https://doi.org/10.48047/AFJBS.7.4.2025.1323-1348

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Electromagnetic Water Treatment for Scale Mitigation and Physicochemical Quality Enhancement

Merwan Saadsaoud[1,2], Moussa Attia[2*], Abderrahmane Gouasmia[2], Ismail Khalfaoui[2]

[1] Materials and Electronic Systems Laboratory (LMSE), Mohamed El Bachir El Ibrahimi University, Bordj Bou Arreridj 34000, Algeria.

[2] Environment Laboratory, Institute of Mines, Echahid Cheikh Larbi Tebessi University, Tebessa 12002, Algeria

Corresponding Author: Moussa Attia* **Email:** moussa.attia@univ-tebessa.dz **Address:** Institute of Mines, Echahid Cheikh Larbi Tebessi University, Tebessa 12002, Algeria **Phone:** +213671336015

Volume 7, Issue 4,Apr 2025

Received: 15 Feb 2025

Accepted: 05 Mar 2025

Published: 05 Apr 2025

doi:10.48047/AFJBS.7.4.2025.1323-1348

Abstract: This study investigates the effectiveness of an electromagnetic water treatment (EMWT) system in improving the physicochemical quality of tap water through a controlled laboratory-based experiment. The system applies pulsed electromagnetic fields to flowing water, eliminating the need for chemicals, membranes, or filtration media. Two tap water samples underwent identical EMWT exposure, and seven key quality indicators were analyzed before and after treatment: pH, electrical conductivity (EC), TDS, total hardness, salinity, calcium and magnesium ion concentrations, and dissolved oxygen (DO). The results revealed notable improvements: EC decreased by 28.0% and 29.2%, TDS dropped by 44.3% and 43.5%, total hardness declined by 8.0% and 8.5%, salinity was reduced by 24.2% and 21.4%, calcium and magnesium concentrations dropped by up to 14.3%, while DO increased by 21.4% and 22.6%. The pH values stabilized at a neutral level (7.4 ± 0.2). These findings suggest that EMWT may influence ionic mobility, microstructural arrangement of dissolved species, and gas solubility. Overall, the system demonstrates promising potential for enhancing water quality in applications requiring reduced salinity and hardness and improved oxygenation.

Keywords: Electromagnetic water treatment, scale control, water quality, physicochemical parameters, non-chemical methods, tap water.

1. INTRODUCTION

Water scarcity, pollution, and infrastructure degradation are global challenges, especially in arid and semi-arid regions where climate change, groundwater overexploitation, and aging water systems exacerbate resource vulnerability [1, 2]. According to the World Health Organization, over two billion people lack access to safely managed drinking water, which poses significant public health, environmental, and agricultural concerns [3, 4].

Conventional water treatment methods, such as chlorination, coagulation, and ion exchange, have historically been effective; however, they raise increasing concerns over their environmental impact and the presence of chemical residues [5-7]. For instance, chlorine disinfection may produce harmful byproducts, such as trihalomethanes and haloacetic acids, while chemical softening techniques often leave residual agents that can impact aquatic ecosystems and human health [8-10].

These limitations have sparked interest in non-chemical technologies, such as EMWT. In contrast to conventional water treatment methods, which often rely on the addition of chemicals such as chlorine and salts to reduce hardness and salinity, electromagnetic water treatment (EMWT) offers a non-chemical solution that avoids the use of harmful additives. This makes EMWT a more environmentally friendly option, as it does not leave chemical residues in the water, nor does it generate secondary waste products such as sludge. Additionally, EMWT is a low-energy process that offers a sustainable alternative for water treatment without the need for filtration media or chemicals. This approach involves applying low-frequency electromagnetic fields to flowing water, triggering changes in molecular structure, hydrogen bonding, ionic mobility, and crystallization dynamics [11]. Research suggests that EMWT can reduce TDS, decrease salinity and hardness, and alter mineral deposition behaviors—traits especially valuable in agricultural irrigation and decentralized water conditioning systems.

Electromagnetic Water Treatment (EMWT) utilizes low-frequency electromagnetic fields to affect the molecular structure of water, specifically altering the hydrogen bonds between water molecules. These changes in molecular structure influence the ionic mobility, particularly the mobility of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, which are responsible for water hardness. EMWT leads to a reduction in these ions' ability to form scale, and also enhances gas solubility in water, especially oxygen, by reducing surface tension. These mechanisms contribute to the overall improvement in water quality, including reduced hardness and better oxygenation, without the use of chemical additives.

Environmentally, EMWT requires no chemical additives, generates no secondary sludge, and consumes minimal energy, positioning it as a sustainable water conditioning method. Agriculturally, it improves plant water absorption, mitigates soil salinization, and supports efficient irrigation. Furthermore, by avoiding chemical reagents, EMWT offers potential benefits for decentralized water applications in rural areas.

EMWT technology remains underexplored despite its promise due to inconsistent experimental setups and a lack of standardized testing protocols. This study addresses that gap by designing and evaluating a custom-built EMWT system using municipal tap water samples under controlled laboratory conditions. The system's effectiveness was assessed through detailed physicochemical analysis, including pH, conductivity, TDS, hardness, salinity, calcium and magnesium content, and dissolved oxygen [11].

The outcomes support the broader adoption of EMWT in sustainable water management strategies, particularly in resource-limited or environmentally sensitive regions.

2. Materials and Methods

A custom-built experimental setup was developed in a laboratory setting to assess the non-chemical capabilities of EMWT in enhancing water quality. The study focused on evaluating changes in physicochemical properties—specifically pH, EC, TDS, salinity, hardness, calcium, magnesium, and DO—in municipal tap water samples. Control samples were processed through the same system without activating the electromagnetic coils, serving as baseline references.

Analytical procedures followed internationally accepted water analysis protocols to ensure measurement accuracy and repeatability. All instruments were calibrated before use, and measurements were performed in triplicate to ensure statistical reliability.

The electromagnetic water treatment (EMWT) system employed a pulsed electromagnetic field generated by a signal frequency of 16.6 kHz. The electromagnetic field was induced using an NE555 timer circuit that controlled the frequency. The field strength was adjustable by varying the resistor-capacitor (RC) network, with an optimized field strength of 100 mT. The exposure time for each water sample was varied between 1, 2, and 5 cycles to determine the optimal treatment time.

The system parameters were calculated based on the following equation for the magnetic field strength (B):

$$B = (\mu_0 * N * I) / L$$

Where:

B: magnetic field strength (Tesla)

μ_0: permeability of free space ($4\pi \times 10^{-7}$ T·m/A)

N: number of coil turns

I: current (Amperes)

L: length of the coil (meters)

The optimal exposure time was determined by measuring changes in water quality indicators such as TDS, conductivity, and pH over time, with the most effective exposure time chosen for subsequent tests.

2.1.Structural and Functional Design of the Electromagnetic Water Treatment Device

The EMWT device is powered by a 9–18 V DC source based on an NE555 timer circuit configured in astable mode. This design enables the generation of a pulsed square wave signal at approximately 16.6 kHz, which induces a fluctuating electromagnetic field as water flows through a PVC pipe wrapped with copper coils. Signal frequency and amplitude are adjustable through a resistor-capacitor (RC) network consisting of two 470 Ω resistors, one 6.8 kΩ resistor, and capacitors rated at 4.7 nF, 100 nF, and 200 nF. A potentiometer can be used to fine-tune the oscillation characteristics. The coils, each with 10 turns of insulated copper wire, are symmetrically placed along the inlet and outlet zones of the pipe, ensuring complete and balanced exposure to the field [12].

