Matching relationship between land salinity and utilization based on the synergy of OLI and ground measurements

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Abstract: Timely and accurate grasp of land salinization status and its matching relationship with land use is the basis for scientific improvement of saline land and rational land use. The current land use types of Shouguang City on the south coast of the Bohai Sea were obtained based on Landsat 8 OLI multispectral images using supervised classification. And the spatial distribution map of land salinization was obtained by IDW interpolation. By superimposed analysis of the current land use types and the spatial distribution of salinization, the information of salinization degree was obtained. The matching relationship between salinization and land use was analyzed from both quantitative and spatial aspects. The results show that OLI multispectral image and filed survey can improve the extraction accuracy of land types and salinization degree information. The distribution of salinized land in Shouguang City has prominent regional characteristics, with non-saline, mild, moderate, severe, and saline soil distributed in a pattern of "large concentration and small insertion" from south to north. The spatial consistency of land use and salinization in Shouguang is remarkable, forming spatial characteristics of "vegetable in the south, grain and cotton in the middle, and fishery and salt in the north". However, no matter from space or quantity, the land use and salinization in Shouguang City have the problem of "overall match, local mismatch". It is suggested to take differentiated measures to regulate land use according to the current situation of distribution characteristics of land salinization and utilization.

1. Introduction

Soil salinization is a difficult problem plaguing agricultural production, economic construction, ecological protection, and people’s living in arid semi-arid areas, and coastal areas\[^{1-2}\]. Timely and accurate grasp of land salinization is the basis of scientific improvement and rational use of salinized land. Soil salinization is widely distributed and dynamic. Manual sampling and laboratory analysis has high accuracy, but, due to the high cost and time consumption, it is challenging to meet the needs of large-scale, high-density, and persistent dynamic monitoring. Remote sensing has the advantage of acquiring spectral information of features in a fast, timely, macroscopic, and periodic manner, and is widely used in feature information extraction and land use monitoring. In terms of sensing monitoring soil salinization, Yuan monitored soil salinity at field scale in the Abbey Lake region based on remote sensing images\[^{3}\], Bian analyzed salinization extent in the Yellow River Delta using remote sensing inversion\[^{4}\], Li used multispectral and hyperspectral image fusion and built machine learning models to improve the inversion accuracy of soil salinity\[^{5}\]. Due to spectral confusion, only using remote sensing classification to determine the spatial distribution and degree of soil salinization will lead to large errors. The use of spectral inversion is similarly affected. However, the research based on the synergy of remote
sensing and ground measurement is not deep enough.

The low plain area around the Bohai Sea is an important grain, cotton, fruit, and vegetable producing area and also one of the main distribution areas of salinized land in China. Shouguang City, Shandong Province, is located on the southwestern coast of Laizhou Bay of the Bohai Sea. The topography and geomorphology, soil and vegetation, climate and hydrology, agricultural production and land development and utilization, and soil salinization are typical in the region. Therefore, taking Shouguang City as an example, combing RS supervised classification and ground measurement, this paper extracted land use and salinization information precisely through GIS spatial interpolation and overlay analysis. And the matching relationship between land salinization and use was analyzed, providing a reference for taking targeted measures to manage and use salinized land.

2. Data sources and research methods

2.1. Overview of the study area

The geographical coordinates of Shouguang City are 118°32'-119°10'E, 36°41'-37°19N, with an area of 199011.58hm². The topography is high in the south and low in the north, with an elevation of 49.5-1m and an average slope drop of 1:10000. Rivers and surface runoff flow from southwest to northeast, forming a micro-land formation of large flat and small uneven. Soil types include brown soil, tidal brown soil, tidal soil, browned tidal soil, sand ginger black soil, coastal tidal salt soil, and coastal salt soil. It has a warm temperate continental monsoon climate with an average annual temperature of 12.4°C. The average annual precipitation is 593.8mm, mainly concentrated in summer. The average annual evaporation is 1834.0 mm, and the evaporation ratio is as high as 3.09. In recent years, a large amount of water for industry and agriculture relies on water transfer from the south to the north, and the annual use of external water exceeds 120 million m³. Shouguang has seen the rapid development of industry and agriculture in recent years, with high intensity of groundwater exploitation. The formation of several groundwater funnels in the northwest has caused the invasion of salty water in the north and increased soil salinization. Shouguang is the hometown of Chinese greenhouse vegetables, and also an important grain and cotton production area. The irrational application of water and fertilizer in agricultural production also causes secondary salinization of soil.

