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Interactions Between Soils and Laboratory Simulated Electrolyte Solution

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Abstract To study the impact of salt water intrusion on two types of soils from west coast region of India were investigated in the laboratory. The key characteristics evaluated included Atterberg limits, compaction characteristics, hydraulic conductivity and chemical characteristics of selected soils. The sea at this coast receives effluent from different points and hence the characteristics change with time and locality. Therefore, to maintain uniform composition, 0.5 N sodium chloride solution (NaCl) was prepared in the laboratory and batch tests were used to determine the immediate effect on soils. Soil specimens were prepared by mixing the soils with 0.5 N NaCl in the increments of 0, 5, 10 and 20% by weight to vary the degree of contamination. Experimental results of soils mixed with 0.5 N NaCl showed that the maximum dry density increases and the optimum moisture content (OMC) decreases with increasing sodium chloride concentration. The study also revealed that the hydraulic conductivity of the soils tested increases with increase in sodium chloride concentration. The Atterberg limits of contaminated specimens show a remarkable change when compared with uncontaminated specimens.

Keywords Soils · Sodium chloride solution · Contamination · Atterberg limits · Hydraulic conductivity · Compaction characteristics

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1 Introduction

One may think of soil and ground water pollution in the coastal areas is due to salt water intrusion. The objective of the present investigation is to study the impact of salt water intrusion on the properties of the soils encountered in the study region. Such studies may be useful in connection with any possible applications during geotechnical investigation for the construction of structures. The study area is situated in southwest coast of India (Latitude 12°52′N, Longitude 74°49′E). It receives very heavy rainfall (3,500 mm annually) during southwest monsoon for 4 months (June to September). Many seasonal rivers in the lower reaches of the region become saline due to salt water ingression during non-monsoon periods. Therefore, soil and groundwater systems are affected by salt water intrusion and seepage of saline water from polluted rivers (Gajendragad 1986). Lateritic soil and shedi soil are the two types of soils commonly found in the study region. Lateritic soils are being successfully used in almost all the civil engineering works. Shedi soil is a whitish soft silty soil with some proportion of clay. The thickness of shedi soil profile varies at different places and is usually found beneath the lateritic soil. The shedi soils are problematic with low bearing capacity. When need arise to construct foundations on shedi soil, necessary precautions are taken and this forms a general practice in this region whenever problematic soils are encountered. Whatever the case may be, presence of fine grained fraction (silt and clay) makes both lateritic soil and shedi soil susceptible for contamination. Contaminants get adsorbed onto the clay particles leading to marked changes in the geotechnical and chemical characteristics of the soils. Past work (Foreman and Daniel 1986; Gnanapragasam et al. 1995; Kamon et al. 1996; Khan and Pise 1994; Kirov 1989; Kumapley and Ishola 1985; Mesri and Olson 1970; Nayak et al. 2007; Roque and Didier 2006; Sivapullaiah and Savitha 1997; Soule and Burns 2001; Sridharan et al. 1981; Sridharan and Venkatappa Rao 1979; Sunil et al. 2006, 2008; Uppot and Stephenson 1989) has shown that the index and engineering properties of contaminated soil tend to change due to chemical reactions between the soil mineral particles and the contaminant.

2 Scope of the Problem

Salt-water intrusion in the coastal zones may lead to the pollution of soil and groundwater systems. Once the saline water intrudes the ground water zone, it is very difficult to remove the contamination caused by saltwater. There are many instances in the study area where well water is polluted by saltwater intrusion thus rendering it unfit for the purpose of drinking. Similarly structures built on soils close to the coast are vulnerable due to seepage from seawater, which contains very high concentration of sodium chloride and other salts. Continuous seepage of saline water for a long duration may have significant effect on the soil properties and also affect the foundations built on such soils (due to corrosion of reinforcement). From geotechnical point of view the study finds useful where the engineer is concerned about, change in the properties of soils, induced due to presence of saline water. For example any change in the permeability characteristics of the original soil would affect the amount of seepage that take place through the soils. More seepage of saline water means the geotechnical properties of the original soil and the foundations resting on such soils are vulnerable for contamination. Also for any possible applications in geoenvironmental engineering, studies on such systems are required. Hence the present study is undertaken to investigate the impact of salt water on the geotechnical properties and chemical characteristics of two soils with different varying amount of clay fraction.