From an electrical engineering perspective, the device was validated through physical testing and simulation. Figure 1 presents the schematic layout of the circuit, and Figure 2 illustrates the simulated waveform output generated using LTspice software.

A summarized overview of the system's technical specifications is presented in Table 1.

Table 1: Technical Specifications of the EMWT Device

Specification	Value
Operating Voltage	9–18 V DC
Core Circuit	NE555 Timer (Astable Mode)
Output Signal Type	Pulsed Square Wave (~16.6 kHz)
Coil Material	Insulated Copper Wire
Number of Coil Turns	10 turns per coil (2 coils)
Resistors Used	2 × 470 Ω, 1 × 6.8 kΩ
Capacitors Used	4.7 nF, 100 nF, 200 nF
Field Frequency	16.6 kHz (calculated)

Specification	**Value**
Tube Material	PVC
Device Weight	500 grams (approx.)
Adjustability	Frequency & Field Strength Tunable

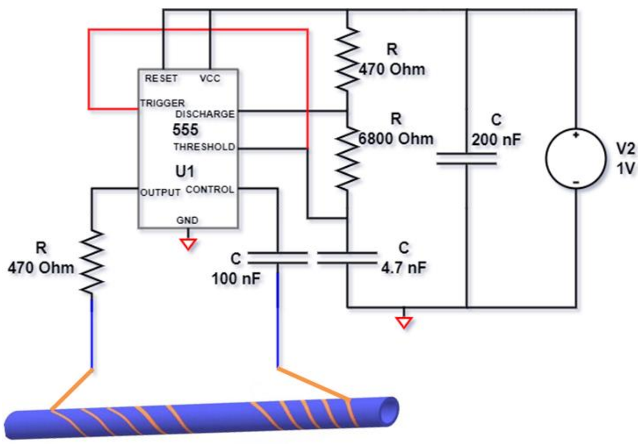

Figure 1: Circuit schematic of the EMWT system based on the NE555 timer IC.

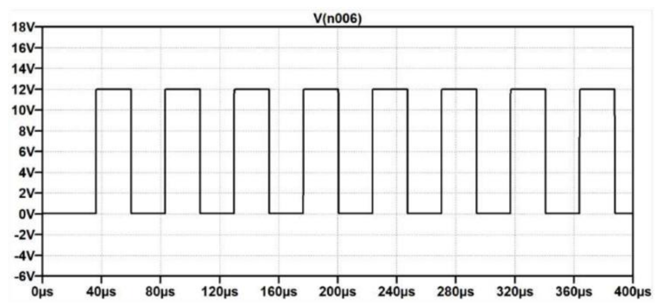

Figure 2: Simulated output voltage waveform of the EMWT circuit using LTspice.

2.2.Experimental Setup and Measurement of Water Properties

A series of laboratory experiments was conducted to evaluate the effects of the EMWT device on water quality. The tests were performed using municipal tap water under controlled ambient conditions (≈20 °C). Water samples were passed through a PVC pipe surrounded by dual electromagnetic coils connected to the NE555-based pulse generator. Samples were exposed to one, two, or five consecutive electromagnetic treatment cycles. For control purposes, identical water samples were passed through the same apparatus without activating the coils. All samples were gently stirred using a magnetic stirrer before and after treatment to ensure homogenization.

The study focused on seven key physicochemical indicators: pH, EC, TDS, Total Hardness, Salinity, Calcium and Magnesium ion concentrations, and DO. Each parameter was measured using calibrated instruments or standard volumetric titration methods. Where applicable, real-time digital logging was used via Logger Pro software to ensure high-resolution data acquisition.

2.2.1. Analysis of pH Levels

pH is a fundamental indicator of water quality, reflecting the balance between acidity and alkalinity. In this study, untreated tap water samples recorded initial pH values of approximately 7.45 and 7.49. After exposure to the electromagnetic field generated by the EMWT device, pH levels increased to 7.95 and 7.89, respectively, indicating a measurable shift toward alkalinity. This change is attributed to the electromagnetic field's influence on dissolved gases and ionic species. Specifically, EMWT likely promotes the desorption of dissolved CO_2, thereby reducing the formation of carbonic acid and increasing the activity of hydroxide ions (OH^-). These alterations contribute to a higher pH level, which is desirable in both domestic and agricultural contexts, as it reduces corrosivity and enhances nutrient availability in soils [13]. During testing, water samples were gently stirred to ensure homogeneity and then vortexed for two minutes following treatment. This step simulated flow dynamics and encouraged gas exchange. Samples were subjected to one, two, and five passes through the EMWT system to assess cumulative effects. Control samples were processed through the same setup without coil activation to isolate the electromagnetic influence.

The experimental configuration used for pH and DO testing is shown in Figure 3, where dual copper coils are wrapped around a glass burette to ensure continuous exposure to the oscillating electromagnetic field.

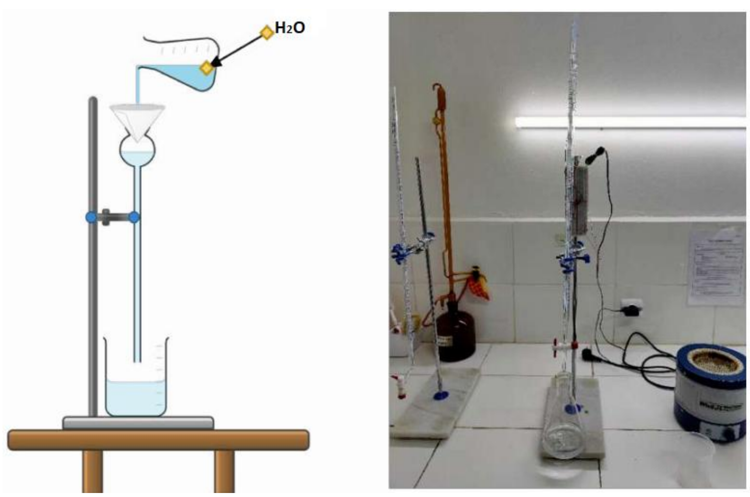

Figure 3: Electromagnetic Coils of the EMWT Device Wrapped Around a Burette.

2.2.2. Analysis of Electrical Conductivity

EC is a key indicator of water's ionic strength and salinity, reflecting the concentration of dissolved ions. In untreated tap water samples, EC values were measured at 1743 µS/cm and 1695 µS/cm. After electromagnetic treatment using the EMWT device, these values dropped significantly to 1255 µS/cm and 1201 µS/cm, representing reductions of approximately 28.0% and 29.2%, respectively.

The observed decline in conductivity is attributed to the EMWT's influence on ionic behavior. Pulsed electromagnetic fields may alter the arrangement, charge mobility, or aggregation of dissolved ions, reducing their electrical activity and measurable conductivity. These changes are consistent with related reductions in TDS and salinity, suggesting a broader physicochemical restructuring effect.

