

RESEARCH ARTICLE

STUDYING THE EFFECT OF MAGNETICALLY TREATED SALT WATER ON SOME CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE SANDY, SANDY CALCAREOUS, AND CLAY SOIL

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ABSTRACT

The main purpose of this laboratory study is to indicate the variation in some characteristics of the sandy, sandy calcareous, and clay soil under the effect of the magnetically treated tap and/or salt water. Salt water (SW, 2000-ppm) was prepared by dissolving the sodium chloride (NaCl) salt in tap water TW (2 g L⁻¹). Tap water and/or SW were magnetically treated by passage through a permanent electromagnetic field of 14.000 G (1.4 Tesla) strength for 10 min, and then allowed to percolate through a soil column continuously for 2 h. Some characteristics of the studied soil samples were estimated after the infiltrate of the magnetically (M) and non-magnetically (NM) treated TW and/or SW. The MSW has decreased the hydraulic conductivity (HC, m day⁻¹) by 41.1, 12.8, and 51.4% compared to NMSW for sandy, sandy calcareous, and clay soil, respectively. Magnetic induction may affect the coagulation of the fine particles to form larger aggregates. For clay soil, MTW decreased the sum of fine particles by 40.5%, while the MSW decreased it by 28.75%, which may be a dispersing effect of NaCl soluble salt. The Zeta potential ζ values were slightly shifted by SW and MSW. The calculated electrophoretic mobility (U) of the colloidal particles has increased under the effect of the SW by 15.6%, 28.6%, and 58.1% for the sandy, sandy calcareous, and clay soil, respectively. Magnetized water may affect the soil properties positively and/or negatively depending on the soil class and the application conditions.

KEYWORDS

Calcareous, Clay Soil, Magnetized Water, Salt water, Sandy

1. INTRODUCTION

The magnetic water treatment (MWT) is an environment-friendly technique easy to handle especially in the arid and semi-arid regions for the sustainable agriculture purposes (Khoshnavesh et al., 2011). It is a technology can enhance the water quality and use efficiency (WUE) to face the limited availability of high-quality irrigation water. Novel properties of the magnetized water (MW) showed promising applications agriculturally, industrially, and in medicine (Xiao-Feng and Boa, 2008). The technology of the MWT has been used for more than a half century in which water is exposed to a MF. In agriculture, it had been applied by passing the irrigation water through a MF of a specific strength created by permanent magnets or electromagnets installed at the feeding pipeline. Different devices with a variety of structures and shapes have been produced to magnetize water but their performing mechanism is almost the same.

Field strength of 1.5 T (Tesla) at a flow rate 3 litres per minute (L min⁻¹) was defined in a previous study (Abedinpour and Rohani, 2017). Further research may be required to clarify a more detailed mechanism of the technology action within the soil matrix. It was found that the MF affects some of the physical and chemical properties of water. It decreases the water conductivity, which is inversely proportional to the flow rate of water through the MF. It decreases the water contact angle, surface

tension, viscosity, the hydrophobicity of materials towards aqueous medium, but increases the soaking degree to a solid matter and enhances the flowing of water in pipes. This can be attributed to the hydrogen bond network strengthening and the perturbation of gas/liquid interface from the air nano-bubbles in the water (Szczęś et al., 2011).

Infrared, Raman, visible, ultraviolet and X-ray spectra of the MW has been revealed that its properties differ from that of the NMW. An Externally applied MF influences macroscopic properties and microscopic structures of water including molecular and atomic structures and electronic motions, and their rules of changes (Xiao-Feng and Boa, 2008). Water molecules may be induced by the MT that affects the polarization of molecules and changes their dipole moment, but the constitution of molecules and atoms are unchanged. The distribution of molecules and the transition probability of electrons are induced, which alters the clustering of water molecules. A competition between intra- and intermolecular hydrogen bonds networks weakens the stronger intra-cluster hydrogen bonds, breaking the larger clusters and forming smaller ones, with stronger inter-cluster hydrogen bonds (Szczęś et al., 2011).

Strong and shifted infrared peaks indicated the presence of H-bonded and non-H-bonded — OH groups. Closed hydrogen-bonded chains become some ring electric-current or “molecular electric-current” elements due to the proton conductivity in them under the action of Lorentz force of MF.

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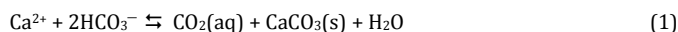
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These effects were dependent on the time of magnetization, the intensity of applied MF and the temperature of water (Xiao-Feng and Boa, 2008). When water passes through a magnetic water softener, Lorentz force is exerted on each ion, in the opposite direction to each other. The redirection of particles increases the frequency of collisions between ions of opposite sides, combining to form a mineral precipitate or insoluble compound. The electrical charge of suspended particles decreases and stay in the form of snowball phenomenon and suspend in water.

It may be suggested that the colloidal stability is influenced by MFs through alteration of the structure of water molecules and ions adsorbed either on the particle surface, or in the medium (Szcze's et al., 2011; Xiao-Feng and Bo, 2008). Precipitation of CaCO_3 is a key parameter in evaluating the effectiveness of MWT. In a static fluid system, MF strengthens the hydrate structure in the magnetized ions, which reduces the precipitation process. In a dynamic fluid system, Lorentz forces and magneto-hydrodynamic effect on the charged ions or particles played a role in increasing the CaCO_3 precipitation as follow:



Two mechanisms have been developed to address the MF effects on the CaCO_3 precipitation in the static fluid system; (1) a direct effect on the dissolved ions "ionic mechanism", and (2) a magnetic effect on the existing CaCO_3 particles "particle mechanism" (Saksono et al., 2007). Irrigation with MW could reduce the irrigation intervals and increase the irrigation efficiency (Khoshravesh et al., 2011). It has improved the emergence of maize seeds and increased their vegetative growth compared to the non-magnetized water NMW. It has affected the soil pH, electrical conductivity (EC), available N and P, the soil moisture content (SM,%), and reduced the loss of water (Abedinpour and Rohani, 2017). Magnetization of the irrigation water could be used to alleviate the salinity stress due to the saline water (SW) or salt affected soil (Abd-Elrahman and Shalaby, 2017; Amer et al., 2014; Hilal et al., 2013).

Exposure of the SW to a magnetic field (MF) may affect the salt solubility

and/or decreases the hydration of the salt ions and colloids. Magnetized saline water (MSW) may increase the leaching of the excess soluble salts, lower soil alkalinity and dissolve slightly soluble salts (Mohamed, 2013). This leads to a lower salt concentration in the soil and better conditions for the plant growth (Mostafazadeh-Fard et al., 2012). Soil sulphate ions has decreased significantly, which reduces the chance of calcium sulphate precipitations in soil and increases the leaching from the soil profile (Mostafazadeh-Fard et al., 2011). Additionally, MF can induce the metabolic, photochemical and enzyme activity in plants (Yadollahpour and Rashidi, 2017). This study aims to define the effect of the MSW on some chemical and physical characteristics of the sandy, sandy calcareous and clay soil in Egypt. Some details about the action mechanism of the MT on the different constituents in soil are to be discussed.

