

Spatial Variability of Soil Salinity and Organic Matter Content Following Reclamation of Abandoned Salt Pans (Postprint)

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Abstract

To address the limiting factors of soil salinity, alkalinity, and barrenness during the reclamation of abandoned salt pans on the southern coast of Laizhou Bay, this study selected two typical reclaimed plots in the area as research objects. Using a combination of classical statistics and the Kriging method from geostatistics, we investigated the spatial variability of soil salinity in various layers and surface soil organic matter under different reclamation years, conducted correlation analysis between the two, and mapped the spatial distribution of salt content in each soil layer and surface soil organic matter content. The results showed that: soil salt content in all layers of both areas was relatively high, exceeding 1 g/kg; influenced by anthropogenic reclamation measures such as reclamation years, land leveling standard, and fertilization, the soil salt content in Area II was significantly lower than that in Area I; soil organic matter content in both areas was generally low, at 4.37 g/kg in Area I and 3.66 g/kg in Area II; the coefficient of variation for soil salt content in all layers and surface soil organic matter in both areas ranged from 32.79% to 83.83%, showing moderate variation intensity in the horizontal direction; correlation analysis results indicated that soil salt content in all layers was extremely significantly negatively correlated with organic matter content; the nugget-to-sill ratios of soil salt content and organic matter content in all layers were less than 25%, indicating strong spatial correlation for both; the minimum spatial autocorrelation distance was 440 m, exceeding the sampling interval (minimum 160 m), indicating that the sampling interval was reasonably set; Kriging interpolation results showed that soil salt content and organic matter content in both areas exhibited banded distribution patterns; in Area I, soil salt content was highest in the central region and gradually decreased towards the north and south, while in Area II, soil salt content was lowest in the southeast and gradually transitioned towards a high-value zone in the northwest; soil organic matter content in Area

I was low in the center and higher in the north and south, whereas in Area II it was highest in the southeast and lower in the central-northern region. The research results provide preliminary validation for subsequent water-salt transport simulation studies in high-salinity contexts, and also offer technical support for rational zoning, improvement and utilization, and scientific management of saline-alkali soils in salt pan reclamation areas.

Full Text

Preamble

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Spatial Variation of Soil Salinity and Organic Matter Under Reclamation in an Abandoned Salt Pan

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Abstract

Soil salinization and low fertility are major obstacles in the reclamation of abandoned salt pans along the southern coast of Laizhou Bay. This study investigated two typical reclamation plots in this region, employing classical statistics and geostatistical Kriging methods to evaluate the spatial variability of soil salinity across different soil layers and organic matter in the surface layer under varying reclamation durations. The correlation between soil salinity and organic matter was analyzed, and spatial distribution maps of soil salinity in different layers and surface organic matter content were generated.

Results indicated that both reclamation areas exhibited high soil salinity levels exceeding 1 g/kg. Due to differences in reclamation years, land leveling, irrigation, and tillage practices, Area Two showed significantly lower soil salinity than Area One. Organic matter content was also low in both areas, averaging 4.37 g/kg and 3.66 g/kg respectively. Both soil salinity and organic matter displayed moderate spatial variability in the horizontal direction, with variation coefficients ranging from 32.79% to 83.83%. Correlation analysis revealed a highly significant negative correlation between salinity and organic matter across all soil layers. The nugget-to-sill ratio was less than 25%, indicating strong spatial correlation. The minimum autocorrelation distance was 440 m, exceeding the sampling interval (minimum 160 m), demonstrating that the sampling design was appropriate. Kriging interpolation revealed a strip-shaped distribution pattern for both parameters. In Area One, soil salinity was highest in the central region and gradually decreased toward the north and south. In Area Two, the lowest salinity occurred in the southeast, gradually transitioning to higher values in the northwest. Organic matter distribution showed the opposite pattern: low in the center and high in the north and south in Area One, while highest in the southeast and lower in the central-northern region in Area Two. These findings provide a theoretical basis and technical support for rational zoning, improvement, utilization, and scientific management of saline soils in salt pan reclamation areas.