The improvements observed in water quality, such as reductions in hardness, TDS, and salinity, can be attributed to the electromagnetic fields' effect on the molecular and ionic structure of water. Specifically, the EMWT process induces changes in ionic interactions by promoting the clustering or precipitation of hardness-causing ions like calcium and magnesium, which reduces their ability to form scale. Additionally, the electromagnetic field influences the solubility of gases like oxygen by disrupting hydrogen bonding and lowering the surface tension of water, allowing for better gas exchange and improving dissolved oxygen levels.

Measurements were conducted using a calibrated multi-parameter water quality meter with an integrated EC probe. Each sample was analyzed after one, two, and five treatment cycles to determine cumulative effects. Control samples were processed under the same conditions without electromagnetic activation. Table 2 summarizes the numerical results, and Figure 4 visually compares conductivity levels before and after treatment.

Table 2: Electrical Conductivity Before and After EMWT

Sample	**Conductivity Before (µS/cm)**	**Conductivity After (µS/cm)**	**Reduction (%)**
Tap Water 1	1743	1255	28.0%
Tap Water 2	1695	1201	29.2%

Figure 4 further visualizes the changes, showing a side-by-side comparison of conductivity levels before and after EMWT exposure.

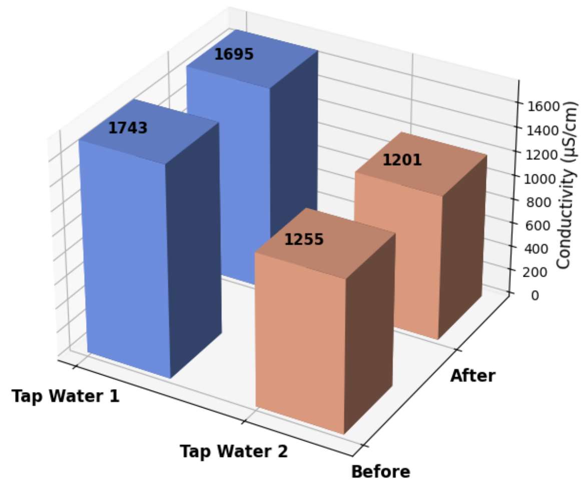

Figure 4: Change in Electrical Conductivity Before and After Electromagnetic Treatment.

2.2.3. Analysis of Total Dissolved Solids

TDS refers to the combined concentration of all inorganic and organic substances dissolved in water, including minerals, salts, and trace metals. Elevated TDS levels can adversely affect the taste of water, increase scaling in pipes and appliances, and reduce the suitability of water for irrigation due to excessive salinity [14].

In this study, untreated tap water samples exhibited high TDS values of 889 ppm and 842 ppm. After electromagnetic treatment, the TDS levels dropped significantly to 495 ppm and 476 ppm, corresponding to reductions of 44.3% and 43.5%, respectively. These reductions indicate a substantial improvement in overall water purity. The decrease in TDS is likely a result of the electromagnetic field-induced reorganization of ionic species in the water matrix. This may promote aggregation or clustering of ions, leading to partial precipitation or decreased ionic mobility, which reduces their contribution to conductivity and TDS readings. Measurements were conducted using a multi-parameter water quality meter with a combined EC/TDS probe. The system was connected to Logger Pro software, enabling real-time data visualization and digital recording of results. The actual measurement setup is shown in Figure 5, while the comparative results are presented in Table 3 and visualized in Figure 6.

Table 3: Total Dissolved Solids Before and After EMWT

Sample	TDS Before (ppm)	TDS After (ppm)	Reduction (%)
Tap Water 1	889	495	44.3%

Sample	**TDS Before (ppm)**	**TDS After (ppm)**	**Reduction (%)**
Tap Water 2	842	476	43.5%

The results clearly demonstrate the positive effects of the electromagnetic water treatment (EMWT) system on key water quality indicators, including electrical conductivity, total dissolved solids (TDS), and dissolved oxygen levels. Significant reductions in TDS and conductivity were observed, alongside a notable increase in oxygen solubility, highlighting the potential of EMWT in improving water quality without the need for chemical treatments.

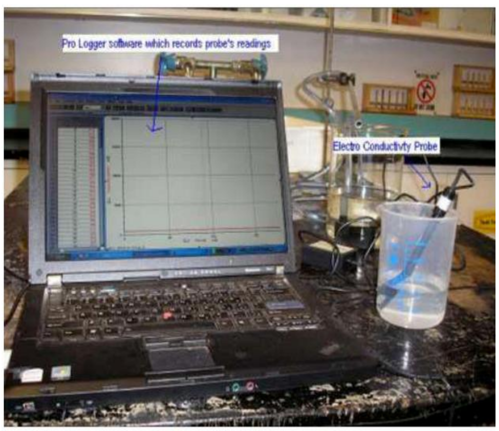

Figure 5: Measurement of Electrical Conductivity Using Logger Pro Software and an Electroconductivity Probe [11].

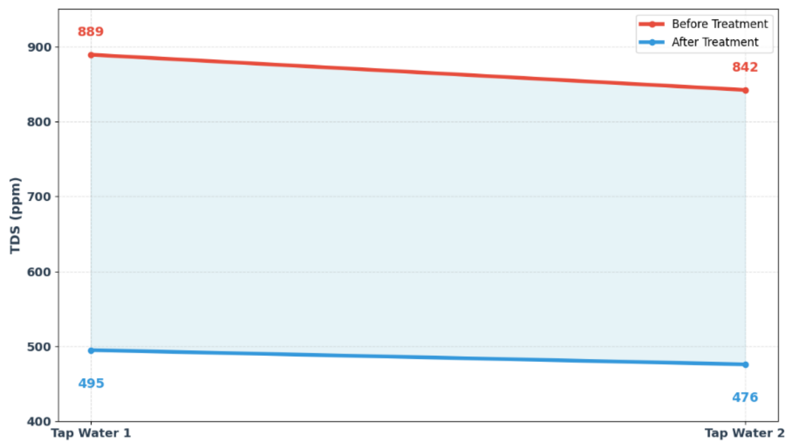

Figure 6: Reduction in Total Dissolved Solids in Tap Water Samples After EMWT.

The changes in physicochemical properties such as TDS, conductivity, and hardness were statistically validated using the paired t-test for two sets of data and one-way ANOVA for comparisons among multiple treatment conditions. A significance level of $p < 0.05$ was considered statistically significant.

For paired t-test, the formula used was:

$t = (\bar{X}_1 - \bar{X}_2) / (s / \sqrt{n})$

Where:

$\bar{X}_1$: mean of the first sample group (before EMWT treatment)

$\bar{X}_2$: mean of the second sample group (after EMWT treatment) s: standard deviation of the differences

n: number of paired observations

For ANOVA, the F-statistic was calculated as follows:

F = (variance between groups) / (variance within groups)

Where: variance between groups measures the differences between the treatment groups, and variance within groups measures the variability within each treatment group.

The results confirmed that the observed changes in water quality indicators were statistically significant ($p < 0.05$), indicating that the EMWT system effectively improved water quality.

2.2.4. Analysis of Total Hardness

Total hardness in water is primarily attributed to the presence of divalent cations, mainly calcium (Ca^{2+}) and magnesium (Mg^{2+}). High hardness levels contribute to scale formation in plumbing systems, reduce soap efficiency, and hinder nutrient uptake in agricultural soils [13].

In this study, untreated tap water samples recorded total hardness values of 250 mg/L and 340 mg/L (as $CaCO_3$). After treatment with the EMWT device, these values decreased to 230 mg/L and 311 mg/L, respectively, reflecting reductions of 8.0% and 8.5%.