3 Methodology

This work was carried out in the laboratories of civil engineering department at National Institute of Technology Karnataka Surathkal, India. The main focus of this study was to determine the effect of saline water on the properties of the locally available soils. Since sea water contains various salts and during the initial investigation of this study sodium chloride solution was simulated in the laboratory in order to maintain uniform composition. Lateritic soil and shedi soil are the two types of soils commonly found in the study region. Hence it is proposed to use these soils in the present work.

3.1 Index Properties

The specific gravity of soil solids were determined as per IS: 2720 (Part 3/Sec 1)-1980 (Reaffirmed 1987). The grain-size analysis of lateritic soil samples were done as per IS: 2720 (Part 4)-1985. The liquid limit of soil was determined using the standard liquid limit apparatus IS: 9259-1979 (Reaffirmed 1987). The plastic limit of lateritic soil and shedi soil was determined as per IS: 2720 (Part 5)-1985.

3.2 Compaction Characteristics

The compaction characteristics [IS: 2720(Part 7)-1980 (Reaffirmed 1987)] of lateritic soils were studied in the laboratory using standard Proctor test. The equipment used in the test consists of cylindrical mould (with detachable base plate) having an internal diameter of 100 and 127.5 mm effective height, whose internal volume is 1,000 ml. The rammer has a mass of 2.6 kg with a drop of 310 mm.

3.3 Hydraulic Conductivity

Falling head permeability tests (IS: 2720 (Part 17)-1986) were carried out on uncontaminated and contaminated soil samples to study the hydraulic conductivity compacted to standard Proctor maximum dry density in the permeability mould. After compaction of the soil, the collar was removed and the soil specimen was carefully trimmed.

Before the beginning of the seepage stage, a filter paper was placed on each face of the soil specimen so as to prevent the clogging of the perforated disks by the soil fines. After placing the bottom and top plate of the permeameter, the nuts were fastened and assembled properly. The permeameter is then connected to stand pipe (when testing uncontaminated soil the stand pipe was filled with distilled water and during testing of contaminated soil the stand pipe was filled with leachate); the soil is saturated by allowing distilled water/leachate to flow continuously through the sample from the stand pipe. Saturation of the soil sample was ensured under steady state flow conditions. The following method was followed:

a) the heights h_1, h_2 and $\sqrt{h_1 h_2}$ are marked on the stand pipe (the heights are measured above the centre of the outlet);
b) the stand pipe is then filled with distilled water/leachate and the time intervals is recorded for the level to fall from height h_1 to $\sqrt{h_1 h_2}$ and from $\sqrt{h_1 h_2}$ to h_2.

These two time intervals will be equal if a steady flow condition has been established. This was repeated at least twice changing the heights h_1 and h_2.

The termination criteria of the tests followed in this study were as follows:

a) flow rate of water proportional to hydraulic gradient;
b) volume of water proportional to time.

The hydraulic conductivity values reported in Table 2 were calculated using the following equation. Table 2 also presents the voids ratio values.

$$k = \frac{2.303aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

where, k- coefficient of permeability in cm/s; a- cross-sectional area of the stand pipe in cm^2; A cross-sectional area of the sample in cm^2; t time taken for the drop from height h_1 to h_2 in sec; h_1 initial height of the fluid in stand pipe in cm; h_2 final height of the fluid in stand pipe in cm after time t.

3.4 Properties of Soils Prior to Contamination

During this investigation, lateritic soil samples and shedi soil sample were obtained from test pits of 1.2 to 1.5 m. The soils were air dried and passed through 425 μm sieve before using the same for laboratory tests. Tables 1, 2, 3 show the main physical and chemical characteristics of lateritic soil and shedi soil. The maximum dry density (γ_{dmax}) and optimum moisture content (w_{opt}) values were established for the study soils.

3.5 Contamination Studies

Batch tests were used to determine the immediate effect on soils. Dry soil samples were mixed with 5, 10 and 20, 0.5 N NaCl concentration by weight of dry soil. A standard Proctor test and hydraulic conductivity tests were carried out on samples after 48 h. The maximum dry density and optimum moisture content values were established for uncontaminated soil. To study the hydraulic characteristics of lateritic soils after contamination with NaCl the soil specimens were compacted to corresponding standard Proctor maximum dry density using standard Proctor optimum moisture content (w_{opt}).