2.2. Data source and processing

(1) Remote sensing image data: Given that spring is the peak salt return period in soil, the OLI image of March 14, 2020 (line number 34, strip number 121) was selected as the data source (download from the Geospatial Data Cloud, http://www.gscloud.cn). This image has a low cloud size (0.16%), rich information in the bands, and significant differences between land types. Envi5.3 software was used for image radiometric calibration, atmospheric correction, crop and synthesize.

(2) Ground measured data: A 3×3 km grid on the image map covering the study area (avoiding water) was designed, with one survey sample point in the center of each grid (figure 1). Field survey based on site conditions to determine the site sampling locations. Hand-held GPS was used to record the coordinates of the sample points and the current land-use types etc. Soil conductivity was measured with a conductivity meter (EC110). About 1 kg soil samples of 0-20cm were taken from typical sample sites, sealed in bags and brought back to the laboratory. The field survey was conducted from the end of April 2019. A total of 96 groups of soil conductivity were measured and 62 soil samples were collected. The soil samples were naturally air-dried, ground, sieved, and the soil salt content (g/kg) of 62 samples were measured by leaching and drying with a water-soil ratio of 5:1. Soil salinity was modeled with the corresponding conductivity, and all the measured soil conductivity in the field was converted to soil salt content (g/kg).
2.3. Research Methodology

2.3.1. Land use classification and accuracy check. According to the current land use classification standard and remote sensing monitoring land use/cover classification system, the land use types of Shouguang City were classified into 8: dry land, irrigated land, garden land, construction land, water area, aquaculture water, saline wasteland, and other unused land. Using ENVI 5.3, the remote sensing image information was extracted by supervised classification and post-processing. The initial land use map was obtained by maximum likelihood method. To ensure more consistent with the current land use map with the actual situation, the classification results were checked and corrected according to the actual use types of field survey sample points and referring to Tiantu map. The overall accuracy of the final transfer matrix is 0.98, and the kappa coefficient is 0.97.

2.3.2. Statistical analysis of soil salinization characteristics. Referring to "Soil Agricultural Chemical Analysis (Lu R, 2000)", and combining salt tolerance of crops and the actual land use management of Shouguang City, the soil salinity degree was divided into 5: non-saline, mild, moderate, severe and saline soil, and the intervals of salt content (g/kg) were: (0, 1), [1, 2), [2, 4), [4, 6), and [6, ∞). SPSS was used to analyze the statistical characteristics of soil salinization.

2.3.3. Superposition analysis and co-processing. Salinity values were interpolated by IDW using Arcgis10.2, the salinization map and land use classification map were overlaid to collaboratively analyze the distribution of different salinization levels by category, and the matching status between land salinization and use.

3. Results and Analysis

3.1. Land Use Characteristics of Shouguang City

The spatial distribution of land use types in Shouguang City are shown in figure 2, and the areas of each type are shown in Table 1. The spatial distribution of land use in Shouguang formed a characteristic of "vegetable in the south, grain and cotton in the middle, and fishing and salt in the north". The arable land is distributed in the south and the center. In the south, the primary type of arable land use is irrigated land, mainly planting vegetables, with an area of 47677.48 hm², accounting for 23.96% of the total area. In the central part, the primary type is dry land, mainly planting grain (to the south) and cotton (to the north), with an area of 74494.97 hm², accounting for 37.43%. The area of garden land is 5954.72hm², accounting for 2.99%, showing an inset distribution. The area of construction land is 54566.68hm², accounting for 27.42%, with a more scattered distribution. The water area is 9902.911hm², accounting for 4.98%. The aquaculture water is 1817.75hm², accounting for 0.91%, and the seawater aquaculture is more concentrated in the north. The area of saline wasteland is 3893.89hm², accounting for 1.96%, mainly distributed in the northwestern area near the sea. The area of other unused land is 703.18hm², accounting for 0.35%, sporadically distributed.

