security

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ABSTRACT

Groundwater overextraction and contamination by heavy metals such as cadmium and arsenic have resulted in ecological degradation and increased risks of renal disease, particularly in water-scarce regions. To address these challenges, this review aimed to evaluate the ecological potential of dew water harvesting as a sustainable and safe alternative water source. Literature published between 2000 and 2024 was systematically searched in PubMed, Scopus, Web of Science, and Google Scholar using the terms “dew water,” “atmospheric water harvesting,” “groundwater pollution,” “heavy metals,” “ecosystem restoration,” and “sustainable water systems.” Studies were included if they focused on dew water quality, ecological functions, or health-related outcomes, while non-English publications, conference abstracts without full text, and studies not directly addressing dew water were excluded. A total of 46 studies and 7 official guidelines met the eligibility criteria. Findings indicate that natural dew water generally exhibits a neutral pH (6.5–8.5), negligible concentrations of heavy metals, and relatively high dissolved oxygen content (~9 mg/L). Case studies from Morocco, Israel, China, and India illustrate its contributions to soil moisture retention, plant survival, biodiversity support, and microclimate regulation. Moreover, dew water produced through the Systemized Dew Process (SDP) consistently complied with WHO (2024) standards for drinking water, showing contaminant levels below detection thresholds. In conclusion, dew water harvesting represents a low-impact, climate-resilient, and safe alternative that mitigates exposure to nephrotoxic pollutants, reduces reliance on overexploited groundwater, and enhances long-term ecological restoration and water security in degraded and water-scarce environments.

Keywords: Ecological Sustainability; Water Conservation; Heavy Metal Pollution; Ecosystem Restoration; Climate Change Adaptation; Renewable Water Sources; Applied Ecology

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1. Introduction

Water is essential not only for human survival but also for maintaining the delicate balance of our planet's ecosystems. Yet today, we are facing an escalating ecological crisis driven by the overuse and pollution of groundwater, which serves as a critical freshwater resource for billions of people. In many parts of the world, especially in developing countries, groundwater is being extracted faster than it can naturally recharge. This unsustainable use has led to serious environmental consequences, such as land subsidence, saltwater intrusion, and the degradation of groundwater-dependent ecosystems (GDEs), including springs, wetlands, and underground rivers, which are vital for supporting biodiversity and ecological health [1–3].

The former capital of Indonesia, Jakarta, has come under the global spotlight in recent years due to the alarming and rapid rate of land subsidence, leading to the widely discussed issue of "Jakarta is sinking.". Jakarta is recognized as one of the most rapidly subsiding urban areas globally, with recorded land subsidence rates ranging from 2 to 15 centimeters per year over the past five decades. In certain high-risk zones, the rate has been observed to accelerate to as much as 20 to 28 centimeters annually [4]. Several actual cases show the impact of groundwater-dependent ecosystem (GDE) degradation. In Jakarta, the city's only remaining mangrove ecosystems, located in Pantai Indah Kapuk and Muara Angke, are increasingly under threat. Excessive groundwater extraction has led to land subsidence, which in turn has triggered saltwater intrusion. This salinization process damages the mangrove habitats, jeopardizing their survival. The loss of mangrove forests also means the loss of their crucial ecological function as natural barriers against coastal erosion [4,5]. A similar case is found in Vietnam's Mekong Delta, where intensive groundwater extraction for rice irrigation and aquaculture has caused significant land subsidence and saltwater intrusion into agricultural and residential areas. As groundwater becomes increasingly saline, the agricultural ecosystems suffer, often resulting in crop failure and long-term damage to local livelihoods [6,7].

At the same time, pollution from industrial activities, especially the release of heavy metals, has contaminated many water sources. These toxic substances dissolve easily in water and accumulate in living organisms, harming not only aquatic life but also the humans who depend on these ecosystems [8,9]. Exposure to heavy metals such as cadmium and arsenic poses significant ecotoxicological threats, with well-documented impacts on both aquatic ecosystems and terrestrial food chains. These contaminants are often introduced into groundwater through industrial discharge and improper waste management, where they persist and bioaccumulate in organisms, disrupting metabolic processes and reducing reproductive capacity across multiple species. Studies from Sri Lanka, Taiwan, and China have also observed that prolonged exposure to contaminated drinking water correlates with biomarkers of renal dysfunction, a global health burden affecting an estimated 843.6 million people, suggesting that groundwater pollution may affect not just ecological but also physiological functions across trophic levels [10–13]. In Indonesia, particularly in North Jakarta, groundwater quality has been severely compromised—with 80% of samples failing to meet national health standards due to elevated contaminant levels, including heavy metals [3].

