# Influence of Coastal Soil Salinity Type on Capillary Rise of Groundwater

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**Abstract.** Soil salinization in coastal areas is closely related to the capillary rise of groundwater. However, the water-salt distribution pattern due to capillary rise in soils with different salinization types is not clear. Through indoor soil column experiments, the capillary rise process in typical coastal saline soils in China was analyzed, and the effects of different salinization types on the height of capillary rise, water content and salt content were studied. The results showed that the largest capillary rise height was found in Cl--SO42- type saline soils, followed by Cl- type, SO42--Cl-, and the smallest capillary rise height was found in SO42- type saline soils; saline soils were prone to salt accumulation at 50 - 70 cm above the diving surface under the effect of capillary rise, and the salt accumulation effect was more significant in the Cl--SO42- type and the SO42--Cl- type saline soils; The water content of different types of saline soils was similar within 60 cm above the diving surface, while the water content of the soil at the top of capillary action was in the order of Cl--SO42- type > SO42--Cl- type > Cl- type > SO42- type. The results of the study may provide a theoretical basis for the law of capillary rise in saline soils.

**Keywords:** coastal saline soil; salinization type; capillary rise; water-salt transport

## 1 Introduction

The intrusion of seawater into the aquifer in coastal areas causes the salinity of groundwater to rise, and the groundwater depth in the coastal zone is shallow, and the salts are more likely to migrate to the surface layer under the action of capillary rise and evaporation, which leads to soil salinization[1]. Coastal saline soils are widely distributed in the world, and salinization problems exist in coastal areas of Asia, Africa, and the

© The Author(s) 2024
H. Bilgin et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Engineering, Environment Resources and Energy Materials (CCESEM 2024)*, Advances in Engineering Research 253,
https://doi.org/10.2991/978-94-6463-606-2_46

Americas[2], and changes in water and salinity in salinized soils will cause great obstacles to the development of coastal agriculture[3] as well as coastal engineering and construction, so it is necessary to study the impact of the capillary uplift process on the distribution of saline soils in saline soils in the coastal area.

Currently about the effect of soil on the mechanism of capillary rise of water scholars in various countries have done a lot of research. Different texture of the soil will make differences in the height of capillary rise, a study found that the rise height of silt is the smallest, followed by chalk, and the rise height of pulverized clay is the largest[4]; in the field of highway foundation related research found that there is a big difference in the height of capillary rise of the roadbed of coarse-grained and fine-grained soil filler, and the height of rise of the coarse filler is much lower than that of the fine-grained filler[5]; in the relevant research on the building stone, it was found that the capillary water is the The capillary water was found to be an important cause of swelling of building materials in the studies related to building stones, and a study was done on the capillary water absorption capacity of Döğer tuff in the northern part of Afyonkarahisar province, Turkey, and it was concluded that Döğer tuff, which has more micropores, has a stronger capillary water absorption capacity[6].

It can be seen that the research on the effect of soil on capillary rise is concentrated on the physical properties of soil, such as particle size, porosity, soil texture, etc., and the research on the effect of chemical properties of soil itself on capillary rise is less. Saline soils in coastal areas can cause differences in the type of soil salinization due to seawater intrusion, leaching and capillary uplift, making differences in the chemical properties of the soils. The types of coastal saline soils in China's coastal areas are divided into four types: $Cl^-$ type, $SO_4^{2-}$-$Cl^-$ type, $Cl^-$-$SO_4^{2-}$ type, and $SO_4^{2-}$ type. In this paper, we analyzed the law of capillary rise in soils with different typical coastal salinization types through soil column experiments, and explored the law of water and salt transport in capillary channels in soils with different coastal salinization types.

# 2 Materials and Method

## 2.1 Experimental Setup and Materials

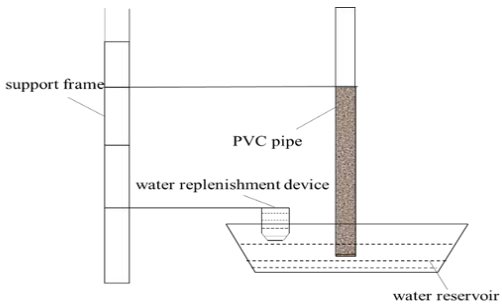


**Fig. 1.** Experimental setup.

The experimental setup consisted of four parts: PVC pipe, water replenishment device, water reservoir, and support frame, as shown in Figure. 1. The PVC pipe was 1 m in height, with an inner diameter of 5 cm, and filled to a height of 90 cm. holes were punched at intervals of 5 cm from 0 - 30 cm, and at intervals of 10 cm from 30 - 90 cm, and the diameter of the holes was 1 cm, which made it convenient to take the soil for water-salt analysis. To prevent the soil from flowing out from underneath in the soil column, the bottom of the PVC pipe was lined with 400 mesh gauze mesh, and the water refill bottle was used to ensure a constant water level of 4 cm.