Keywords: abandoned salt pan; reclamation; salinity; organic matter; Kriging interpolation

1. Introduction

China's eastern coastal regions contain extensive salt pan areas. According to relevant statistics, the salt pan area in the Laizhou Bay region alone reaches 33.7×10^3 hm², accounting for one-quarter of national raw salt production. The southern coast of Laizhou Bay, located along the Bohai Sea, has experienced multiple major marine transgression events historically, with high-mineralization brine stored in the shallow aquifer. Local development of underground brine resources for salt production has been a pillar industry. However, due to gradual

depletion of shallow brine resources, high costs of deep brine extraction, and fluctuations in raw salt market prices, many salt pans have become abandoned.

Under national policies, some abandoned salt pans have been reclaimed for agricultural use. Despite comprehensive agricultural and engineering remediation measures, soils still contain high levels of soluble salts due to years of salt production, while nutrient content remains extremely low. Crop relative yield shows a negative correlation with the electrical conductivity of saturated soil extracts at certain salt concentrations. High salinity affects crop growth, soil microorganisms, and ultimately leads to soil erosion and desertification. Research on the dynamics of salinity and fertility in reclaimed salt pan areas provides a theoretical foundation for regional saline soil classification, rational utilization, and scientific management.

Geostatistics and Kriging interpolation methods have been gradually introduced to study spatial variability of soil properties. Combining these techniques with GIS provides an effective approach for quantifying spatial variation of soil characteristics in coastal areas or other farmland features. Panagopoulos et al. used geostatistics and GIS to study soil salinity spatial variability in Mediterranean regions, providing theoretical support for lettuce yield improvement and precision agriculture. Yang Jingsong et al. applied indicator Kriging to evaluate soil salinity spatial variability in two typical plots of the Yellow River Delta, producing conditional probability maps of soil salinity meeting certain standards at different times. He et al. studied annual variation trends of soil salinity under different vegetation communities on Chongming Island using geostatistical methods, revealing significant effects of vegetation on soil salinity spatial distribution. Yao et al. analyzed the relationship between soil salinity and crop biomass in coastal Zhejiang using geostatistics, demonstrating that increased root-zone salinity reduces crop biomass.

Compared with numerous studies on coastal soil salinity spatial variation, research on soil salinity in reclaimed salt pan areas remains relatively scarce. Soil salinity in abandoned salt pans generally exceeds 1%–1.5%, and poor drainage impedes salt leaching, resulting in low crop yields. Different zones of abandoned salt pans along the southern coast of Laizhou Bay have been reclaimed for several years, with most comparative studies focusing on cotton yield. To explore reclamation effects more deeply and propose more scientific measures, this study targeted the main factors affecting agricultural production in this region, using typical plots in a reclaimed salt pan area. Based on geostatistics and Kriging interpolation, we investigated spatial variability of soil salinity and organic matter—two critical indicators affecting crop growth—mapped their spatial distribution at different depths and reclamation years, and analyzed their interrelationships to provide theoretical and technical support for rational utilization, improvement, and management of reclaimed salt pan land.

2. Study Area Overview

The study area is located in the northern salt pan reclamation zone of Liutuan Town, Changyi City, on the southern coast of Laizhou Bay. The geographical location is shown in [Figure 1: see original paper]. Area One has a reclamation history of 6 years, while Area Two has been reclaimed for 4 years. Both areas were previously brine salt pans with an average brine concentration of 5–10‰. In the first reclamation year, slightly saline groundwater (887 mg/L) was introduced from Liutuan Town for large-scale flood irrigation to leach salts. Salt-tolerant cotton was planted starting from the second year, but yields were extremely low (2.25 t/hm²). As planting years increased, cotton yields began to improve, though the fields remained low-yielding.

The region has a warm temperate semi-humid East Asian monsoon continental climate, characterized by hot, rainy summers, mild and cool autumns, windy and dry springs with droughts at season's end. Annual average temperature is 11.9°C, precipitation is 660.1 mm (concentrated in summer), evaporation is 1859.4 mm, and the average evaporation-to-precipitation ratio is 64.5%. The main soil type is salinized fluvo-aquic soil. Salt pans are widespread, with some areas planted with cotton, peanuts, and corn. Due to high-mineralization underground brine and lack of water storage facilities, freshwater resources are scarce during non-rainy seasons. Irrigation water is obtained through underground pipelines from Liutuan Town in the south, using subsurface drip irrigation (450–600 m³ per application) to meet crop water requirements. Soil salinity shows seasonal variation.

