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A concise review on health benefits of alkaline reduced water

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ABSTRACT

Alkaline reduced water (ARW), produced through electrolysis, has emerged as a health-promoting beverage due to its elevated pH and reduced oxidation–reduction potential (ORP). This type of water offers several notable health benefits. ARW effectively neutralizes excess body acidity, promoting a balanced internal pH, which is beneficial in counteracting the effects of an acid-heavy diet. Its smaller molecular clusters enhance cellular absorption, improving hydration and nutrient uptake, which is particularly advantageous for athletes and physically active individuals. The antioxidant properties of ARW, attributed to its negative ORP, play a crucial role in reducing oxidative stress, thereby protecting cells from damage and potentially lowering the risk of chronic diseases such as cancer, cardiovascular diseases, and neurodegenerative disorders. ARW also supports digestive health by promoting a balanced gut environment and reducing harmful bacterial load. It also enhances the solubility and bioavailability of nutrients, improving their utilization in the body. Regular consumption of ARW has been linked to a lower incidence of chronic diseases and reduced fatigue, further enhancing energy levels. Overall ARW is a valuable addition to a health-conscious lifestyle, offering comprehensive benefits by enhancing hydration and preventing diseases. However, further research is needed to fully elucidate the long-term effects of ARW.

1. Introduction

Water is considered a crucial element in the emergence of life on earth. The food that we eat and the water we drink are what keep our bodies in good condition. Water is crucial for effective digestion and the development of balanced gut flora, both of which are necessary for an animal to absorb all the nutrients it needs [1]. Through sweating and breathing, it regulates and manages our body temperature, which is necessary for the normal operation of many physiological processes in the human body. Human health is impacted by water quality, which is significantly influenced by terrain, geological formations, and climate [1]. The consumption of poor-quality water that contains high levels of toxins or consuming water that has been polluted by infections, and disease vectors may sometimes cause a few ailments, including death. Cancer, diabetes mellitus, cardiovascular diseases, and chronic respiratory diseases fall under the category caused by consuming poor-quality water [2]. According to the literature review, alkaline water has a pH between 8 and 10 and is characterized by having a high concentration of alkaline properties. Unique properties of alkaline water have the potential to have medicinal effects, such as dihydrogen and antioxidant effects. Alkaline water is known to have a protective effect on the deoxyribonucleic acid (DNA) against oxidative damage, since it can scavenge reactive oxygen species (ROS), reduce inflammation, and result in disease prevention. An investigation into the clinical consequences of alkaline water and how it functions revealed that its copious amount of dissolved hydrogen and poor oxidation potential are the mechanisms [2]. As the body lacks some minerals, Ca^{2+}, Mg^{2+}, and bicarbonate, due to our busy lifestyle so consuming this water we can get

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all these benefits that contain all alkaline minerals and has antioxidant properties. Alkaline water shows bactericidal, virucidal, and fungicidal effects. Inflammation and overproduction of ROS badly affect the GI metabolism and cause constipation and inflammatory bowel diseases (IBD), which include Crohn's disease (CD), Ulcerative colitis (UC), functional dyspepsia, acid reflux, diverticular disease, irritable bowel syndrome (IBS). Intake of alkaline water reported to reduce the bacterial load in the digestive tract and improves the GI tract [3].

Alkaline water has therapeutic benefits, helping to reduce insulin levels, prevent dental erosion from acidic foods, and protect against diseases such as gingivitis and periodontitis.It increases the muscle mass and bone mineral density (BMD), reduces the risk of cardiovascular and coronary heart disease, and finally lowers the mortality rate [3,4]. Aquaculture and medical uses of alkaline electrolyzed water are very common [5,6]. As a result, scientists have been attempting to make use of this fact by investigating the effects of consuming alkaline water on the gut microbiome and determining whether the results of these investigations can be advantageous to human health, more specifically, the treatment of metabolic diseases.

The global market for alkaline water electrolysis is projected to exhibit a strong upward trajectory between 2025 and 2034 [7]. As illustrated in Fig. 1, the market size is expected to increase steadily from approximately USD 200 million in 2025 to nearly USD 1 billion by 2034. This consistent year-on-year growth reflects the expanding adoption of alkaline electrolysis systems as a preferred technology for large-scale green hydrogen production. The early phase of the forecast period (2025–2028) demonstrates moderate growth, rising from USD 201.05 million to roughly USD 344.20 million. However, the market begins to accelerate significantly after 2029, reaching USD 411.77 million in 2029, USD 589.30 million in 2031, and surpassing USD 843.36 million by 2033. By 2034, the market is anticipated to exceed USD 1 billion, indicating a more than four-fold increase over the decade. This growth trend can be attributed to rising global decarbonization initiatives, increased investment in hydrogen infrastructure, and technological improvements that enhance the efficiency, scalability, and cost-effectiveness of alkaline water electrolysis systems.

Millions of people worldwide drink Zamzam water, a natural alkaline water treasure, because of their religious convictions and because of its therapeutic benefits [8]. Zamzam water is also a type of alkaline water and has several health benefits, including antioxidant properties that can help prevent various diseases. Both alkaline reduced water and Zamzam water are known for their potential health benefits. Zamzam water is a natural alkaline water found in Makkah AlMukarramah, kingdom of Saudi Arabia (KSA) [9]. It has never been chemically preserved or treated and has become alkaline due to its natural environment. On the other hand, alkaline-reduced water is a functional water produced through water electrolysis to increase its alkalinity [3]. Generally, the pH of Zamzam water is between 7.9 – 8 (Fig. 2) and the pH of alkaline-reduced water is between 8–10 [2,3]. Zamzam water is free from any type of microbial contamination. It is also rich in various minerals such as potassium, sodium, magnesium, calcium, and some trace elements like iron, copper, silver, manganese, aluminium, and many more. Many studies have concluded the presence of natural heavy metals such as arsenic, cadmium, selenium, and lead. Alkaline-reduced water (ARW) is known to be high in hydrogen content, low oxygen content as well as low oxidation–reduction potential (ORP) [10].

It has significant concentrations of minerals like magnesium, sodium, and calcium and has an alkaline pH of 8.0. Furthermore, no germs can

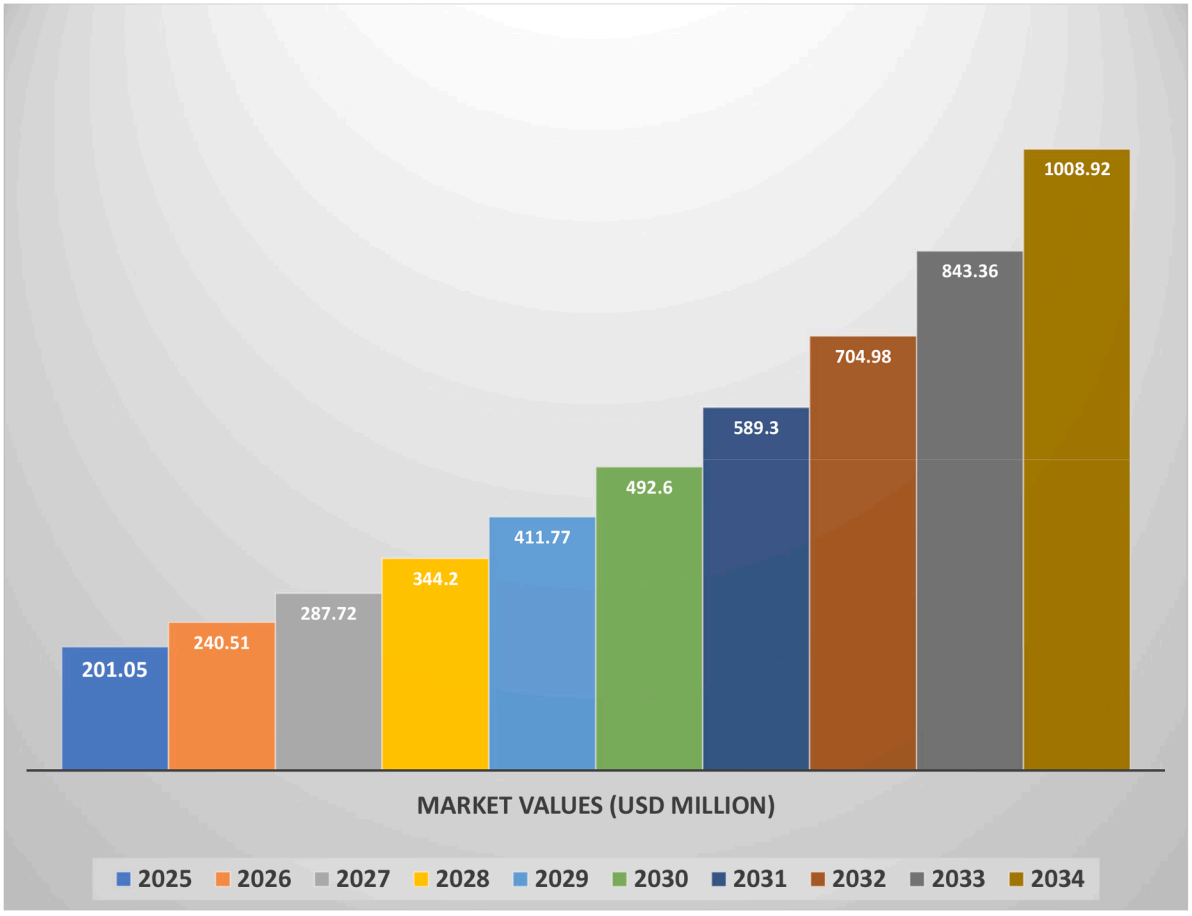

Fig. 1. Projected market size for alkaline water electrolysis, 2025–2034 in USD Million. (Source: www.precedenceresearch.com; data retrieved on November 25, 2025) [7].