This review is grounded in the principles of ecological economics and the natural capital framework, which view water resources as crucial components of ecosystem services that sustain both biodiversity and human wellbeing. According to the Daly Model of Sustainable Development, conservation of natural capital, like clean water, is essential for longterm ecological balance and socioeconomic resilience [14,15]. The ecological sustainability–water conservation nexus posits that conserving water reduces ecological pressure (e.g., aquifer depletion, habitat degradation) and enhances ecosystems' regenerative capacity. Healthy ecosystems, in turn, support regulating services such as soil moisture retention, climate moderation, and natural filtration [16]. The expected causal direction is bidirectional but asymmetrical: while ecological sustainability fosters water conservation behaviors and policies, water conservation exerts a stronger enabling effect on ecological stability in water-scarce contexts. Integrating dew water harvesting supports this feedback loop by minimizing groundwater extraction, reducing ecological degradation, and enhancing environmental resilience, while also offering public health and economic cobenefits.

Given the cumulative environmental burden of water resources, including groundwater degradation, there is an urgent need to explore alternative water sources that are both safe and ecologically sustainable. Dew water harvesting emerges as a promising nature-based solution. In addition, dew water in various regions was found to have a neutral pH range and is purer than other water sources [17], leading to the hypothesis that dew water can be processed into pure oxygen-rich drinking water that has many benefits for humans. By not relying on groundwater extraction, dew water helps mitigate further depletion of aquifers, protecting groundwater-dependent ecosystems (GDEs) like wetlands, springs, and mangrove forests that are vital for maintaining biodiversity and hydrological resilience [18].

In this context, dew water represents a viable and environmentally sound alternative to conventional water sources. Beyond its purity, its integration into water systems can contribute to reducing anthropogenic pressures on ecosystems, reinforcing long-term ecological health, and enhancing water security in regions facing contamination and overextraction challenges.

2. Methods

This review employed a structured literature search to assess the ecological and health-related potential of dew water as a sustainable water resource. Searches were conducted during 2024–2025 across four academic databases—PubMed, Scopus, Web of Science, and Google Scholar—using combinations of the following keywords: *"dew water," "atmospheric water harvesting," "groundwater pollution," "heavy metals," "ecosystem restoration,"* and *"sustainable water systems."*

Selection procedures involved three stages: (1) database searches for titles and abstracts; (2) screening of abstracts based on predefined eligibility criteria; and (3) full-text reviews to confirm inclusion. Reference lists of relevant articles were also examined to identify additional sources.

Inclusion criteria were:

- Publications in English, between 2000 and 2025.
- Peer-reviewed journal articles, academic books, or official reports/guidelines.
- Studies addressing dew water quality (e.g., pH, heavy metal content, dissolved oxygen), ecological functions (e.g., biodiversity support, soil moisture, microclimate regulation), or potential roles in water security and public health.
- Only studies presenting quantitative data or clearly described qualitative assessments were considered.

Exclusion criteria included:

- Publications without accessible full texts.
- Studies not directly related to dew water or without relevance to ecosystem functions or water quality.

After screening, a total of 47 peer-reviewed journal articles, 4 academic books or book chapters, and 14 official reports or guidelines (including WHO drinking-water standards and national regulations) were retained for analysis.

The extracted information was synthesized into three thematic categories: (1) chemical and physical composition of natural dew water; (2) ecological roles and contributions to ecosystem services; and (3) implications for human health and water security, including comparisons to WHO (2024) standards.

3. Results

3.1. Interconnectedness of Water, Human Health, and Ecosystems

Water is fundamental to the interconnectedness and sustenance of all Earth's ecosystems. Its primary roles include fostering plant growth, serving as a habitat for aquatic species, and providing temporary breeding grounds for various amphibians, insects, and other water-dependent organisms [19]. Approximately 75% of the Earth's surface is covered by water, and the human body consists predominantly of water. Water plays a crucial role in sustaining all forms of life [20]. Water delivers essential nutrients and minerals vital for sustaining physical life. As nature's most crucial nutrient, it is indispensable for human survival. Within the human body, water facilitates the transport of oxygen, minerals, nutrients, and waste products to and from cells [19].

A study by the World Health Organization (WHO) estimates that 1.4 million annual deaths could be prevented by improving access to safely managed water, sanitation, and hygiene services. In 2022, 2.2 billion individuals lacked safely managed drinking water at home, 3.5 billion did not have safely managed sanitation, and 2 billion were unable to wash their hands with soap and water at home. Furthermore, since mid-2021, several low- and middle-income countries have experienced a surge in cholera outbreaks, including some that had been unaffected for decades [21].