3. Methods

3.1 Sample Collection

Soil sampling points were established in the study area using a grid method for uniform sampling. In Area One, sample spacing was 160 m; in Area Two, spacing was 180 m. A total of 48 soil samples were collected. Sampling profiles were set at each point with depths of 0–30 cm, 30–60 cm, and 60–100 cm. Sampling was conducted in early May 2015 before cotton sowing. Coordinates of each sampling point were recorded using differential GPS. Soil samples were sealed in plastic bags, labeled, and transported to the laboratory for natural air-drying.

3.2 Sample Processing and Analysis

All soil samples were prepared as 1:5 soil-water extracts, and electrical conductivity was measured using a YSI EC300 instrument. Surface soil organic matter content was determined by the potassium dichromate volumetric method, following standard soil agrochemical analysis procedures. Laboratory work was completed at the Key Laboratory of Marine Sedimentology and Environmental

Geology, State Oceanic Administration. Literature indicates a positive correlation between soil salinity and extract electrical conductivity. To ensure data accuracy, 48 randomly selected samples were measured for soil salinity using the gravimetric method, establishing the conversion relationship:

Soil salinity (g/kg) = 0.056 × EC (mS/m) - 0.55 ($r = 0.95$, $P < 0.05$, $n = 48$).

For remaining samples, salinity was calculated from measured EC values using this equation.

3.3 Geostatistical Analysis Methods

This study employed geostatistical methods to analyze spatial variability of soil salinity and organic matter. Geostatistics, based on regionalized variable theory and using variograms as the primary tool, studies natural phenomena with both random and structural characteristics in spatial distribution. The theoretical model formula is:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2$$

where $\gamma(h)$ is the variogram, h is the lag distance, $Z(x_i)$ and $Z(x_i + h)$ are variable values at spatial positions x_i and $x_i + h$, and $N(h)$ is the number of point pairs at interval h .

3.4 Data Processing

Soil salinity and organic matter data were analyzed using SPSS 19.0. All data were preprocessed and log-transformed to meet normal distribution requirements. Semivariogram calculations were performed in ArcGIS 9.3 geostatistical analysis module to avoid proportional effects. Kriging interpolation was used to generate spatial distribution maps of soil salinity and organic matter in the reclaimed salt pan area.

4. Results

4.1 Distribution Characteristics of Soil Salinity and Organic Matter

Statistical characteristics of measured soil salinity and organic matter at different depths are shown in . The two areas showed significant differences in soil salinity and organic matter content. The maximum variation ranges reached 16.4 g/kg and 15.48 g/kg respectively. Mean salinity levels were high in both areas, increasing with soil depth. Surface organic matter content was low, averaging 4.37 g/kg in Area One and 3.66 g/kg in Area Two.

Variation coefficients ranged from 32.79% to 83.83%, indicating moderate variability (10%-100%). Area One showed higher variation coefficients than Area Two, suggesting more uniform distribution of salinity and organic matter in Area Two. All data followed log-normal distributions.

4.2 Correlation Analysis of Soil Salinity and Organic Matter

Correlation analysis revealed highly significant negative correlations between salinity and organic matter across all layers in both areas. The negative correlation coefficient was most pronounced in the 0-30 cm layer. All soil layers showed highly significant positive correlations with each other, indicating that vertical salt movement connects each layer's salinity dynamics.

4.3 Spatial Variability Analysis of Soil Salinity and Organic Matter

Classical statistics only partially reflect sample populations and variability but cannot quantify the randomness, structure, independence, and correlation of soil properties. Geostatistical methods were therefore used to analyze spatial structure. Gaussian, exponential, and spherical models were fitted, with final models selected based on higher determination coefficients (R^2) and lower residual sum of squares (RSS).

The nugget-to-sill ratio ($C/(C+C)$) indicates spatial correlation degree: <25% indicates strong spatial correlation, 25%-75% moderate, and >75% weak. All layers showed ratios <25%, demonstrating strong spatial correlation. The minimum autocorrelation distance (range) was 0.44 km, exceeding the sampling interval (0.16-0.18 km), confirming appropriate sampling design. Fractal dimension (D) values ranged from 1.776 to 1.993, indicating high spatial variability caused by autocorrelation.

4.4 Spatial Interpolation Analysis

Kriging interpolation was used to visualize spatial distributions. In Area One, soil salinity showed banded and patchy patterns, highest in the center and decreasing north-southward. Organic matter distribution was inverse: low in the center and high in the north-south, particularly in the northwest and southeast. In Area Two, salinity was lowest in the southeast, increasing toward the northwest, while organic matter was highest in the southeast and lower in central-northern regions. These patterns validated the correlation analysis results.