2. EXPERIMENTAL

The experiments of this study were carried out during the year 2021 at the research lab of the Sandy and Calcareous Soil Research Department at the Soils, Water and Environment Research Institute (SWERI) – Agricultural Research Center (ARC, Giza, Egypt). The main goal of the experiments is to measure the response of the studied soil types to the magnetically treated water (MW) based on the variations in the estimated soil properties due to its contact with the MW. This is to indicate whether it is an enhancing effect or deteriorating effect on a soil type when MW is used for irrigation. The plan of the study was performed as follows:

Three samples of disturbed surface soil (0 – 30 cm depth) represent three types in Egypt were selected. They were air-dried, sieved with a 2 mm sieve and kept for the study. Sandy soil (*Typic Torripsamment*; Entisol [Arenosol AR]) was brought from the Ismailia Agricultural Research Station (30° 35' 30" N 32° 14' 50" E elevation 3 m) (FAO 2014). Sandy calcareous soil (Aridisol [Calcisol]) was brought from the Nubaria Agricultural Research Station (latitude of 30° 30' N longitude of 30° 20' E). Clay soil [Vertisol] was brought from a cultivated area at the Menoufia governorate. Some properties of the control soil samples are presented in Table 1.

Table 1: Some Properties of The Control Soil Sample Before The Experiments

Soil	pH	EC, $\mu\text{S cm}^{-1}$	CaCO_3 , %	OM, %	Soluble ions, meq 100 g soil ⁻¹					
					K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	HCO ₃ ⁻
Sandy	8.04	245	2.21	1.17	0.11	0.55	0.24	0.33	0.66	0.53
Calcareous	8.26	309	33.66	4.13	0.06	0.57	0.48	0.44	0.14	1.40
Clay	8.01	662	6.20	3.85	0.22	0.80	0.95	1.34	0.78	2.55

2.1 Magnetic Treatment (MT) of Water

The instrument used for the water magnetization was an insulated permanent magnet surrounding an open-ended tube (70 cm Length × 1.5-inch diameter) that was connected to a water tank at one end and to a tab at the other end (Scheme 1). The magnetic field (MF) strength inside the tube was 1.4 T (14000 G) through which water passes at a flow rate 1 L min⁻¹. Salt water (SW) used in the study was 2000 ppm NaCl (2 g L⁻¹) prepared using the tap water (TW). The tank was filled by water, either TW or SW, water allowed to flow through the magnetic tube at a flow rate 1 L min⁻¹ and the magnetically treated water (MW) was then received in a suitable container to be used in the experiments on the soil samples.

2.2 Tests and Measurements on the Soil Samples

The moisture content (%), gravimetric) after 2 h of saturation by water, water holding capacity (WHC, %) and field capacity (FC, %) of the studied soil samples as well as their bulk density (BD, g cm⁻³) were measured using the magnetized (M) and non-magnetized (NM) TW and/or SW using the core method (Black, 1982). A series of cylindrical cores (metallic tubes: 5 cm height and 5 cm diameter with two open ends) was used for the experiment. One end was sealed by a filter paper supported by a filter tissue. The air-dry soil sample was packed in the core by gentle manual vibration (sandy soil 150 g, calcareous and clay soil 100 g). The core containing the sample was weighed then immersed in water to the half of its height, left for 2 h then removed from water and weighed. Same sample was then re-immersed in water, left 24 h for equilibrium, then weighed again to calculate the WHC (%). After that, the wet samples were removed from water, covered to prevent evaporation, left another 24 h to drain excess water, and then weighed to calculate the FC (%). The height of the soil column inside the core was measured, and then the sample was oven dried at 105 °C for 48 h.

The SM, WHC, or FC (%) was calculated by the formula:

$$\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight of soil sample}} \times 100 \quad (2)$$

The (BD, g cm⁻³) values have been calculated according to the equation:

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{\text{oven dried weight of soil column (g)}}{\text{volume of soil column } (\pi r^2 \times \text{soil height}) \text{ (cm}^3\text{)}} \quad (3)$$

Porosity was calculated from the measured (BD, g cm⁻³), assuming a particle density of sandy soil of 2.65 g cm.

$$\text{Total porosity (\%)} = \frac{\text{Particle density of sandy soil} - \text{Dry bulk density}}{\text{Particle density of sandy soil}} \times 100 \quad (4)$$

$$\text{Void ratio } e = \frac{(\text{TP}/100)}{1 - (\text{TP}/100)} \quad (5)$$

The studied soil samples were tested for their saturated hydraulic conductivity HC (Ks, m day⁻¹) by the constant head method using M and NM water as mentioned previously (Hussien et al., 2012; Klute and Direksen, 1986). The metallic cylindrical core (15 cm height × 5 cm diameter) was packed by disturbed soil (150 g for sandy soil, 100 g for calcareous and/or clay soil) to get a 5 cm initial height. They were weighed then immersed in water to the half of its height and left 24 h for equilibrium. After that, the wet samples were removed from water and weighed. A piece of blotting paper was placed on the top of the soil sample and water slowly poured in the upper cylinder until it is 2/3 to 3/4 full. The siphon was started to maintain a constant water head on the soil column. When the water level on the top of the soil has become stabilized (after ~20–30 min), water percolate was continued for 120 min, and the percolates were collected in beakers at 15 min constant time intervals. The soil column kept saturated during the experiment. The HC (Ks) of the soil to water was calculated in the case of M and NM water flow by equation #5:

$$\text{Ks (m/day)} = \frac{QL}{HAT} \quad (5)$$

Where K_s (cm/h which was plotted as m/day): the saturated HC, Q (mL): the volume of the percolating water, L (cm): the height of the soil column inside the core, H (cm): the total head, A (cm²): the cross-sectional area of the sample, T (h): the time of collecting percolates 15 min. At the end of the HC test, same soil samples were oven-dried at 105 °C for 48 h then subjected to other tests according to the recommended methods of soil analysis (Black, 1982; Page et al., 1982). This is to estimate the effect of the continuous flow of MW through soil on some of its characteristics compared to that of the NMW. All tests were carried out in a triplicate and the result values were the average of three data points. The estimated characteristics were the soil pH (1:2.5 soil: water suspensions), EC and soluble cations and anions volumetrically (1:5 soil: water extract), CaCO₃ (% by the Calcimeter method), and organic matter OM% (Page et al., 1982; Walkley and Black, 1934). Aggregates size distribution was determined by the dry sieving method using vibratory sieve shaker (frequency 50/60 Hz) FRITSCH analysette 3 SPARTAN pulverisette 0, Germany.

