Study on the Salt Release Pattern of Saline Strata in the Lower Reaches of the Yellow River

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Abstract. Due to offshore and land salinization, salinized strata exist in the lower reaches of the Yellow River to varying degrees. The salt in the saline strata is slowly released to the overlying freshwater layer under natural conditions, and its salt release pattern is still unclear. In this paper, an indoor sand column experiment was used to figure out the salt release pattern of saline strata in the lower Yellow River region by dynamically monitoring the spatial and temporal changes of salt content through high-density electrical method. The experimental results show that the trend of salt release flux in saline stratum with time is in accordance with the negative power index function, and its salt release rate is fast and then slow, and the salt release reaches a stable level after 220 h, which is about 1.27 $g \cdot m^{-2} \cdot h^{-1}$; the salinity content of the overlying sand layer has an obvious stratification phenomenon, and the influence range is about 5 cm above the interface, and the trend of salt accumulation with time is in accordance with the power index function; the higher the degree of stratum salinization, the more salt accumulation in the overlying sand layer, the greater the salt release flux, and the faster the rate of its decrease with time.

Keywords: lower reaches of the Yellow River; salt release; salt accumulation; salt release flux.

1   Introduction

The lower reaches of the Yellow River, with its developed agriculture and industry and dense population, are rich in ecological and water resources. The region is an important food production area in China, and groundwater is not only used for agricultural irrigation, but also as a source of drinking water for residents, the quality of which is closely related to food security and residents' health. However, the water table in the lower reaches of the Yellow River is shallow, and salts are transported through capillary tubes and evaporated to the surface, resulting in the widespread distribution of salty water.

At present, scholars have carried out various researches on the saline stratum in the region, mainly focusing on the spatial distribution of saline soils[1, 2], the causes of salinization[3], the influencing factors and their intensity[4]. The geochemical element distribution characteristics of saline soils in the lower reaches of the Yellow River are mainly affected by geology, topography and regional hydrogeological conditions, and are obviously positively correlated with the water quality conditions of shallow groundwater. Hosseini et al.[5] also mentioned that hydrologic factors such as soil hydraulic conductivity and evapotranspiration coefficients have a stronger influence on the concentration and flux of salt ions in the aquifer system relative to the initial salt concentration in the formation and groundwater. Whereas little research has been done on the pattern of salt release from saline strata to overlying aquifers, and the studies that have been done have focused on the exchange of material between sediments in the oceans, lakes and rivers and the overlying water bodies. For example, Gao[6] et al. analyzed the temporal scale of influence of salt release from bay sediments on salinization of overlying water bodies for the salinization of bay reservoirs, and Katsav[7] et al. calculated the rate of phosphorus release from surface sediments of eutrophic lakes to overlying water bodies. Therefore, it is necessary to clarify the salt release pattern of saline strata in the lower Yellow River.

In this study, aquifer samples from typical saline strata in the lower reaches of the Yellow River were selected for indoor salt release experiments, and the change of salt content in the sand column was dynamically monitored by the high-density electrical method, with the aim of analyzing the law of salt release from saline strata, and providing a reliable scientific basis for the comprehensive management and ecological protection of the lower reaches of the Yellow River.

2   Materials and Method
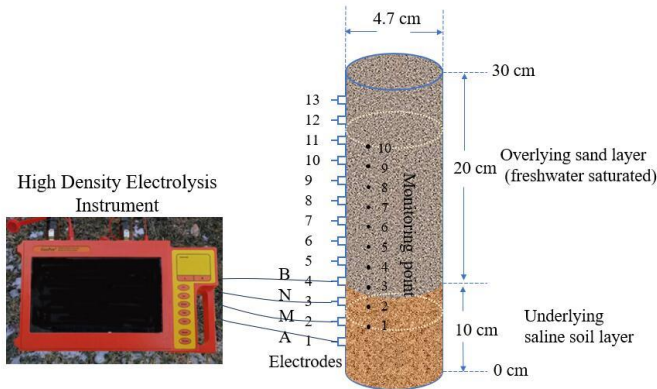
2.1   Experimental Setup and Materials

Fig. 1. Experimental setup.

The experimental setup was a transparent bottomed PC tube with an inner diameter of 4.7 cm and a height of 30 cm with an opening at the upper end. Holes were drilled and electrodes were inserted at a height of 4 cm on the side wall of the device, followed by drilling holes vertically upward at 2 cm intervals, for a total of 13 electrodes. Then, the four cables of the high-density electroprocessing apparatus were connected to the electrodes, where A and B corresponded to the power supply electrodes, and M and N corresponded to the measurement electrodes. The distribution of the 10 monitoring points corresponding to the manually run electrodes is shown in Figure 1.

The bottom of the device was filled with 10 cm of in-situ soil samples taken from 1 km south of Gaojian Village, Renfeng Town, Jiyang County, downstream of the Yellow River, and the top of the device was filled with quartz sand with a grain size of 0.28-0.50 mm in order to monitor the change of the salt content in the overlying sand layer after the release of salts in a shorter period of time.