| Land type       | Dry | Irrigated | Garden | Construction | Water | Aquaculture | Saline waste | Other unused | Total       |
|-----------------|-----|-----------|--------|--------------|-------|-------------|--------------|--------------|-------------|
| Area (hm²)      | 74494.97 | 47677.48 | 5954.72 | 54566.68     | 9902.91 | 1817.75     | 3893.89      | 703.18       | 19901.58    |
| Percent (%)     | 37.43 | 23.96     | 2.99   | 27.42        | 4.98   | 0.91        | 1.96         | 0.35         | 100.00      |

3.2. Status of soil salinization in Shouguang

3.2.1. Statistical characteristics of soil salinity in Shouguang City. To facilitate the analysis of the spatial characteristics of land salinization, the city was divided into three regions, namely, north, middle, and south, for statistical analysis according to the topography and geomorphology, combined with groundwater mineralization and land use distribution (table 2).
Table 2 Statistical characteristics of soil salt content in Shouguang City.

| Region | Sample | Average | Median | Sd | Max | Min | Kurtosis | Skewness | Cv |
|--------|--------|---------|--------|----|-----|-----|----------|----------|----|
| North  | 15     | 5.33    | 5.31   | 0.94 | 6.82 | 3.56 | -0.76    | -0.35    | 0.18 |
| Middle | 65     | 1.48    | 1.06   | 1.36 | 6.30 | 0.28 | 4.36     | 2.16     | 0.92 |
| South  | 16     | 1.20    | 0.53   | 1.76 | 6.30 | 0.34 | 5.41     | 2.53     | 1.46 |
| Overall| 96     | 1.98    | 1.12   | 1.93 | 6.82 | 0.28 | 0.01     | 1.22     | 0.98 |

As shown in table 2, the overall mean soil salinity in Shouguang is 1.98±1.93 g/kg, with a median of 1.12 g/kg, which is mild salinity. The coefficient of variation is 0.98, which is moderately high variability, with a kurtosis of 0.01 (cusp) and skewness of 1.22 (positively skewed). Both kurtosis and skewness deviate to a small degree, closing to a normal distribution. The mean soil salinity in the north is 5.33±0.94 g/kg, and the median is 5.31 g/kg, which belongs to severe salinity. The coefficient of variation is 0.18 (small variation). The kurtosis is -0.76 (flat top peak) and the skewness is -0.35 (negative skewness). The deviation degree of both kurtosis and skewness are not large, which is more close to normal distribution. The mean soil salinity in the central part is 1.48±1.36 g/kg, and the median is 1.06 g/kg, which is mildly saline overall, but slightly higher than that in the south. The coefficient of variation is 0.92 (moderately high). The kurtosis is 4.36 (sharp peak) and the skewness is 2.16 (positive skewness), indicating that the soil salinity is more extreme and more discrete on the side of higher content. The mean soil salinity in the south is 1.20±1.76 g/kg and the median is 0.53 g/kg, which is mild salinization. The coefficient of variation is 1.46, showing strong variability. The kurtosis is 5.41 (cusp) and the skewness is 2.53 (positive skewness). This indicates that soil salinity has more extreme values and strong dispersion on the side of higher content.

3.2.2. Spatial characteristics of soil salinization in Shouguang City. The spatial interpolation map of soil salinization in Shouguang City is shown in figure 3, and the statistical results of different salinization areas are shown in Table 3. The overall salinization in Shouguang City has a distribution of "large concentration and small insertion", and the overall situation is gradually aggravated from south to north. Non-salinized soils accounts for 43.15%, concentrated in the southwest; mild salinized soils accounts for 11.95%, concentrated in the central and eastern part; moderately salinized accounts for 22.43%, concentrated in the central north and with patchy intercalation distribution in the central and eastern part; severe salinized soils accounts for 18.36%, concentrated in the northern coastal area; saline soils accounts for 4.10%, adjacent to severe salinized soils in the north.