3.6 Preparation of Sodium Chloride Solution

Coastal districts of Karnataka, (Dakshina Kannada and Udupi districts) India, are situated almost parallel to the Arabian Sea. Salt water intrusion into the soils is quite common in these places. Hence to study the impact of salt water on the properties of soils; sodium chloride solution was prepared in the laboratory by dissolving sodium chloride (NaCl) pallets in distilled water.

4 Results and Discussion

4.1 Atterberg Limits

The soil moisture has direct influence on the geotechnical properties of the soil. Water molecules,

Table 1 Index properties of typical soil samples

	G_s	Atterberg limits			Grain-size distribution			
		w_L (%)	w_p (%)	w_s (%)	Gravel (%) (4.75–80 mm)	Sand (%) (75 microns–4.75 mm)	Silt (%) (2–75 microns)	Clay (%) (<2 microns)
Lateritic Soil	2.65	50	29	21	8	62	19	11
Shedi soil	2.65	59	39	26	–	59	23	18

G_s Specific gravity of soil solids, w_L Liquid limit, w_P Plastic limit, w_S Shrinkage limit

Table 2 Compaction and hydraulic characteristics of soil samples

	Compaction characteristics		Void ratio (e) at γ_{dmax}	k (cm/s)
	wopt (%)	γ_{dmax} (kN/m^3)		
Lateritic soil	16	14.8	0.94	3.2×10^{-5}
Shedi soil	20	15.9	0.75	1.6×10^{-6}

w_{opt} Optimum moisture content, γ_{dmax} Maximum dry density, *k* Hydraulic conductivity

Table 3 Chemical characteristics of typical lateritic soil sample

	pH of soil 25°C	EC of soil solution, 25°C (μS/cm)	CEC (meq/100 g)	$CaCO_3$ (%)	OM of soil (%)	$SO_4 \times 10^{-3}$ (%)	Fe_2O_3 (%)	SiO_2 (%)	Al_2O_3 (%)
Lateritic soil	5.28	34	9.14	3.08	0.41	6	5.1	70	37.0
Shedi soil	5.4	42.2	11.5	1.5	0.3	1	3.1	75.4	10.2

EC Electrical conductance, *CEC* Cation exchange capacity, $CaCO_3$ Calcium carbonate, *OM* Organic matter, SO_4 Soluble sulphate, Fe_2O_3 Iron content, SiO_2 Silica, Al_2O_3 Alumina content

being bi-polar, are attracted to the clay particle surface. Adjacent to the clay surface the water molecules are held so tightly that a layer of water, several molecules thick, is attached to the soil grain. As the distance from the clay surface increases, the water molecules are less tightly held and form a relatively thick layer of water attached to the soil particle. The inner most layer of water held firmly to the clay particle is called adsorbed water. The outside viscous layer is called as double layer. The viscous water layer between the soil particles is responsible for the plasticity of the clay (Das 1983).

Laboratory study results on soils mixed with 0.5 N sodium chloride solution is presented in Table 4. The properties of the soils are likely to change when the nature of pore fluid change. The liquid limit of the soils decreased when mixed with 0.5 N sodium chloride solution (Fig. 1). As observed from Table 4 the effect of NaCl on Atterberg limits is more in the case of shedi soil when compared with lateritic soil. The presence of high electrolyte concentration of the pore fluid decreases the double layer thickness and the effect is to decrease the liquid limit and plasticity index of the soil as shown in Figs. 1 and 2.

4.2 Effect on Compaction Characteristics and Hydraulic Conductivity of the Soils

The compaction characteristics and the hydraulic conductivity of the two soils mixed with 0.5 N sodium chloride solution are presented in Figs. 3, 4, 5 and 6. The experimental data in Figs. 3 and 4 indicated that, maximum dry density of both the soils tested increases with sodium chloride added. The change in compaction characteristics of the two soils when contacted with NaCl solution is shown in Table 4. It is observed that γ_{dmax} increases from an initial value of 14.8 to 15.7 kN/m^3 for lateratic soil and 15.9 to 17.2 kN/m^3 for shedi soil. This may be due to the reduction of double layer water surrounding the clay particles.