Although the percentage reduction is more modest compared to TDS and EC, it remains significant considering that the treatment involves no chemical additives or filtration. The observed reduction may result from electromagnetic field-induced microcrystallization and aggregation of hardness-causing ions, which alters their solubility and detectability.

The measurements were performed using standard EDTA titration with Eriochrome Black T as an indicator. Each sample was titrated in triplicate, and the results were averaged for accuracy. The values are presented in Table 4, and the trend is illustrated in Figure 7.

Table 4: Total Hardness Before and After EMWT

Sample	Hardness Before (mg/L as $CaCO_3$)	Hardness After (mg/L as $CaCO_3$)	Reduction (%)
Tap Water 1	250	230	8.0%
Tap Water 2	340	311	8.5%

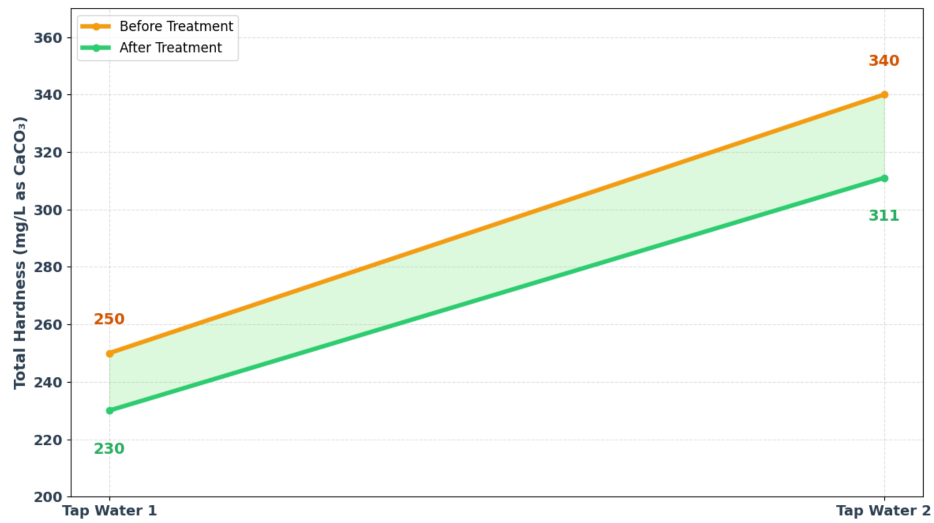

Figure 7: Reduction in Total Hardness After EMWT

2.2.5. Analysis of Salinity

Salinity refers to the total concentration of dissolved salts in water and is typically expressed in Practical Salinity Units (PSU). It is a critical parameter in assessing water quality for irrigation, environmental sustainability, and the longevity of infrastructure. Elevated salinity can impair plant growth, degrade soil permeability, and accelerate corrosion in distribution systems [15].

In this study, salinity levels in untreated tap water were measured at 0.91 PSU and 0.84 PSU. After exposure to the EMWT device, values decreased to 0.69 PSU and 0.66 PSU, indicating reductions of 24.2% and 21.4%, respectively.

These declines align with parallel reductions in TDS and EC, reinforcing the hypothesis that EMWT influences the ionic structure and behavior of dissolved salts. Although the treatment does not physically remove salts, it may alter their aggregation state or mobility, leading to a lower detectable salinity. Salinity was measured using a calibrated digital multi-parameter meter with automatic temperature compensation. Samples were gently stirred before measurement to ensure uniform distribution of ions. Results are detailed in Table 5 and illustrated graphically in Figure 8.

Table 5: Salinity Before and After EMWT

Sample	Salinity Before (PSU)	Salinity After (PSU)	Reduction (%)
Tap Water 1	0.91	0.69	24.2%

Sample	Salinity Before (PSU)	Salinity After (PSU)	Reduction (%)
Tap Water 2	0.84	0.66	21.4%

Figure 8: Reduction in Water Salinity After EMWT

2.2.6. Analysis of Calcium and Magnesium Ions

Ca^{2+} and Mg^{2+} ions are primarily responsible for water hardness and the formation of scale. Their high concentrations harm domestic appliances, industrial equipment, and the permeability of agricultural soils [16, 17].

This study measured calcium concentrations in untreated tap water at 105 mg/L and 115 mg/L, while magnesium levels were 42 mg/L and 48 mg/L. After treatment with the EMWT device, calcium concentrations decreased to 91 mg/L and 102 mg/L, and magnesium levels dropped to 36 mg/L and 42 mg/L. These results reflect an average reduction of 12–14%, indicating a measurable softening effect.

These reductions confirm the EMWT system's ability to induce measurable water softening without the use of chemical additives, as reflected in lower concentrations of calcium and magnesium ions.

Concentrations were determined using standard complexometric titration with EDTA. Each titration was repeated three times per sample to ensure accuracy. The data are presented in Table 6 and visually summarized in Figure 9.

Table 6: Calcium and Magnesium Concentrations Before and After EMWT

Ion	Sample	Before (mg/L)	After (mg/L)	Reduction (%)
Calcium (Ca^{2+})	Tap Water 1	105	91	13.3
Calcium (Ca^{2+})	Tap Water 2	115	102	11.3
Magnesium (Mg^{2+})	Tap Water 1	42	36	14.3
Magnesium (Mg^{2+})	Tap Water 2	48	42	12.5

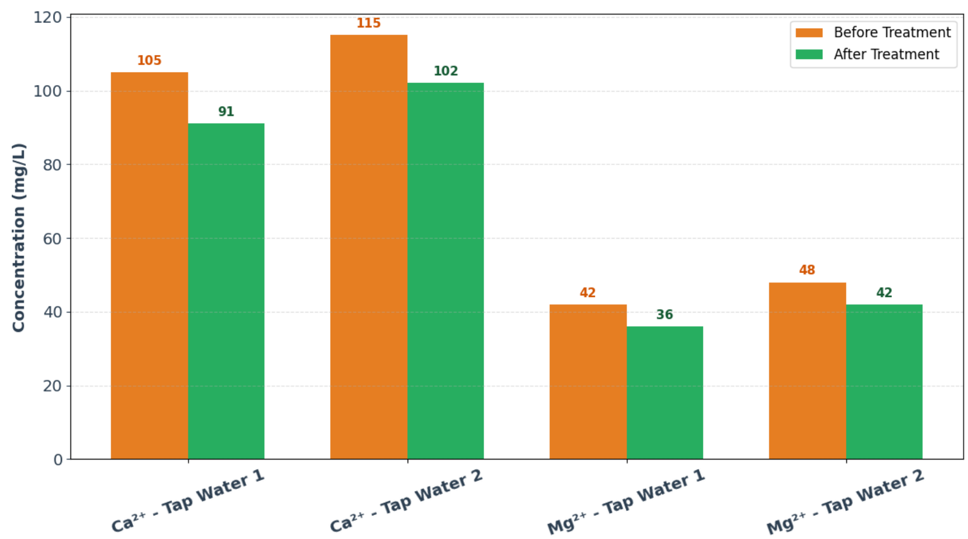

Figure 9: Calcium and Magnesium Levels Before and After EMWT

2.2.7. Analysis of Dissolved Oxygen (DO)

DO is a critical parameter for assessing water quality, particularly in applications related to aquatic life, microbial activity, and biochemical processes. Higher DO levels generally indicate better water aeration and less organic pollution [18].