3.2. Ecotoxicology of Groundwater Contaminants: Implications for Chronic Kidney Disease

Over the past 10 years, many unidentified cases of CKD have been found to be closely linked to exposure to environmental pollutants. Several risk factors for CKD have been identified including metabolic disorders such as diabetes and hypertension, advanced age, smoking, and certain genetic predispositions. There is increasing evidence that environmental toxicants play a significant role in its pathogenesis. Heavy metals are one of the major environmental pollutants that affect various organ functions. Cadmium, lead, mercury, copper, uranium, arsenic, iron, mercury, bismuth and chromium are the main nephrotoxic heavy metals that can cause tubular damage and glomerulopathy. These metals can enter the human body through contaminated water.

Arsenic is a naturally occurring metalloid found in many parts of the world, especially in groundwater. Arsenic can also enter water through mining and metal smelting. Worldwide, more than 200 million people are estimated to be chronically exposed to arsenic in drinking water at concentrations above the World Health Organization (WHO) interim guideline value of 10 μg/L [22]. A cross-sectional population study in China found the levels of 1-MG (as a marker of kidney damage) detected in urine samples had statistically significant differences between the high As group (As > 0.05 mg/L) and the low and moderate As exposure groups (As < 0.05 mg/L; $p = 0.018$), as well as between the high As group patients (As in the two groups were both higher than 0.05 mg/L, $p < 0.001$) [12]. The study by Cheng (2018) identified 5442 new CKD patients during the study period and found that residents in areas with arsenic levels ≥ 50 μg/L in drinking water had a hazard ratio (HR) of 1.14 (95% CI: 1.08–1.21) for CKD [13].

Research by Waningsuriya (2021) [11] found a significant relationship between the amount of Cadmium (Cd) and the incidence of CKD in 886 subjects, as summarized in **Table 1**. The subjects in this study were all farmers, with drinking water sources coming from groundwater and wells. Wells located in fields had higher concentrations of Cd and other toxic compounds, attributed to the use of pesticides and fertilizers in rice cultivation in the study area. Research by Filler (2022) [23] suggested a significant association between elevated blood Pb concentrations (21.1 ± 15.8 μg/L) and decreased eGFR in pediatric CKD patients (see **Table 1**).

Table 1. Epidemiologic Studies on Chronic Kidney Disease and Heavy Metal Exposure.

Research	Country	Sample Quantity	Heavy Metals	Result Findings
Wasana 2015 [10]	Sri Lanka	543	Cadmium (Cd)	There were significantly higher Cd values than WHO recommendations in groups with a higher incidence of renal failure.
			Arsenic (As)	Total As levels in subjects with CKD were found to be lower than the WHO requirement, so there was no correlation with CKD.
Chen 2021 [24]	Taiwan	1043	Arsenic (As)	Significant differences between elevated serum creatinine values and elevated levels of lead (Pb), cadmium (Cd), and arsenic (As).
Wanigasurya 2021 [11]	Sri Lanka	886	Cadmium (Cd)	Significant association between blood Cd levels and the incidence of CKD
Mandour 2022 [25]	Egypt	30	Lead (Pb) Cadmium (Cd)	The relationship between total heavy metals (Pb and Cd) increased and the incidence of CKD, but was not significant.
Feng 2023 [12]	China	1067	Arsenic (As)	Significant differences in 1-MG levels as a marker of renal damage in patients with high As group and low As group.

3.3. Dew Water

Dew water is formed naturally in nature, a product of the vapor to liquid phase transition. Dew formation typically involves the following stages: surface cooling due to radiative heat loss, increase in relative humidity, attainment of the dew point, and subsequent condensation of water vapor onto the cooled surface [26]. This cycle occurs under certain atmospheric conditions and with conditions that must be met, including temperature, humidity, and pressure. Dew generally forms at the surface when the temperature cools between the lower temperature limit and freezing point, accompanied by moist air saturation and constant pressure [27]. In addition, dew formation can occur when there is high humidity near the ground mixed with turbulence moving fresh air towards the ground [28].

Dew water is different from rain or groundwater that comes directly from nature and is affected by surrounding pollutants. Dew water consists of liquid droplets formed through the condensation of atmospheric water vapor near cooled surfaces. However, this process also captures airborne pollutants such as soluble gases (e.g., SO_2, NO_x), aerosols, and particulate matter. As a result, dew can contain higher concentrations of ions and contaminants compared to rainwater, especially in polluted environments. In contrast, dew collected in clean, rural, or high-altitude areas may be relatively less polluted [29]. Therefore, dew formation depends on the characteristics of the surrounding atmospheric layers, i.e. precipitation and cloud homogeneity; as well as convective heat exchange, i.e. airflow near the condensation surface [30].