Table 4 Properties of soils mixed with 0.5 N sodium chloride solution

Lateritic soil					Shedi soil			
Parameter	Soil mixed with sodium chloride % by weight of soil				Soil mixed with sodium chloride % by weight of soil			
	0	5%	10%	20%	0	5%	10%	20%
Clay (%) (<2 microns)	11	10.6	9.9	9.0	18	17	16	14
w_L (%)	50	49	47	44	59	57	53	48
I_p (%)	21	21	20	19	20	19	18	15
γ_{dmax} (kN/m^3)	14.8	15.3	15.7	16.2	15.9	16.2	16.6	17.2
OMC (%)	16	14	13	12	20.1	19	18	16.3
k (cm/sec)	3.2×10^{-5}	4.0×10^{-5}	5.1×10^{-5}	5.8×10^{-5}	1.6×10^{-6}	1.63×10^{-6}	1.8×10^{-6}	2.6×10^{-6}
e	0.94	1.02	1.06	1.12	0.75	0.81	0.92	1.10

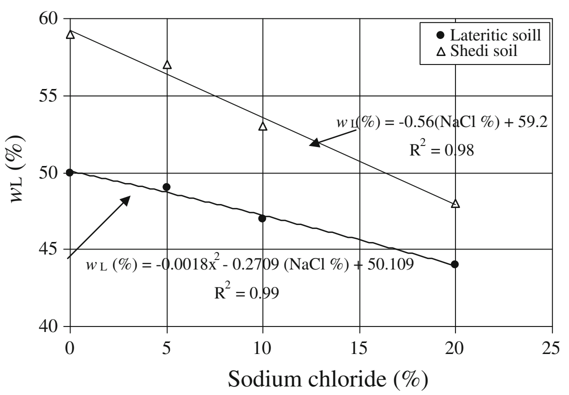

Fig. 1 Variation of liquid limit with sodium chloride added (%)

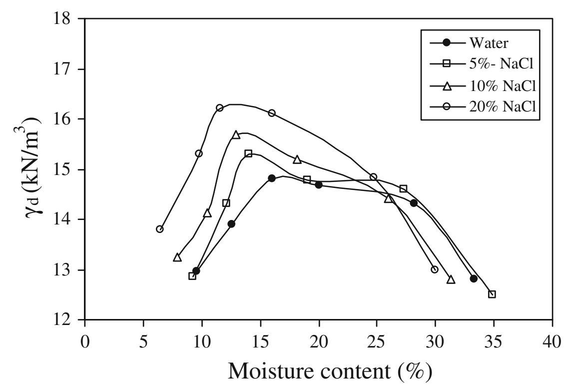

Fig. 3 Effect of sodium chloride on compaction characteristics of lateritic soil

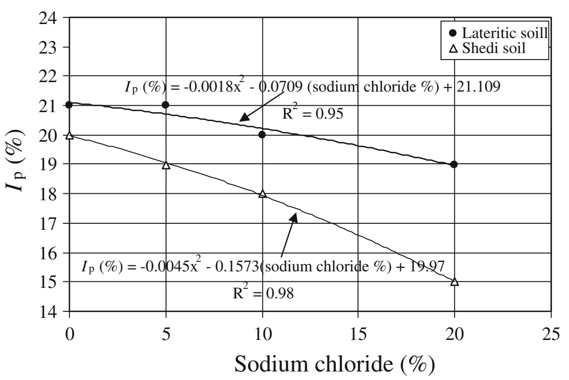

Fig. 2 Variation of plasticity index with sodium chloride added (%)

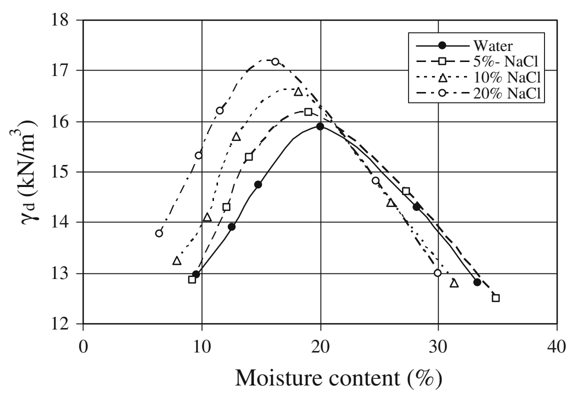

Fig. 4 Effect of sodium chloride on compaction characteristics of shedi soil

The reduction of the double layer thickness brings the particles closer and hence the maximum dry density increases. Consequent on particles becoming closer and decreased water holding capacity the optimum water content decreases.

