Experimental Investigation for Determining the Influence of Salt and Acid Concentrations on the Hydraulic Conductivity of Soil

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Abstract: Hydraulic conductivity of soil is an important property involved in the flow of water through soil media. With increase in infrastructure development, deforestation and urbanisation, conductivity of soil is varying on daily basis. The phenomenon of acid rain, excessive use of fertilizers in irrigation, sewage discharge from industries and wastewater from treatment plants leads to increase in salt and acid concentration of the soil due to increased concentration of sulphides. Besides, sewage discharge from different sources such as household, pharmaceuticals, wood and paper industries, food industry, paints and glass manufacturing industries contain sodium hydroxide (NaOH). Furthermore, NaOH is used in wastewater treatment plants to control water acidity and sodium hypochlorite is used as a water disinfectant. Such discharge when comes in contact with soil, leads to increase in the basicity of the soil which further affects the effectiveness of irrigation and soil properties. The study presented here was performed to analyse the impact of salts and acids on the saturated hydraulic conductivity (K_{sat}) of three different textured soils viz. sandy loam, loamy sand and fine sand. A set of 36 soil samples were collected from different locations in Rajasthan and Himachal Pradesh. In the study, benchtop KSAT apparatus employing constant head method was used to determine the K_{sat} of all the soil samples. Laboratory experiments were performed considering different concentrations of acid (0.025N, 0.1N H_2SO_4) and salt (10gm, 20gm NaCl) in 100gm of water. The effect of salt and acid concentrations on the K_{sat} of the soil was investigated on 1st, 7th and 15th day after the application. Results of the study revealed that both salt and acid concentration of soil considerably affects the K_{sat}. However, the effect of salt (NaCl) was found less, whereas, acid (H_2SO_4) concentration exhibited instant change in the soil K_{sat} value. A decrease up-to 50% in K_{sat} value of soil has been observed in first 7 days after applying H_2SO_4 concentration. This residual value of K_{sat} further decreased by 50% in next 7 days leading to a total decrement of 75% in Ksat in 15 days.

Keywords: KSAT; Hydraulic Conductivity; Soil salinity; Acid; Salts.

1. Introduction

Seventy percent of the earth surface is covered by water. Out of this, 97.2% is in saline form (seas and oceans) and the remaining 2.8% is in the form of freshwater. From freshwater resources comprising groundwater and rivers, about 70% is utilized for irrigation practises (Subramanya, 2007)). With the rise in demand of freshwater and its reducing storage, it is obligatory to use wastewater or saline water in irrigation purposes. This saline water affects the soil health like hydraulic conductivity, density, mineralogy etc. Besides, the phenomenon of acid rain, excessive use of fertilizers in irrigation, sewage discharge from industries and wastewater from treatment plants leads to increase in salt and acid concentration of the soil due to increased concentration of chlorides, sulphides and hydroxides (Pusch and Yong, 2006)). Such discharge when meets soil, leads to increase in the basicity of the soil which further affects the effectiveness of soil conductivity.

Hydraulic conductivity is a measure of the ease with which water flows through sediments, determining renewal rates of water, dissolved gases, and nutrients (Jones and Mulholland (2000), Streams and Ground Waters). When this movement takes place through a saturated media, it is described as saturated hydraulic conductivity (K_{sat}). Saturated hydraulic conductivity of soil depends on both particle size as well as orientation of the particles (Gupta

and Larson, 1979; Assouline and Rouault, 1997; Jorda et al., 2015). To determine the K_{sat} a wide range of applied hydraulic gradient are considered. It is reported that K_{sat} is affected by the montmorillonite content, type of exchangeable cations and compaction dry density (Ahn and Jo, 2009) of the soil. A study by Godoy *et al.* (2018) shows the errors that could be incurred when using certain deterministic analysis for the analysis of ground water conductivity. The specimens with a larger voids showed greater hydraulic conductivity (Wang *et al.*, 2013). Soils which are rich in clays goes through a great volume change and hence less conductive (Mitchell, 1993).

