Characteristics and sustainability of land salinization and utilization in the Yellow River Delta

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Abstract. It is of great significance to strengthen the research on the relationship between land use/cover and environmental sustainable development. Taking Hekou District in the Yellow River Delta as an example, based on “3S” technology, using the methods of field investigation, sampling test and statistical analysis, combining remote sensing classification with spatial interpolation, the land information is accurately extracted, and the land salinization and utilization characteristics and their matching relationship are analyzed. The spatial characteristics of land use in Hekou District are obvious. Cultivated land is concentrated in the southwest and southeast, a little in the middle. Aquaculture water surface and saline wasteland are concentrated in the northeast and northwest coastal area. Construction land is concentrated in the south, and salt pan fields are mainly distributed in the northwest. The spatial distribution of soil salinization in Hekou District increased from southwest to east and north in spring, showing strong variability. The spatial distribution and quantity of land use and salinization are in the relationship of "overall matching and partial mismatch". Land use should be adjusted according to the characteristics of salinization and land demand. Hekou District should strengthen the protection of cultivated land, develop characteristic gardens and animal husbandry, explore the multi-functional utilization of saline land resources, and promote regional ecological improvement and sustainable development.

1. Introduction
Land use is an important factor causing environmental change. Improper land development and utilization will aggravate the greenhouse effect and lead to the instability of climate change. Therefore, the relationship between land use/cover and the sustainable development of environment has attracted much attention. The Yellow River Delta is one of the fastest growing regions of land resources in China and even in the world, and it is also a hot area of LUCC research[1]. The habitat of this area is fragile, vulnerable to the destruction and interference of natural environment and socio-economic factors. Because it is close to the Bohai Sea, soil salinization is very serious[2]. Soil salinization will not only lead to soil fertility degradation, ecological environment deterioration, seriously threaten regional agricultural development, but also corrode building materials, endanger engineering and human safety. In recent years, in the coastal area of the Yellow River Delta, the intensity of human interference activities such as port construction, aquaculture development, salt industry manufacturing, farmland development and oilfield construction has been increasing. Human activities and natural factors work together in the process of land use/cover change in this Area, and some human activities have caused adverse effects on the sustainable development of regional ecology[3]. In view of this, further deepening the understanding...
of the characteristics of land salinization and land use and their relationship in the Yellow River Delta is of great significance for taking countermeasures to ensure the sustainable use of land in this area.

In land use/cover research, remote sensing technology has been widely used [4]. However, in the remote sensing extraction of soil salinization information, it is difficult to achieve a high degree of consistency with the actual situation only based on indoor image classification. Moreover, due to the problem of "same object with different spectrum, foreign matter with same spectrum" in remote sensing image, it will lead to misjudgement. Therefore, in order to accurately extract soil salinization information, it is necessary to combine with field measurement. However, due to human and material resources and time constraints, the number of soil salinization field monitoring sample points can’t be too many and too dense. A small number of monitoring points can’t form a large-scale monitoring of soil salinity in the whole region, and the spatial distribution of monitoring points is uneven, so it is necessary to obtain the spatial distribution of soil salinity through spatial interpolation prediction [5]. Based on the monitoring point data to establish a model inversion method to obtain regional salinization information [6], there will also be large errors in the problem of spectral confusion. The existing researches on land salinization in the Yellow River Delta mainly focus on Kenli County in the east and Wudi County in the northwest of the delta. This paper will take Hekou District in the Yellow River Delta as the research area, on the basis of field investigation, based on 3S technology, accurately extract land type and salinization information, find out the land salinization and land use situation in this area, analyze the matching relationship between the two, and provide scientific basis for the sustainable use of land in this area.

2. Materials and methods

2.1. Overview of the study area

Hekou District is located in the lower reaches of the Yellow River and the north side of the estuary. Its geographical coordinates are 37°45’-38°10’N and 118°07’-119°05’E, with a total area of 226744 hm². The terrain is high in the south and low in the north, high in the west and low in the east, with a natural gradient of 1:10000-1:15000. The altitude is generally 6-5 m, and the coastal area is 3-2 m. The main geomorphic types are gentle hillock and river beach highland, shallow flat depression, slightly inclined flat land and beach land. There are 2 types of soil: fluvo-aquic soil and solonchaks, and 3 subtypes: fluvo-aquic soil, saline fluvo-aquic soil and coastal solonchaks. This area is located in warm temperate monsoon continental climate zone, with average annual temperature of 12.1℃, precipitation of 547.6 mm and evaporation of 1280 mm. There’s a shortage of fresh water, and the runoff is concentrated in the precipitation in flood season. Surface and ground water have high salt content, both are difficult to use. Yellow River water is the only available fresh water resource. Hekou has jurisdiction over 6 towns, with a population of 219133 by 2019. In recent years, the development and utilization of saline alkali land resources has been accelerating under the promotion of national strategies such as the efficient ecological economic zone of the Yellow River Delta and the blue economic zone of Shandong Peninsula, and driven by relevant interests under the policy of "balance of occupation and compensation" of cultivated land.