The chemical composition of the dew water formed depends on the nature of the local environment. Things that affect the differences in dew water composition between regions are the characteristics of solid and dry substances carried during condensation, the dissolution of solutes from the atmosphere by dew water, and the absorption of gases into dew water [31].

There are nine literatures that examined dew water composition in different regions with different conditions; deserts, islands, and cities (**Table 2**).

Table 2. Chemical Composition of Natural Dew in Different Regions.

Research	Location	Dew Water Chemical Composition (mg/L)								
		pH	Ca^{2+}	K^+	Na^+	Mg^{2+}	Cl^-	NH_4^+	NO_3^-	SO_4^{2+}
Kidron et al. [32]	Israel	7.31	2.87	1.44	0.87	3.90	1.76	0.012	0.079	0.166
Muselli et al. 2006 [29]	France	6.5	5.0	1.6	3.5	1.2	5.4	0.2	0.9	3.1
Polkowska et al. 2008 [33]	Polandia	6.0	9.3	1.7	6.9	1.8	8.7	4.8	9.1	7.1
Yadav et al. 2014 [34]	India	6.78	6.93	2.6	1.66	3.29	1.93	0.166	0.131	0.138
Shohel et al. 2017 [35]	Bangladesh	6.8	6.93	1.35	2.43	2.05	2.91	< 0.001	0.223	0.359
Xu et al. 2015 [36]	Changchun, China	6.01	3.13	0.88	1.31	0.49	1.14	1.22	2.12	3.26
Muselli et al. 2020 [27]	Polynesian Island	6.5	8.78	3.15	2.42	3.47	4.67	0.001	0.002	0.015
Muselli et al. 2022 [37]	Morocco	7.5	2.44	0.47	0.76	3.13	0.85	< 0.001	0.257	0.419
Lei Hong et al. 2019 [38]	Nanjing, China	7.2	10.02	0.16	3.22	0.73	4.96	5.05	11.16	27.38

The results of chemical analysis of natural dew in different regions show different results, with uniform pH at neutral results (pH 6.5–8.0).

The natural dew water studied in different regions was found to have amounts of harmful contaminants; such as nitrate (NO_3^-), ammonia (NH_4^+), and sulfate (SO_4^{2+}); although dew water has potential as an alternative water source, a purification process such as the Systemized Dew Process (SDP) is required to obtain clean and safe dew water. There were mixed results on the cation; Ca^{2+}, K^+, Na^+, Mg^{2+}; and anion; Cl^-; composition of the dew water in all nine studies. However, all had a neutral pH range (6.5–8.5), leading to the hypothesis that dew water can be processed into drinking water.

3.4. Process (SDP)

According to WHO (2024) [39], drinking water requirements include pH 6.5–8.5, free from harmful microbial and chemical contaminants (such as arsenic ≤ 0.01 mg/L, nitrate ≤ 50 mg/L, and lead ≤ 0.01 mg/L), and originating from a clear and protected source. In addition, safe drinking water should meet aesthetic standards (such as being colorless, odorless, and tasteless), be managed under a Water Safety Plan (WSP) to prevent contamination from catchment to consumer, and be subject to independent surveillance to ensure compliance with health-based targets and long-term safety. Based on PP No. 82 of 2001, water is divided into four classes; Class I is water used for drinking water raw water; Class II is water used for water recreation infrastructure / facilities, freshwater fish farming, and animal husbandry; Class III is water for freshwater fish farming, animal husbandry, and crops; Class IV is water for irrigating crops [40]. Pure dew water originating from mountains or regions is classified as Class I, but further research is needed regarding the conditions of the dewatering area.

Systemized Dew Process (SDP) was developed as a standardized natural condensation technology that converts air moisture into dew drinking water droplets. The concept of SDP is to combine the right temperature, pressure, and humidity to convert dew water into drinking water. This SDP technology captures air moisture and then filters it, resulting in pure water (H2O) rich in natural dissolved oxygen.

The process of condensation through SDP begins by preparing a room filled with clean, standardized air. The clean air then enters the machine and is filtered using a Micro Particle Separation System (MPSS) to separate the micro particles present in the air. Next, the moist air is condensed using programmed low temperature and constant pressure. The result of SDP is directly collected dew drinking water and clean and cold exhaust air (**Figure 1**). This SDP technology has several advantages, namely, it is environmentally friendly, energy efficient, does not damage the ozone layer, and does not produce hazardous waste.