Figure 5 shows the variation of hydraulic conductivity with void ratio when the two soil were mixed with 0.5 N sodium chloride solution. Figure 6 shows the variation of void ratio with sodium chloride solution added. It is seen from Figs. 5 and 6 that the

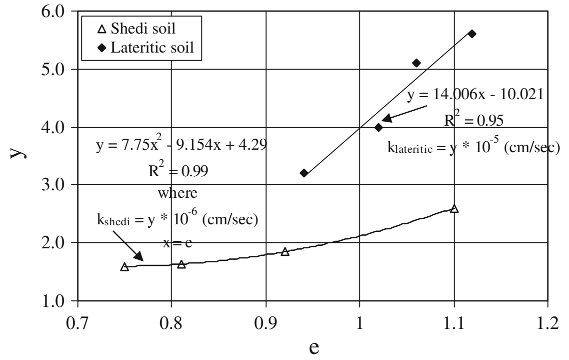

Fig. 5 Variation of hydraulic conductivity with void ratio

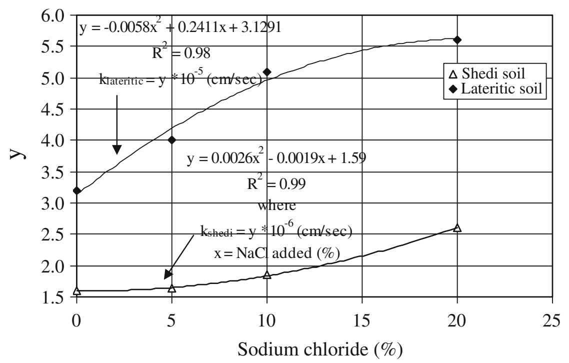

Fig. 6 Variation of hydraulic conductivity with sodium chloride added

hydraulic conductivity and void ratio increases with the increase in the sodium chloride concentration. Suppression of diffuse double layer is responsible for the steep increase in hydraulic conductivity of the soil. Researchers (Sridharan and Sivapullaiah 1985; Sivapullaiah and Savitha 1997) report higher the concentration of electrolyte solution the higher is the depression of the double layer water.

4.3 Effect of NaCl on Chemical Characteristics of Soils

The data of the chemical analysis of the two soils mixed with 0.5 N sodium chloride solution are presented in Figs. 7, 8 and 9.

Figure 7 shows the variation of soil pH with sodium chloride solution. The pH results shown in Fig. 7 indicate that the soil pH increases with the increasing sodium chloride concentration. The results of EC of soil mixed with 5, 10 and 20% sodium

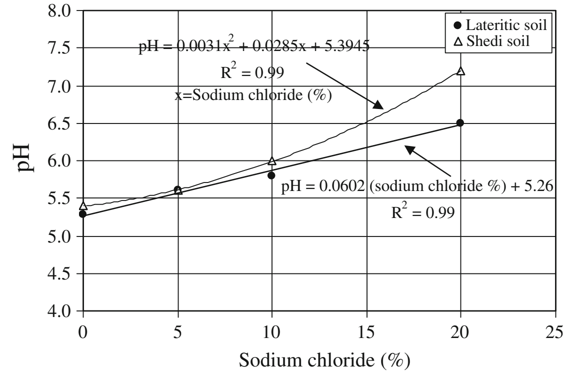

Fig. 7 Variation of soil pH with sodium chloride added (%)

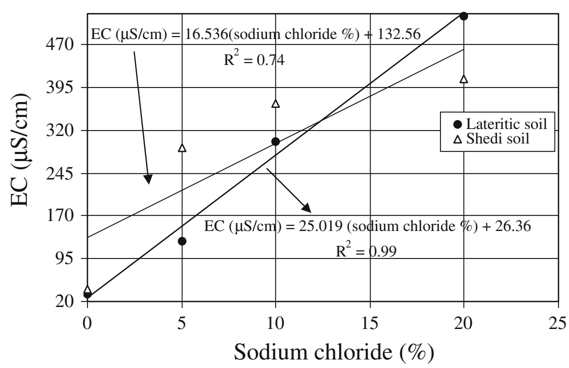

Fig. 8 Variation of EC with sodium chloride added (%)