The experimental soil was obtained from the coastal area on the west coast of Laizhou Bay, Dongying District, Dongying City, Shandong Province, China (37°21′N, 118°91′E), which belongs to the saline area of the coastal mudflat, and it is one of the most typical saline soils distribution areas in China. The experimental soil was air-dried to remove water, passed through a 2 mm sieve to remove impurities in the soil, and then mixed homogeneously and prepared for use. The soil samples were then washed with salt to remove the original salts, and then the dry soil with different salt solutions was used to remodel different saline soils.

### 2.2 Experimental Method

The soil column was filled with the aid of a funnel, and to ensure compaction and homogeneity of the specimen, the soil column was filled with a heavy-duty hammer for compaction in layers at 25 cm intervals, and after compaction the column was left to stabilize for 12 h. The column was filled with water using a rechargeable bottle. The cistern was filled with water using a recharge bottle, and the experiment was started when the liquid touched the bottom of the soil sample.

The capillary rise height was determined by recording the height of the wetting front at different moments according to the change in soil color; water content was determined by the most commonly used drying method[7]; and salt content was determined by chemical titration, using silver nitrate titration to determine the chloride content and EDTA indirect titration to determine the sulfate content.

### 2.3 Experimental Parameters

**Table 1.** Experimental Group.

| Group | Type of salinisation | Initial salt content(%) | Initial water content(%) |
|---|---|---|---|
| A1 | $Cl^-$ | 1 | 7 |
| A2 | $SO_4^{2-}$-$Cl^-$ | 1 | 7 |
| A3 | $Cl^-$-$SO_4^{2-}$ | 1 | 7 |
| A4 | $SO_4^{2-}$ | 1 | 7 |

NaCl solution and Na2SO4 solution were utilized to configure the four most common types of salinization in Marina: Cl- type, SO42--Cl- type (Cl-:SO42-=2:1), Cl--SO42- type (Cl-:SO42-=1:2), and SO42- type. According to the field water content of the soil used for the experiment, the initial soil water content was fixed to be 7%; the initial salinity was set to be 1% to simulate the effect of different salinity types on capillary uplift under the degree of heavy salinization.The specific experimental groupings are presented in Table 1.

# 3 Results and Discussions

## 3.1 Capillary Rise

As shown in Figure. 2, during the capillary rise process, the capillary rise height increased with time, and the final capillary rise heights of Cl- type, SO42--Cl- type, Cl--SO42-type, and SO42-type salinized soils were 71 cm, 70 cm, 72 cm, and 69 cm, respectively, and the ratio of the size of the rise heights was Cl--SO42- type>Cl->SO42--Cl-type>SO42-type. The main reason is that with the increase of time, the original salts of the soil will gradually crystallize, and the salt crystals after crystallization will change the size of the capillary channel, thus affecting the capillary suction. Different types of salt crystallization change the capillary channels differently, resulting in different capillary suction, and thus also showing different capillary rise heights. In contrast, in Cl--SO42- type saline soils, the proportional content of SO42- and Cl- (i.e., 0.67% SO42- and 0.33% Cl-) may result in the narrowing of the larger capillary channels, which allows the soil to form the most suitable capillary diameter, which strengthens the capillary suction, and promotes the upward movement of water[8].