SDP consists of four stages, namely (1) incoming moisture-containing air, (2) filtration using MPSS (Micro Particle Separation System), (3) controlled condensation process, and (4) clean exhaust air.

SDP technology produces 20,000 to 25,000 drops of dew drinking water per cycle, which is equivalent to about 1.5 liters. Dew drinking water has more dissolved oxygen than the quality requirements according to BPOM [41] (**Table 2**), so it can be classified as a type of natural oxygen-rich drinking water. In addition, the dew drinking water from SDP also has a TDS (Total Dissolved Solid) content below 10 ppm, which is lower than mineral drinking water, shown in **Table 3.** Furthermore, the analysis of heavy metal content in dew drinking water is summarized in **Table 4.**

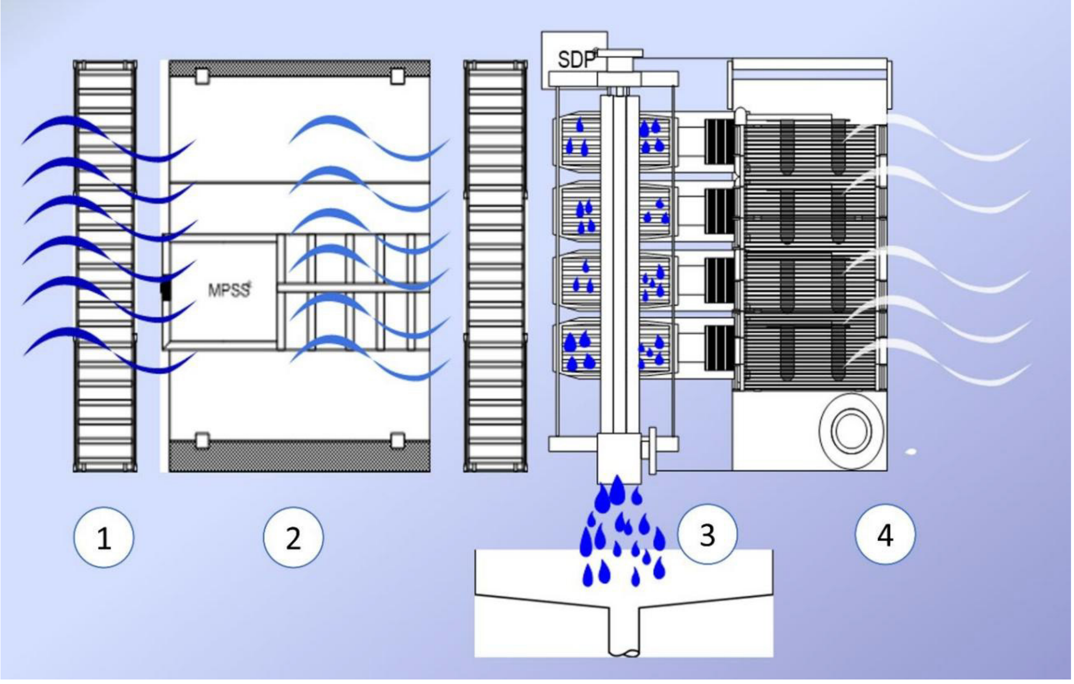

Figure 1. Systemized Dew Process (SDP) technology.

Table 3. Composition of dew water from the Systemized Dew Process.

Parameters	Unit	Results	Quality Requirements [40]
pH	-	7.07	6.0–7.5
Dissolved solids	ppm	< 5.00	150.0
Dissolved oxygen	mg/L	9.16	2
Ca^{2+}	mg/L	< 1.00	< 1.00
Mg^{2+}	mg/L	< 1.00	< 1.00
Na^{+}	mg/L	< 1.00	< 1.00
K^{+}	mg/L	< 1.00	< 1.00
Cl^{-}	mg/L	< 1.00	< 1.00
NO^{-3}	mg/L	< 0.001	< 1.00
NH^{4+}	mg/L	< 0.001	< 1.00
$SO4^{2+}$	mg/L	< 0.001	< 1.00

Table 4. Heavy metals in drinking water processed through SDP.