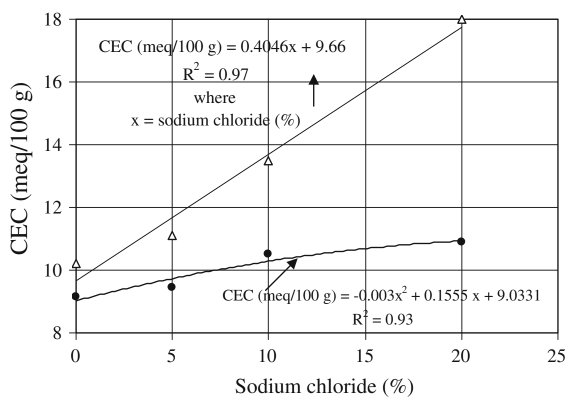

Fig. 9 Variation in cation exchange capacity with sodium chloride added (%)

chloride (by weight of soil) is shown in Fig. 8. The data in Fig. 8 indicates that the EC of soil increases with the electrolytic concentration. The increase in soil pH and the electrical conductivity (Figs. 7, 8) is attributed to adsorption of cations and species of anions by the soil particles. The results presented here are short term effect of NaCl solution on soils.

The capacity of soil to absorb and exchange ions varies greatly with the amount of clay. Exchange of ions takes place due to isomorphous substitution (i.e., substitution of one element for another). Similarly the results of cation exchange capacity (CEC) of lateritic soil and shedi soil [determined as per IS: 2720 (Part 24)-1976 (Reaffirmed 1987)] mixed with sodium chloride solution is presented in Fig. 9. From the results it can be seen that the CEC of lateritic soil increased from an initial value of 9.14 meq/100 g to a maximum value 10.90 meq/100 g at 20% sodium chloride concentration. Since the variation is not very large it is hard to make conclusions. However, Mathew and Rao (1997) report the changes in CEC to be pH dependent. Similarly, the cation exchange capacity of a shedi soil mixed with sodium chloride increases from 10.2 to 18 meq/100 g at 20% sodium chloride concentration.

During this study it is found that the effect of 0.5 N sodium chloride solution was more significant on shedi soil than lateritic soil with data regarding physical and chemical properties of soils. This is because shedi soil is predominantly a fine grained soil with more clay content (18%) compared to lateritic soil (11%). Hence soils with more percentage of clay size particles are more vulnerable for contamination.

5 Conclusions

From the results and discussions presented above, it is clear that sodium chloride solution has effect on geotechnical characteristics and chemical properties of lateritic soil and shedi soil. Excessive chloride concentration in soils will be detrimental to the foundations of the structures founded on such soils. The results from this study show that, there were significant changes in some of the properties of the tested soils. For example, the study results showed that the hydraulic conductivity of both the soils increased with NaCl concentration. This implies the soils become more permeable and more water flows through it. Interaction of NaCl solution with soil particles alters the soil structure. We see from the above results that shedi soil has around 18% clay and is predominantly fine grained soil. In the present case if hydraulic conductivity of soils increase, it means fine grained fraction produce flocculated or aggregated soil structure due to adsorption of sodium and chloride ions by the soil. The major concern in coastal zones is seawater attack on reinforced concrete. Chloride ions can penetrate into the concrete and cause accelerated corrosion of the reinforcement. Sodium and potassium ions may produce or intensify alkali aggregate reaction if reactive aggregates are used. The following are the important conclusions drawn based on the test results.

1. The results of this study show that the impact of NaCl is more on shedi soil.
2. Liquid limit and plasticity index of the soils tested decrease as a result of interaction with sodium chloride solution.
3. Lateritic soil and shedi soil mixed with 0.5 N sodium chloride solution showed that the maximum dry density increases and the OMC decrease with increasing sodium chloride concentration.
4. Hydraulic conductivity of both soils increase due to interaction with sodium chloride solution.
5. Chemical characteristics such as pH, electrical conductivity and cation exchange capacity of soils change due to interaction with sodium chloride solution. Significant increase in the EC value and change in pH and cation exchange capacity of soils is attributed due to adsorption of sodium and chloride ions on the surface of clay particles.

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