5. Discussion

Research indicates that when high-salinity subsoil lies within the limit evaporation depth, dissolved salts directly accumulate at the surface; when below this

depth, salts increase upper soil salinity without surface accumulation. Our results show that despite years of reclamation, the Laizhou Bay salt pan area still has high subsoil salinity with relatively lower surface salinity. Limited fresh-water resources restrict drip irrigation to crop requirements only, preventing leaching of deeper salts. Consequently, salinity increases with depth.

Area One' s significantly higher salinity than Area Two reflects the influence of reclamation duration—longer reclamation reduces salinity, consistent with other studies on soil property changes under different reclamation years. Soil organic matter, crucial for coordinating soil water, structure, and tilth, was extremely low in both areas (Level 5 by national standards). This results from inherently poor coastal soils and minimal fertilizer application during reclamation (525–600 kg/hm²).

The strong spatial correlation (low nugget-to-sill ratios) indicates that structural factors (soil type, natural salinity) dominate over random factors (tillage, amendments). Although reclamation measures have been implemented for years, natural soil properties still outweigh anthropogenic influences. Kriging interpolation smooths data, reducing abrupt spatial changes.

Topography explains distribution patterns: Area One' s slightly lower central elevation causes water and salt accumulation after irrigation, while Area Two' s lower central-northern elevation concentrates salinity there. Organic matter distribution inversely correlates with salinity, consistent with findings by Xie Chengtao and Yang Qiyong. The reclaimed land' s uneven microtopography from incomplete leveling and low fertilizer rates contribute to this pattern.

Study area salinity (1–1.5 g/kg) exceeds surrounding farmland (0.5%–1.0%), while organic matter is lower. Future management should increase leaching intensity, irrigation frequency, and apply more organic fertilizer combined with deep tillage to improve organic matter content.

6. Conclusion

1. Despite several years of reclamation, both areas maintain high soil salinity across all layers, increasing with depth. Area Two' s salinity is significantly lower than Area One' s. Organic matter content remains very low in both areas.
2. Variation coefficients of salinity and organic matter range from 32.79% to 83.83%, showing moderate horizontal variability. Area Two exhibits more uniform distribution than Area One.
3. Soil salinity and organic matter are tightly linked, showing highly significant negative correlations across all layers, approximately following an exponential relationship—high salinity zones correspond to low organic matter.

4. Nugget-to-sill ratios range from 12.24% to 23.62%, indicating strong spatial correlation. Organic matter shows stronger spatial autocorrelation than salinity. Ranges exceed actual sampling intervals, reflecting adequate spatial autocorrelation.
 5. Salinity and surface organic matter show banded distributions. Area One's salinity is highest centrally, decreasing north-southward; Area Two's is lowest in the southeast, increasing northwestward. Organic matter distribution is inverse: Area One shows low center and high north-south; Area Two shows highest southeast and lower central-north.
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References

- [1] China Construction Southwest Survey & Design Institute Co., Ltd. *Northern China Salt Pan Ecological Aquaculture Technology*. Weifang Abandoned Salt Pan, 2012, (9): 13-17.
- [2] (2015-05-20) [2017-05-09]. <http://www.ne21.com/news/show-76524.html>.
- [3] *Paleogeographic Conditions of Quaternary Underground Brine Formation in Laizhou Bay*. Science Press, 1996: 14-15.
- [4] *Study on Shallow Buried Paleochannel Zones in the Southern Laizhou Bay Plain*. *Marine Geology & Quaternary Geology*, 2000, 20(1): 23-29.
- [5] *Marine Geology and Quaternary Geology*, 2015, 61(2): 393-400.
- [6] Maas E V, Hoffman G J. Crop salt tolerance: current assessment. *Journal of the Irrigation and Drainage Division*, 1977, 103(2): 115-134.
- [7] Amezketta E. An integrated methodology for assessing soil salinization, a precondition for land desertification. *Journal of Arid Environments*, 2006, 67(4): 594-606.
- [8] Gorji T, Tanik A, Sertel E. Soil salinity prediction, monitoring and mapping using modern technologies. *Procedia Earth and Planetary Science*, 2015, 15: 507-512.
- [9] *Acta Ecologica Sinica*, 2012, 32(4): 1202-1210.
- [10] Yao R J, Yang J S, Zhang T J, Gao P, Wang X P, Hong L Z, Wang M W. Determination of site-specific management zones using soil physico-chemical properties and crop yields in coastal reclaimed farmland. *Geoderma*, 2014, 232-234: 381-393.
- [11] He B, Cai Y L, Ran W R, Zhao X L, Jiang H. Spatiotemporal heterogeneity of soil salinity after the establishment of vegetation on a coastal saline field. *CATENA*, 2015, 127: 129-134.