Fang (1987) has demonstrated the relationship between pollution sensitivity index (PSI) v/s particle sizes. Fang, F. (1993) has suggested a classification of infected soil based on silica ratio, sorption potential of soils and dielectric constant of soil. The study by Lang et al. (2018) advances the understanding of the influence of preliminary desiccation on the swelling pressure and hydraulic conductivity of compacted bentonite.

This study deals with the determination of the influence of salt and acid concentrations on the K_{sat} of the soil. In the present study KSAT instrument is used to determine K_{sat}. The present study is focused on analysing changes in K_{sat} of soil which has occurred due to the application of salts and acids concentrations, on day 1^{st}, 7^{th} and 15^{th} respectively. The focus point of the investigation was to understand the impact of chemicals (salts/acids) on soils. Not many examinations have been accounted for the impact of modern effluents on farming soils in previous studies and for the better results, in study KSAT instrument is used.

2. Methodology

Sampling Locations

The soil samples are collected from two locations in Rajasthan (Arniya and Dibsya) and one in Himachal Pradesh (Hamirpur). The soil samples included: (1) red soil from village Arniya Rajasthan, (2) brown soil from village Dibsya Rajasthan, (3) brown podzolic soil from - Hamirpur. The sand, silt and clay proportions in the soil were obtained from particle sieve and hydrometer analysis. The soil texture was then derived from the USDA soil textural triangle. The saturated soil hydraulic conductivity (K_{sat}) was measured by KSAT instrument in Soil Hydraulics laboratory of Civil Engineering Department, National Institute of Technology, Hamirpur. Other relevant soil parameters tests were obtained by both in-situ and laboratory-based methods.

Theoretical Background

The presence of pores in the soil is the main cause of soil conductivity which assess moisture retention ability against gravity through which both air and water passage. More the connectivity between pores, higher the K_{sat} occurs and vice versa. Presence of impurities in the soil creates resistance for the flow of water through soil medium, which results in a decrease of the K_{sat} of soil (Daniel and Trautwein, 1994). The soil moisture characteristics (water retention characteristics or θ-Ψ relationship) describe the ability to release and store water in soil (Gupta and Larson, 1979). One of the highly variable parameters of soil is moisture retention, which sustains and governs irrigated agricultural and drylands. Various chemical and physical properties affect this significant property. Darcy (1856) stated that when water flows through soil or other pores media, velocity of water is directly proportional to the hydraulic gradient.

$$V \propto i \qquad (1)$$

$$V = Ki \qquad (2)$$

Where, V is hydraulic flux in m/s, K is hydraulic conductivity (m/s).

Soil Property Determination

In this study, several experiments were carried out for the determination of soil properties and classification of soils. These properties were useful in determining the saturation time of the samples used in the K_{sat} test. Methodologies used for determining the properties of soils are described below. Table 1 contains a list of apparatus and properties of soil used for classification.

Table 1. Apparatus used and Properties of soil

Sr. No.	Method/Equipment used	Measured variable	
1	Sieve analysis	Sand content	Soil Texture
2	Hydrometer	Silt and Clay content	
3	Core Cutter Test	Bulk Density	
4	KSAT Equipment	Saturated Hydraulic Conductivity	

KSAT Equipment

For determination of K_{sat} of soil in a precise manner, KSAT is the best instrument based on Darcy's equation. It is an instrument in its simplest form that uses both constant head (non-automated) and falling head (automated) on a soil core. The effective conductivity of the overall system is determined by the resistance of the soil, the porous plate, resistance of connecting elements such as tubes and valves, and possibly by the contact resistance between plate and soil (normally this is not a problem under fully saturated conditions). In the manner of accuracy KSAT can be operated on wide range from 5,000 to 0.01cm/d of conductivity. With together it stores and reads data automatically on computer via USB so human error is reduced. Data is temperature corrected so data quality is improved for the results.