This study measured DO concentrations in untreated tap water at 5.6 mg/L and 5.3 mg/L. After electromagnetic treatment, the values increased significantly to 6.8 mg/L and 6.5 mg/L, corresponding to improvements of 21.4% and 22.6%, respectively.

This increase in DO may be attributed to several effects induced by the electromagnetic field. The field may enhance oxygen solubility by disrupting hydrogen bonding networks and altering surface tension, allowing greater gas exchange. Additionally, the vortexing step following treatment may further promote oxygen dissolution by simulating dynamic water movement [17].

DO measurements were taken using a calibrated digital dissolved oxygen probe with automatic temperature compensation. All samples were stirred before testing to ensure consistency. The numerical results are presented in Table 7, and the observed trend is depicted in Figure 10.

Table 7: Dissolved Oxygen Concentrations Before and After EMWT

Sample	DO Before (mg/L)	DO After (mg/L)	Increase (%)
Tap Water 1	5.6	6.8	21.4
Tap Water 2	5.3	6.5	22.6

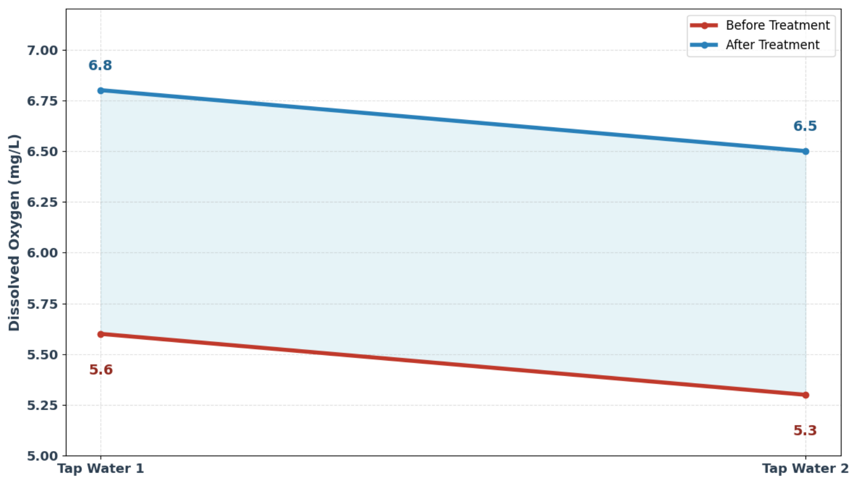

Figure 10: Increase in Dissolved Oxygen After Electromagnetic Water Treatment.

2.3. Assessment of TDS and Water Conductivity

TDS and EC are closely related parameters that reflect the concentration of dissolved ions in water. High TDS levels are often associated with poor taste, increased scaling potential, and reduced suitability for irrigation and industrial use. EC provides a rapid indication of a water sample's ionic strength and is commonly used as a proxy for TDS estimation [19-21].

In this study, both parameters were measured using a calibrated 5-in-1 digital water quality meter. Water samples (50 mL each) from both untreated and EMWT-treated conditions were analyzed under identical laboratory settings. The results showed clear and consistent reductions in TDS and EC values following electromagnetic exposure, aligning with earlier observations regarding the behavior of calcium, magnesium, and salinity. These reductions are likely the result of the electromagnetic field altering the behavior and aggregation state of dissolved ions. The field may encourage ion clustering or microprecipitation, leading to a measurable decrease in the number of free, mobile ions that contribute to conductivity and total solids. The chemical analysis process relied on careful reagent preparation and standardized volumetric titration techniques, as shown in Figure 11. This ensured the accuracy and repeatability of the analytical results.

Figure 11: Preparation of Reagents and Solutions for Water Sample Titration.

To complement the TDS and EC measurements, chloride ion concentrations were determined using titration with silver nitrate ($AgNO_3$), employing potassium chromate as an indicator. The endpoint was marked by the appearance of a reddish-brown precipitate, signaling the complete reaction with chloride ions. The setup for this procedure is illustrated in Figure 12.

Figure 12: Preparation of Chloride Test Solutions for Water Analysis.

3. Results and Discussion

The experimental study was conducted under controlled laboratory conditions using municipal tap water. All samples were treated using the EMWT device for one (1x) and five (5x) exposure cycles, while untreated samples served as controls. The physicochemical parameters assessed included pH, EC, TDS, total hardness, salinity, calcium and magnesium ion concentrations, and DO. Figure 13 illustrates the laboratory setup and procedures used during the chemical analysis phase, including titration and instrumentation workflows. This visual reference provides a practical overview of the analytical environment in which all measurements were performed.

Figure 13: Laboratory Procedures for Chemical Analysis of Water Samples.

The discussion below presents and interprets the results for each parameter, highlighting the impact of EMWT treatment compared to baseline values.

3.1.pH Analysis of Water Samples Treated with EMWT

pH is a critical indicator of water's chemical balance, influencing corrosion potential, microbial activity, and nutrient solubility. In this study, untreated tap water samples recorded pH values of 7.45 and 7.49, which are typical of neutral municipal water.

After electromagnetic treatment using the EMWT device, pH values increased to 7.89 and 7.95 after one and five treatment cycles, respectively. This consistent upward shift suggests a move toward alkalinity, attributed to the reduction of dissolved carbon dioxide (CO_2), which lowers the formation of carbonic acid and thereby decreases hydrogen ion (H^+) concentration.

The most notable pH increase occurred after the first treatment cycle, with a stabilizing effect seen after repeated exposures. This trend indicates that EMWT has a rapid and saturable influence on water chemistry, likely through the structural reorganization of ionic species and dissolved gases.

From an application standpoint, a mildly alkaline pH improves water stability, reduces plumbing corrosion, and enhances nutrient absorption in agricultural soils.

Figure 14 visually supports these findings by showing the evolution of pH values over multiple EMWT exposure cycles.

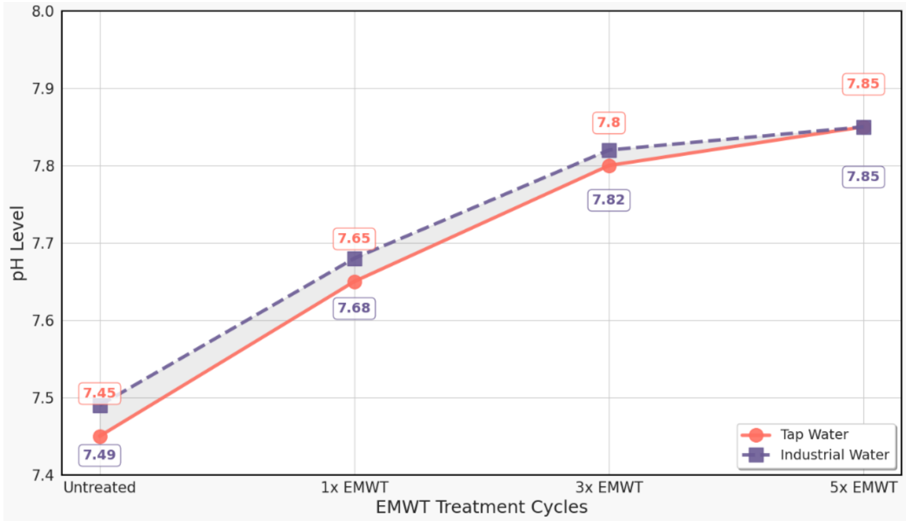

Figure 14: Impact of Electromagnetic Water Treatment Cycles on Water pH Levels – Comparison of pH Values in Water Samples Treated with the EMWT Device.