Zeta potential (ζ) of the colloidal fraction in the studied soil samples suspended in double distilled water as a dispersant have been measured in clear disposable zeta cells at room temperature (25°C) using the Zeta sizer nano series (Nano ZS), Malvern, UK -Size range (nm): 0.6:6000 nm and Zeta potential range (mV): (-200:200 mV). Dispersant RI = 1.33, Viscosity (cP) = 0.8872, Dielectric constant = 78.5 and Conductivity of samples ranged between 0.058 to 0.152 mS cm⁻¹. The samples were ultra-sonicated for 5 minutes prior to measurements and the count rate was varied for different samples during 12 zeta runs based on the Dynamic/Electrophoretic Light Scattering technique (DLS/ELS). Electrophoretic mobility (U) was calculated using the formula for particles approximation for spheres (Hubbe, <https://projects.ncsu.edu/project/hubbepaperchem/Defnits/ZetaPotl.htm> (seen on 20/01/2020)):

$$U = (\zeta \epsilon) / (4\pi\eta) \quad (5)$$

Where: ζ is the Zeta potential (mV), η is the viscosity (cP) of the medium (water) = 0.8872, ϵ is the dielectric constant of the medium = 78.5.

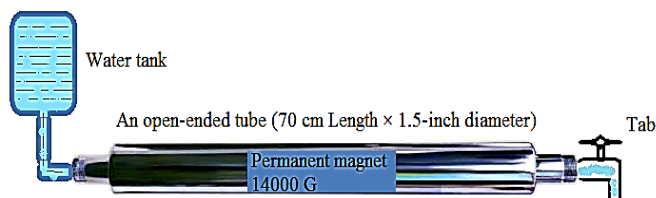
2.3 Statistical Analysis of the Data

The statistical significance (LSD) of results was estimated by the one-way analysis of variance (ANOVA) (Gomez and Gomez, 1984). Calculations were carried out at a significance level $P = .05$ using the Co-State software Package (Ver. 6.311), a product of Cohort software Inc., Berkley, California.

3. RESULTS

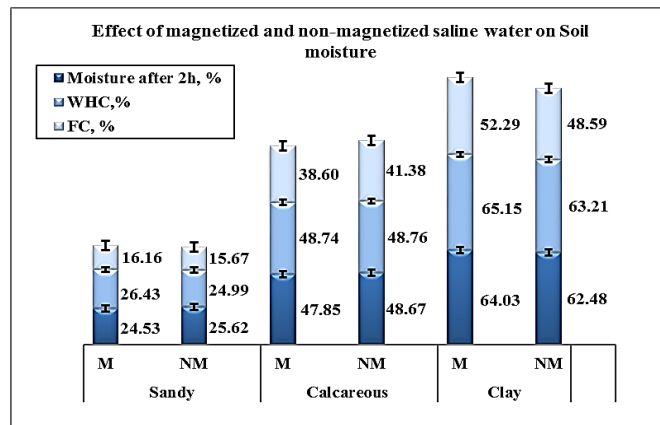
3.1 Effect of The MW on The Soil Moisture Content (SM, %)

The SM of the sandy soil after 2 h of saturation by MSW was less than the NMSW by 4.3% as presented in Figure 1. This refers to a slower rate of partial initial saturation of soil by moisture during the 1st two hours opposite to TW. After 24 h, equilibrated saturation of soil may be attained at which the WHC and FC of soil saturated by MSW were increased by 5.6 and 3.2% compared to the saturation by NMSW. In a contrast, the initial partial saturation of sandy soil by the MTW was faster and higher than the NMTW by 2.8%. However, WHC and FC of sandy soil was decreased by 4 and 15.3% in case of MTW compared to NMTW. It can be said that magnetization effect on SW differs from that on TW. For calcareous soil, magnetization of water decreased the SM content after 2 h saturation, WHC and FC in both cases of SW and TW.

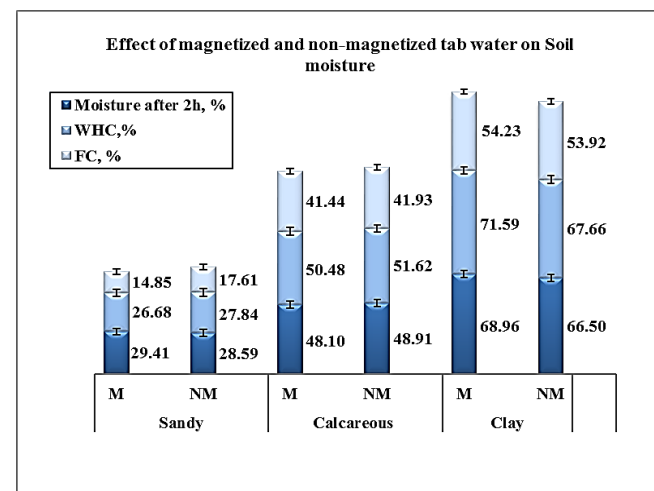


Scheme 1 Water magnetization instrument used in the study

Field capacity decreased by 6.8% because of MSW compared to NMSW. Clay soil exhibited a more regular trend under the effect of MW. Soil moisture after 2 h as well as WHC and FC of soil has increased by MSW and MTW more than NMSW and NMTW, respectively. Water holding capacity was increased by 3 and 5.8% while FC was increased by 7.6 and 0.6% for MSW and MTW compared to NMSW and NMTW, respectively. It can be said that clay soil may be more magnetically induced by MW compared with sandy and sandy calcareous soil. This can be attributed to its rich content of clay and nutrients some of them have positive χ_m like Mg, Fe, Mn, ..., etc, and absence of high CaCO₃ content.



(a)

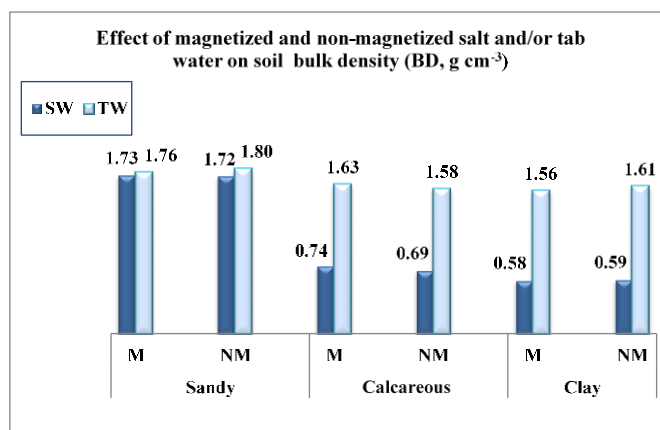


(b)

Figure 1: Effect of magnetized and non-magnetized (a) saline water, (b) tap water on soil moisture (Error bars refer to the maximum value of SD calculated for different treatments)

3.2 Effect of The MW on The Soil Bulk Density (BD, G Cm⁻³), Total Porosity (TP, %) and Void Ratio (E)

Figure 2(a-c) shows that SW has decreased the BD (g cm⁻³) of sandy, sandy calcareous, and clay soil while increased their corresponding calculated TP (%) and void ratio (e) compared to the TW. The MSW has decreased the BD by 1.6, 59.6, and 62.8%, while increased the TP by 3.8, 132.9, and 89.9% for sandy, sandy calcareous, and clay soil, respectively. It may be dependent on the variable response of soil to the electromagnetic induction emerged from the contact with magnetized SW related to soil type. The calculated void ratio of sandy and clay soil has almost increased by MW for both TW and SW compared to the NMTW. Void ratio of clay soil was increased by 8.2% and 2.2% due to MTW and MSW, respectively. Oppositely, void ratio of sandy calcareous soil was decreased by 7.5% and 9.2% due to MTW and MSW, respectively.



