

Improvement of Supplementary Irrigation Water Quality for Rain-Fed Agriculture in the Semi-Arid Region Using Magnetization Techniques

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Abstract

Rain-fed agriculture depends on the groundwater as a supplementary source of irrigation. The poor quality of water from the hard rock area is applied to the crops to save the crop. Continuous irrigation leads to degradation of soil, drip irrigation system as well plants. This study assessed the damages on the drip irrigation system and soil, inflicted by the use of low-quality irrigation water. The quality of water was improved with reference to raw water in terms of pH (1.57% - 5.88%), EC (3.08% - 10.08%), ions (0.96% - 46%) by using magnetization method, without disrupting the existing irrigation system in the basaltic aquifer in semi-arid to the arid condition. This was demonstrated before the farmers in central India.

Keywords

Supplementary Irrigation, Low Water Quality, Hard Rock Aquifer, Dissolved Salts, Semi-Arid Region, Magnetization Method

1. Introduction

About 60% of the total net sown area in India is under rain-fed agriculture and 48% of food crops is generated from this practice. Rain-fed agriculture is practised in areas receiving an annual rainfall of 375 to 1125 mm by using supplementary irrigation from groundwater. The success of rain-fed agriculture depends on the onset of monsoon, the periodicity of rainfall, rainy days, wet and dry spells during the growing period. Hence, hard rock aquifers are subjected to

intensive abstraction mostly from rural areas of 1) weathered zone of the Deccan Traps Basalt underlying Maharashtra and in Andhra Pradesh and 2) low-storage variably weathered crystalline basement aquifer underlying most of drought-prone Tamil Nadu, India. These areas experience drought situations once in two years, as well water stress at regular interval. The depletion of the water table is attributed to uncontrolled and excessive exploitation in saving the crop growth and yield. There is a widespread depletion of irrigation wells before the end of Rabi (winter) season and no groundwater even for drinking after January till the onset of monsoon in June.

The quality of groundwater varies from season to season and place to place depending on the depth of water table, extent and composition of dissolved solids. The hydrological imbalance has triggered the geochemical processes expressed as a spatiotemporal variation in groundwater chemistry [1]. Groundwater contains dissolved salts and traces elements from the natural weathering. Groundwater contains dissolved salts and traces elements from the natural weathering. Groundwater chemistry depends on geology, the degree of chemical weathering of rock types, and quality of recharge water [2]. In recent years, an increasingly significant threat to groundwater quality is from human activities [3] [4]. The most critical factor in agriculture is the prediction and managing and forecasting the crop production using the low-quality irrigation water. There is a need to optimize the use of groundwater, improve the quality to permissible limits and apply as supplementary irrigation in preventing long-term impacts.

The objective of this study is to 1) assess the quality of irrigation water with their impacts on the irrigation delivery system & soil 2) improve the quality by the magnetized method & assessment of the impacts.

2. Water Quality Parameters

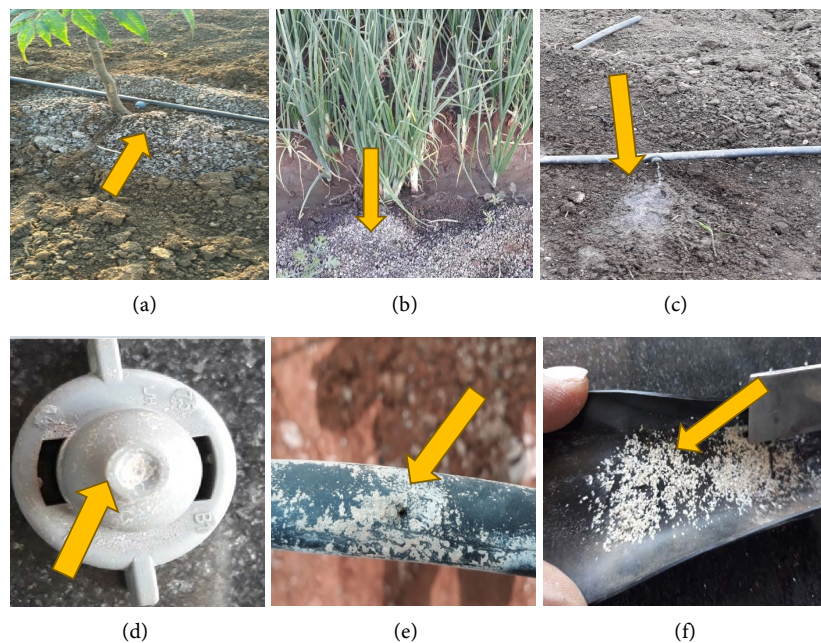
The salts in irrigation water affect both the soil structure and crop yield. Salts and other dissolved substances begin to accumulate/deposit as water evaporates from the surface. High concentrations of salt in the soil result in physiological drought condition - even though the field appears to have plenty of moisture, the plant's wilt because the roots are unable to absorb the water. These impacts attributed to pH, Salinity hazard (total soluble salt content), Sodium hazard (proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, Alkalinity - carbonate and bicarbonate and presence of specific ions like chloride (Cl), sulfate (SO_4^{2-}), boron (B), and nitrate-nitrogen ($\text{NO}_3\text{-N}$). The anticipated impact of poor quality irrigation water on soil and plants that could affect the sustainable agriculture and food security are listed in **Table 1**.