K_{sat} is calculated from volumetric water flux V divided by soil sample area A and time t, length of soil sample L and hydraulic gradient head H along the flow direction, as the following equation

$$K_{sat} = \frac{LV}{HAT} \quad (3)$$

Chemical Used for Concentration

In this study, a total of 4 concentrations of sodium chloride salt (NaCl) and sulphuric acid (H_2SO_4) are used to determine the effect of their concentration on K_{sat}. On all three types of soils, two concentrations of sodium chloride were used (i) 10 gm of NaCl in 100 gm of water, and (ii) 20 gm of NaCl in 100 gm of water. H_2SO_4 is soluble in water, colourless, syrupy liquid and it is odourless in highly exothermic reactions. Concentrations of sulphuric acid used in the present study are (i) 0.025N H_2SO_4 and (ii) 0.1N H_2SO_4.

3. Result and Discussion

Soil Textural Analysis

Soil samples were subjected to hydrometer test and grain size analysis. It is observed that pattern for distribution curves are different for all the soils and these particle distribution curves

are shown in Figure 1 (a), (b) & (c). However, a close resemblance was found between sandy loam and loamy sand. From the derivation of these curves, soils were separated into sand, clay, silt and gravel. Percentage of clay, silt and sand fractions are used as input for determining soil texture by using U.S.D.A soil textural triangle. Information regarding gravel, sand clay and silt is shown in Table 2. In this study, soils are classified as fine sand, sandy loam and loamy sand.