Heavy Metal Parameter	Unit	Results	Quality Recuirements [41]
Aluminum	mg/L	< 0.01	0.01
Arsenic	mg/L	< 0.001	0.001
Cadmium	mg/L	< 0.0001	0.0001
Cromium	mg/L	< 0.001	0.001
Copper	mg/L	< 0.001	0.001
Lead	mg/L	< 0.001	0.001
Manganese	mg/L	< 0.001	0.001
Molibdenum	mg/L	< 0.001	0.001
Nickel	mg/L	< 0.001	0.001
Selenium	mg/L	< 0.010	0.010
Silver	mg/L	< 0.001	0.001
Boron	mg/L	< 0.05	0.05

The result from PURENCE dew water composition analysis shows that the heavy metal exposure is nearly zero and suitable for consumption. The quality requirements obey the standard according SNI (Indonesian National Standard) and BPOM (Food and Drug Monitoring Agency).

The results of the analysis of SDP technology dew drinking water have a pH of 7.07, free from harmful contaminants; namely nitrates, nitrites, ammonia, and dissolved substances lower than 5.00 ppm, and has a clear source; namely water condensed from clean standardized air, so that PURENCE dew water is declared suitable for consumption as drinking water, in accordance with WHO requirements (2024) [39].

3.5. The Role of Dew Drinking Water for Health

Dew drinking water according to BPOM is defined as drinking water obtained from the process of condensing water vapor from humid air into dew water droplets which are further processed into packaged dew drinking water. The dew drinking water produced by SDP also has high natural dissolved oxygen of 9.16 mg/L, above the normal range of 6.5–8.0 mg/L [41].

Studies conducted by Fang et al. [42] on mice state that consumption of oxygenated water can reduce uric acid in the serum of hyperuricemia mice compared to the serum of hyperuricemia mice drinking ordinary mineral water. Water absorbed by the intestine enters the enterohepatic circulation and is excreted by the kidneys. Consumption of oxygenated water increases the supply of oxygen into the body [43]. Previous research by Forth & Adam, 2001 [44] showed that intragastrically administered oxygenated water, which contains more than 45 mg/L dissolved oxygen, delivers oxygen into the abdominal cavity and portal vein. This is evidenced by the increase in pO2 in the abdominal cavity and portal vein within 20–40 minutes after the administration of oxygenated drinking water [17].

Research by Sommer et al. also showed an increase in pO2 in the blood after giving oxygenated drinking water to mice. The addition of parenteral oxygen increases the amount of oxygen absorbed by the body, which then affects the increase in glycolysis, mitochondrial protein synthesis, and myofibrillar protein synthesis. Therefore, oxygenated drinking water can increase the concentration of oxygen in the blood, which in turn increases the cellular activity and metabolism of the liver, and then increases the rate of uric acid clearance in plasma, thereby reducing the level of uric acid in serum [45].

The study by Izawa et al examined the direct effects of oxygenated drinking water consumption on young adult subjects, by comparing changes in SpO2 and pulse rate during exercise in hypoxic conditions after consumption of oxygenated drinking water (treatment group) or plain mineral water (control group). It was found that the decrease in SpO2 was smaller and the increase in pulse rate was greater in the group that drank oxygenated water compared to the group that drank ordinary mineral water. This smaller decrease in SpO2 can prevent acute mountain sickness, prolong walking time, and increase walking speed. The results of this randomized, placebo-controlled trial proved that oxygenated dewatered water can maintain blood oxygen levels in exercising individuals [46].

4. Discussion

4.1. Implications for the Interconnectedness of Water, Human Health, and Ecosystems

The One Health approach offers a comprehensive framework that recognizes the interconnectedness of human, animal, and ecosystem well-being [47]. It suggests that effectively addressing complex health challenges necessitates collaborative, transdisciplinary, and multi-sectoral interventions. This framework acknowledges the transmission of diseases between humans and animals and highlights the significant role of environmental factors in disease emergence and transmission. Consequently, environmental degradation, climate change, and pollution are understood as major causes capable of leading to the emergence and spread of diseases, disrupting ecosystems, and negatively impacting community well-being [48].

Clean water is vital for sustainable development [19,20]. In 2015, the United Nations introduced seventeen Sustainable Development Goals (SDGs) as a global initiative to eliminate extreme poverty, reduce inequality, and protect the environment by 2030. Goal 6 specifically aims to ensure that everyone has access to clean and sustainable water sources, along with adequate sanitation. Clean water also plays an important role in supporting economic and social progress. When communities have access to a reliable and safe water supply, it strengthens local economies and helps reduce poverty. In addition, clean water is essential for food and energy production. Without it, people may be forced to use untreated wastewater for irrigation, which can lead to the spread of waterborne diseases. From a health perspective, access to clean water is critical for survival. Each year, around 3.575 million people die from illnesses caused by unsafe or contaminated water [49].

Clean water is also necessary for maintaining healthy ecosystems. With about 60 percent of the human body and 75 percent of the brain made up of water, and around 75% of the Earth's surface covered by it, the importance of clean water for both people and the environment is undeniable [49].