The prevalent effects of the application on low-quality water the delivery system (nostril, delivery pipes), soil surface, and structure in these areas are shown in **Figure 1**.

pH affects the toxicity of other elements and pronounced effect on many chemical reactions. The ranges of pH of the groundwater in basaltic aquifers are

Table 1. Water quality parameters & its impact on soil, irrigation system and crop growth.

Irrigation Quality parameter	Permissible limit (ICAR)	Impact on agriculture
pH	6.5 - 8.4	Contains more carbonates and bicarbonates which precipitates with calcium and <i>blockage in water delivery system</i>
EC mS/cm	<1.0	<i>Specific toxicity</i> of a particular ion (such as Sodium) The higher osmotic pressure around the roots.
Na ⁺ (meq/lit)	1.0 - 3.0	Severe water <i>infiltration problem</i>
Ca ⁺⁺ (meq/lit)	1.0 - 3.0	<i>Precipitate and clogging of drip irrigation delivery system</i> Change of Sodium absorption ratio
Mg ⁺⁺ (meq/lit)	1.0 - 3.0	<i>Precipitate and clogging of drip irrigation delivery system</i>
CO ₃ ²⁻ (meq/lit)	<1.0	<i>Reduce uptake</i> of the nutrients
HCO ₃ ⁻ (meq/lit)	<2.5	<i>Toxic & reduce uptake</i> of the nutrients <i>Precipitate</i> with calcium and forms a white crust on the soil.
Cl ⁻ (meq/lit)	<2.0	Onset of <i>Leaf burn problem</i> arise
Sodium absorption ratio (SAR) (meq/lit)	<3.00	Causes of the potential hazard and severe <i>soil permeability</i>
RSC (Residual sodium Carbonate) (meq/lit)	<1.25	Potential hazard to <i>soil structure</i>

**Figure 1.** Impact of poor quality irrigation water on the soil. Where figure (a) salt accumulation by drip irrigation; (b) salt accumulation on soil by flood irrigation; (c) reduced infiltration rate; (d) clogging; (e) salt deposited on outer side of the lateral; (f) salt accumulation inside the lateral.

7.16 - 8.35 and 7.2 to 10.32 in granitic aquifers. **Total Hardness** is due to the presence of polyvalent Calcium and magnesium arising from the dissolution of minerals. The total hardness of groundwater samples from basaltic aquifers was found in the range of 55 - 300 mg/l.

Electrical conductivity (EC) is the conductance of the one-centimetre cube of the substances in micromhos/cm at 25°C. The presence of ions in solution increases the conductivity of water from all the ions dissolved such as negatively charged ions (Cl^- , NO_3^-) and positively charged ions (Ca^{++} , Na^+). The effect of high ECw water on crop productivity is their inability of the plant to compete with ions in the soil-water solution (physiological drought). The usable plant water in the soil solution decreases significantly as EC increases. The long-term impact of EC high water is the salt loading through the irrigation water.

Ions

Different ions and their concentration level plays critical role as far as water quality is concerned. Olivine, biotite, hornblende, serpentine are the major magnesium-bearing minerals. Crops grown on soils having an imbalance of calcium and magnesium exhibit toxic symptoms. High concentrations of potassium may introduce a magnesium deficiency and iron chlorosis. The sources of calcium in groundwater from basalt are plagioclase and pyroxene. The range of calcium content in groundwater is largely dependent on the solubility of calcium carbonate, sulphide and rarely chloride. Magnesium's solubility in water is around five times that of calcium. The maximum acceptable limit of calcium for domestic use is 75 ppm.