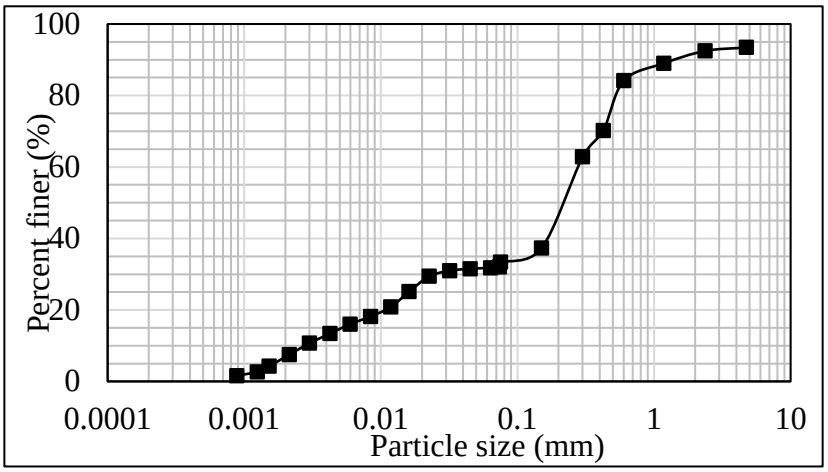

Fig. 1 (a): Particle size distributions for fine sand

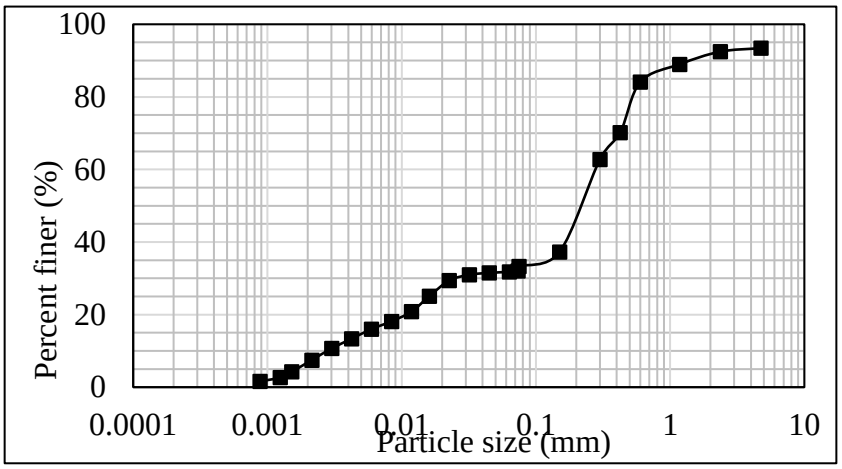

Fig. 1 (b): Particle size distributions for sandy loam

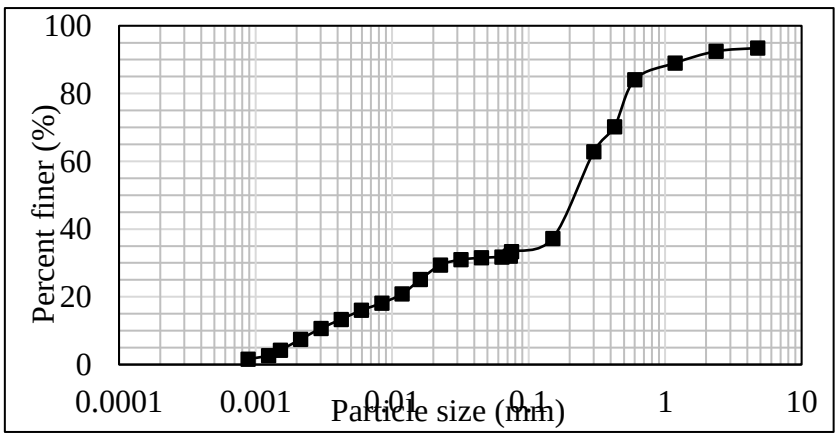

Fig. 1 (c): Particle size distributions for loamy sand

Soil Properties for Different Type of Soil

Some soil parameters which were calculated to aid saturated hydraulic conductivity are illustrated in Table 1 for a different type of soils. These properties play a crucial role in understanding soil's capacity of retaining and transmit water through it and the behaviour of soil. Variations in soil properties were observed with variation in soil type. Bulk density and hydraulic conductivity were increasing with decreasing in clay content.

Table 2. Properties of Different Soils

Property	**Soil 1**	**Soil 2**	**Soil 3**
Texture	Fine sand	Loamy sand	Sandy loam
Specific gravity	2.6	2.6	2.61
Bulk density(gm/cc)	1.17	1.75	1.35
Excavation depth from surface(cm)	10	10	10

Hydraulic Conductivity of Different Soils

Several experiments were performed by KSAT apparatus for different type of soils. The obtained curves are shown in Figure 2 (a), (b) & (c). Total 36 sets of observations were taken for determination of KSAT accurately. The duration of the experiment varied from sample to sample and for the different characteristic of soils. In the study, the maximum and minimum duration encountered were 30 minutes and 4 hours respectively.

After comparing the impact of salts and acid concentrations on different soil samples it was clear that acids have more rigorous impact on Ksat. Ammonium based fertilisers are major contributors to soil acidification. Due to the reduced Ksat soil fertility reduces, as it leads to clogging of soil pores which results in the water logging.