As human populations and economic activities expand, the global demand for freshwater is rising sharply [21]. Beyond posing a threat to food security, water scarcity significantly diminishes biodiversity across both aquatic and terrestrial ecosystems. Consequently, there is an increasing awareness of the critical need for water conservation. Therefore, renewable sources of clean water are needed to meet water demands without overexploiting traditional resources [20].

4.2. The Role of Dew Water in Supporting Ecosystems

Excessive groundwater extraction leads to a wide range of interconnected environmental, economic, and social consequences. Environmentally, it causes aquifer depletion, disrupts hydrological cycles, and results in severe land subsidence, as seen in regions such as Mexico City, Jakarta, and California's Central Valley. It also degrades water quality, promoting seawater intrusion in coastal areas and increasing contamination by nitrates and heavy metals. Agriculturally, it reduces crop yields, raises production costs, and places smallholder farmers under financial stress, threatening food security in countries like India and Iran. Economically, over-extraction generates both direct costs—such as infrastructure damage and increased pumping expenses—and long-term losses, including decreased land value and instability in agricultural markets. Socially, dwindling groundwater supplies drive rural-to-urban migration, straining urban infrastructure and disrupting community cohesion. Additionally, contaminated or scarce water sources heighten public health risks and increase vulnerability among low-income populations. These pressures also deepen socioeconomic inequality, as wealthier groups can afford alternatives while marginalized communities face mounting hardship [50,51].

Dew harvesting, as a supplementary source of water—especially for drinking—plays a crucial role in advancing water sustainability, particularly in regions with limited access to freshwater [26,52]. As a naturally recurring phenomenon, dew provides a renewable and passive means to generate potable water with minimal ecological disturbance [53]. By reducing reliance on conventional water sources, dew collection alleviates pressure on groundwater-dependent ecosystems (GDEs) such as wetlands, springs, and mangrove forests, thereby helping to preserve biodiversity, stabilize ecological functions, and support hydrological balance [54].

In arid and semi-arid regions, dew harvesting has shown notable environmental benefits beyond drinking water provision. Dew deposition contributes to soil moisture retention, especially during dry seasons or prolonged droughts. This moisture, although limited, supports microclimate regulation by reducing diurnal temperature fluctuations and maintaining localized humidity [54]. In degraded environments, dew helps maintain plant hydration, allowing certain native or drought-tolerant species to survive where rainfall is insufficient. Long-term observations in regions like southern Spain, the Negev Desert, and parts of India have demonstrated that dew-assisted hydration can enhance vegetation cover, control erosion, and support insect and bird biodiversity, particularly when combined with ecological restoration practices [55].

From a landscape ecology standpoint, dew water contributes to patch-level resilience by sustaining fragmented vegetation clusters in otherwise degraded or desertified zones. These microhabitats serve as ecological stepping stones that support habitat connectivity, encourage natural regeneration, and assist in ecosystem recovery [53,56–59]. By integrating dew harvesting into reforestation or revegetation programs, especially in water-scarce environments, restoration efforts can become more adaptive and less dependent on external irrigation or groundwater abstraction.

Furthermore, the technological simplicity of dew harvesting systems—particularly passive radiative condensers—makes this method economically accessible for deployment in remote or low-resource communities [53,57–59]. Constructed with locally available materials and requiring no energy input, these systems can support household and community-level water access, reduce vulnerability to seasonal supply disruptions, and promote a decentralized water infrastructure that is more resilient to climate variability.

While rainwater harvesting and fog collection have long been recognized as sustainable water solutions, dew water harvesting offers distinct ecological advantages, particularly in regions where rainfall is limited or highly variable. Rainwater systems generally require large roof or land-based catchment areas, substantial storage infrastructure, and filtration mechanisms, which may not be feasible in dense urban or arid settings. Fog harvesting, although effective, is geographically constrained to coastal and high-elevation regions where fog is frequent and dense, such as parts of Chile, Morocco, and South Africa. In contrast, dew forms through nocturnal condensation on surfaces exposed to the open sky, requiring minimal infrastructure and operating passively without energy input, even under semi-arid or degraded conditions [26,52].

Unlike fog and rain, dew can form consistently throughout dry seasons, making it an ideal supplementary source in regions with prolonged drought or irregular precipitation patterns [27]. Its formation on radiative surfaces contributes to localized soil moisture, plant hydration, and microclimate stability, especially in fragile ecosystems or reforestation areas [55,60]. Moreover, dew harvesting reduces dependence on overexploited groundwater systems, supporting the resilience of groundwater-dependent ecosystems (GDEs) while avoiding ecological disturbances often associated with larger-scale water infrastructure. In this way, dew water serves not only as a low-cost, low-impact technology, but also as a strategic ecological buffer in landscape management and climate adaptation frameworks.