The contributions of various parameters in aquifers of hard rock are:

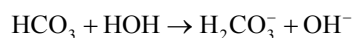
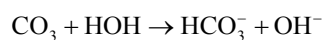
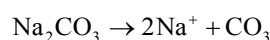
Most sodium salts are readily soluble in water, but take no active part in chemical reactions. Sodium is released into groundwater by weathering of plagioclase feldspar, clay mineral and amphiboles. Potassium minerals orthoclase, microcline and biotite etc., are resistant to decomposition by weathering. Slow circulation, a longer period of contact between aquifer and water, dissolving of minerals at the time of weathering, residential time, drainage pattern etc. and surface water link is responsible for the variations in chemical concentrations of groundwater. Sodium in irrigation water cause toxicity problems for some crops. The amount of water transpired through a crop is directly related to yield. The sodium content of groundwater from basaltic and granitic aquifers ranges between 16 to 150 mg/l and 32 to 129.3 mg/l respectively. The potassium content of ground waters from basaltic and granitic aquifers ranges between 1.0 to 66 mg/l and 11 to 54.4 mg/l respectively.

High salt concentration in water leads to the formation of saline soil. Sodium in irrigation water is absorbed by the soils and high sodium leads to the development of an alkaline soil. An imbalance of magnesium and potassium may be toxic, but the effects of both can be reduced by high calcium levels. Many crops have little tolerance for salinity during seed germination, but significant tolerance during later growth stages. Barley, wheat and corn are more sensitive to salinity during the early growth period than germination and later growth periods.

Evaporation rates from water surfaces often exceed 0.25 inch a day during summer.

Sulphate salts affect the crops by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a cationic imbalance within the plant. Sulfate content in basaltic and granitic aquifers range between 12.0 to 56.1 mg/l and 14.0 to 62.0 mg/l respectively. They are found to be within the desirable limit in basaltic and granitic aquifers. In the presence of CO₂, Calcium bicarbonates can normally be dissolved up to 20 ppm at atmospheric pressure and up to 100 ppm at higher pressure. The bicarbonate ion in soil solution harms the mineral nutrition of the plant through its effects on the uptake and metabolism of nutrients.

RSC (Residual sodium Carbonate) residual sodium carbonate, as forming OH ions hydrolysis, increase soil pH as follows



In high pH of soil, Plants cannot take up few nutrients. In addition, excess of Na ions in soil solution exchange other ions on the exchange complex and Na ions on the exchange complex increase (*i.e.* high ESP). High exchangeable sodium (ESP) causes dispersion of soil particle and specific ion toxicity some plants also. Residual sodium carbonate (RSC) can be used as a criterion to evaluate the suitability of groundwater for irrigation. Carbonate and bicarbonate ions are important in irrigation water due to their tendency to precipitate calcium and magnesium in soil solution in the form of calcium and magnesium carbonate. Thus, the value of SAR for irrigation water is increased due to the sodium ion is dominant and the low concentration of calcium and magnesium in irrigation water. The effect of Carbonate and bicarbonate ions concentration on water quality is expressed by the term Residual sodium carbonate (RSC).

Sodium absorption ration (SAR) The risk of high sodium content in irrigation water is due to the tendency of the clay particles to absorb sodium and release the magnesium and calcium ions. This results in reduced soil permeability due to this ion exchange and eventually, the soil has a weak internal drainage.

3. Deccan Basalt Aquifer

82% of the area in Maharashtra is occupied by Deccan basaltic lava flows of upper Cretaceous to lower Eocene age. They occur in layered sequences ranging in thickness from 7 to 45 m and represented by a massive unit at the bottom and vesicular unit at the top of the flow and are horizontally disposed of. The flow layers are separated by red bole. Groundwater in Deccan Basalt area occurs in the upper weathered and fractured parts down to 20 - 25 m depth. At places potential zones are encountered at deeper levels in the form of fractures and inter-flow zones. The upper weathered and fractured parts form phreatic aquifer

and groundwater occurs under unconfined) conditions and occurs under semi-confined conditions at deeper levels. The yield of dug wells tapping the upper phreatic aquifer ranges between 20 and 90 m³/day. Borewells drilled down to 70 m depth, tapping weathered and vesicular basalt are found to yield 2 to 10 m³/day. The yield of the dug wells ranges from 30 to 150 lpm/day depending upon the local hydro-geological conditions and bore wells show wide variations from traces to 30.62 lps. The unit area specific capacity of dug wells ranges from 0.77 to 18.9 lpm/dd/sq.m; permeability from 12 to 65 m/day; transmissivity of phreatic aquifer between 18 and 89 m²/day; specific yield between 1.7% to 9.7% in the district. Groundwater level rises after monsoon due to natural recharge and water level (**Table 2**) and falls down in accordance with withdrawal leading to salt concentration [5].