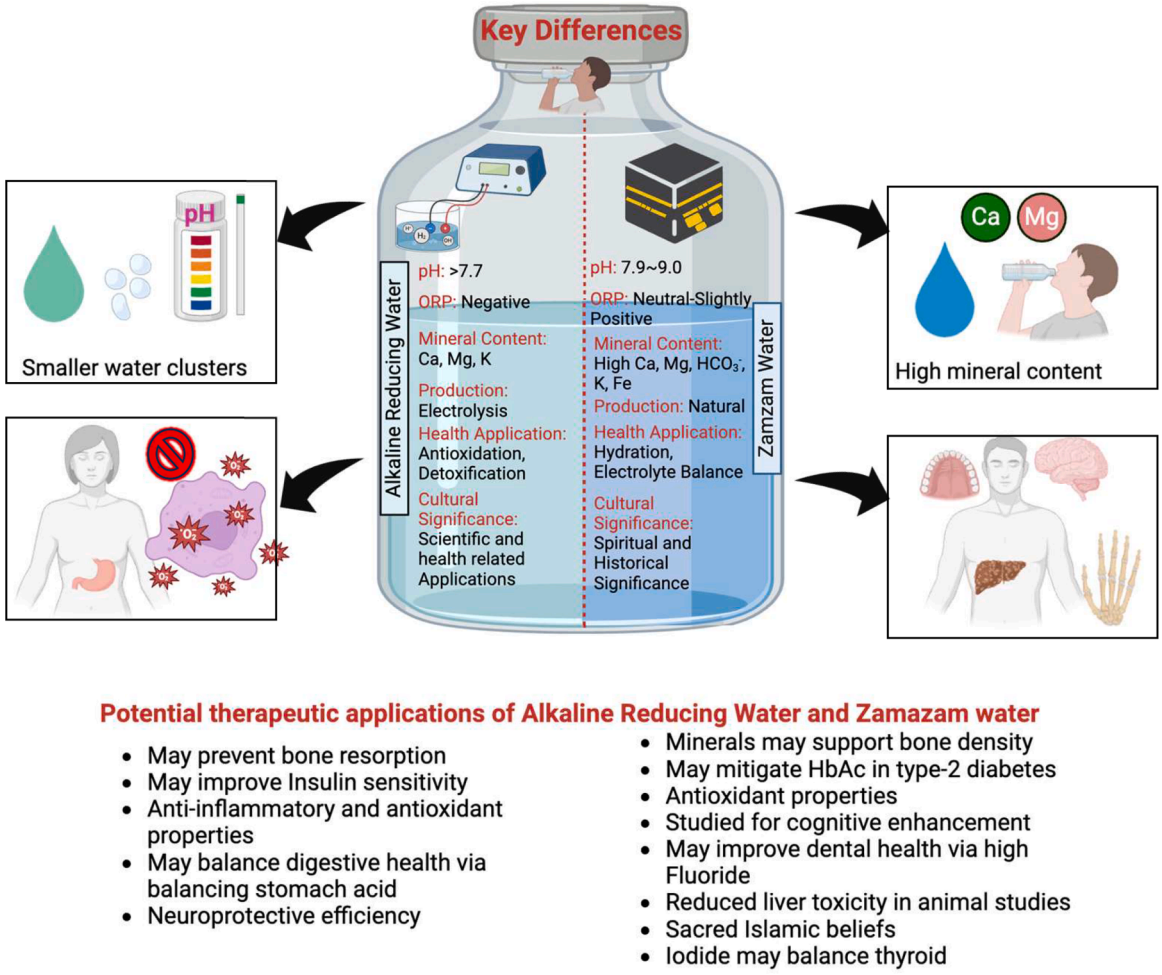

Fig. 2. Key differences and potential therapeutic applications of alkaline reducing water and Zamzam water.

grow at the source of or within Zamzam water [11]. Nonetheless, NO_3 is found in 2 % of waterways, albeit in marginally higher concentrations. 94 % of the samples met the water quality index (WQI) criteria for being fit for human consumption (class I). Zamzam water has properties of wound healing and prevents dental erosion [1,12]. Another study reported the effective usage of Zamzam water in the treatment and tolerance of opioid dependence [13]. The holy belief and increase in consumption of Zamzam water and alkaline water are on the rise these days. The rising yearly trend depicted in Fig. 3 encouraged us to prepare this review, aiming to deliver clearer and more comprehensive information for readers. This research aimed to deliver people an adequate information about alkaline water, Zamzam water, and their effects on health.

2. Mechanisms underlying ARW's role in cellular absorption, nutrient uptake, and protection against oxidative stress and chronic diseases

Alkaline reduced water (ARW), or hydrogen-rich water, is produced through electrolysis, which yields water with elevated pH, a higher concentration of molecular hydrogen (H_2), and a negative oxidation–reduction potential (ORP). These physicochemical characteristics are believed to support various biological benefits, including improved cellular absorption, enhanced nutrient uptake, reduced oxidative stress, and protection against chronic diseases. Its effectiveness is primarily attributed to dissolved molecular hydrogen and reactive mineral ions that promote antioxidant activity and contribute to physiological pH balance. At the cellular level, ARW is thought to enhance membrane permeability by modulating the local microenvironment and preserving ideal electrochemical gradients [14,15]. These changes may facilitate more effective nutrient diffusion, increased water influx, and more efficient transport through membrane channels and aquaporins, ultimately supporting improved cellular absorption (Fig. 4).

As represented in Fig. 5, a major mechanism underlying the biological effects of ARW is its strong electron-donating ability. Its negative ORP enables ARW to function as a potent, selective antioxidant, targeting harmful reactive oxygen species (ROS) such as hydroxyl radicals (•OH) and peroxynitrite ($ONOO^-$), which are key drivers of oxidative damage to cellular biomolecules [16]. Molecular hydrogen, being a small and neutral gas, easily penetrates cell membranes, mitochondria, and even passes through the blood–brain barrier. Once inside cells, hydrogen interacts directly with highly reactive ROS produced as byproducts of mitochondrial oxidative phosphorylation, reducing oxidative stress at its primary source. By mitigating these harmful oxidants, ARW protects cellular lipids from peroxidation, preserves protein structure and enzyme function, and prevents DNA strand breaks and mutations, which are significant risk factors for cancer and degenerative disorders. The chemical reactions underlying this protective effect can be summarized as:

$$H_2 + \bullet OH \rightarrow H_2O \text{ and } H_2 + ONOO^- \rightarrow NO_2^- + H_2O$$

Additionally, ARW may enhance nutrient absorption by modulating gastrointestinal function. Studies indicate that alkaline water can help regulate gastric acid secretion, particularly in individuals experiencing

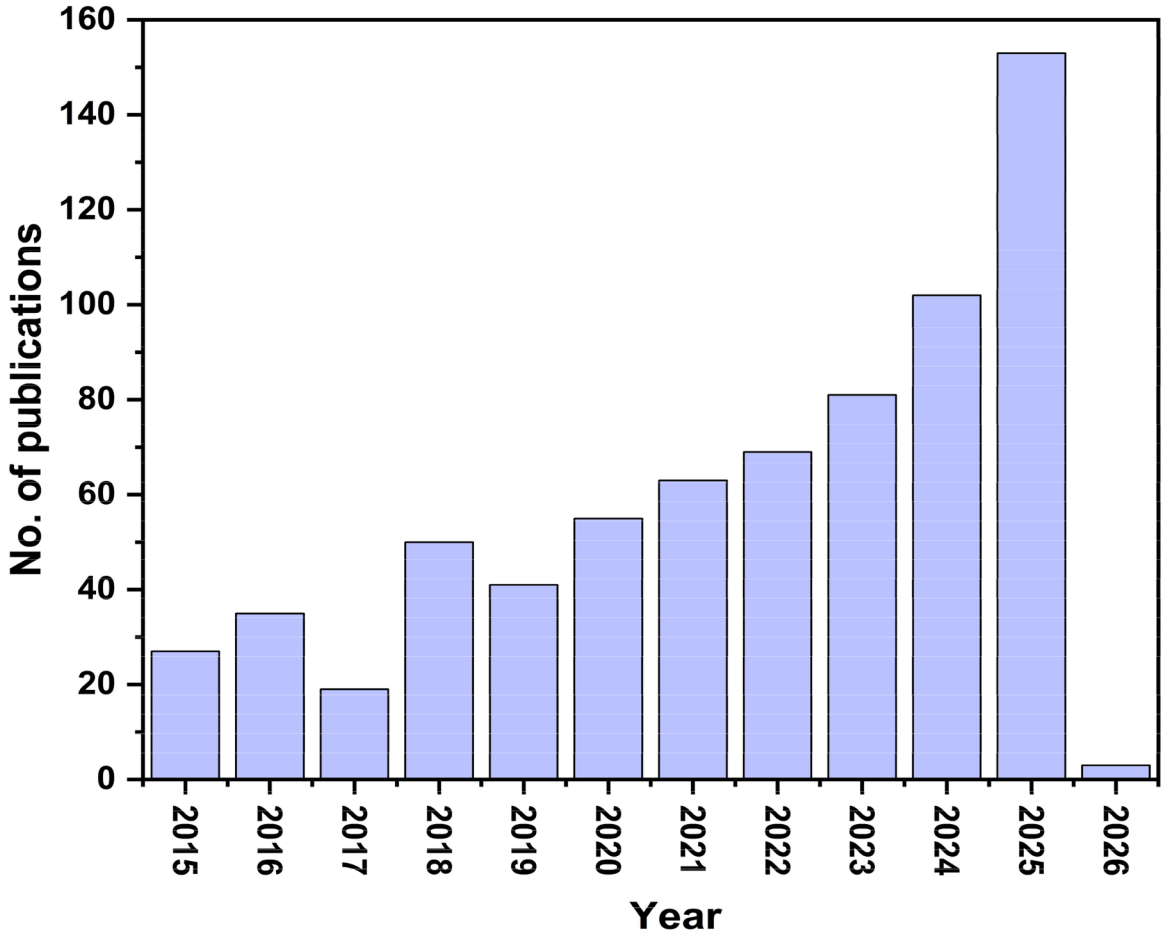

Fig. 3. Number of publications related to this research topic from 2015 to 2026 (data retrieved on November 25, 2025).