Table 3. Area and proportion of soil salinized in different degrees.

| Region | Salinized soil | Non | Mild | Moderate | Severe | Saline | Total |
|--------|----------------|-----|------|----------|--------|--------|-------|
| North  | Area (hm²)     | 0.00| 3881.94 | 15640.43 | 16950.09 | 8159.50 | 44631.95 |
|        | Percentage (%)  | 0.00| 8.70 | 35.04    | 37.98   | 18.28   | 100.00 |
| Middle | Area (hm²)     | 59461.26 | 12113.37 | 27503.67 | 18223.15 | 0.00 | 117301.45 |
|        | Percentage (%)  | 50.69| 10.33 | 23.45    | 15.54   | 0.00    | 100.00 |
| South  | Area (hm²)     | 26413.19 | 7795.16 | 1503.25 | 1366.58 | 0.00 | 37078.18 |
|        | Percentage (%)  | 71.24| 21.02 | 4.05     | 3.69    | 0.00    | 100.00 |
| Overall| Area (hm²)     | 85874.45 | 23790.47 | 44647.35 | 36539.82 | 8159.50 | 199011.58 |
|        | Percentage (%)  | 43.15| 11.95 | 22.43    | 18.36   | 4.10    | 100.00 |

From the three areas divided, the salinization in the south is lighter overall, with non-salinized soils (71.24%) and mild salinized soils (21.02%) dominating. Most areas in the central region are non-salinized (50.69%) and moderately salinized (23.45%), but in the eastern part of the central region, salinization is more severe. In the northern region, soil salinity is generally high, with more than half belonging to severe salinized (37.98%) and saline soils (18.28%).
3.2.3. Matching relationship between land use and salinization. (1) Spatial matching relationship: The overlay results of land use map and salinity distribution map of Shouguang City are shown in figure 4.

![Figure 1. Sampling sites distribution.](image1)
![Figure 2. Land use classification.](image2)
![Figure 3. Classification of soil salt.](image3)
![Figure 4. Salinization degree of different land use types.](image4)

As shown in figure 4, the arable land is mainly widely distributed in areas with less than moderate salinity, but there is also a small amount of distribution in areas with heavy salinity in the north and northeast. A small portion of irrigated land is located in the heavily salinized area, mainly in the vicinity of Yangkou town. The mild and moderately saline soils in the dry land are mainly located in the central part, where grain crop are grown, and cotton are grown in the heavily saline areas. The construction land is mainly distributed in the south area with less than mild salinization, while the construction land in the north is mainly marine chemical enterprises and salt fields. The distribution of garden land is more fragmented, with a relative concentration on both sides of the Mihe River and less distribution in the northern area of moderate and severe salinization. Saline wasteland in salt soil is located in the northern area, adjacent to salt fields. The high salt content of the soil makes agricultural use difficult and has not been utilized for a long time. In summary, there is an obvious spatial consistency between land use status and salinization distribution in Shouguang City as a whole, but there is a mismatch in local areas.

(2) Quantitative matching relationship: The area and proportion of land use types of different salinization degrees are shown in table 4 (excluding water area).

| Land Type          | Salinized soil | Non   | Mild  | Moderate | Severe | Saline | Total  |
|--------------------|---------------|-------|-------|----------|--------|--------|--------|
| Dry land           | Area (hm²)    | 31753.73 | 7241.82 | 19490.88 | 12489.43 | 3519.11 | 74494.97 |
|                    | Percentage (%)| 42.63  | 9.72  | 16.77    | 14.72  | 4.72   | 100.00 |
| Irrigated land     | Area (hm²)    | 22857.13 | 12213.21 | 8056.40  | 4550.74  | 0.00    | 47677.48 |
|                    | Percentage (%)| 47.94  | 25.62 | 16.90    | 9.54    | 0.00   | 100.00 |
| Garden land        | Area (hm²)    | 1459.81  | 1846.38 | 843.55   | 1545.22  | 259.76  | 5954.72 |
|                    | Percentage (%)| 24.52  | 31.01 | 14.17    | 25.95   | 4.36   | 100.00 |
| Construction land  | Area (hm²)    | 10031.42 | 14135.54 | 8011.40  | 17953.20 | 4435.12 | 54566.68 |
|                    | Percentage (%)| 18.38  | 25.91 | 14.68    | 32.90   | 8.13   | 100.00 |
| Saline wasteland   | Area (hm²)    | 0.00    | 0.00  | 0.94     | 36.68   | 0.00   | 3893.89 |
|                    | Percentage (%)| 0.00   | 0.00  | 0.04     | 68.46   | 0.00   | 100.00 |
| Other unused land  | Area (hm²)    | 0.00    | 0.22  | 23.23    | 536.18  | 143.56 | 703.18 |
|                    | Percentage (%)| 0.00   | 0.03  | 3.30     | 76.25   | 20.42  | 100.00 |
| Total              | Area (hm²)    | 66102.09 | 35437.17 | 36462.13 | 39740.46 | 9549.06 | 187290.92 |
|                    | Percentage (%)| 35.29  | 18.92 | 19.47    | 21.22   | 5.10   | 100.00 |