(a)

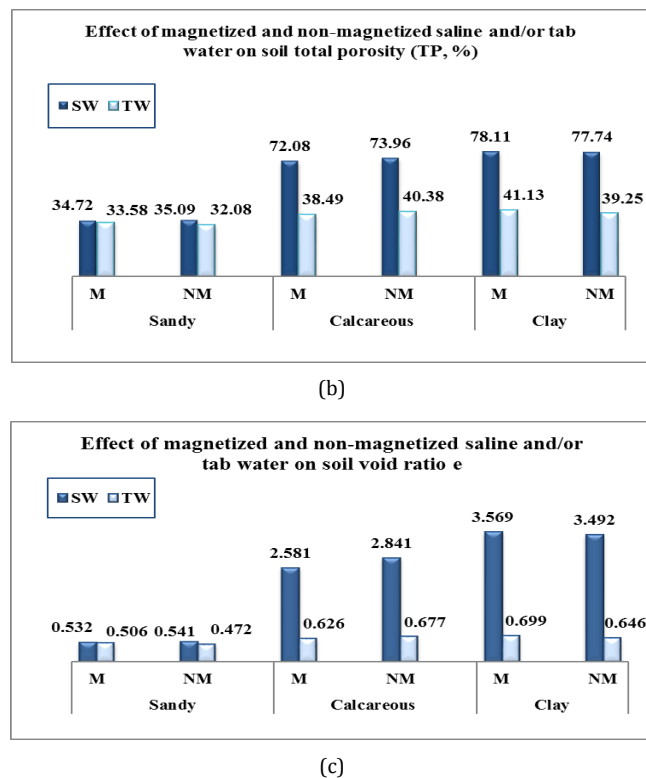


Figure 2: (a) Effect of magnetized and non-magnetized saline water and/or tap water on soil bulk density (BD, g cm⁻³); Effect of magnetized and non-magnetized saline water and/or tap water on soil total porosity (TP, %)

3.3 Effect of The MW on The Hydraulic Conductivity (HC, M Day⁻¹) of Soil

It can be observed from Figure 3 that magnetization of both SW and TW has decreased the hydraulic conductivity (HC, m day⁻¹) of soil compared to NMSW and NMTW, respectively. The MSW has decreased the HC by 41.1, 12.8, and 51.4% compared to NMSW for sandy, sandy calcareous, and clay soil, respectively. The MTW has also decreased the HC by 8.73, 52.3, and 27.2% for same soil samples, respectively.

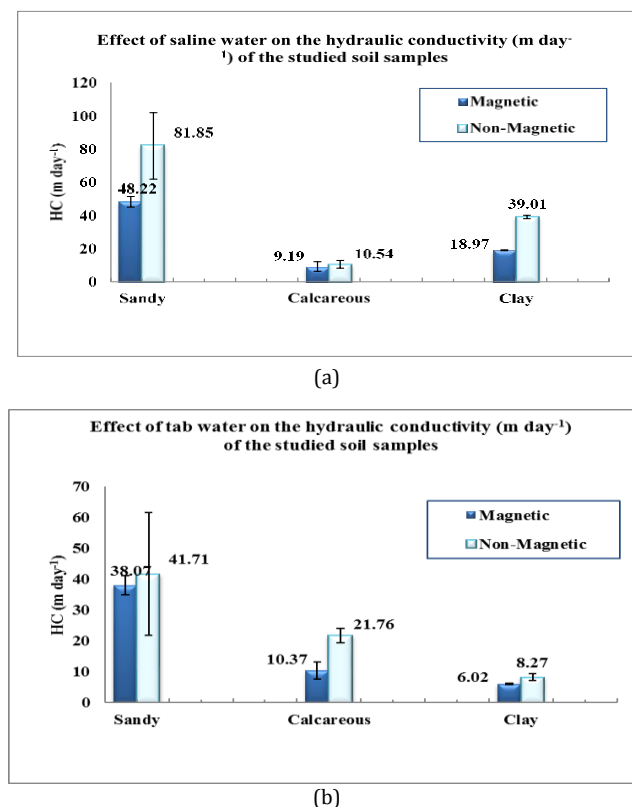


Figure 3: Effect of (a) salt water, (b) tap water on the hydraulic conductivity (m day⁻¹) of the studied soil samples

3.4 Effect of the MW on the aggregate size distribution of the studied soil samples

Dry sieving results are plotted in Figure 4 (a-c). Aggregate size ranges for sandy soil indicate a variation between the sum of the more fine fractions (710-500, <500 μ m) and the more coarse fractions (>1 mm, 1 mm -710 μ m) under the effect of SW and TW both M and NM. Control soil sample not subjected to water flow has a 95.5% sum of fine fractions (710-500 and <500 μ m). The MSW kept the sum of fine fractions at 95.55% compared to 93.4% for NMSW. The MTW has increased the sum of fine fractions to 88.95% compared to 87% for NMTW.

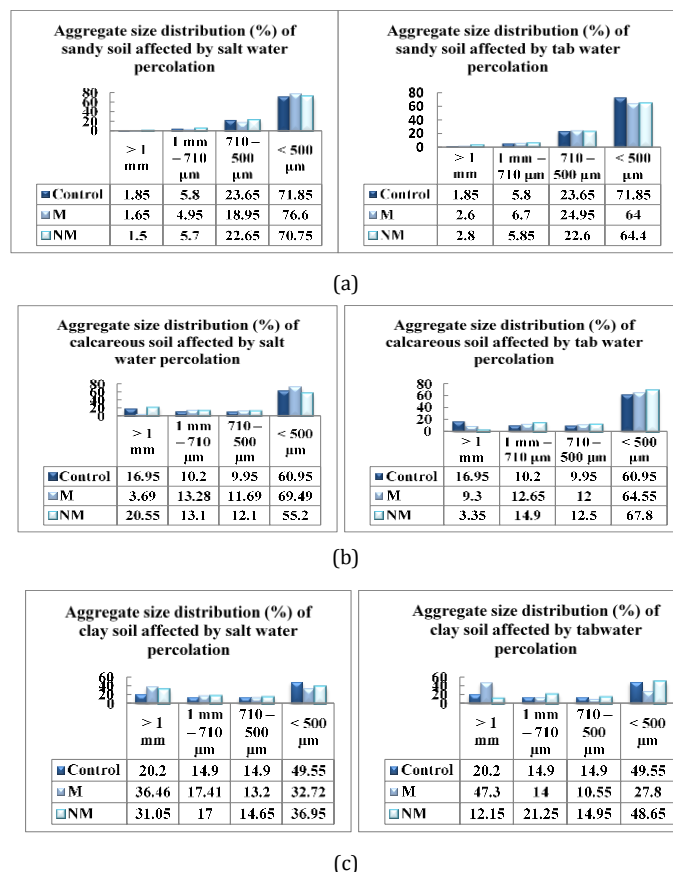


Figure 4: (a) Aggregate size distribution (%) of sandy soil affected by salt and tap water percolate; (b) Aggregate size distribution (%) of calcareous soil affected by salt and tap water percolate; (c) Aggregate size distribution (%) of clay soil affected by salt and tap water percolate