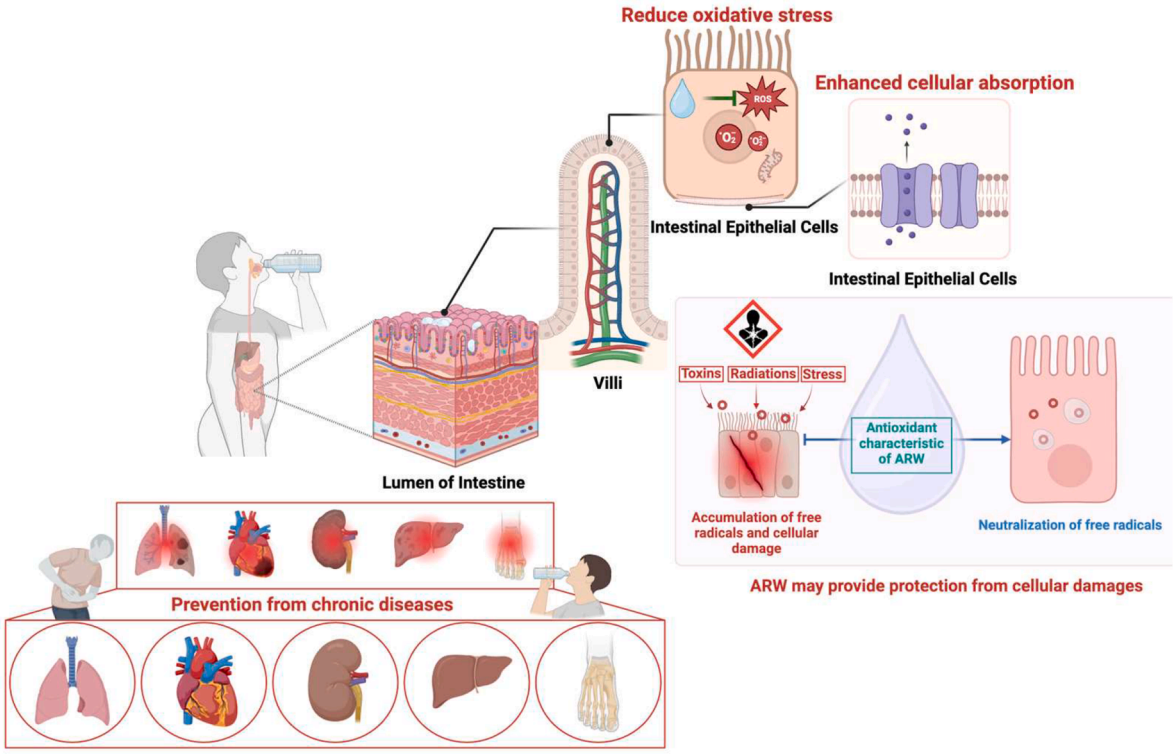

Fig. 4. The interactive regulatory mechanism of molecular hydrogen on liver oxidative stress and inflammatory cascade reaction.

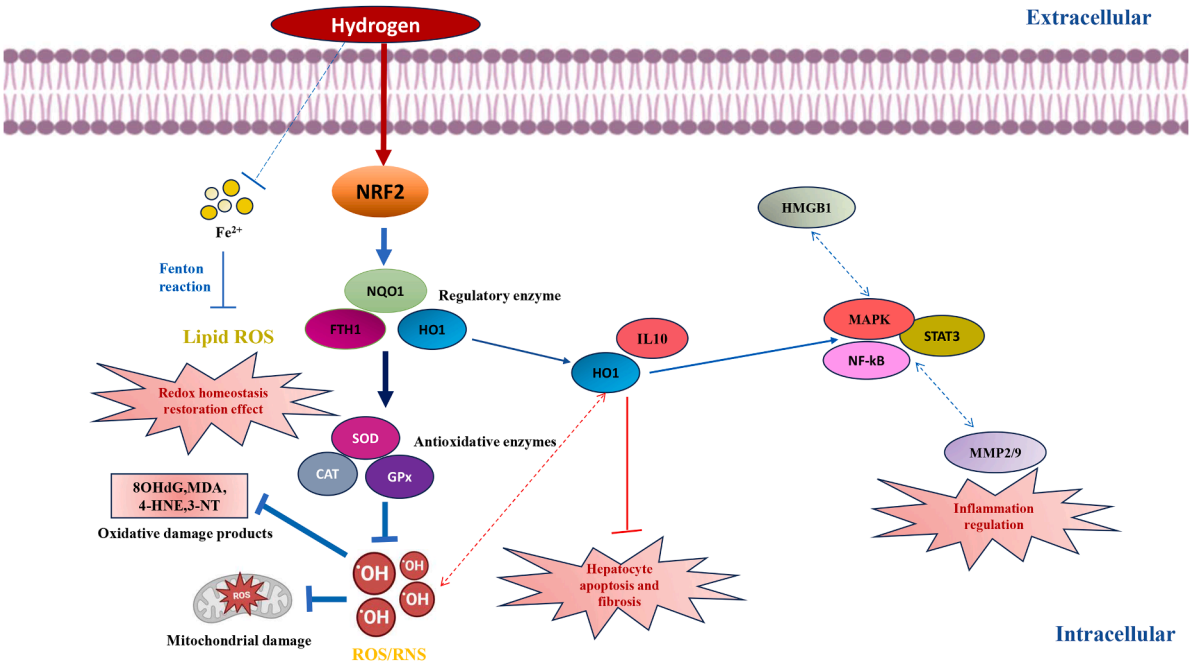

Fig. 5. Overview of the reported health benefits of alkaline reduced water across multiple physiological systems.

metabolic acidosis or consuming diets high in acidity [17]. A balanced extracellular pH improves transporter protein conformation, optimizing micronutrient absorption across epithelial membranes in the stomach and intestines. Furthermore, the micro-clustered water hypothesis proposes that ARW may form smaller molecular clusters, potentially increasing solubility and dispersion of nutrients, although this

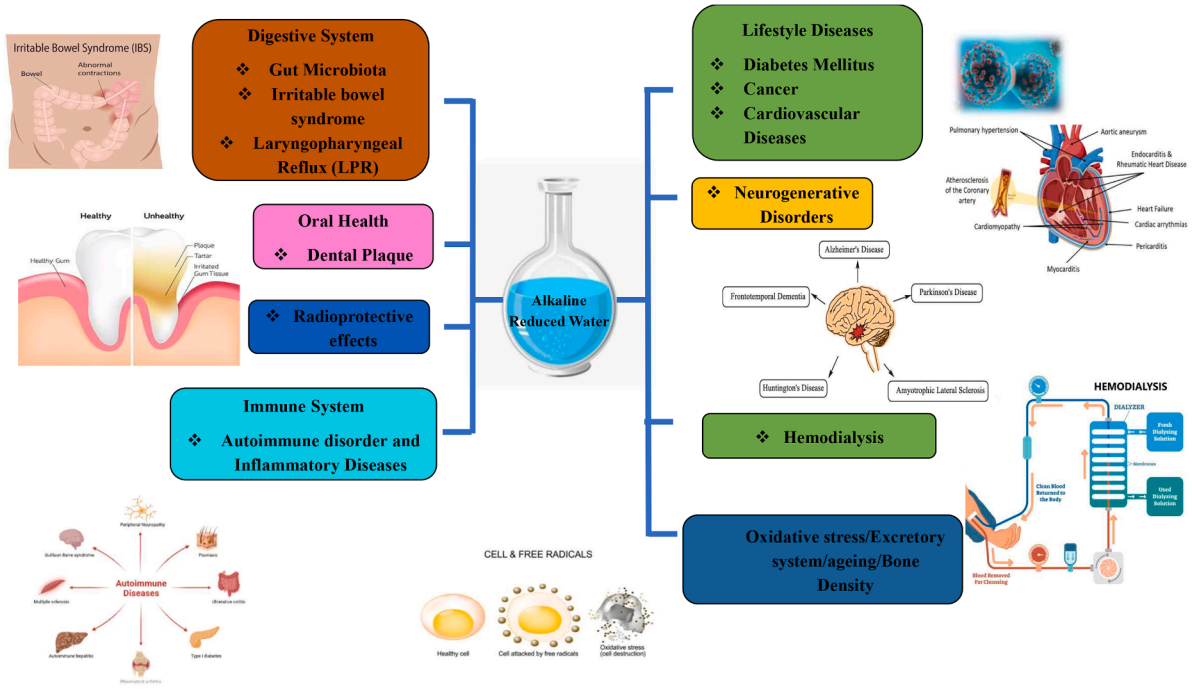

Fig. 6. The mechanisms by which ARW enhances cellular absorption improve nutrient uptake, reduce oxidative stress, protect cells from damage, and lower the risk of chronic diseases.