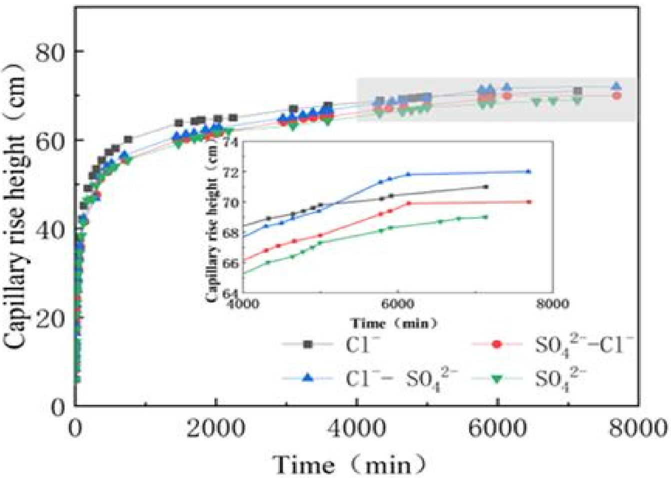


**Fig. 2.** Plot of capillary rise height under different salinity types.

Data were also fitted to the rise height and time for different saline soil types, which conformed to the form of a logarithmic function, and the parameters are detailed in Table 2, with $R^2$ showing a high accuracy of the fit. The first-order derivation of each fitted model for the duration t $dh/dt$ can be obtained as the trend of the capillary rise velocity with time, which can be seen that the capillary rise velocity decreases gradually with the increase of time. This is because the capillary water rise is carried out under the combined effect of matrix potential and gravitational potential, the beginning of the matrix potential is much larger than the gravitational potential, resulting in a fast capillary rise speed; however, with the gradual dissolution of salts in salinized soil in the water and the capillary rise process, the density and height of the capillary water column are increasing, which enhances the gravitational potential, so that the capillary rise speed decreases until the size of gravitational potential and the matrix tends to equalize, the capillary rise speed tends to be zero.

**Table 2.** Rise height fitting parameters.

| Type of salinization | fit a model | $R^2$ | dh/dt |
|---|---|---|---|
| $Cl^-$ | h=8.04 ln (t+0.010 )+3.26 | 0.9914 | $8.04(t+0.010)^{-1}$ |
| $SO_4^{2-}$-$Cl^-$ | h=7.99 ln (t+0.532 )+0.64 | 0.9841 | $7.99(t+0.532)^{-1}$ |
| $Cl^-$-$SO_4^{2-}$ | h=8.14 ln (t+0.514 )+0.86 | 0.9687 | $8.14(t+0.514)^{-1}$ |
| $SO_4^{2-}$ | h=7.71 ln (t+0.174 )+0.86 | 0.9852 | $7.71(t+0.174)^{-1}$ |

## 3.2 Water Content

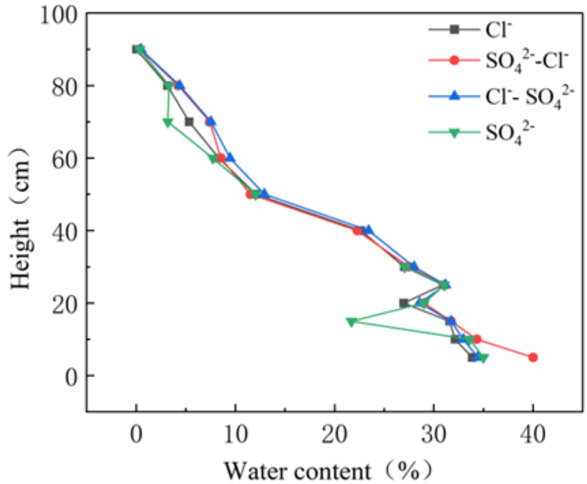


**Fig. 3.** Distribution of water content under different salinity types.

According to Figure. 3, the water content showed a decreasing trend during the gradual rise of the height of the soil column, and the upper soil was gradually reduced by the influence of groundwater. The Pearson correlation coefficients of rising height and soil water content were analyzed, and the results were -0.971, -0.979, -0.972, -0.938. At the significance level of 0.01, these coefficients showed significant negative correlation, which further verified the accuracy of the law in the figure.

The average water content of different saline soils at 0 - 20 cm above the groundwater surface varied, and at 20 ~ 60 cm above the submerged surface the water content of soil Cl- type, SO42--Cl- type, Cl--SO42- type, SO42- type soils were close to each other, with an average of 31.14%, 33.77%, 31.93%, and 29.82%, respectively. However, the water content of various types of soils in the capillary action surface layer was

5.34%, 7.42%, 7.53%, and 3.19%, respectively, and the water content of different types of saline soils showed Cl--SO42->SO42--Cl->Cl->SO42-. It was found that the magnitude of water content in the surface layer was not consistent with the capillary rise height, and the composite types Cl--SO42- type and SO42--Cl- type saline soils had higher water content in the surface layer, while the Cl-type saline soils with higher rise heights contained more water, probably because the pore tubes formed by their crystallization did enhance the capillary suction force and promoted capillary rise, but at the same time, it also made pores on the profiles at this height decrease, and the unit One of the reasons for the low water content of SO42- type saline soils is that the narrow channels of the chalk allow a large amount of Na2SO4 to come into contact with the soil, forming Na2SO4-10H2O. at conventional drying temperatures this bound water does not readily segregate, leading to their low water content[9].