Percolate of SW through sandy calcareous soil decreased the sum of fine fractions (710-500 and <500 μ m) from 70.9% of the control to 67.3% by the NMSW but increased it to 81.18% by the MSW. Percolate of TW through sandy calcareous soil increased the sum of fine fractions (710-500 and <500 μ m) from 70.9% of the control to 77.05% for the MTW and/or 80.3% for the NMTW. This may be caused by dissociation of larger aggregates into smaller ones and/or partial dispersion of CaCO₃ particles. In case of clay soil, the sum of fine fractions was decreased under the effect of SW percolate from 64.45% of the control to 51.6% by NMSW and to 45.92% by MSW. In addition, TW decreased the sum of fine fractions to 63.6% by NMTW and to 38.35% by MTW. Magnetized TW decreased the sum of fine particles by 40.5%, while the MSW decreased it by 28.75% that can be attributed to the dispersing effect of NaCl soluble salt

3.5 Effect of Magnetized and Non-Magnetized Tab (MTW/NMTW) and Salt (MSW/NMSW) Water on Some Chemical Properties of The Studied Soil Samples

It is well established that the soil pH is one of the most constant soil characteristics not easily altered due to the buffering action of soil solution that often makes any pH change temporary. In the present study, the soil pH mentioned in Table 2 was measured for a control soil sample and for soil samples after subjection to continuous water (M and/or NM / TW and/or SW) percolate for 2 h. Flow of the MTW decreased soil pH significantly at a significance level $P= .05$ compared to the control for sandy, calcareous, and clay soil by 9.7%, 8.7%, and 4.4%, respectively. Oppositely, MSW increased the soil pH by 13.2%, 6.7%, and 10.4%, respectively. The electrical conductivity (EC, μ S cm⁻¹) of the soil normally decreased significantly after washing by M / NMTW for 2 h.

Table 2: Effect of the Magnetized and Non-Magnetized Tab and Salt Water after 2 h percolation time on Some Chemical Properties of The Studied Soil Samples

Soil	Treatment	pH			EC, $\mu\text{S cm}^{-1}$			CaCO ₃ , %			OM, %		
		C	NM	M	C	NM	M	C	NM	M	C	NM	M
Sandy	Control	8.04			245			2.21			1.17		
	Tab water		7.21	7.26		77.2	70.3		2.40	3.20		1.18	1.37
	Salt water		8.95	9.10		123.4	184.1		2.60	2.65		1.09	2.23
Calcareous		8.26			309			33.66			4.13		
	Tab water		7.48	7.54		212.0	205.0		36.00	35.20		2.03	1.54
	Salt water		8.83	8.81		441.0	627.0		34.55	34.55		3.32	3.40
Clay		8.01			662			6.20			3.85		
	Tab water		7.68	7.66		238.0	219.0		4.00	6.40		4.41	3.20
	Salt water		8.88	8.84		593.0	694.0		6.20	6.75		4.09	5.27
LSD _{5%}		0.93			65.29			0.35			0.12		
Significance of factors		***			***			***			***		

Magnetization of TW decreased the soil EC more than NMTW. This may be caused by a magnetic induction exerted on the soil particles as well as soluble ions by MW leading to more leaching loss than NMTW. Non-magnetized TW decreased soil EC by 68.5%, 31.4%, and 64.0%, while MTW decreased EC by 71.3%, 33.7%, and 66.9%, for sandy, calcareous, and clay soil, respectively. However, MSW increased soil EC by 102.9% for calcareous soil and by 4.8% for clay soil, while decreased EC of sandy soil by 24.9%. It may be due to its low clay content versus higher clay content of calcareous and clay soil. Regarding the CaCO₃ and organic matter (OM) content of soil, Table 2 indicates that MW increased the CaCO₃ in sandy soil by 44.8% and 19.9%, in calcareous soil by 4.6% and 2.6%, and in clay soil by 3.2% and 8.9% for the TW and SW, respectively.

The MSW has increased sandy soil OC by 90.6% and clay soil by 36.9% relative to the control. Negative χ_m of CaCO₃ in the calcareous soil may retard such reactions, which increases loss of OC via oxidation, dissociation, and/or leaching loss. It was decreased in the calcareous soil by 17.7% relative to the control. Table 3 indicates a possible leach of the soluble cations and anions caused by the flow of TW or SW except for Na⁺ in SW. Concentrations of the K⁺, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, and HCO₃⁻ have almost decreased in case of the sandy, calcareous, and clay soil after percolate of TW or SW compared to the control soil sample not subjected to water flow. Predominance of Na⁺ in SW and its positive susceptibility (χ_m) may increase its adsorption on the soil particles especially with MSW. This may apply for Mg²⁺, Cl⁻, and HCO₃⁻ in calcareous soil of poor drainage.

Table 3: Effect of Magnetized and Non-Magnetized Salt Water on The Concentration of Soluble Ions (meq 100 g Soil-1) in Soil Solution of The Studied Soil Samples After 2 h Percolation Time

Soil	Treatment	Soluble Ions, meq 100 g Soil ⁻¹																	
		K ⁺			Na ⁺			Ca ²⁺			Mg ²⁺			Cl ⁻			HCO ₃ ⁻		
		C	NM	M	C	NM	M	C	NM	M	C	NM	M	C	NM	M	C	NM	M
Sandy	Control	0.11			0.55			0.24			0.33			0.66			0.53		
	Tab Water		0.06	0.06		0.05	0.06		0.07	0.05		0.21	0.18		0.09	0.06		0.30	0.28
	Salt Water		0.03	0.04		0.50	0.69		0.14	0.24		0.01	0.01		0.23	0.35		0.39	0.57
Calcareous	Control	0.06			0.57			0.48			0.44			0.14			1.40		
	Tab Water		0.11	0.14		0.11	0.16		0.48	0.35		0.36	0.38		0.14	0.07		0.92	0.96
	Salt Water		0.10	0.09		1.08	1.32		0.24	0.48		0.79	1.25		0.36	1.18		1.84	1.95
Clay	Control	0.22			0.80			0.95			1.34			0.78			2.55		
	Tab Water		0.17	0.19		0.20	0.24		0.47	0.22		0.35	0.46		0.10	0.10		1.09	0.99
	Salt Water		0.24	0.16		1.38	1.46		0.71	0.71		0.63	1.14		0.58	1.31		2.41	1.91
LSD _{5%}		0.035			0.033			0.033			0.032			2.50			0.042		
Significance of Factors		***			***			***			***			ns			***		