Molecular hydrogen exerts regulatory effects on hepatic oxidative stress and the associated inflammatory cascade through multiple interconnected pathways. It helps balance the production and clearance of reactive oxygen species (ROS) and influences various antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). Hydrogen also modulates NRF2 signaling, promoting the expression of downstream cytoprotective molecules such as NQO1, HO1, and FTH1.

In addition to reducing oxidative markers like MDA, 4-HNE, 3-NT, and 8-OHdG, molecular hydrogen attenuates inflammatory responses. It interferes with pathways involving NF-κB, STAT3, and MAPK, thereby lowering the expression of pro-inflammatory cytokines such as TNF-α, IL family members, and IFN-γ. It also impacts enzymes and mediators related to tissue remodeling and inflammation, including iNOS, HMGB1, and MMP-2/9. Collectively, these mechanisms contribute to hydrogen's protective role against liver injury.

mechanism remains debated. Improved hydration efficiency enhances circulation, nutrient delivery, and metabolic waste removal, collectively supporting cellular homeostasis [3]. In addition, mineral ions such as calcium, magnesium, and potassium in ARW exist in more bioavailable ionic forms, contributing to enhanced uptake and regulation of physiological electrolyte balance, which is crucial for enzymatic reactions, nerve conduction, and muscle activity [18].

The antioxidative capabilities of ARW extend to modulation of cellular signaling pathways and gene expression patterns involved in inflammation and metabolic health. By lowering oxidative stress, ARW may reduce activation of nuclear factor-kappa B (NF-κB), a transcription factor central to pro-inflammatory cytokine production. This anti-inflammatory effect plays a role in preventing chronic low-grade inflammation, a major driver of lifestyle disorders such as type 2 diabetes, cardiovascular disease, and neurodegenerative illnesses. Hydrogen has additionally been shown to activate the Nrf2 pathway, the master regulator of the cellular antioxidant defense system [19,20]. Through this pathway, ARW upregulates intracellular antioxidant enzymes including superoxide dismutase (SOD), catalase, and glutathione peroxidase, strengthening natural defense mechanisms that protect cells from cumulative oxidative injury over time. Such regulation contributes to improved mitochondrial function and energy metabolism, which are crucial for preventing fatigue and metabolic dysfunction.

Moreover, ARW may contribute to the prevention of chronic diseases through its role in reducing oxidative stress-induced cellular apoptosis and maintaining genomic integrity. As summarized in Fig. 6, alkaline reduced water has been investigated for its potential roles in digestive health, immune regulation, oxidative stress reduction, and several chronic diseases conditions. These diverse biological effects highlight their emerging relevance across multiple physiological systems. Excessive ROS disrupt mitochondrial membranes, trigger cytochrome c release, and activate caspase pathways leading to programmed cell death. By blocking this cascade, ARW preserves cell viability and delays senescence-related cellular degeneration. The reduction of oxidative modification of LDL particles also improves lipid metabolism and decreases atherosclerotic plaque formation, thereby supporting cardiovascular health. In neurological tissues, hydrogen-rich water has demonstrated potential in reducing neuronal inflammation, preventing aggregation of misfolded proteins, and supporting synaptic protection, offering prospects for reducing the risk of disorders such as Alzheimer's and Parkinson's disease [21]. Collectively, these mechanisms indicate that ARW supports multiple aspects of cellular health through hydration enhancement, improved nutrient availability, selective antioxidant action, and modulation of inflammation and metabolic signaling. While a growing number of animal studies and preliminary human clinical data provide encouraging results, further long-term randomized controlled trials are essential to definitively establish the therapeutic efficacy of ARW across different populations and disease models. Nonetheless, the currently understood biological actions highlight promising potential for ARW as a complementary strategy in promoting wellness, enhancing cellular resilience, and reducing the risk of oxidative stress-associated chronic illnesses.

3. Effect of alkaline reducing water on lifestyle diseases – diabetes, cancer, and cardiovascular diseases (CVDs)

The effect of alkaline reduced water (ARW) or alkaline ionized water (AIW) on lifestyle diseases are shown in Figs. 2and 6 and Table 1. ARW or AIW is known to act as an antioxidant due to its radical scavenging properties. It has a higher pH than normal water due to the addition of alkaline minerals and the removal of acidic minerals. It has gained attention due to its health properties, as it reduces oxidative stress and is beneficial in various disorders like diabetes, some cancers, renal impairment, cardiovascular diseases (CVDs), obesity, and non-alcoholic fatty liver disease [10]. Various studies and work done on some of these lifestyle diseases like diabetes, cancer, and cardio-vascular diseases are discussed below.

3.1. Diabetes

Diabetes mellitus is a metabolic disorder caused by insufficient insulin synthesis by the pancreas or the body's inability to use insulin adequately. Uncontrolled diabetes is distinguished by hyperglycemia, or elevated blood sugar levels, which can harm organ systems such as the eyes, neurons, kidneys, and blood vessels. Jin et al. [22] evaluated the anti-diabetic benefits of ARW on type 2 diabetes rat models. Two groups of rats: an experimental group given ARW and a control group receiving laboratory tap water. From weeks 6 to 32, rats' blood glucose levels, body weight, and lipid composition were evaluated. The control group had a glucose level of 202:5 96:5mmol/dl at week 18, whereas the ARW group only achieved 202:5 96:5mmol/dl in week 26. The blood glucose levels in the ARW group were consistently lower than those in the control group. These findings suggest that ARW caused a drop in blood glucose levels [22]. Another study on Wistar rats found that ZW water significantly lowered fasting blood glucose and insulin resistance without affecting lipid profiles or body composition [24]. Maleky et al. [23] examine the preventive effects of ZW alone or with gliclazide against streptozotocin (STZ)-induced diabetic nephropathy in rats. The control normal group, control diabetic group, diabetic rats with ip injections of 10 mg/kg gliclazide, diabetic rats with ZW ad libitum, and diabetic rats with both were monitored for 8 weeks. ZW and gliclazide were profoundly reduced STZ-induced blood pressure, heart rate, hyperglycemia, oxidative stress biomarkers, renal function impairment (urea, creatinine, albumin), kidney morphology, and apoptosis [23]. Taha et al. [25] demonstrated that ZW significantly reduced depression-like and anxiety-like behavior in diabetic rats. ZW elevated the levels of serotonin, dopamine, and norepinephrine in the brain regions of diabetic rats. This study also proved that ZW upregulated the expression of BDNF, p-ERK1/2, and p-CREP, indicating enhanced neuroprotection and reduced inflammation markers (TNF-α, IL-1β, IL-6) and GFAP expression in the brain [26]. Another experiment of Taha et al. revealed that combined treatment with dapagliflozin and ZW significantly improved wound closure, antioxidant enzyme levels, and histological features. It reduced inflammatory markers (NF-κB, TNF-α, IL-1β, IL6, CD45), promoted angiogenesis markers (VEGF, CD34, eNOS, EGF-β1, FGF, Ang II, HIF-1α), and increased Ki-67 for cellular proliferation. Additionally, it enhanced the remodeling stage by boosting MMP-2, TGF-β1, and Col1A1 levels in diabetic rats [25]. According to AlJuwaie et al. [24], intake of ketogenic diet alone for 10 weeks fails to reduce LDL cholesterol and fasting blood glucose level. While the combination of ketogenic diet and Zamzam water drastically lower fasting blood glucose and LDL cholesterol [27]. Bamosa et al. [8] concluded that in type 2 diabetic patients, consuming Zamzam water significantly reduced HbA1c levels, indicating improved long-term blood glucose control. However, fasting blood sugar levels did not show a significant change [8].

3.2. Cancer

ARW has shown promise in cancer research, demonstrating various mechanisms that may inhibit cancer progression and support treatment. Al Zahrani et al. [28] investigated the anti-proliferative and apoptotic effects of Zamzam water at pH 7.2 (Z1) and pH 8.0 (Z2) on the human breast cancer cell line MCF-7. Their study revealed that both Z1 and Z2 significantly reduced the viability of MCF-7 cells, with Z2 inducing higher levels of apoptosis and increasing cytoplasmic and mitochondrial reactive oxygen species (ROS) production. In contrast, Z1 had a minimal effect on ROS levels. Both treatments arrested MCF-7 cells in the G2/M phase and reduced the G1 phase population [28]. In a similar study, the effects of Z1 and Z2 were examined on A549 lung cancer cells and HSF skin fibroblast cells. Both treatments significantly reduced the viability of A549 cells, with Z2 inducing necrosis. Z1 did not significantly induce

Table 1
Summary of various studies conducted to explore the effects of alkaline water on lifestyle diseases.