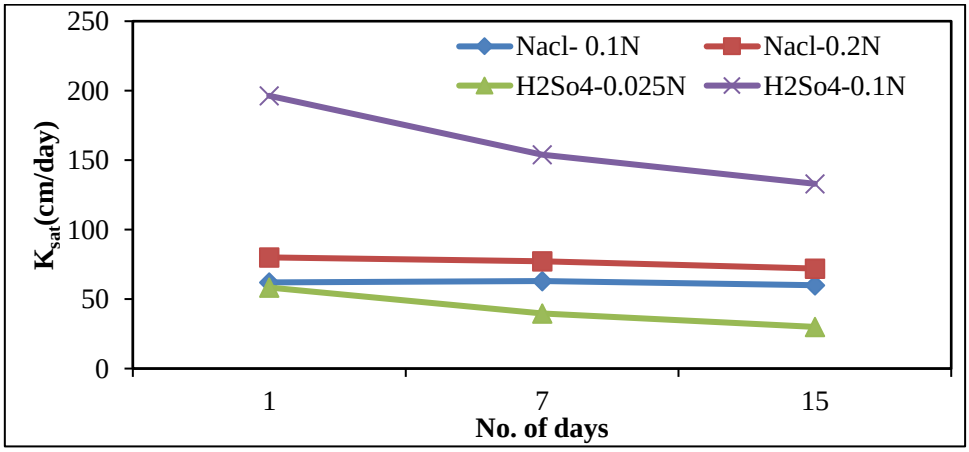

Fig. 2 (a) Hydraulic conductivity for various concentrations in fine sand

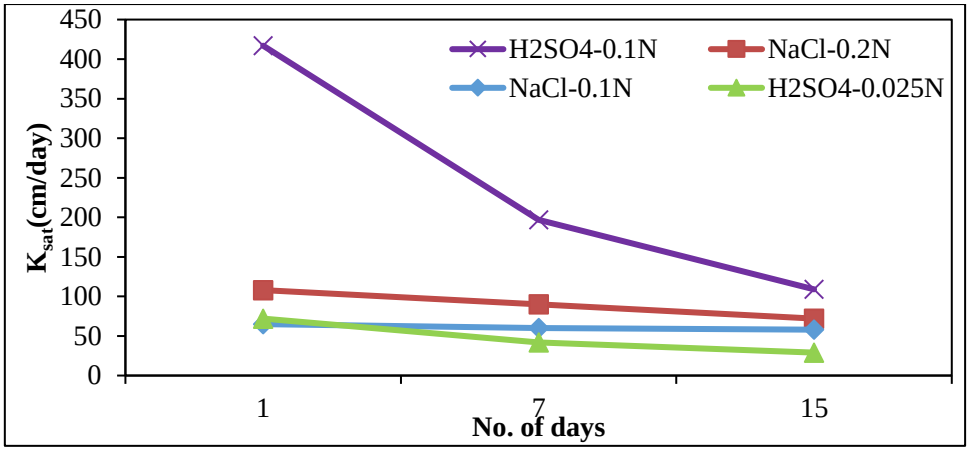

Fig. 2(b) Hydraulic conductivity for various concentrations in sandy loam

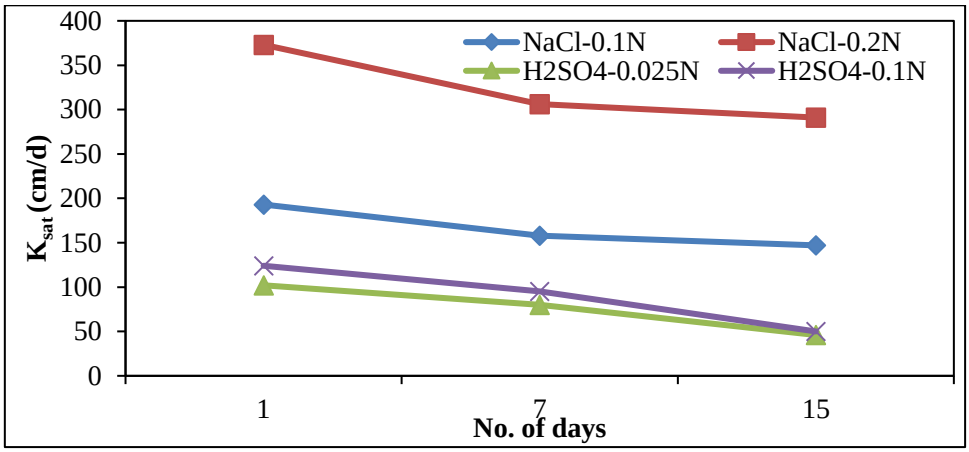

Fig. 2(c) Hydraulic conductivity for various concentrations in loamy sand

4. Conclusions

Following conclusions have been obtained from this experimental study:

- Effect of NaCl on saturated hydraulic conductivity (K_{sat}) of soil was less in the short term. Two concentrations of NaCl were applied to all three types of soil. Although fine sand and sandy loam soils depicted very less variation but in loamy sand there was significant reduction in K_{sat} with increase in concentration of NaCl.

- Application of different concentrations of H_2SO_4 exhibited an instant change in soil's saturated hydraulic conductivity. Upto 50% reduction in K_{sat} of soils was observed in first 7 days of exposure, which further decreased by 50% in next 8 days. Hence it can be concluded that the effect of acid is more prominent than that of salt on the K_{sat} of soil.

- A decline in the K_{sat} of sandy loam textured soil has been noticed on application of 0.1N H_2SO_4, as observed after exposure period of 7 and 15 days. This signifies that increase in electrolyte concentration leads to decrease in the saturated hydraulic conductivity of soil.

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