As seen from table 4, land use and salinization in Shouguang City show an overall matching and local mismatch relationship. The overall salinization of arable land is light, with 52.35% of dry land and
73.56% of irrigated land below mild. However, some of the arable lands are distributed in severe and
even saline soil areas, 21.46% of dry land with severe and saline soil and 9.54% of irrigated land with
severe. 55.53% of garden land is below mild degree, and 30.31% of which is severe and saline soil. In
construction land, mild salinization accounts for 44.29%; moderate, severe and saline soil accounted for
47.58% (mainly salt fields). This shows that construction utilization did not pay attention to the
avoidance of land below moderate. 99.06% of saline wasteland belongs to severe and saline soil. In other
unused lands, severe and saline soils accounts for 96.67%, soils below moderate accounts for 3.33%.

4. Conclusions and Recommendations

4.1. Conclusion
In this paper, OLI multispectral images and ground measurements were used to extract land type and
salinization degree information, and the accuracy of extraction was improved. The results show that the
spatial distribution of salinization in Shouguang City is obvious, with non-saline, mild, moderate, severe
and saline soils being distributed in a "large concentration and small insertion" pattern from south to
north, with salinization degree gradually increasing obviously. The spatial consistency of land use and
salinization in Shouguang is remarkable, forming a spatial characteristic of "vegetable in the south, grain
and cotton in the middle, and fishing and salt in the north". The overall salinization of soil in Shouguang
City is mild to moderate, with 77.54% below moderate and 22.46% in severe and saline soils. There is a
spatial and quantitative problem of "overall matching but local mismatch" between land use and
salinization in Shouguang. In particular, dry land and irrigated land are distributed in the range of severe
salinity and even salt soil, which should be improved and utilized or returned to forest and wetland.

4.2. Recommendations
1) Developing saline wasteland in the north moderately. Salt wasteland is distributing widely in the
north of Shouguang and being not effectively utilized. The ecology is fragile and freshwater is scarce
here. The development and utilization should pay attention to the principle of moderation and
diversification. Saline wasteland could be developed and used as salt fields or mariculture. We should
strengthen the allocation of ecological land, improve its utilization rate and comprehensive benefits.

2) Adjusting space layout of utilization types. The severe salinized arable land should be converted
to forest and wetland, to improve the ecological environment. The protected cultivation area should
be moved to the north, and the soilless protected cultivation should be developed in the northern
salinization area. The slightly salinized land in the South can be changed into grain field.

3) Strengthening the prevention and control of secondary salinization in the central and southern
regions. In order to prevent new secondary salinization, we should strengthen the control of soil
secondary salinization in grain and cotton planting areas in the middle and vegetable planting areas in
the south, improve crop planting water-fertilizer and agronomic techniques.

Acknowledgements
This paper is supported by Shandong Province Key R&D Plan (Soft Science) "The development path of
comprehensive utilization of saline alkali land in Shandong Province" (2019RZB01015) and Industrial
Upgrading Project of Shandong Agricultural Science and Technology Area "Construction and
demonstration of green and efficient production mode for grain and feed crops" (2019YQ014).

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