S. No.	Type of alkaline water	Organ /tissue investigated	Cell line/ animal model	Treatment conditions used	Techniques used	Outcome	References
Diabetes							
1.	Alkaline reduced water	Blood/serum	OLETF rats	4-week old rats were supplied with food and ARW water, and reared at a temperature of 22 °C, a humidity of 56 5 %, and a 12 hour photoperiod	Cholestech L.D.X: to measure blood parameters	Reduced blood glucose level in ARW group that control.	[22]
2.	Zamzam	Serum and Kidney	STZ-DN rats	Diabetic rat groups received 10 mg/kg gliclazide injection, zamzam water ad libitum, and 10 mg/kg gliclazide + zamzam water ad libitum for 8 weeks.	Serum Glu: Spectrophotomer at 546 nm Insulin: ELISA kit IHC: Caspase-3	Renoprotective effect against STZ induced DN rats	[23]
3.	Zamzam	Blood, and adipose pads and musculoskeletal	Wistar albino rats	Chow diet along with either tap or Zamzam water as the only fluid source for 10 weeks.	-	Decreases fasting blood sugar, serum insulin, and insulin resistance in rats, but has no effect on lipid profile, redox homeostasis, and body composition.	[24]
4.	Zamzam	Blood and brain tissue	STZ-induced male albino rats	Group1: Control Group II: Zamzam water Group III: Diabetic group Group IV: Diabetic + Zamzam water Duration: 28–30 days	Behavioural test: Forced swimming test, Elevated plus maze test, Open field test IHC: TNFα, GFAP, HO-1, Caspase 3	Exhibit neuroprotective effect in rats.	[25]
5.	Zamzam	Skin	STZ-induced male albino rats	Group 1: Control rats Group II: Untreated diabetic rats Group III: Diabetic rats drinking ZW Group IV: Diabetic rats with dapagliflozin Group V: Diabetic rats with both dapagliflozin and ZW.	Excisional wound: Wound closure assessment IHC: NF-κB, VEGF, CD34, CD45, Ki-67, and eNOS	Improved cell proliferation and enhanced angiogenesis.	[26]
6.	Zamzam	Blood, and adipose pads and musculoskeletal	Male Wistar rat	Group 1: Chow diet + ordinary water Group II: Ketogenic diet + Ordinary water Group III: Ketogenic diet + Zamzam water Duration: 10 weeks	Blood glucose: Glucometer Serum insulin: ELISA kit	Reduce blood glucose and LDL-cholestrol	[27]
Cancer							
7.	Zamzam	-	MCF-7 breast cancer cell line	Cell lines treated with ZW of different pH 7.4 and pH 8.0.	Morphological: Microscope	Anti-proliferative and apoptotic effects	[28]
8.	Zamzam	-	A549 lung cancer cell line and human skin fibroblasts		Cell viability: MTT assay Cell death: annexin-V/PI assay Cell cycle: Flow cytometry ROS: Spectrophotometer	Inhibit cell viability and induce necrosis	[29]
9.	Zamzam	-	HCT-116 and HSF			Apoptotic activity in HCT-116	[30]
10.	Zamzam	-	Breast, colorectal, and ovarian cancer cell lines.	Cancer cells were treated with ZW or DW, with and without chemotherapeutic agents (paclitaxel, 5-fluorouracil, cisplatin) for 24 h.	Cell viability: MTT assays Apoptosis: Flow cytometry with annexin V/PI staining Protein expression: Western blotting	Suppressed the effect of chemotherapeutic agents	[31]
Cardiovascular disease							
11.	Zamzam	Serum and heart	Wistar albino rats	Group-1: Normal control Group 2: Doxorubicin control Group 3: Doxorubicin + Zamzam Group 4: Zamzam control Duration: 28 days	ELISA kit: Fibrinogen, IL-10, CRP, Renin Histological examination: HandE staining	Anti-inflammatory action	[32]
12.	Zamzam	Serum and kidney	White albino mice	Group 1: Tap water Group 2: Distilled water Group 3: Zamzam water Duration: 3 months	Serum analysis: ELISA kits Histological examination: HandE staining	Cardio-protective effect	[33]
13.	Zamzam	Serum, heart, liver, and kidney	Male rats	Group 1: Normal Control Group 2: Zamzam Control (ZC) Group 3: Disease Control (DC) - treated with doxorubicin Group 4: Therapeutic Control (DZ) - treated with Zamzam water and doxorubicin	Serum analysis: ELISA kits Histological examination: HandE staining	Reduce inflammation and oxidative stress	[34]

cell death, while Z2 showed significant necrotic cell death in A549 cells. Additionally, Z2 caused cell cycle arrest in the G0/G1 phase in A549 cells, with no significant effect on HSF cells. Neither Z1 nor Z2 significantly affected cellular and mitochondrial ROS levels in A549 cells [29]. Al Doghaither et al. [30] observed that ZW treatments significantly reduced the cell viability of HCT-116 cells to 87 % for Z1 and 66 % for Z2 in MTT assay. Cell death occurred via apoptosis under both treatments. Early apoptosis percentages were 3 % for control, 3.5 % for Z1, and 2.8 % for Z2. Z2 treatment significantly increased late apoptosis to 4.2 % compared to control ($p \leq 0.001$). Cells were arrested in the G2/M phase and decreased in the G1 phase after 24 h of ZW treatment. Only Z2 treatment increased both cytoplasmic and mitochondrial ROS production. These findings suggest that ZW induces apoptosis in human colon cancer HCT-116 cells, indicating its potential anticancer effect against colon cancer [30]. Siraj et al. [31] highlighted that ZW diminished the impact of chemotherapeutic agents (paclitaxel, 5-fluorouracil, cisplatin) in decreasing cell viability and inducing apoptosis in breast, colorectal, and ovarian cancer cells. ZW increased the phosphorylation of MAPK proteins (CRAF, MEK1/2, ERK1/2, P38), counteracting the chemotherapy-induced reduction in these proteins, thus promoting cell survival. Silencing ERK1/2 increased chemotherapy-induced apoptosis, indicating that ERK1/2 activation by ZW helps protect cancer cells from chemotherapy [31].

3.3. Cardiovascular disease

Several studies have suggested that consumption of alkaline water may contribute to cardiovascular health by influencing blood pressure, cholesterol levels, and overall heart function. Almujtaba et al. [32] explored the cardioprotective effects of Zamzam water in Wistar albino rats. The experiment involved four groups: normal control (NC), Dox control (DC), Dox + ZW (DZ), and ZW (ZZ). Over 28 days, the study found that Zamzam water, which is high in zinc and alkaline, significantly restored altered serum biomarkers, improved heart histology, and reduced oxidative stress markers in doxorubicin (DOX)-treated rats. These findings suggest that the zinc content and alkaline nature of Zamzam water contribute to its cardioprotective properties [32]. Mahmoud et al. [33] evaluated the health impacts of Zamzam water, specifically addressing concerns about its nitrate and arsenic content. The study, which involved 18 mice divided into three groups (tap water, distilled water, and Zamzam water) over three months, concluded that Zamzam water showed no microbial contamination, did not adversely affect kidney or liver functions, and maintained normal serum biomarkers. Additionally, it exhibited cardioprotective properties, leading to the conclusion that Zamzam water is safe, pathogen-free, and has potential therapeutic benefits [33]. In another investigation, Sheikh et al. [34] demonstrated that Zamzam water mitigates cardiac toxicity risk by positively affecting gut microbiota, the renin-angiotensin system, and reducing inflammation and oxidative stress. These findings suggest that Zamzam water could serve as an adjunct therapy to alleviate the cardiotoxic side effects of doxorubicin [34]. Al-Qurashi et al. [35] examined the effects of rehydration with mineral water on the cardiorespiratory fitness of athletes following exercise-induced dehydration. The study revealed that rehydration with Zamzam water preserved key cardiorespiratory fitness markers such as VO2peak (peak oxygen uptake), VT1 (ventilatory threshold 1), VT2, and VE peak (peak minute ventilation). Conversely, rehydration with bottled water resulted in significant reductions in both VO2peak and VEpeak. This indicates that Zamzam water does not impair cardiorespiratory fitness, even when the rehydration volume matches the total body mass lost due to exercise-induced dehydration [35].

4. Effect of alkaline reducing water on brain

Aging-related neurodegenerative disorders are closely associated with mitochondrial dysfunction and oxidative stress, and their incidence tends to increase with aging. Brain is the most vulnerable to reactive species generated by a higher rate of oxygen consumption and glucose utilization compared to other organs. Electrochemically reduced water (ERW) was demonstrated to scavenge reactive oxygen species (ROS) in several cell types. In the present study, the protective effect of ERW against hydrogen peroxide (H_2O_2) and nitric oxide (NO) was investigated in several rodent neuronal cell lines and primary cells. ERW was found to significantly suppress H_2O_2 (50–200 μM) induced PC12 and SFME cell deaths. ERW scavenged intracellular ROS and exhibited a protective effect against neuronal network damage caused by 200 μM H_2O_2 in N1E-115 cells. ERW significantly suppressed NO-induced cytotoxicity in PC12 cells despite the fact that it did not have the ability to scavenge intracellular NO. ERW significantly suppressed both glutamate induced Ca ($^{2+}$) influx and the resulting cytotoxicity in primary cells. These results collectively demonstrated for the first time that ERW protects several types of neuronal cells by scavenging ROS because of the presence of hydrogen and platinum nanoparticles dissolved in ERW [36].

We have proposed an active hydrogen reduced water theory that active hydrogen produced by electrolysis of water is stabilized in the form of hydrogenated metal nano colloids in electrolyzed reduced water (ERW) and scavenges intracellular reactive oxygen species (ROS). Because various brain diseases are caused by oxygen stress, we examined the effect of ERW on oxidative stress-induced apoptosis of neuronal cells. ERW suppressed the H_2 O_2-induced cell death of mouse neuroblastoma N1E115 cells, rat pheochromocytoma PC12 cells and mouse neuronal stem SFME cells. ERW lowered the intracellular ROS level of N1E115 cells, suppressing the H_2 O_2-induced decrease of mitochondrial membrane potential and intracellular ATP level, which are markers of apoptosis. These results suggested the effectiveness of ERW for prevention of various brain diseases caused by oxidative stress [37].

Human brain is the biggest energy consuming tissue in human body. Although it only represents 2 % of the body weight, it receives 20 % of total body oxygen consumption and 25 % of total body glucose utilization. For that reason, brain is the most vulnerable part of human body against the reactive oxygen species (ROS), a by-product of aerobic respiration. Oxi- dative stress is directly related to a series of brain dysfunctional disease such as Alzheimer's disease, Parkinson's disease etc. Electrolyzed reduced water (ERW) is a functional drinking water containing a lot of molecular hydrogen and a small amount of platinum nanoparticles. ERW is known to scavenge ROS and protect DNA from oxidative damage [38]. We previously showed that ERW could extend lifespan of Caenorhabditis elegans by scavenging ROS [39]. Molecular hydrogen could scavenge ROS and protected brain from oxidative stress. Pt NPs are also a new type of multi-functional ROS scavenger [39].