### 3.3 Salt Content

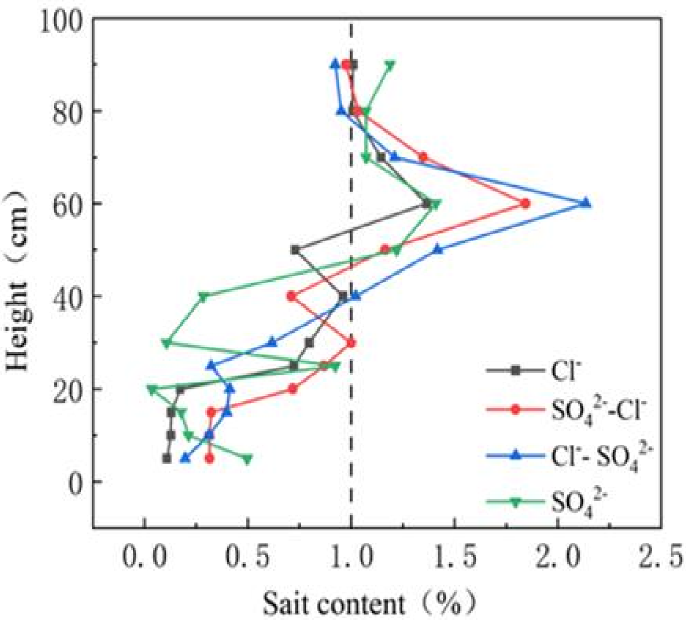


**Fig. 4.** Distribution of salinity under different types of salinity.

Figure 4 shows the salt content of different saline types of soils in the vertical direction after capillary action. As can be seen from the figure, below 20 cm, all saline soils, regardless of their type, are strongly affected by the capillary rise of fresh groundwater. This can lead to a significant reduction in the salt content of the soil, and the diffusion of salt ions can cause the salt content of the soil to deviate from its original level. Even if the salt content of groundwater is low, further accumulation in the middle soil layer (50 cm-70 cm) can occur, which is influenced by two factors: one is the "water follows salt" in the lower saline soil, which leads to the migration of salts to higher locations;

the other is the downward movement of salt solution in the upper saline soil due to gravity, which leads to the accumulation of salts in the middle soil layer, which leads to the accumulation of salts in the middle soil layer. salts accumulate in the middle soil layer[10].

From the figure, it can be seen that the peak salt content of $Cl^-$ type, $SO_4^{2-}$-$Cl^-$ type, $Cl^-$-$SO_4^{2-}$ type and $SO_4^{2-}$ type saline soils are 1.01%, 1.84%, 2.14% and 1.41%, respectively. It can be seen that $SO_4^{2-}$-$Cl^-$ type and $Cl^-$-$SO_4^{2-}$type saline soils have significant changes in their internal soil salinity under capillary action, which tends to accumulate salts internally and further aggravate the degree of salinization, whereas the changes of $Cl^-$ type and $SO_4^{2-}$ type are relatively small and stable. This suggests that when the quality of groundwater improves, the degree of salinization of the middle and upper saline soils, with which we are closely associated, does not decrease, and particular attention should be paid to the re-accumulation of salts in $SO_4^{2-}$-$Cl^-$ and $Cl^-$-$SO_4^{2-}$ type saline soils, and further joint measures need to be taken to prevent the evolution of such salinization.

## 4 Conclusion

In this study, the effect of different salinization types of soils on the capillary rise process was simulated using a soil column device, and the height of capillary rise, water content and salt content in the soil were recorded. The study aimed to investigate the redistribution pattern of water and salt in different salinization types of soils in the coastal area under capillary rise, and the following conclusions were drawn:

(1) The order of capillary rise height in different types of saline soils is $Cl^-$-$SO_4^{2-}$ type > $Cl^-$ type > $SO_4^{2-}$-$Cl^-$ type > $SO_4^{2-}$ type. The relationship between capillary rise height and time in the soil can be fitted by a function, and the size of the parameter can directly reflect the size of capillary rise height of different salinization types of soils.

(2) The water content of saline soils of the capillary rise tip complex types $Cl^-$-$SO_4^{2-}$ type and $SO_4^{2-}$-$Cl^-$ type is higher. The reduction of salinity in coastal groundwater does not reduce the salinization of the original soil, and the salinized soil will re-accumulate salt in the soil layer of 50 cm - 70 cm, and the order of the degree of salt accumulation is $Cl^-$-$SO_4^{2-}$ type > $SO_4^{2-}$-$Cl^-$ type > $SO_4^{2-}$ type > $Cl^-$ type.

## Acknowledgements

This study was financially supported by the National Key Research and Development Program of China (2023YFC3709002) and the Geological Survey Project of the Shandong Provincial Department of Natural Resources (Lu Kan Zi (2022) 3). The completion of this article was inseparable from the contributions of all authors, Their support is gratefully acknowledged.

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