Dew harvesting is increasingly recognized as a viable ecological engineering solution for water-scarce regions, offering a low-impact and renewable water source that does not depend on traditional hydrological inputs such as rainfall or groundwater [52]. By utilizing radiative cooling surfaces to condense atmospheric moisture, dew collectors provide decentralized water access with minimal energy use and environmental disruption, making them ideal for arid and semi-arid landscapes [53]. This approach contributes significantly to climate change adaptation by offering a stable water supply that can buffer communities against the growing intensity and frequency of drought events [61]. Unlike rainwater harvesting, which is increasingly unreliable under shifting precipitation patterns, dew collection remains functional even during extended dry spells, supporting vegetation, improving soil moisture, and sustaining microclimates critical for local biodiversity [26,27]. As such, dew harvesting represents not only a tool for water security, but also a regenerative strategy that enhances ecosystem resilience and landscape sustainability under changing climate conditions.

A compelling real-world example of atmospheric water harvesting in a water-scarce region is the Dar Si Hmad (DSH) project in southwest Morocco. Situated in the arid Aït Baamrane region, this initiative utilizes a combination of fog and dew collection technologies to provide potable water to remote Berber communities facing chronic water shortages. While primarily known for its large fog nets, the largest operational fog-harvesting system in the world, the project also leverages early-morning dew condensation as a supplementary water source, particularly during periods of low fog density. The collected water is naturally filtered and gravity-fed to households, significantly reducing the burden on local women and girls who previously walked long distances to fetch water. By integrating dew harvesting into its design, the project not only increases total water yield but also contributes to ecosystem resilience, soil moisture retention, and climate change adaptation in a region prone to prolonged droughts. This innovative approach highlights the potential of dew collection as an ecological engineering solution in drylands, offering both humanitarian and environmental co-benefits [62,63].

In sum, dew water serves as a multifunctional resource that not only addresses immediate water needs but also contributes to long-term ecological stability. As part of a broader strategy for climate adaptation, biodiversity conservation, and groundwater protection, dew harvesting holds significant potential to support both human and environmental well-being in a changing world.

In addition to its ecological functions and role in ecosystem restoration, dew water harvesting also brings substantial economic implications. Beyond ecological value, dew water harvesting yields notable economic advantages. It reduces exposure to heavy metals (e.g., cadmium and arsenic), toxins well-known for their health risks, thus potentially lowering chronic kidney disease (CKD) cases and associated long-term healthcare costs [64]. Additionally, dew harvesting can reduce reliance on infrastructure-intensive solutions like deep-well drilling or desalination, which are costly and energyheavy. Evidence from rainwater harvesting (a comparable decentralized model) demonstrates substantial energy and cost savings at the watershed scale [65]. In rural or remote communities, dew collectors can provide low-cost, decentralized water access, easing economic burdens on households and local governments. At landscape and restoration scales, integrating dew harvesting can improve agricultural productivity, enhance ecosystem services, and support livelihoods, aligning with green growth and climate-resilient development frameworks [17,39–46].

5. Conclusions

Dew water, particularly dew drinking water, offers a sustainable and ecologically sound alternative to conventional water sources, especially in regions affected by heavy metal contamination, groundwater overexploitation, and water scarcity. Harvested passively through the Systemized Dew Process (SDP), it provides a clean, energy-efficient solution that alleviates pressure on groundwater-dependent ecosystems and supports biodiversity by minimizing environmental disruption. Its use can also contribute to the restoration of polluted aquatic systems by reducing reliance on contaminated water sources. In addition to its purity and high dissolved oxygen content (9.16 mg/L), dew water aligns with broader goals of ecological resilience and decentralized water management. Future research in applied ecology should investigate its potential to enhance ecosystem services such as soil moisture retention, plant hydration, and landscape restoration in degraded or arid environments.

Author Contributions

Conceptualization, J.J.; methodology, J.J and P.Z.; validation, J.J. and P.Z.; formal analysis, P.Z.; investigation, P.Z. and F.R.A.; resources, P.Z. and F.R.A.; data curation, P.Z.; writing—original draft preparation, P.Z. and F.R.A.; writing—review and editing, P.Z. and J.J.; visualization, P.Z.; supervision, J.J.; project administration, P.Z. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

All authors declare no conflict of interest related to this manuscript that could influence the outcome of the study.

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