5. Effect of alkaline reducing water on hemodialysis

Research into the impact of alkaline-reducing water on hemodialysis is scarce, with few studies directly addressing this specific inquiry. Bajgai et al. [40] investigated the effects of electrolyzed alkaline-reduced water on patients with functional dyspepsia, a common gastrointestinal disorder. The findings indicated that those who consumed electrolyzed alkaline-reduced water experienced a notable reduction in gastrointestinal symptoms and an improvement in overall quality of life compared to those who consumed purified water. This study suggests that alkaline-reduced water can have a positive impact on digestive health, potentially benefiting individuals with chronic gastrointestinal issues [40]. In a study by Sharma et al. [41], the impact of electrolyzed weakly ARW at pH 8.5 was examined on renal proximal tubular epithelial cells. The study found that this treatment improved cell viability, reduced oxidative stress markers, regulated inflammatory markers, enhanced antioxidant defenses, and improved cellular metabolism, indicating significant anti-oxidative and anti-diabetic effects [41]. These findings point to the potential of alkaline-reduced water in supporting renal health, which is particularly relevant for hemodialysis

patients, as it suggests a possible avenue for enhancing the treatment's efficacy or mitigating some of its side effects. Tama and Sagiran [42] explored the significant effect of Zamzam water on the lipid profiles of *Rattus norvegicus*, showing changes in HDL and LDL levels [42]. Although this study does not directly relate to hemodialysis, it indicates Zamzam water's potential in influencing metabolic processes, which could be beneficial for hemodialysis patients who often face lipid metabolism disorders.

6. Effect of alkaline-reducing water on the digestive system

Increasing evidence suggests that molecular hydrogen-dissolved alkaline electrolyzed water (AEW) exhibits various physiological activities, including antioxidative activity. Gut microbiota is deeply associated with our health through a symbiotic relationship. Recent reports have described that most gastrointestinal microbial species encode the genetic capacity to metabolize molecular hydrogen, meaning that molecular hydrogen might affect the gut microbial composition. Nevertheless, the effects of AEW on gut microbiota remain unknown. This study investigated AEW effects on the intestinal environment in mice, including microbial composition and short-chain fatty acid contents. After mice were administered AEW for 4 weeks, 16S rRNA gene sequencing analyses revealed their fecal microbiota profiles. Organic acid concentrations in cecal contents were measured using an HPLC system. Compared to the control group, AEW administration mice had significantly lower serum low-density lipoprotein cholesterol levels and alanine aminotransferase activity. Organic acid concentrations of propionic, isobutyric, and isovaleric acids were higher in AEW-administered mice. Results of 16S rRNA gene sequencing analyses showed that the relative abundances of 20 taxa differed significantly in AEW-administered mice. Although the definitive role of gut microbes of AEW-administered mice remains unknown, our data demonstrate the possibility that AEW administration affects the gut microbial composition and that it has beneficial health effects in terms of cholesterol metabolism and liver protection [43]. Table 2 shows the impact of alkaline water on the digestive tract.

Furthermore, the ingestion of alkaline-reduced water (ARW) helps to improve the symptoms of diarrhea-predominant irritable bowel syndrome (IBS) along with improvement in abdominal pain score. Researchers hav e mentioned that drinking ARW for eight weeks improves the quality of life with diarrhea-predominant IBS patients [52]. Hydrogen-rich alkaline water was also found to be effective in relieving the gastric injury induced by aspirin-HCl, and the inhibitory effect is dose-dependent [53]. Researchers have also mentioned that alkaline water improve laryngopharyngeal reflux (LPR), a condition where the gastric acid creates damage associated with mucosa of the larynx, pharynx, trachea and bronchi. Alkaline water (pH 8.8) significantly reduced the acid reflux in the body [45].

7. Effect of alkaline reducing water on dentistry-related issues

The potential benefits of alkaline reducing water in dentistry have been explored in various studies, revealing its efficacy in improving oral health outcomes (Table 3). One study highlighted the use of magnetized water, which, while not exactly alkaline reducing water, serves as a comparable alternative in terms of altering water properties for health benefits. This study found magnetized water to be an effective and safe alternative to chlorhexidine for reducing plaque and gingivitis among children aged 12–15 years, suggesting that modified water properties can positively impact oral hygiene [54]. Another pertinent study focused on alkaline ionized water (AIW) as a mouthwash, which demonstrated effectiveness in reducing dental plaque. This study posits AIW's effectiveness as comparable to mouthwashes containing Chlorhexidine, a standard in dental care for controlling plaque and gingivitis [55]. Such findings underscore alkaline water's potential as an adjunctive tool in dental hygiene regimens, although the specific study's publication details were not provided. Further exploring the antioxidative properties of alkaline-reduced water, a study by Trinh et al. [56] suggested its potential in promoting health by demonstrating anti-oxidative effects in murine macrophage cells. This indicates a broader health-promoting potential, including possibly for dental health, by mitigating oxidative stress, which is a contributing factor in various oral diseases [56].

Moreover, the general antioxidative and anti-inflammatory properties of ARW could be beneficial in stabilizing physiological conditions caused by oxidative stress and inflammation in dental contexts. Such properties could theoretically aid in the management of periodontal diseases and other dentistry-related issues where inflammation plays a key role [2]. The antioxidative and anti-inflammatory properties, along with the ability to reduce dental plaque, position alkaline reducing water as a promising area for further investigation in dentistry.

8. Effect of alkaline reducing water on immune system

One pivotal study found that ARW can mitigate immunological imbalance caused by intestinal barrier dysfunction, rescuing cells from oxidative stress. Several studies based on this prospective have been cited in Table 4. This suggests that ARW may have a regulatory effect on the immune system, promoting a more balanced immune response and potentially protecting against autoimmune disorders and inflammatory diseases [60]. Furthermore, research on weaned piglets by [44] showed that supplementation with alkaline mineral complex (AMC) water improved growth performance and immune system functioning. This indicates that alkaline water, enriched with minerals, can enhance the body's immune response, making it more effective at fighting infections and diseases [61]. Although this study was conducted on animals, it opens the door to exploring similar benefits in humans, especially regarding the modulation of immune responses through dietary and environmental interventions. Adamia et al. though not directly related to alkaline reducing water, highlighted the health benefits of Tskaltubo radon-containing water in orthodontics, showing positive effects on bone mineralization and osteointegration by influencing markers related to bone formation and resorption processes [62]. While this study focuses on bone health, it underscores the potential for specific types of water to have systemic health benefits, including possible implications for immune health.

9. Effect of alkaline reducing water on excretory system/ oxidative stress/ageing/bone density

[64] highlighted the benefits of alkaline-reduced water consumption, specifically mentioning its ability to effectively decrease levels of oxidative stress and fatigue markers after intense exercise compared to purified water intake. This suggests that alkaline-reduced water could serve as an antioxidant and anti-fatigue supplement following exhaustive physical activities [64]. Antonio et al. [60] discussed the cytoprotective effect of alkaline-reduced water against H_2O_2 induced oxidative stress in DLD1 intestinal epithelial cells. It was found to reverse the immunological effects caused by barrier dysfunction, indicating its potential to mitigate oxidative stress at the cellular level [60]. Additionally, a study explored the synergistic effect of combining alkaline electrolyzed water (AEW) consumption and regular walking. It was shown to reduce oxidative stress and inflammation while improving the quality of life in individuals with type 2 diabetes [65]. This research provides evidence that alkaline water, possibly through its antioxidant properties, can contribute to managing and potentially reducing oxidative stress. Ademi et al. indicated that adding alkaline water to white laboratory rats during hyperthermic stress led to a preventive action against oxidative stress [66,67]. This finding supports the hypothesis that alkaline water may offer protective benefits against oxidative damage under stress conditions.

Research exploring the effects of alkaline water and Zamzam water

Table 2
Summary of various studies conducted to explore impact of alkaline water on digestive system.