4. DISCUSSION

The presence of Na⁺ and Cl⁻ salt ions in water may play a role in the water absorption and storage inside soil. Hydration shell of Na⁺ and Cl⁻ ions as well as the electrostatic attraction/repulsion between ions and exchange surface sites on soil particles may affect void volume between soil particles by expansion and/or shrinkage, which in turn increases the SM content. Magnetization of SW increases this effect. Therefore, FC of sandy soil was increased by 8.7% in case of MSW compared to MTW free of charged salt ions although soil FC in case of NMTW was greater than that in case of NMSW by 12.1%. This is harmonizing with previous studies (Jiménez et al., 2017). The soil content of CaCO₃ can affect the magnetic induction of soil via the electromagnetic force carried by MW. The dissolution/precipitation of CaCO₃ particles within the soil profile is affected by MW as mentioned previously (Saksono et al., 2007).

Also, negative magnetic susceptibility (χ_m) of CaCO₃ is $-38.2 \text{ m}^3 \text{ mol}^{-1}$ as well as its other compounds possibly exist in soil like CaCl₂, Ca(OH)₂, CaSO₄ may compensate positive χ_m of magnetically induced TW, SW, and sodium

(Na) in SW (Landolt-Brnstein, 1986; Numrique, 1957). Since magnetized water (MW) has short clusters in addition to finely textured soil (sandy clay loam), absorption, and storage of water by soil may be restricted resulting in a reduced WHC and FC. Soluble hydrated salt ions in SW may penetrate to soil voids difficulty and hence create some osmotic pressure around some particles, which in turn leads to water diffusion outside soil. Results of the soil BD (g cm^{-3}) and TP (%) refer to an increased volume of soil upon contact with and absorption of SW. Electrostatic repulsion between soluble and adsorbed salt ions within soil matrix can expand voids between particles, causes their displacement, expands soil volume, and increases TP (Estabragh et al., 2013; Mishra et al., 2005).

Generally, the HC of sandy and clay soil in case of SW was faster than TW. It may be due to the electrostatic repulsion between Na⁺ ions adsorbed on soil particles and soluble in salt solution that increased the void ratio and in turn, the rate of water flows through soil column. This is in agreement with results obtained previously (Estabragh et al., 2013; Mishra et al., 2005). The calcareous soil has showed a lower HC than the clay soil under the effect of saline water flow that can be attributed to the presence of CaCO₃. Precipitation of Na₂CO₃ particles is possible and can clog soil voids

and slow down the rate of water flow so that it decreases the HC. It is suggested that the electromagnetic force carried out by MW has induced the soil magnetically, mediated the electrostatic attraction/repulsion forces *in situ*, and slowed down the water flow rate represented by HC of soil.

The poor drainage of calcareous soil represented by its slow HC perhaps became worse under the effect of SW and magnetization of water could not enhance it. This can be caused by its high content of CaCO_3 that is negatively susceptible to magnetic induction by MW. The difference between calcareous and clay soil is the high clay content with active exchange surface sites rather than inert fine sand in sandy loam calcareous soil. Flow of water through soil column seems to have a corrosive action due to the adsorption of polar water molecules as H^+ and OH^- onto soil aggregates. This can dissociate larger aggregates into smaller size that increase the more fine fractions. This behaviour is more pronounced under SW than TW. Magnetization of water may restrict or decrease the re-coagulation of some fine particles to form larger aggregates in case of NM water flow through the studied sandy soil.

As fine fractions of coarse sandy soil increase, lose of water and nutrient leaching due to fast drainage may decrease. Saline water may saturate the surface of calcareous soil particles by Na^+ and Cl^- as exchangeable ions. In addition, mobile Cl^- ions in soil solution can form H^+Cl^- as conjugate acid capable to dissolve a portion of CaCO_3 and produce soluble Ca^{+2} ions, which act as a cementing agent links particles together into larger aggregates. So that, sum of finer fraction decreased by NMSW compared to the control. Magnetized SW may enhance the re-precipitation of dissolved Ca^{+2} ions in the CaCO_3 form other than adsorption on soil surface to link particles. Repulsion between ions of Na^+ adsorbed on soil surface disperses particles and cause destruction of aggregates.

As a result, the sum of finer fractions increased to 81.18% for MSW. Systematic variation of aggregate size of clay soil may be dependent on soil content of soluble ions and clay fraction. Surface of clay particles adsorbs polar water molecules as H^+OH^- of TW and/or soluble cations and anions including Na^+ and Cl^- of SW. Thus, soil particles carry a charge and still suspended then moves with the mobility of water through soil column so that they can re-coagulate under the effect of attraction/repulsion forces and form larger aggregates. Therefore, the sum of the fine particles decreases while percentage of coarser particles increases. This effect is more pronounced by MW both SW and TW. Magnetic susceptibility (χ_m) of clay soil particles as well as soluble ions may play a role in the response of soil to MW. Charged soil particles may be induced magnetically by MW that is enforced by electromagnetic force.

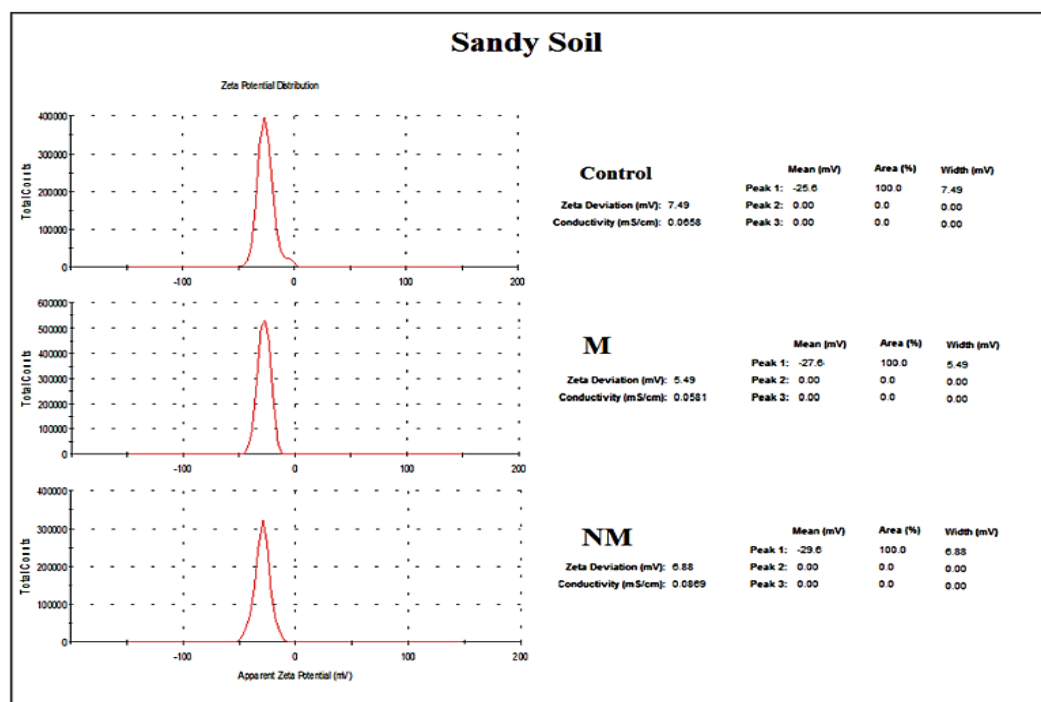
This magnetic induction can increase the coagulation of fine particles to form larger aggregates. Variation of soil pH may be a result of leaching of soluble ions from soil leading to some disturbance in the equilibrium between soluble and adsorbed ions at soil surface. Some exchangeable