As the level of salt concentration increase with a reduction in depth to water level, there is a need to improve the water quality prior to irrigation.

4. Improvement in Water Quality

The prevailing and predicted scarcity situation warrants the optimization of water consumed by agriculture per unit area. Use of low quality of irrigation hampers the plant growth and crop yield. The methods available to improve the quality of irrigated water is given in **Table 3**.

Chemical treatment methods require additional facilities at the farm for reaction time and new structures. There is a time delay between the uptake from the well and the application to crops, in addition to the loss of precious water by storage, release and evaporation. Even though, physical and mechanical conditioning methods are in continuity with pumping, filtration methods are applicable to turbid waters, leaving magnetic water conditioning suitable for the application. It is reported that even a low magnetic field can change the water [6] density, salt solution capacity, pH, electrical conductivity, dielectric constant etc [7]. The magnetized water can improve water productivity [7] and crop yield [8]; increased germination percentage of seeds [9], emergence rate [10], and root growth [11]. The benefits of magnetically treated water depend upon the plant species, pathway in the magnetic unit and flow rate [12]. Magnetic fields change the physicochemical properties of water [13]; [14].

Table 2. Salt concentration and water levels in pre and post-monsoon season in Auran-gabad area.

	Season	WL	pH	EC	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃
1	Post	5.42	7.12	1.67	12	38	294	39	255	288	244
	Pre	16.70	8.16	1.19	52	75	221	38	248	97	287
2	Post	4.23	7.18	1.09	90	41	69	20	163	206	85
	Pre	15.91	7.45	2.37	160	100	184	33	383	379	171
3	Post	12.70	7.6	1.85	116	73	184	15	269	211	305
	pre	8.47	7.21	1.70	160	112	207	14	461	384	110

WL-water level (m, bgl), EC (mS/cm), ions meq/l).

Table 3. Existing water treatment methods and their suitability.

Existing Method/treatment	Suitability of the method
A. Physical/mechanical conditioning	
Magnetic water conditioner	Effective for deactivation of anions
Filtration of water	Only turbid/physical matter trapping
B. Chemical Treatment methods	
Chemical-Water treatments	
Ion exchange by mean of the calcium and magnesium.	The continuous chemical addition required and effective for stored water.
Use of Water-softening agents like sodium hexametaphosphate	
Use of lime	
pH adjustment using acid-base treatments	
Water blending with other good quality water	Effective when the availability of the alternate source

5. Water Improvement Device

The water quality improvement device was fixed between the take-off point from the well and irrigation water delivery system. The various components of the Water quality improvement device consisting of the electrolysis unit, dynamic pulse unit and the electromagnetic unit is shown in **Figure 2**. This device works on the basis of, ionization of dissolved solid using cathode and anode, electrolysis process of water with the help of 50 kHz dynamic pulse current and energization of the cations through 1200 Gauss electromagnet respectively. 2 HP submersible pump with the discharge of 100 litres/minute from the well. The input pressure was adjusted to 1 kg/cm² by pressure control valves to suit the rate of inflow of the device. The water inflow enters into the electromagnetic unit and flows amidst the cathode and anode coils. The **electrolysis process** begins with the ionization of dissolved solids from the water. The ionized water moves on to the **dynamic pulse unit** where 50 kHz frequency generated by 440 V current and works with Faraday's law of EMF phenomenon. Deactivation of anions of water takes place in the dynamic pulse unit. Deactivated anions of water enter into an **electromagnetic unit** having electromagnets (South and North Pole) that energize the cations and left to flow out. The processed water outflows through the pipeline are applied. Irrigation set up. Irrigation water quality parameters were analyzed before and after the trial.

6. Field Trials

Trial tests were carried out on the agriculture fields at four sites without disturbing the existing delivery system (Site 1. Shahpur, Akola, N 20.520638, E76.756993; Site 2. Pokhri, Buldhana, N 20.499097, E76.239373; Site 3. Imam-pur, Aurangabad, N19.731105, E75.234089; Site 4. Dhamori, Ahmednagar,

N19.313289, E74.667779) using the water quality improvement device. Farmers of the plot were present during the entire activity. Field setup described above is shown in **Figure 3**.