S. No.	Type of alkaline water	Investigated organ/ tissue	Cell line/ model organism	Treatment conditions used	Technique used	Inference	Reference
1.	Sodium Metasilicate-based alkaline mineral water (SM-based AMW)	Diarrhea and intestinal inflammatory disease	Piglets	SMP group was supplemented with basal water plus 500 mg/L SMP (pH 8.8)	Quantitative real-time PCR (qRT-PCR), Western blotting, Immunofluorescence assay, Enzyme-linked immunosorbent assay.	Reduction of diarrhea in MS piglets under weaning stress, possibly due to reduced intestinal damage. Also, there is reduced gut microbiota gene abundance related to apoptosis and suppressed disease infection genes.	[44]
2.	Alkaline water	Laryngopharyngeal reflux (LPR) -mucosal damage of the larynx, gastrointestinal tract.	-	pH 8.8	Reflux scoring index (RSI), ENT examination, and reflux finding score (RFS) using flexible laryngoscopy/ fiberoptic laryngoscope (FOL)	Reduction in acid reflux as the presence of a higher pH level will inhibit pepsin, an enzyme majorly involved in protein breakdown and is the main cause of acidity.	[45]
3.	Alkaline Water	Laryngopharyngeal Reflux	-	Alkaline water (pH >8.0)	PS Cohorts (2010–2012) - given either esomeprazole twice daily or dexlansoprazole daily and standard reflux diet and precautions (PS) AMS Cohorts (2013–2015) - given alkaline water (pH >8.0), a plant-based, Mediterranean-style diet, and standard reflux precautions.	LPR symptoms can be improved with alkaline water and a plant-based diet, similar to a standard PPI regimen, while also avoiding the cost and adverse effects of pharmacological intervention.	[46]
4.	Alkaline water	Gastritis and miRNA expression	miR-7, miR-155, miR-135b and miR-29	pH of 8.5 to 10.0	1)Esophagogastroduodenoscopy (EGD) to evaluate anatomopathological parameters. 2) Total RNA extraction - mirVana miRNA isolation kit 3) Histological analysis and real-time PCR for the identification of H. pylori bacteria	Reduced gastritis severity after consuming alkaline water for 5 months, as per the Sidney classification system, indicating a clinical benefit for patients in the Amazon region.	[47]
5.	Alkaline water and Fresh water	Intestine microbiota of marine animals	Amur ide (*Leuciscus waleckii*)	alkaline water conditions -water temperature 24 °*C* − 25 °C, pH of 9.4–9.6, the dissolved oxygen level of 8.86–9.34 mg/ L, and alkalinity of 52.8–53.6 mmol/L.	aquatic microbial collection method, pure Soil DNA Mini Kit, TruSeq® DNA PCR-Free Sample Preparation Kit, Qubit@ 2.0 Fluorometer (Thermo Scientific), and Agilent Bioanalyzer 2100 system	The slight difference in intestinal microbiota was seen between alkaline water and freshwater environments in terms of composition, abundance and diversity.	[48]
6.	Molecular hydrogen-dissolved alkaline electrolyzed water	Intestinal environment in mice	5-week-old male C57BL/6 N mice	H2 concentrations (pH) of normal water and, AEW were 0.00 (6.83) and 0.32 (9.90) ppm	16 s rRna sequencing HPLC	AEW administration in mice improved gut microbial composition, cholesterol metabolism, and liver protection, reducing serum low-density lipoprotein cholesterol levels and alanine aminotransferase activity compared to the control group.	[43]
7.	Alkaline electrolyzed water (AEW)	Gastrointestinal symptoms	-	pH 7.6 ± 0.2 for the PW (purified tap water) group, and 9.2 ± 0.2 for the AEW group.	General blood test, biochemical examination, urinalysis	The results of this study show that consuming AEW daily improves health and exercise capacity, even in healthy people who do not have gastrointestinal symptoms.	[49]
8.	Alkaline Natural Mineral Water and Distilled Water	Gastric Ulcers	Kunming male mice	Distilled water (pH = 5.6 ± 0.3), alkaline natural mineral water (pH = 9.3 ± 0.6)	ELISA, Western blot analysis	Ethanol-induced gastric ulcers were reduced and prevented to a certain content after the administration of alkaline natural mineral water in mice. It may be due to the improved levels of gastric mucous protective factor and by the inhibition the pepsin activity.	[50]

(*continued on next page*)

Table 2 (*continued*)

S. No.	Type of alkaline water	Investigated organ/ tissue	Cell line/ model organism	Treatment conditions used	Technique used	Inference	Reference
9.	High saline and alkaline water	Intestinal ion regulation in *Gymnocypris przewalskii* (naked carp or the scale-less carp)	SLC26 and SLC4	pH 9.1–9.5	Fluorescence quantitative PCR analysis,spectrophotometry,agrose gel electrophoresis	The current findings demonstrated that naked carp drink at night and feed during the day, indicating that intestinal ion regulation follows a daily pattern when exposed to high saline and alkaline lake water.	[51]
10.	Alkaline reduced water	Diarrhea - predominant irritable bowel syndrome (IBS)	-	ARW pH 8.5 - 10	Bristol stool scale ARW prepared by using alkali water ionizer Sham device for preparation of placebo water	The IBS quality - of-life score as well as abdominal pain score improved in AEW ingested groups. Thus, AEW is proved to be beneficial in patients with diarrhea-predominant IBS	[52]

Table 3
Summary of various studies conducted to explore impact of alkaline water on dentistry related issues.

S. No.	Type of Alkaline water	Investigated organ/ tissue	Cell line	Treatment conditions used	Techniques used	Inferences	References
1.	Alkaline electrolyzed water	Acid erosion -a dental disease	-	pH 10.0 to 10.5	Two-way anova	The results suggest that Mouth rinsing with AEW has the potential to prevent the initiation and progression of dental erosion and dental caries.	[57]
2.	Mineral and alkaline water	Salivary pH of adults, dental carries	-	pH 7.9	Kolmogorov-Smirnov and Shapiro-Wilk tests and One-way ANOVA followed by Paired sample *t*-test	Rinsing mouth with water after acidic challenge leads to neutralization of salivary pH thus preventing caries process in young adults.	[58]
3.	Electrolyzed reduced water (ERW)	Wistar rats (*R. norvegicus*)	Gingival tissue to determine Number of neutrophils and MDA (malondialdehyde) levels in wistar rats.	Control group - Distilled water (pH - 7) Treatment group - ERW (pH- 9.8,20 ml/d)	Hematoxylin eosin staining, colorimetric assay.	ERW effectively treated aggressive periodontitis in Wistar rats by reducing neutrophil cells while maintaining MDA levels, indicating its potential as a treatment option.	[59]

Table 4
Summary of various studies conducted to explore the effects of alkaline reducing water on immune system.

S. No.	Type of alkaline water	Organ/Tissue investigated	Cell line	Treatment conditions used	Technique used	Inferences	References
1.	Electrolyzed reduced water (ERW)	Wistar rats (*R. norvegicus*)	Gingival tissue to determine Number of neutrophils and MDA (malondialdehyde) levels in wistar rats.	Control group - Distilled water (pH - 7) Treatment group - ERW (pH- 9.8,20 ml/d)	Hematoxylin eosin staining, colorimetric assay.	ERW effectively treated aggressive periodontitis in Wistar rats by reducing neutrophil cells while maintaining MDA levels, indicating its potential as a treatment option.	[59]
2.	Zamzam (alkaline) water	Mice bone marrow	-	Light: dark, 12:12 h, two kinds of water (Tap and Zamzam water)	Micronucleus assay	The Zamzam water has reduced the effect of radiation on bone marrow cells and its radioprotective effect was increased by the duration of use in mice	[63]
3.	Alkaline reduced water	Intestinal epithelial cells	DLD1 cells	Alkaline water pH 8.5, alkaline water pH 10 (pH 10 group	Western blot assay, Catalase Assay, Multiplex assay.	ARW reduces H2O2-induced oxidative damage in DLD1 by assessing the MAPK signaling and catalase activity.	[60]
4.	Weak Alkaline Reduced Water	Murine Macrophage Cells	-	pH 9.5–10.0	Western blot analysis	ARW_8.5, showed anti-oxidative properties by regulating the MAPK signaling pathway in RAW 264.7 murine macrophage cells, indicating its potential health benefits through daily consumption.	[56]

on bone density reveals some promising findings, particularly regarding alkaline water. One study demonstrated an improvement in spine T-scores among postmenopausal women with osteoporosis after consuming alkaline water, indicating an increase in bone density. However, this study noted that the impact of alkaline water on femur density remains unclear and warrants further investigation [68]. Mousa discussed the health effects of an alkaline diet and water, including improvements in bone mineral density and muscle mass, prevention of chronic illnesses, and protection against heart disease and cancer. It also mentioned that alkaline water consumption may prevent osteoporosis, supporting the idea that alkaline water can positively affect bone health [69].

10. Radioprotective effect of alkaline reduce water

Research into the radioprotective effects of alkaline water, including Zamzam water, has revealed some promising findings. Notably, Zamzam water, known for its unique alkaline properties, has been studied for its potential to mitigate the harmful effects of radiation. A study by Yazdi et al. demonstrated that Zamzam water could significantly reduce the clastogenic (chromosome-breaking) and cytotoxic (cell-damaging) effects of gamma irradiation in mice bone marrow. This radioprotective effect was observed in both 10-day and 20-day treatment groups, suggesting that Zamzam water may offer protective benefits against radiation-induced damage [70]., 2017). Another study by Tama and Sagiran [42] explored the effects of Zamzam water administration on the levels of HDL (high-density lipoprotein) and LDL (low-density lipoprotein) in white mice. Their findings indicated a potential radioprotective effect of Zamzam water, demonstrating its influence on lipid profiles, which could be indirectly related to its capacity to modulate oxidative stress and inflammation, both of which are key factors in radiation-induced damage [42].These studies collectively highlight the potential of alkaline and Zamzam waters as radioprotective agents. The mechanism behind this protective effect may involve the mitigation of oxidative stress, enhancement of antioxidant defense systems, or modulation of inflammatory responses, all of which are crucial in managing radiation-induced cellular damage. However, the specific pathways and the extent of protection offered by these types of water require further investigation.