3.2.Changes in Electrical Conductivity and TDS

EC and TDS are two interrelated parameters that reflect the concentration of dissolved ions in water. Both serve as proxies for water purity, salinity, and scaling potential—critical factors in domestic, agricultural, and industrial contexts.

In the untreated tap water samples, EC was recorded at 1743 µS/cm and 1695 µS/cm, while TDS values reached 889 ppm and 842 ppm. After electromagnetic water treatment, EC decreased to 1255 µS/cm and 1201 µS/cm, and TDS dropped to 495 ppm and 476 ppm, respectively. These reductions correspond to an average decrease of approximately 28–29% in EC and 43–44% in TDS.

The decline in these values suggests that the EMWT device induces structural changes in dissolved ionic species. These results suggest that EMWT affects ionic interactions and solubility dynamics, leading to reduced ionic mobility, altered crystallization behavior, and improved water quality.

The treatment's impact was consistent across repeated tests and independent of minor variations in initial water quality. The drop in EC and TDS reflects not only enhanced water quality but also a potential reduction in scaling risk and improved taste and usability.

The comparative results are presented graphically in Figure 15, which highlights the difference in EC and TDS values before and after EMWT exposure.

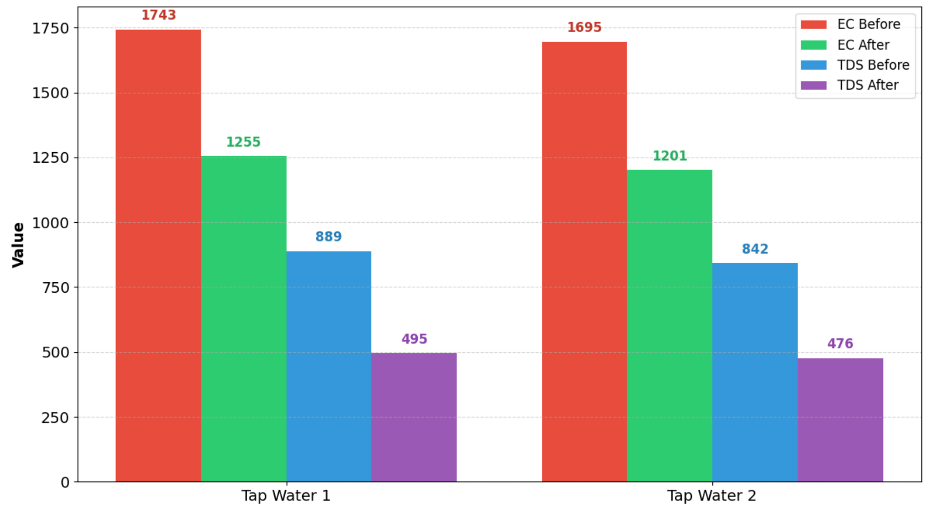

Figure 15: Effect of Electromagnetic Water Treatment on Electrical Conductivity and TDS Values in Tap Water Samples.

3.3.Total Hardness and Salinity Analysis

Total hardness is primarily caused by divalent cations, particularly Ca^{2+} and Mg^{2+}, which contribute to scale formation and reduced efficiency in both domestic and industrial water systems. Salinity, conversely, reflects the total concentration of dissolved salts and is a key factor in agricultural suitability and corrosion risk.

In this study, untreated tap water samples had total hardness values of 250 mg/L and 340 mg/L, expressed as $CaCO_3$. After electromagnetic treatment, hardness levels decreased to 230 mg/L and 311 mg/L, representing reductions of 8.0% and 8.5%, respectively. Though less dramatic than changes in TDS or conductivity, these reductions are notable given the non-chemical nature of the treatment and its potential to alter ion crystallization and solubility behavior.

Salinity measurements showed similarly encouraging results. Initial values of 0.91 PSU and 0.84 PSU were reduced to 0.69 PSU and 0.66 PSU, respectively, post-treatment, marking reductions of 24.2% and 21.4%. These changes suggest that EMWT influences the arrangement and mobility of dissolved salts, possibly through micro-aggregation or charge distribution effects that lower their detectability.

The consistent reduction in both hardness and salinity supports the hypothesis that pulsed electromagnetic fields affect not only water structure but also the behavior of dissolved ions, particularly those responsible for scaling and salinity stress.

These effects are visualized in Figure 16, which presents a comparative bar chart of total hardness and salinity before and after EMWT application across both samples.

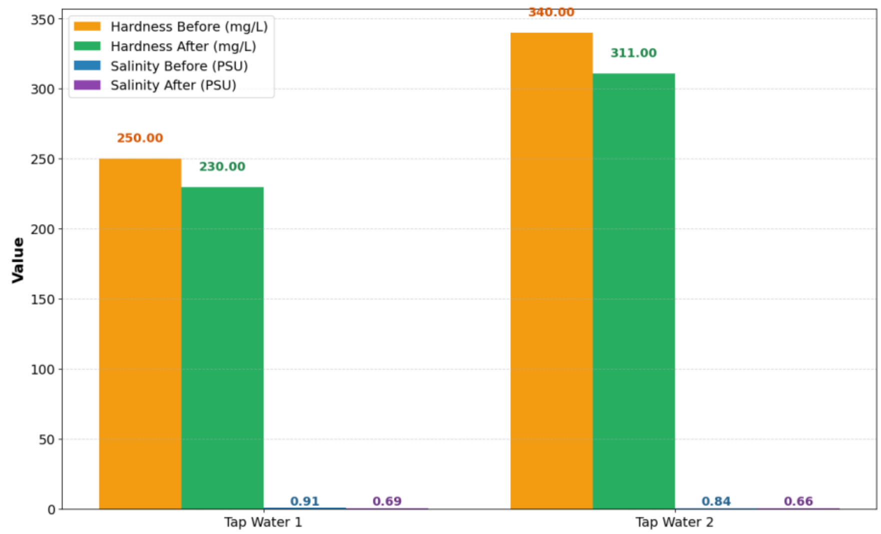

Figure 16: Reduction in Total Hardness and Salinity After Electromagnetic Water Treatment.

3.4.Calcium and Magnesium Ion Reduction

Ca^{2+} and Mg^{2+} ions are primarily responsible for water hardness and the formation of scale. Their presence in elevated concentrations affects the taste of water and leads to mineral buildup in plumbing systems, industrial equipment, and agricultural irrigation lines [16, 17].

This study measured initial calcium concentrations in untreated water at 105 mg/L and 115 mg/L, while magnesium levels reached 42 mg/L and 48 mg/L. After electromagnetic treatment, calcium levels decreased to 91 mg/L and 102 mg/L, and magnesium concentrations dropped to 36 mg/L and 42 mg/L. These values represent reductions ranging from 11% to 14%, confirming the EMWT device's ability to induce ionic restructuring.

The reduction mechanism may involve changes in solubility and crystallization behavior in response to the pulsed electromagnetic field. This field could promote ion aggregation or conversion to less mobile forms, effectively reducing their measurable concentration in solution without physical filtration or chemical precipitation.