2.2   Experimental Method

An in-situ soil sample of 4.7 cm in diameter and 10 cm in thickness was loaded into the experimental setup, and then a salt solution consistent with its soaking water was passed into the setup, and saturation was completed after 96 h of resting. The apparent resistivity of monitoring point 1 was recorded for subsequent calculation and correction of salt content. Subsequently, the natural quartz sand saturated with water was loaded in layers above it. At the beginning of loading, the underlying soil layer immediately released salts due to the difference in salt concentration, which was recorded as the initial moment of the experiment. Immediately after the column was filled, the apparent resistivity of 10 monitoring points was recorded with the corresponding experimental moments, and the above operation was repeated every 3 h.

In the experiment, the solution content within the overlying sand layer is small, and the use of traditional destructive sampling or injection pinhole extraction of aquifer solution sampling will cause greater interference with the experimental results. Therefore, the high-density electrical method was used to determine the apparent resistivity within the sand column, indirectly reflecting the change of salt content. The relevant calculation formula is as follows:

$$\rho = 2\pi \frac{\Delta U}{I} \left(\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}} \right)^{-1} \tag{1}$$

$$C = 1.7635 \frac{1}{\rho} + 0.0119 \tag{2}$$

Where, ρ is the resistivity, $\Omega \cdot m$; ΔU is the potential difference, mV; I is the current intensity supplied by the A and B electrodes, mA; r_{ij} is the distance between each electrode, cm; C is the salt content, g/kg.

The salt accumulation and salt release fluxes were calculated from the above salt content at different moments with the following equations:

$$M = A \times \gamma \times h \times \left(\sum_{i=1}^{n} m_i - m_0 \right) \tag{3}$$

Where M is the cumulative amount of released salts, g; A is the cross-sectional area within the soil column, cm^2; γ is the filling capacity of the soil, 1.82 g/cm^3; h is the height of the overlying sand layer, cm; m_i is the amount of salts in the ith aquifer, g/kg; m_0 is the amount of salts in the aquifer at the initial moment, g/kg; and n is the number of layers in the aquifer.

$$flux = \frac{\Delta m_j}{A \times \left(t_j - t_{j-1} \right)} \tag{4}$$

Where flux is the salt release flux, g/(m^2·h); Δm_j is the salt content released in the jth time period, where m_j and m_{j-1} are the cumulative amount of salts released from the brackish water aquifer in the moment of t_j and t_{j-1}, respectively, g.

2.3 Experimental Parameters

Table 1. Experimental Group.

Group	Sampling depth (m)	Salinity (‰)	Solution concentration (g·L^{-1})	Types of saturated solution water chemistry
A01	39.40~39.60	5.73	9.03	HCO$_3$·SO$_4$-Na
A02	43.10~43.30	4.77	7.51	
A03	81.40~81.60	6.34	9.98	SO$_4$-Cl·Na
A04	97.80~98.00	6.01	9.47	

The lithology of the in-situ soil samples were all chalky clays and were sampled at different depths. By testing and analyzing the eight major ions as well as the salinity of the soaking water of the salty soil samples, the water chemistry type and salinity magnitude were determined, and this was used as a basis for configuring the saturated salt solution for the subsoil layer in the experiment as shown in Table 1.

3　Results and Discussions

3.1　Temporal and Spatial Variation of Salinity in the Overlying Sand Layer

Figure 2 presents the variation of salinity with time at each monitoring point 1 cm, 3 cm, 5 cm, 7 cm, and 15 cm above the soil-sand interface. The pattern of change in salinity trends is basically the same for all groups, and the key to the salt mass transfer mechanism is the concentration difference between the underlying saline strata and the overlying freshwater sands: At the initial stage of salt release, the salt content in the 0~5 cm sand layer above the interface increased rapidly, and then gradually slowed down, and reached a stable state of salt release after about 220 h. The change curves of the salt content in the 7 cm and 15 cm sand layers above the interface basically