11. Effect of alkaline reducing water on other diseases

Apart from the studies mentioned above there are many other diseases in which ARW play its part. In a study by Handayani and Widyawati alkaline water was used to raise haemoglobin levels. There were two groups, each received 42 samples. The intervention group received a mixture of 60 mg iron tablets and alkaline water with a pH of 9.5 as much as 1liter for 14 days, whereas the control group received only 60 mg of iron tablets. Before and after evaluation of Hb levels indicated that the iron supplements and alkaline water together had a favorable impact on adolescent Hb levels [71]. In a study by Zalvan et al. [46], effect of alkaline water in laryngopharyngeal reflux (LPR) was done as it is known to inhibit the pepsin as its presence leads to the acidic conditions which affect the laryngopharynx. The results showed that the patients who received alkaline water, a plant-based Mediterranean diet, and routine reflux precautions did not show difference in reflux symptom index (RSI) as compared to general treatment with standard proton pump inhibitors (PPI) but it can be effective in reducing the symptoms, prevent the expenses and side effects of pharmacological intervention, and allow for the additional health advantages brought on by a balanced, plant-based diet [46]. Another study confirmed that drinking alkaline water with a pH up to 9.3 helps in maintaining acid-base balance during exercise and rest, which will further enhance anaerobic and aerobic performance [72]. The wound healing effect of Zamzam water in Wistar rats were studied by Moni et al. [1], and it displayed 96 % effective due to presence of factors like modulation of pro-inflammatory cytokines and reduction in apoptosis markers (caspase-3 and caspase-9) [1]. To study the effect of electrolyzed reduced water (ERW) against carbon tetra- chloride (CCl_4)-induced liver damage by Tsai et al. [73], male ICR mice were divided into CCl_4, CCl_4 + silymarin, and CCl_4 + ERW groups. ERW or silymarin supplement significantly improved the CCl_4-induced liver lesions, lowered the serum levels of hepatic enzyme markers (ALT and AST) and increased the activities of superoxide dismutase (SOD), catalase, and glutathione peroxidase (GSH-Px) in liver. Therefore, the results of this study show that ERW can be proposed to protect the liver against CCl_4-induced oxidative damage in mice, and the hepatoprotective effect might be correlated with its anti- oxidant and free radical scavenging effect [73]. In the study by Heil et al. [74], 38 young healthy adults were divided into control and experimental groups to determine whether the consumption of a mineral-rich alkalizing (AK) bottled water could improve both acid-base balance and hydration status under free living conditions. Control group consumed non-mineralized placebo bottled water over a 4-week period while the Experimental group consumed the placebo water during the 1st and 4th weeks and the AK water during the middle 2-week treatment period. Blood test and 24-hour urine samples were collected 3 times each week. As a result, there were no significant changes seen in control group whereas in experimental group significant increases in blood and urine pH, decreased blood and increased urine osmolality, and decreased urine output during the second week of the treatment was seen. However, these changes were reversed when subjects switched to the placebo water during the fourth week. Thus, consumption of alkaline water can be seen as a valuable nutritional vector for influencing both acid-base balance and hydration status in healthy adults [74]. Weidman et al. explored the effect of high-pH water consumption after exercise on hydration biomarkers in 100 healthy adults. The participants exercised in a warm environment until their weight was reduced by a normal accepted level of 2.0 $\pm$ 0.2 % due to perspiration reflecting the effects of exercise in producing mild dehydration. Participants were randomized to rehydrate with electrolyzed, high-pH (alkaline) water or standard water of equal volume. After exercise-induced dehydration, high-pH water reduced high-shear viscosity by an average of 6.30 % compared to 3.36 % with standard purified water. Other measured biomarkers (plasma osmolality, bioimpedance, and body mass change) revealed no significant difference between the two types of water for rehydration. Thus, high-pH, electrolyte water was preferred more as compared to standard purified water due to significant difference seen in whole blood viscosity in the recovery phase following strenuous exercise-induced dehydration [75]. Effect of Zamzam water as a radioprotectors in mice bone marrow exposed to gamma radiation by micronuclei test was also studied due to its antioxidant properties. For the study, mice were divided into 5 groups - 1st control group (ordinary water), 2nd group (Zamzam water), and other radiation groups received 2 Gy gamma with ordinary and Zamzam water for 10 days and another for 20 days. Results showed no significant difference between the Zamzam group and control in the absence of radiation. But all these indices were significantly different between irradiated and non- irradiated groups. The frequency of micronuclei in polychromatic erythrocytes was not significantly different between 10 and 20 days Zamzam irradiated groups, but the reduction in micronuclei in nor- mochromatic erythrocytes and an increase in the polychromatic erythrocyte to polychromatic erythrocyte plus normochromatic erythrocyte ratio compared to ordinary water were seen in 20 days Zamzam group. Dose reduction factor was 1.36 and 2 for Zamzam water groups of 10 days and 20 days, respectively. Thus, the results suggest that Zamzam alkaline water can reduce the clastogenic and cytotoxic effects of gamma irradiation [63]. A positive role of ARW in reducing obesity which in turn helps in improving the pathophysiological (hormonal, metabolic, and immunological) imbalances incurred by PCOS were hypothesized by Ara et al. [76]. It is mainly because weight loss helps in reducing adiposity, regulation of levels of adipokines/pro-inflammatory cytokines and induction of cholesterol homeostasis, as well as reducing insulin resistance, which collectively

help in improving infertility in PCOS patients [76].

12. Challenges and future scope of ARW

Despite increasing interest in ARW and naturally alkaline waters, their application into evidence-based practice remains limited due to the absence of standardized criteria for ARW composition. Different studies have employed ARW with different pH ranges, dissolved hydrogen levels, and electrolysis procedures. This makes it difficult to compare findings and establish reproducible physiological effects. In case of natural alkaline waters, variations in sampling location or seasonal changes may also influence their health impacts when considered for therapeutic use.

Limited availability of rigorous clinical studies is another challenge for the application of ARW in evidence-based practice. The majority of studies have been focused on animal models, in vitro work, or small exploratory human trials, sometimes on a specific gender. Thus, these studies provide preliminary insights into the health benefits of ARW but are unable to address long-term safety considerations. In addition, several proposed benefits of ARW remain mechanistically unclear in humans.

Furthermore, the regulatory uncertainty limits evidence-based practice of ARW to clinical or public health settings. ARW is generally marketed as a functional beverage, which leads to variable labeling practices and unverified health claims. Whereas, the cultural significance of natural alkaline water overshadows the need for routine toxicological assessment to ensure permissible limits of trace elements, including heavy metals, during long-term consumption.

Thus, for advancements in this field, it is required to establish acceptable pH ranges, minimum dissolved hydrogen concentrations, and redox potential thresholds for ARW. That in turn would greatly improve comparability across studies. Large, well-controlled human trials focused on specific clinical conditions are necessary to clarify the efficacy of ARW intervention. Future studies should focus on integrating omics-based approaches to reveal how ARW influences gut microbiota, systemic redox balance, and inflammatory signaling. Researchers should also conduct comparative analyses of ARW and natural alkaline waters to identify unique chemical signatures or synergistic components that can contribute towards enhanced biological effects. In addition, user-friendly electrolysis systems with real-time quality monitoring have to be developed. These systems can enhance consumers' safety and reproducibility in both household and clinical environments.

13. Conclusion

ARW has been gaining attention due to its health–promoting benefits. The review of studies done by various authors was done to understand the role of ARW in the prevention and treatment of diseases. Its anti-inflammatory and anti–oxidative properties help in the prevention of diseases such as diabetes, CVDs, and neurodegenerative disorders. Its consumption also helps in reducing the damage related to radiotherapy. In dentistry, it helps in preventing dental erosion. It also reduces the immunological imbalance caused by intestinal barrier dysfunction by rescuing cells from oxidative stress. In hemodialysis, it improves cell viability and cellular metabolism as well as helps in reducing the side effects of the therapy. Overall, ARW continues to show encouraging therapeutic potential; however, inconsistent preparation methods, composition, limited clinical evidence, and unresolved safety concerns hinder its advancement. Future advancements in this area will depend on establishing clear production standards and generating well-designed human studies that clarify its mechanisms and benefits. Addressing these issues will only decide whether ARW can transition from a functional beverage to a reliable component of evidence-based health practice.

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Abbreviations

8-OhdG	8-Hydroxy-2′-deoxyguanosine
AFT	Accelerated failure time
AIW	Alkaline Ionized Water
AK water	Alkalizing water
ALT	Alanine aminotransferase
AMC	Alkaline mineral complex
ANOVA	Analysis of Variance
ARW	Alkaline Reduced Water
AST	Aspartate aminotransferase
ATP	Adenosine triphosphate
BDNF	Brain-derived neurotrophic factor
BMD	Bone mineral density
CCl4	Carbon tetra- chloride
CD	Crohn's disease
CONT	Control
CTX	C- telopeptides
CVDs	Cardiovascular diseases
DNA	Deoxyribonucleic acid
DOX	Doxorubicin
fol	Flexible laryngoscope/ fiberoptic laryngoscope
GFAP	Glial fibrillary acidic protein
GI tract	Gastro-intestinal tract
GSH-Px	Glutathione peroxidase
H_2O_2	Hydrogen peroxide
Hb	Hemoglobin
HbA1c	Glycated hemoglobin or glycosylated hemoglobin
HCl	Hydrochloric acid
HDL	High density lipoprotein
HPLC	High-performance liquid chromatography
HU	Hindlimb unloading
IBD	Inflammatory bowel diseases
IBS	Irritable bowel syndrome
LDL	Low density lipoprotein
LPR	Laryngopharyngeal reflux
MAPK	Mitogen-activated protein kinase
MDA	Malondialdehyde
MPO	Myeloperoxidase
NO	Nitric Oxide
OLETF rat	Otsuka Long–Evans Tokushima fatty rat
ORP	Oxidation-reduction potential
PCOS	Polycystic ovarian syndrome
pH	Potential of Hydrogen
PPI	Proton pump inhibitors
Pt NPs	Platinum nanoparticles
PTH	Parathyroid hormone
RFS	Reflux finding score
ROS	Reactive oxygen species
rRNA	Ribosomal ribonucleic acid
RSI	Reflux scoring index
SFME cells	Serum-free mouse embryo cells
SOD	Superoxide dismutase
SRPA	Self-reported physical activity
STZ	Streptozotocin
UC	Ulcerative colitis
WQI	Water quality index
ZW	Zamzam Water

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Declaration of competing interest

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.

Data availability

No data was used for the research described in the article.

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