The comparative results are summarized in Table 6 and visualized in Figure 17, illustrating a consistent decline in calcium and magnesium levels across the tested samples.

Table 6: Calcium and Magnesium Concentrations Before and After EMWT

Ion	Sample	Before (mg/L)	After (mg/L)	Reduction (%)
Calcium (Ca^{2+})	Tap Water 1	105	91	13.3

Ion	Sample	Before (mg/L)	After (mg/L)	Reduction (%)
Calcium (Ca^{2+})	Tap Water 2	115	102	11.3
Magnesium (Mg^{2+})	Tap Water 1	42	36	14.3
Magnesium (Mg^{2+})	Tap Water 2	48	42	12.5

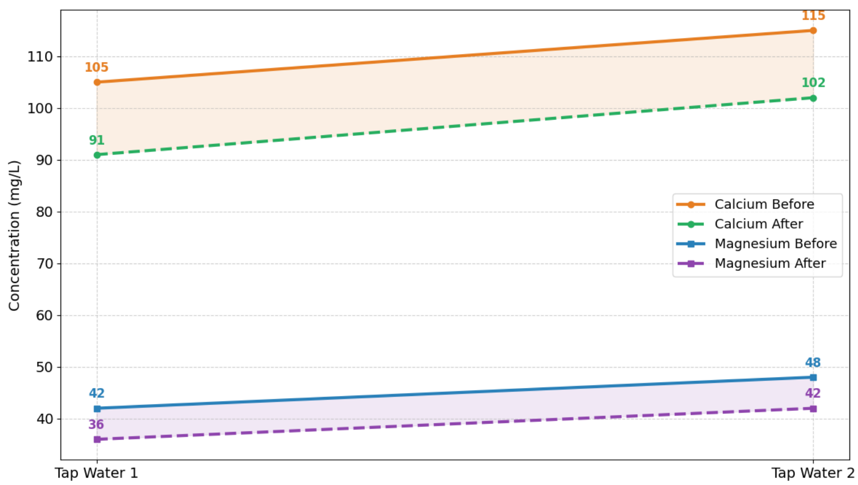

Figure 17: Reduction in Calcium and Magnesium Ion Concentrations After EMWT.

3.5.Dissolved Oxygen Improvement

DO is a fundamental indicator of water quality. It is crucial for sustaining aquatic life, supporting aerobic microbial activity, and ensuring proper biochemical function in both natural and engineered systems. Elevated DO levels are associated with better water aeration and lower levels of organic pollution.

This study measured the initial DO concentrations in untreated tap water samples at 5.6 mg/L and 5.3 mg/L, respectively. After exposure to the EMWT system, these values increased to 6.8 mg/L and 6.5 mg/L, representing 21.4% and 22.6% Improvements, respectively.

This significant increase can be attributed to several mechanisms. The pulsed electromagnetic field may enhance water's molecular agitation and restructuring, lowering surface tension and promoting excellent gas solubility. In addition, post-treatment, the vortexing procedure likely increased air-water contact, allowing more oxygen to dissolve into the samples. These effects have notable implications. Higher DO levels in drinking water improve taste and freshness. In agricultural settings, they enhance soil aeration when used for irrigation. Elevated dissolved oxygen (DO) levels contribute to healthier aquatic environments, benefiting both aquaculture and ecological purposes. The measured values are summarized in Table 7, while Figure 18 illustrates the improvements graphically.

Table 7: Dissolved Oxygen Concentrations Before and After EMWT

Sample	DO Before (mg/L)	DO After (mg/L)	Increase (%)
Tap Water 1	5.6	6.8	21.4
Tap Water 2	5.3	6.5	22.6

The results of this study demonstrate a clear and measurable impact of EMWT on various physicochemical parameters. Across all tested indicators—including pH, EC, TDS, total hardness, salinity, calcium and magnesium concentrations, and DO—EMWT consistently improved water quality without the use of chemicals, membranes, or heat.

The most notable changes include:

- pH increased toward a more alkaline and stable range (~7.9), beneficial for corrosion control and agricultural use.
- EC and TDS experienced reductions up to 29% and 44%, respectively, indicating a significant drop in ionic content.
- Hardness and salinity declined moderately, confirming structural effects on scale-forming ions.
- Calcium and magnesium levels decreased by 11–14%, reinforcing the anti-scaling effect.
- DO increase by more than 22%, enhancing water aeration potential and ecological suitability.

These effects were consistent across independent water samples and repeated trials, underscoring the reproducibility and robustness of the EMWT system. The findings support the potential of EMWT as a sustainable, low-energy, and maintenance-free water conditioning technology suitable for various applications, particularly in regions where water hardness, salinity, or limited access to clean water pose challenges.

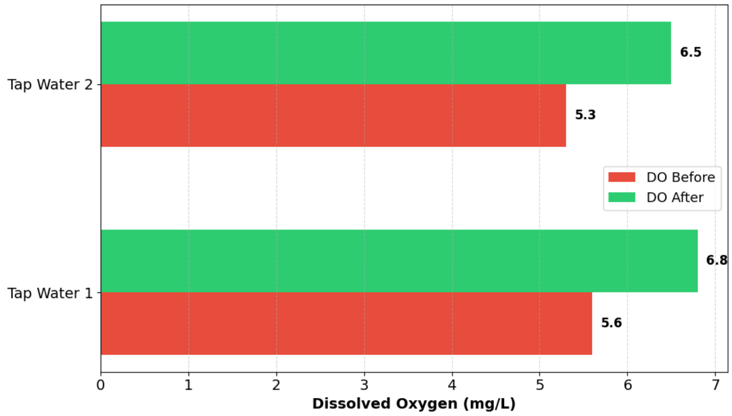

Figure 18: Increase in Dissolved Oxygen After Electromagnetic Water Treatment.

Table 8 presents a comparative overview of the tested water quality parameters, including pH, conductivity, total dissolved solids (TDS), salinity, calcium, magnesium, oxidezability, chloride, and total hardness. These data represent the control samples (Tap Water 1 and 2) and the treated samples (EMWT 1 and 2) [11].

Table 8: Water Quality Parameters Before and After Electromagnetic Treatment

Settings	Tap Water 1	Tap water 2	EMWT 1	EMWT 2
pH	7.45	7.49	7.95	7.89
Conductivity (S/Cm)	1743	1695	1255	1201
TDS (ppm)	889	843	495	512
Salinity (PSU)	0.9	0.85	0.49	0.55
Calcium (mg/L)	132.26	125.81	91	102
Oxydability (mg/L)	0.41	0.33	0.55	0.48
Chlorure (mg/L)	84.5	81.5	82.5	81.5
Temperature (°C)	19.5	22	19.8	19.7
Magnesium (mg/L)	125.77	121.22	36	42
Hardness	250	340	230	311

Figure 19 provides a visual summary of the same parameters, highlighting the comparative impact of EMWT across all tested metrics.