cations may be attracted by water hydroxyl (OH^-) and leached off; after which, water hydrogen (H^+) can re-adsorb to compensate surface charge. So, soil pH decreases in case of TW. In case of SW, predominant Na^+ soluble ions replace almost all exchangeable cations and soil surface is saturated by adsorbed Na^+ with its hydration sphere. Electric double layer surrounding soil particles has polarized HOH molecules with exposed OH^- . Additionally, soluble Cl^- ions may attract H^+ ions and leaches away. Concentration of H^+ in soil solution decreases and becomes more basic.

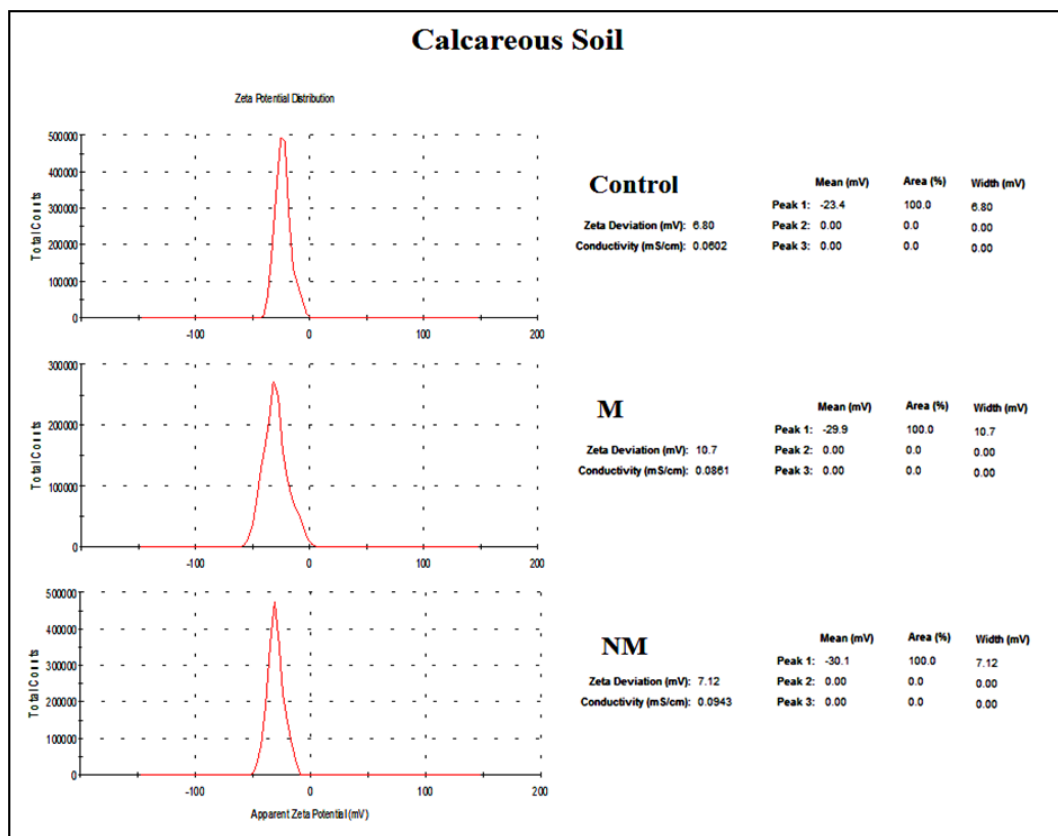
Variation in soil pH between MSW and NMSW was almost non-significant. Positive susceptibility (χ_m) of sodium (Na) can increase its adsorption and entrapment in soil in case of MSW compared to NMSW that increase soil EC. A suggested reason for the increase of CaCO_3 (%) is that the corrosive action of water percolate along 2 h may dissociate larger aggregates into smaller size particles including CaCO_3 particles. Smaller particles shall have exposed larger and more active surface area than larger particles, i.e. estimated active CaCO_3 (%) is increased. Perhaps, the temporary change in soil pH leads to partial dissolution/re-precipitation of CaCO_3 as well as soluble Ca^{+2} ions in soil solution. Therefore, total CaCO_3 (%) in soil increased. Presence of Na^+ ions in SW may affect the equilibrium of CaCO_3 dissolution/precipitation compared to TW.

In addition, magnetic induction of soil particles along with pH change may promote some organic and/or inorganic chemical reaction at particles' surfaces. Organic moieties may be created, transformed, immobilized, dissolved, or precipitated. As a result, organic carbon (OC, %) in soil either increased or decreased. *Zeta Potential* (ζ) is an electro-kinetic parameter indirectly determined by the surface charge of particles when they are suspended in polar media. The charged particles in suspensions can be set into motion under the action of an electric field. At equilibrium, the particles can move at constant speed. The constant velocity acquired under unitary electric field strength is called unitary electrophoretic mobility. It is an indirect measure of the net charge created in the particles of the suspension, either by adsorption of contra ions or dissociation of particles surface groups.