- [12] Panagopoulos T, Jesus J, Antunes M D C, Beltão J. Analysis of spatial interpolation for optimising management of a salinized field cultivated with lettuce. *European Journal of Agronomy*, 2006, 24(1): 1-10.
- [13] *Soil Salinity Spatial Variability Evaluation Using Electromagnetic Induction and Indicator Kriging in the Yellow River Delta*.
- [14] Yao R J, Yang J S, Wu D H, Xie W P, Cui S Y, Wang X P, Yu S P, Zhang X. Determining soil salinity and plant biomass response for a farmed coastal cropland using the electromagnetic induction method. *Computers and Electronics in Agriculture*, 2015, 119: 241-253.
- [15] Liu G M, Li J B, Zhang X C, Wang X P, Lv Z Z, Yang J S, Shao H B, Yu S P. GIS-mapping spatial distribution of soil salinity for eco-restoring the Yellow River Delta in combination with electromagnetic induction. *Ecological Engineering*, 2016, 94: 306-314.
- [16] *Study on Utilization Change and Optimization of Coastal Saline-alkali Land*. China Agricultural Science and Technology Press, 2010.
- [17] *Soil Agrochemical Analysis Methods*. Science Press, 1999: 106-109.
- [18] *Indicator Kriging Analysis of Soil Salinity and Organic Matter in Yucheng City Cultivated Land*. *Acta Ecologica Sinica*, 2011, 31(8): 2196-2202.
- [19] Michot D, Walter C, Adam I, Guéro Y. Digital assessment of soil-salinity dynamics after a major flood in the Niger River valley. *Geoderma*, 2013, 207-208: 193-204.
- [20] *Geostatistics and Its Application in Ecology*. Science Press, 1999: 35-45.
- [21] *Theory and Application of Deposit Statistical Prediction and Geostatistics*. Metallurgical Industry Press, 1993: 309-314.
- [22] *Quantitative Research Theory and Methods for Spatial Heterogeneity*. *Chinese Journal of Applied Ecology*, 1998, 9(6): 651-657.
- [23] Güler M, Arslan H, Cemek B, Erşahin S. Long-term changes in spatial variation of soil electrical conductivity and exchangeable sodium percentage in irrigated mesic ustifluvents. *Agricultural Water Management*, 2014, 135: 1-8.
- [24] *Study on Salt Ion Differentiation in Soil Profiles of Southern Laizhou Bay*. *Geoderma*, 2014, 51(6): 1213-1222.
- [25] Kravchenko A N. Influence of spatial structure on accuracy of interpolation methods. *Soil Science Society of America Journal*, 2003, 67(5): 1564-1571.
- [26] *Investigation and Analysis of Salinization in Salt Pan Landfill Areas*. *North-east Water Resources and Hydropower*, 2015, (9): 19-21, 66.
- [27] *Effects of Different Restoration Years on Soil Organic Carbon Fractions and Aggregate Stability*. *Journal of Soil and Water Conservation*, 2013, 50(6): 1183-1190.

[28] *Study on Soil Physico-chemical Properties in Yongcheng Coal Mining Subsidence Reclamation Area with Different Reclamation Years. Anhui Agricultural Sciences*, 2014, 42(23): 7863-7865.

[29] *Spatial Distribution Characteristics and Influencing Factors of Soil Organic Matter and Trace Elements in Nansi Lake Area Farmland. Acta Ecologica Sinica*, 2014, 34(6): 1596-1605.

[30] Cambardella C A, Moorman T B, Novak J M, Parkin T B, Karlen D L, Turco R F, Konopka A E. Field-scale variability of soil properties in central Iowa soils. *Soil Science Society of America Journal*, 1994, 58(5): 1501-1511.

[31] *Correlation and Mechanism Between Organic Matter and Soil Salinity. Soils*, 1993, (1): 19-22.

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