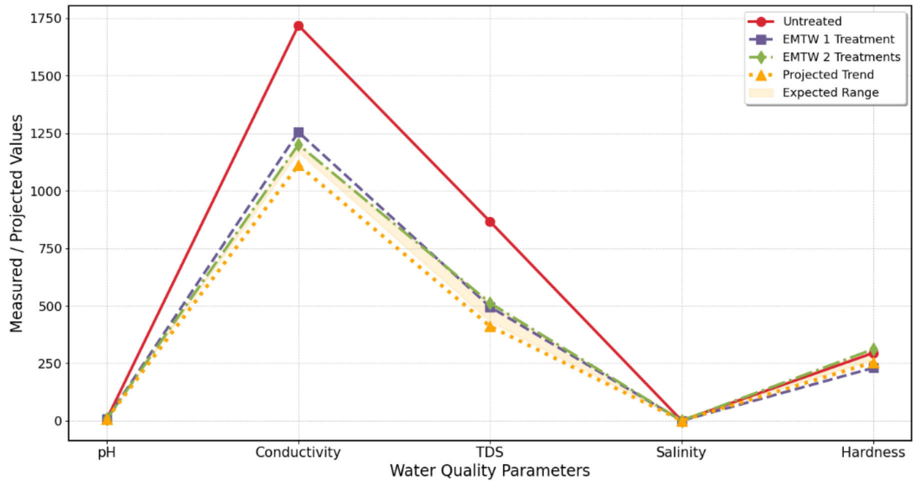

Figure 19: Comparative Trends of Water Quality Parameters Before and After EMWT.

4. Conclusion

This study confirms the effectiveness of a custom-built Electromagnetic Water Treatment system in enhancing the physicochemical quality of tap water under controlled laboratory conditions. Significant improvements were observed across key indicators, including reductions in electrical conductivity and total dissolved solids, which reflect improved ionic restructuring and enhanced water purity. Additional decreases in hardness, calcium, magnesium, and salinity further indicate a measurable softening and demineralization effect.

These outcomes suggest that EMWT modulates ionic interactions and solubility dynamics, contributing to observable improvements in water chemistry. The results were achieved without reliance on chemical agents, membranes, or thermal processes.

EMWT provides a sustainable, low-energy, and chemical-free alternative to conventional water treatment systems. Its simplicity, scalability, and environmental compatibility make it particularly suitable for domestic, agricultural, and industrial water applications, especially in areas affected by mineral scaling, salinity, or limited access to clean water.

Future research should focus on validating these findings in real-world settings, exploring microbial impacts, and establishing standardized protocols to support broader adoption of EMWT technologies.

REFERENCES

[1]. Bhattarai, K., & Yousef, M. (2025). Water scarcity and climate change in MENA: Challenges, innovations, and geopolitical impacts. In The Middle East: Past, Present, and Future (pp. 105-136). Springer.

[2]. Leal Filho, W., et al. (2022). Understanding responses to climate-related water scarcity in Africa. Science of the Total Environment, 806, 150420. https://doi.org/10.1016/j.scitotenv.2021.150420

[3]. Martínez-Santos, P. (2017). Does 91% of the world's population really have "sustainable access to safe drinking water"? International Journal of Water Resources Development, 33(4), 514-533. https://doi.org/10.1080/07900627.2017.1302043

[4]. Fida, M., Li, P., Wang, Y., Alam, S. K., & Nsabimana, A. (2023). Water contamination and human health risks in Pakistan: A review. Exposure and Health, 15(3), 619-639. https://doi.org/10.1007/s12403-023-00492-0

[5]. Owodunni, A. A., & Ismail, S. (2021). Revolutionary technique for sustainable plant-based green coagulants in industrial wastewater treatment—A review. Journal of Water Process Engineering, 42, 102096. https://doi.org/10.1016/j.jwpe.2021.102096

[6]. Ajala, O. J., Tijani, J. O., Bankole, M. T., & Abdulkareem, A. S. (2021). Wastewater treatment technologies. In Inorganic-Organic Composites for Water and Wastewater Treatment: Volume 1 (pp. 1-28). Springer.

[7]. Shah, A. I., Dar, M. U. D., Bhat, R. A., Singh, J., Singh, K., & Bhat, S. A. (2020). Prospects and challenges of wastewater treatment technologies to combat contaminants of emerging concerns. Ecological Engineering, 152, 105882. https://doi.org/10.1016/j.ecoleng.2020.105882

[8]. Prasad, M. N. V. (2020). Disinfection by-products in drinking water: Detection and treatment. Butterworth-Heinemann.

[9]. Priya, T., Mishra, B. K., & Prasad, M. N. V. (2020). Physico-chemical techniques for the removal of disinfection by-products precursors from water. In Disinfection By-products in Drinking Water (pp. 23-58). Elsevier.

[10]. Malik, N., & Kumar, R. (2024). A comparative study of different disinfection processes, and management practices to control the formation of disinfection by-products (DBPs). In Drinking Water Disinfection By-products: Sources, Fate and Remediation (pp. 59-83). Springer.

[11]. Attia, M., Driss, Z., Abd-Elhamid, H. F., & Ennetta, R. (2024). Developing a water magnetization system for scale prevention and water treatment. Journal Name, volume(issue), page range.

[12]. Du, X., et al. (2024). Numerical modeling of electromagnetic field spatiotemporal evolution to evaluate the effects on calcium carbonate crystallization. Desalination, 592, 118128. https://doi.org/10.1016/j.desal.2023.118128

[13]. Attia, M., Belghar, N., Driss, Z., & Soltani, K. (2025). Automated hydroponic system measurement for smart greenhouses in Algeria. Solar Energy and Sustainable Development Journal, 14(1), 111-130. https://doi.org/10.1016/j.sesd.2024.11.003

[14]. Wang, B. B. (2021). Research on drinking water purification technologies for household use by reducing total dissolved solids (TDS). PLoS ONE, 16(9), e0257865. https://doi.org/10.1371/journal.pone.0257865

[15]. Saludo, E. M. F., Lagado, M. F., San Jose, A. M. A., Agustin, C. P., Lipardo, N. J. G., & Agustin, M. A. (2023). Water salinity in agriculture: Analyzing irrigation water quality for farmers. International Journal of Environment, Engineering and Education, 5(3), 111-118.

[16]. Linminhuizhi, M., Jiwei, J., Qiying, F., & Beiyi, X. (2021). Removal of heavy metal chromium in groundwater by sulfidated and carboxymethyl cellulose modified nanoscale zero-valent iron. Materials Science, volume(issue), page range.

[17]. Kaudeer, N. B., Mudhoo, A., & Surroop, D. (2013). Performance of Moringa oleifera extracts and Sudfloc as coagulant aid in raw water treatment in Mauritius. International Journal of Environmental Engineering, 5(3), 273-288.

[18]. Dippong, T., Mihali, C., & Avram, A. (2023). Water physico-chemical indicators and metal assessment of Teceu lake and the adjacent groundwater located in a Natura 2000 protected area, NW of Romania. Water, 15(22), 3996. https://doi.org/10.3390/w15223996

[19]. Dewangana, S. K., & Shrivastava, S. (2023). A correlation between EC and TDS in water: A review. Journal Name, volume(issue), page range.

[20]. Rhoades, J. (1996). Salinity: Electrical conductivity and total dissolved solids. In Methods of Soil Analysis: Part 3 Chemical Methods (Vol. 5, pp. 417-435).

[21]. Corwin, D. L., & Yemoto, K. (2020). Salinity: Electrical conductivity and total dissolved solids. Soil Science Society of America Journal, 84(5), 1442-1461. https://doi.org/10.2136/sssaj2019.11.0427