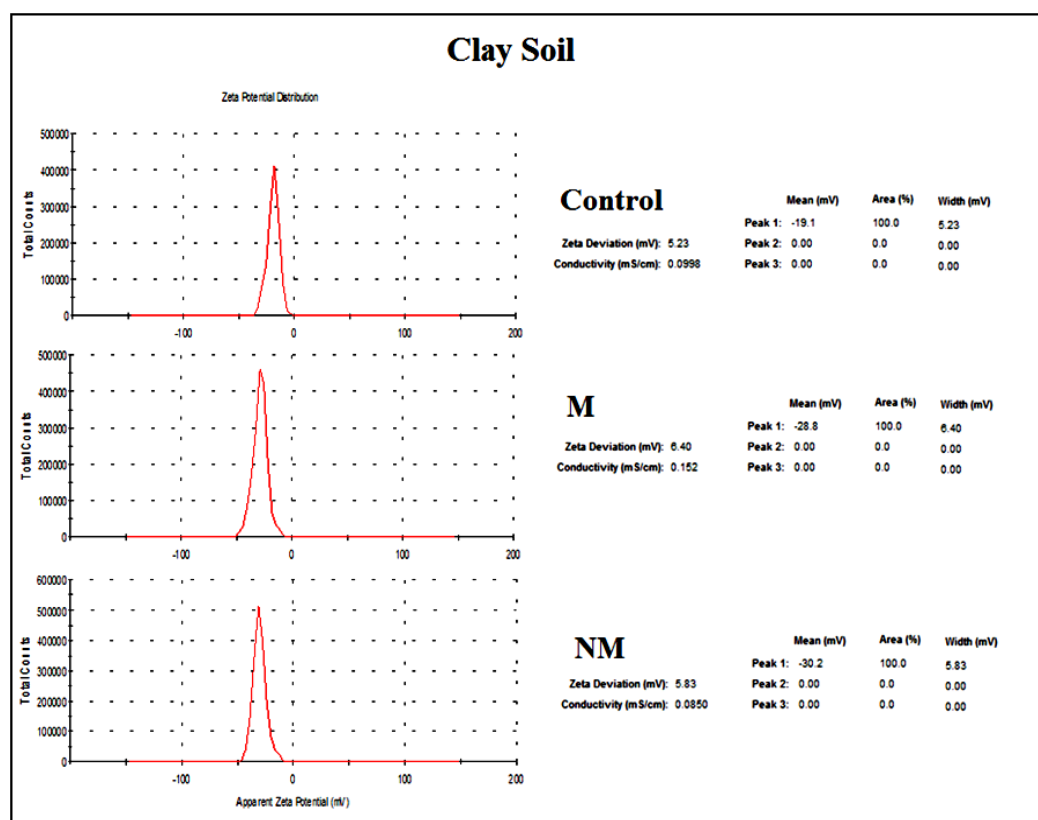
It can be accepted that ζ values of ± 30 mV are enough to promote stable water suspensions. This occurs because particles of like charge repel each other, overcoming the tendency to aggregation caused by the action of the *Van der Waals* forces. by decreasing particle size there is a relative increase in electrophoretic mobility and indirectly also an increase in the apparent zeta potential (Júnior and Baldo, 2014). The response of the studied soil samples to magnetically treated water can be discussed in view of the zeta potential ζ values of soil particles presented in Figure 5(a-c). Salt water increased the ζ value from 25.6 mV (control) to 29.6 mV for the sandy soil, from 23.4 mV (control) to 30.1 mV for the sandy calcareous, and from 19.1 mV (control) to 30.2 mV for the clay soil. It may be attributed to the saturation of soil particles by exchangeable Na^+ cations, which severely disperse particles and deteriorate soil aggregate and structure.



(a)



(b)



(c)

Figure 5: (a) zeta potential analysis results of sandy soil affected by non-magnetized (NM) and magnetized (M) saltwater percolate; (b) zeta potential analysis results of calcareous soil affected by non-magnetized (NM) and magnetized (M) salt water percolate; (c) zeta potential analysis results of clay soil affected by non-magnetized (NM) and magnetized (M) salt water percolate

However, MSW returned the ζ value to 27.6 mV, 29.9 mV, and 28.8 mV for the sandy, sandy calcareous, and clay soil, respectively. This small shift in ζ value may be a part of the mitigation mechanism through which magnetic treatment of SW minimizes its stress on soil. Additionally, the corresponding calculated electrophoretic mobility (U) presented in Figure

6 indicates that the absolute value has increased under the effect of SW by 15.6%, 28.6%, and 58.1% for the sandy, sandy calcareous, and clay soil, respectively. Absolute values of U for the MSW have increased by 7.8%, 27.8%, and 50.8% for the sandy, sandy calcareous, and clay soil, respectively.

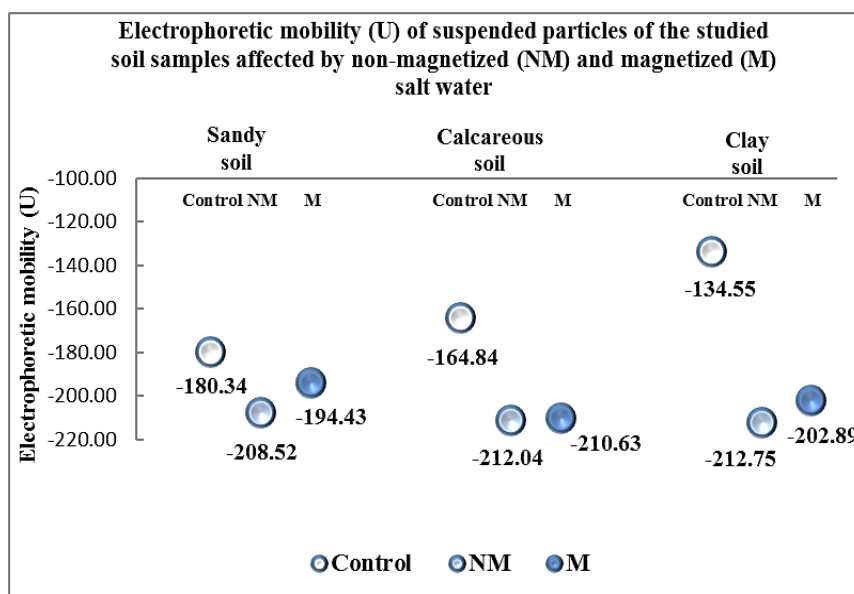


Figure 6: Electrophoretic mobility (U) of the suspended particles of the studied soil samples affected by non-magnetized (NM) and magnetized (M) salt water

5. CONCLUSION

The response of a soil to the magnetic induction exerted by the magnetically treated salt water (MSW) is strongly dependent on the soil type and its CaCO_3 content. The soil moisture after 2 h as well as the WHC and FC of soil has either increased or decreased by the MSW and MTW compared with the NMSW and NMTW for the studied types of soil. Also, the soil bulk density (BD, g cm^{-3}), total porosity (TP, %) and void ratio (e) along with the hydraulic conductivity (HC, m day^{-1}) and the sum of fine fractions (710-500 and $<500 \mu\text{m}$) showed variable trends depending on the soil type. Variation in the zeta potential ζ of the colloidal fraction in soil may be responsible for the variation of many characteristics of the soil treated by the MSW such as pH, EC, HC, and aggregate size distribution.

The MT can accelerate the variation in some soil properties leading to faster change of the soil matrix that need longer time to occur under normal conditions. The contact of the soil components with the MW has showed variable effects on soil and further studies are needed to indicate which effects are temporary or permanent due to the continuous exposure of soil to the MW. Strict control shall be applied to the application of the magnetic technology agriculturally to avoid deterioration or at least the unfavourable and rapid soil change faster than expected. The efficiency of the MWT for use as irrigation water may be related to the type of the cultivated soil especially under salinity conditions.

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