coincided. This indicates that the salinity gradient of the overlying 5 cm sand layer changes significantly, and the height of salt release influence is around 5 cm from the interface. Moreover, the farther away from the interface, the smaller the difference in salinity between aquifers, indicating that the ability of the underlying saline layer to release salts is gradually weakened by spatial and temporal changes.Gao[8] showed a similar pattern in his study of the effect of salt release from bay sediments to the overlying water body, in which the salt concentration at the interface was stabilized at 6.2 g/L after 200 h of sediment-water interaction, and the gradient of salinity in the water body under 7.5 cm changed significantly.
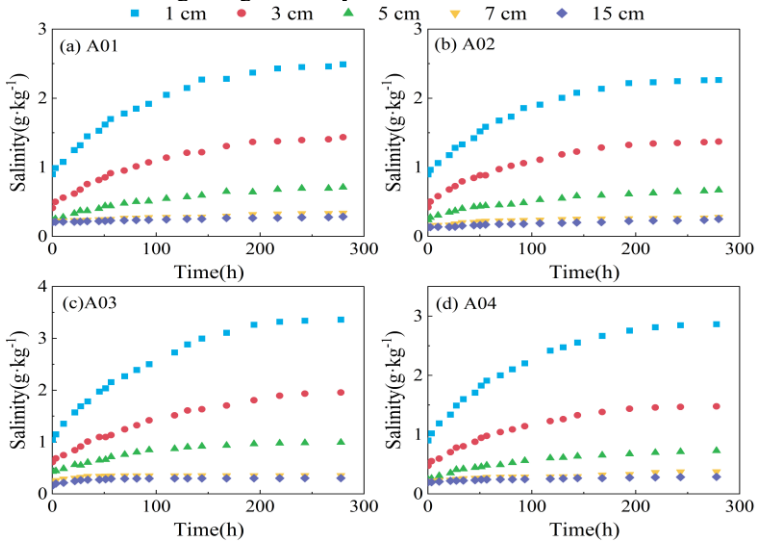

Fig. 2. Temporal and spatial variation map of salt content in overlying sand layer.

3.2   Salt Accumulation and Salt Release Flux
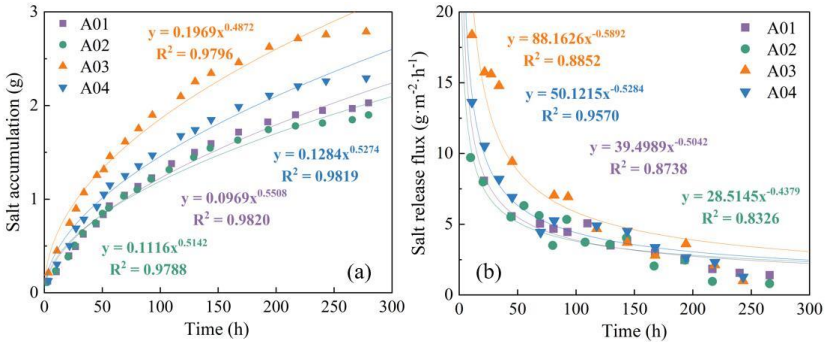

Fig. 3. Variation curve of salt accumulation and salt release flux in different sand columns.

As can be seen from Figure 3a, the changes in the accumulation of salts released upward from different saline strata with time all conform to the form of power exponential function, and the specific fitting equations are shown in Fig. With the increase of time, the salt accumulation gradually becomes higher, and the growth rate of salt accumulation gradually becomes slower. And in the same time, the greater the salt content of the saline stratum itself, the greater the salt accumulation in the overlying sand layer, i.e., the size of the salt accumulation in the overlying sand layer is in the following order: A03>A04>A01>A02.

The salt release fluxes in different saline strata all conformed to the negative power exponential function form, and the specific fitting equations are shown in Figure 3b. At the beginning of the salt release, the salt release flux became sharply smaller and gradually stabilized after 220 h to about 1.27 $g \cdot m^{-2} \cdot h^{-1}$. The salt release fluxes in the four experiments showed a similar trend with time. The trends of salt release fluxes with time were similar in the four groups of experiments, and the release fluxes and their decreasing speeds in the saline stratum decreased in the order of A03, A04, A01, and A02. The results show that the experimental group with high release flux corresponds to high salt accumulation in the overlying sand layer, and the experimental group with low release flux corresponds to low salt accumulation in the overlying sand layer. Zhao[9] also mentioned that in the process of salt release from the marine strata to the overlying water body, the diffusion flux of the subducted strata is greater than that of the medium-fine sand and muddy silt when the underlying lithology is chalky clay.

4   Conclusion

In this study, the spatial and temporal variations of salt content in the upward release of salts from saline strata in the lower reaches of the Yellow River were determined by using the high-density electrical method with the aim of investigating the salt transport law in salinized strata under the effect of concentration difference. By comparing the experimental results of salt release from different salinized strata, the following conclusions were obtained:

(1) Driven by the difference in salt concentration, the rate of salt release from the underlying saline strata was first fast and then slow, and stabilized after 220 h. The salt content of the overlying sand layer had a clear stratification phenomenon, and the influence range was within about 5 cm above the interface.

(2) The trend of salt release flux with time conforms to a negative power-exponential function and is about 1.27 $g \cdot m^{-2} \cdot h^{-1}$ after stabilization; the trend of salt accumulation with time conforms to a power-exponential function.

(3) The higher the degree of stratigraphic salinization, the greater the accumulation of salts in the overlying sands, the greater the salt release flux, and the faster its rate of decrease with time.

However, this paper is limited to analyzing the salt release pattern under hydrostatic conditions, and the effects of the high and low water levels of the Yellow River and the slope descent of the strata on the salt release can be considered in the subsequent studies.

Acknowledgements

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