Irrigation (untreated) water prior to treatment and post-treatment were collected using standard protocol methods of ICAR & FAO. After installation of the water quality improvement device and water passing through the device (untreated) and outlet (treated) water collected and analyzed at MIT-CARS laboratory (@ Maharashtra Institute of technology, Aurangabad), with the help of standard protocol and the results are presented in **Table 4** and **Table 5**.

In order to understand the quality of individual parameters with reference to the duration of processing/treatment by the device, water samples were collected every 30 minutes from the inception of pumping. It is assumed that 4 hours (maximum) of pumping fulfils the irrigation requirement of crops over 1 acre. The observations are shown in **Table 6**. It is observed that pH and SO_4 increases with time, whereas EC, Ca, Cl, CO_3 , and HCO_3 decreases with time. If there is a need for more time for pumping, the activities may be carried out in two phases giving sufficient time to recharge. Simultaneous treatment in adjoining wells and their analysis could explain the larger aquifer characteristics and local influences.

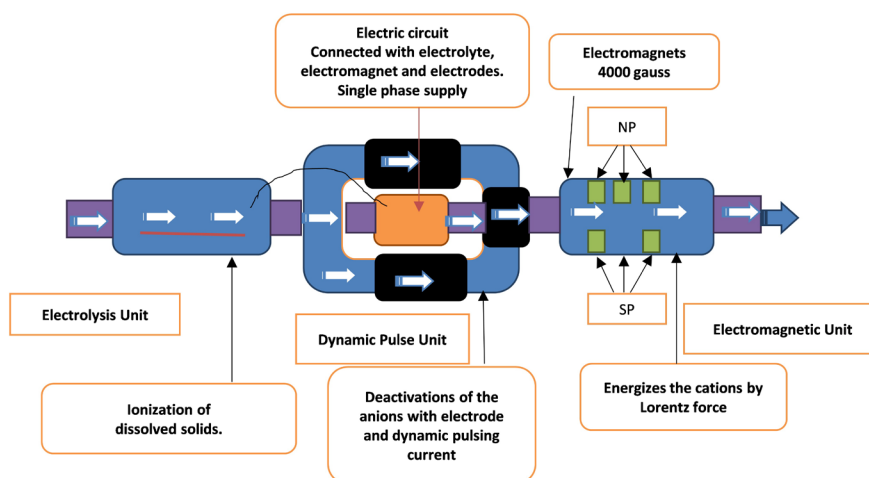


Figure 2. Schematic diagram of water quality device.



Figure 3. Water Quality treatment device setup at site 3 (19.89444N, 74.35694E).

Table 4. Irrigation water quality being used.

Parameter	site 1	site 2	site 3	site 4	site 5	Permissible limit	
						Irrigation water	Drinking water
pH	8.50	7.22	7.64	7.15	7.18	6.5 - 8.4	6.5 - 8.5
EC (mS/cm)	2.20	4.73	2.27	2.47	2.48	<1.0	0.1 - 0.3
Sodium (meq/l)	2.91	25.95	11.03	10.23	10.16	1.0 - 3.0	-
Ca (meq/l)	22.0	9.00	2.00	4.60	5.00	1.0 - 3.0	75 - 200 (ppm)
Mg (meq/l)	4.00	20.00	2.00	9.60	10.00	1.0 - 3.0	30 - 100 (ppm)
k (meq/l)	1.79	0.06	0.09	0.02	0.02	1.0 - 10.0	-
CO ₃ (meq/l)	10.00	61.24	2.80	0.00	0.00	<1.0	-
HCO ₃ (meq/l)	0.00	0.00	7.20	8.00	7.40	<2.5	-
Cl (meq/l)	12.00	8.00	4.00	16.00	13.00	<2.0	250 - 1000 (ppm)
SO ₄ (meq/l)	8.70	0.00	1.12	0.45	0.78	<2.5	200 - 400 (ppm)
SAR (meq/l)	0.81	6.82	7.80	3.84	3.71	<3.00	-
RSC (meq/l)	0.00	32.24	6.00	0.00	0.00	<1.25	-

Note: Indian Council of Agriculture Research (ICAR) & IS: 11614: 1986 for irrigation water quality; Drinking water quality IS 10500: 2012 standard.

Table 5. Water quality before and after treatment.

Parameters	Effect of treatment - Site 1			Effect of treatment - Site 2			Effect of treatment - Site 3		
	Before	After	change %	Before	After	change %	Before	After	change %
pH	7.99	7.52	5.88 (+)	7.22	7.52	4.15 (-)	7.64	7.52	1.57 (+)
EC (mS/cm)	1.55	1.38	10.97 (+)	4.73	4.38	7.39 (+)	2.27	2.20	3.08 (+)
Na (mg/l)	104.0	103.0	0.96 (+)	596.0	590.0	1.00 (+)	253.0	241.0	4.74 (+)
K (mg/l)	2.3	3.0	30.43 (-)	2.3	3.0	30.43 (-)	3.5	4.2	20.00 (-)
Ca + Mg (mg/l)	85.4	97.6	14.29 (-)	72.5	97.6	34.62 (-)	91.0	97.6	7.25 (-)
Ca (mg/l)	120.0	68.0	43.33 (+)	180.0	91.0	49.44 (+)	40.0	32.0	20.00 (+)
HCO ₃ (mg/l)	561.2	366.0	34.78 (+)	500.2	366.0	26.82 (+)	498.2	366.0	26.53 (+)
Chloride (mg/L)	284.0	241.4	15.00 (+)	284.0	247.8	12.74 (+)	142.0	112.4	20.84 (+)

Note: (+) reduction and (-) increased.

Table 6. Quality assessment of water over continuous operation.

Time	pH	EC mS/cm	Ca Mg/L	SO ₄ mg/L	Cl Mg/L	CO ₃ mg/L	HCO ₃ mg/L	Remarks
12.00 hrs	7.73	1.864	60	66.8	354.5	60	475.8	Raw water (before starting)
12:30	7.74	1.86	52	65	354.5	60	427	Treated water
13:00	7.78	1.826	52	66.6	283.6	48	451.4	Treated water
13:30	7.82	1.815	48	63.7	241.1	60	366	Treated water

Continued

14:00	7.84	1.662	48	70	226.9	60	366	Treated water
14:30	7.89	1.661	48	96.3	198.5	48	390.4	Treated water
15:00	7.99	1.659	44	106	198.5	60	366	Treated water
15:30	8.08	1.658	44	96.1	184.3	48	390.4	Treated water
16:00	8.09	1.654	40	95.6	184.3	48	378.2	Treated water
16:30	8.1	1.651	40	92.4	184.3	36	402.6	Treated water
17:00	8.1	1.649	40	90.4	141.8	36	402.6	Treated water

7. Conclusion

In most of the irrigation practices in semi-arid/arid regions experiencing water stress and drought, is concerned with salinity levels that affect the soil structure and crop yield. The salts in the irrigation water are from the natural weathering. The variation in salt content in space and time is observed. Salts as well as other dissolved substances begin to accumulate as water evaporates from the surface. This leads to the underperformance of delivery systems and fertilizers in crop productivity. High concentrations of salt in the soil are contributed by irrigation water where field has plenty of moisture content which causes wilting of plant because roots are unable to absorb the water. To avoid the direct and indirect effects on crops, reduction of salt content is desired, when the water level is at a minimum in the irrigation source. This situation arises for the Kharif and Rabi crops during select irrigation period and for the entire period of growth for summer crops in the semi-arid region.

An electromagnetic and electrolysis water treatment unit is used in this present research to fulfill the objective of improvement of irrigation water quality. Installed setup in controlled trial field results % change of the ions concentration in positive way shown in the **Table 5**. Treated water quality is assessed for three sites in static condition which shows percent improvement of water quality parameters after treatment *i.e.* pH 5.88% (+) & 1.57% (+) of site 1 and site 3 respectively, whereas it is reported that pH value slightly increased on site 2 *i.e.* 4.15% (–). Electrical conductivity reduced in 10.97% (+), 7.39% (+), and 3.08% (+) in site 1, 2, 3 respectively. Na ion reduced to 0.96% (+), 1.00% (+) and 4.74% (+) in site 1, 2, 3 respectively. Ca reduced to 43.33% (+), 49.44% (+) and 20.00% (+) in site 1, 2, 3 respectively. HCO_3 reduced to 34.88% (+), 26.82% (+), 26.53% (+) whereas chloride reduced in 15.00% (+), 12.74% (+), 20.84% (+) in site 1, 2, 3 respectively.

It may be concluded that

- This study has demonstrated that parameters that have a significant impact on the delivery system and soil causing a detrimental impact on the crop yield could be improved at the field level.
- By using this device detrimental parameters found in the irrigation water were reduced to acceptable limits. The successful reduction in chemical pa-

parameter in percentage in terms of treated water are pH (1.57% - 5.88%), EC (3.08% - 10.08%) & Ions (0.96% - 46%).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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