2.2. Data sources

2.2.1. Remote sensing image: The Landsat OLI image (March 9, 2018, line No. 35, strip No. 121) downloaded from geospatial data cloud (http://www.gscloud.cn) is clear, the cloud cover is less (0.09%), and the land type difference is obvious. ENVI5.3 software is used for radiometric calibration, atmospheric correction and RGB color synthesis.

2.2.2. Soil salt content data: On the remote sensing image of the study area, the grid method (3×3km) is used to preset the survey sample points, and the field survey (late April 2019) is combined with the field environment to determine the field sampling points (Fig. 1). About 1kg of 0-20cm topsoil was collected by soil drill and sealed in a sample bag. A total of 83 soil samples were taken. Hand held GPS was used
to record the coordinates of sample points and the information of land use status, vegetation and so on. After natural air drying and grinding, soil salt content was determined by drying method.

2.3. Research method

2.3.1. Land supervision classification. According to China land use/cover classification system of remote sensing monitoring and China land use status classification standard, combined with the land use characteristics of Hekou District, the land types are divided into eight: cultivated land (Cu), construction land (Co), grassland (Gr), garden land (Ga), ditch (Di), aquaculture water surface (Aq), water area (Wa) and saline alkali wasteland (Sa). Using ENVI5.3 software, visual interpretation and referring to Google Earth and sky map to distinguish the categories of ground objects, draw the region of interest on the image, so that the samples are evenly distributed. Carry out supervised classification, and get the land use type map. The calculated ROI separability index of ROI samples is greater than 1.8, and the separability between samples is good. The overall accuracy of transfer matrix is 0.90 and kappa coefficient is 0.86.

2.3.2. Soil salinization characteristics analysis. Referring to the relevant soil salinization classification standards, the degree of soil salinization in the study area was divided into 5 grades: non, mild, moderate, severe salinization and saline soil. The salt content (g/kg) ranges were: (0,1), [1,2), [2,4), [4,6), [6,∞). SPSS software was used to analyze the statistical characteristics of soil salinization. Based on the measured soil salt content data of monitoring points, the spatial interpolation was carried out by using arcgis10.2 inverse distance weight method (IDW), and the distribution map of soil salt content was obtained, and the spatial characteristics of soil salinization were analyzed.

2.3.3. Spatial superposition analysis. Using arcgis10.2, the land use type map and the spatial distribution map of soil salt content were superimposed to get the salinization degree map of different types. The area and proportion of different salinization degree of different types were statistically analyzed.

3. Results and analysis

3.1. Land use characteristics of Hekou District

The spatial distribution of land use types in Hekou District is shown in Figure 2 (See 2.3.1 for land type code, Fig. 3 and 4 are the same), and the statistics of land area of each type are shown in Table 1.

![Soil sampling sites distribution map](image1)

![Land use classification of Hekou District](image2)

Table 1. Area and proportion of land use classification in Hekou District

| Land type                      | Cultivated land | Aquaculture water surface | Saline alkali wasteland | Grassland | Garden land | Construction land | Water area | Ditch | Total |
|-------------------------------|-----------------|---------------------------|------------------------|-----------|-------------|-------------------|------------|-------|-------|
| Area(hm²)                     | 54034           | 56238                     | 30467                  | 16859     | 18506       | 32367             | 14348      | 3924  | 226744|
| Proportion(%)                 | 23.83           | 24.80                     | 13.44                  | 7.44      | 8.16        | 14.27             | 6.33       | 1.73  | 100   |
As can be seen from figure 2 and table 1, the cultivated land area is $5.40 \times 10^4 \text{ hm}^2$, accounting for 23.83% of the total area of Hekou District, mainly concentrated in the southwest (south of Xinhu town) and the southeast, and few of the middle. The aquaculture water surface is $5.62 \times 10^4 \text{ hm}^2$, accounting for 24.80%, mainly distributed in the northwest and northeast corner. The saline alkali wasteland area is $3.05 \times 10^4 \text{ hm}^2$, accounting for 13.44%, mainly distributed in the northeast (the northeast of Xianhe town) and in the northwest (he north of Xinhun town). The grassland area is $1.69 \times 10^4 \text{ hm}^2$, accounting for 7.44%, mainly distributed in the north of Yihe town. The garden area is $1.85 \times 10^4 \text{ hm}^2$, accounting for 8.16%, mainly distributed in the east of the middle, close to the water source area of the Yellow River. The construction land area is $3.24 \times 10^4 \text{ hm}^2$, accounting for 14.27%, mainly concentrated in the towns in the south, the salt pan fields are mainly in the northwest, and the villages and independent construction land are sparse. The water area is $1.43 \times 10^4 \text{ hm}^2$, accounting for 6.33%, mainly including the reservoir and the old yellow river channel. The ditch area is $0.39 \times 10^4 \text{ hm}^2$, accounting for 1.73%, which is northerly but scattered, and is closely related to cultivated land and saline alkali land.

3.2. Characteristics of soil salinization in Hekou District

3.2.1. Statistical characteristics of soil salt content. The descriptive statistical results of soil salt content in Hekou District are shown in Table 2.

| Number of samples | Mean | Median | Standard deviation | Max | Min | Kurtosis | Skewness | Coefficient of variation |
|-------------------|------|-------|--------------------|-----|-----|----------|----------|------------------------|
| 83                | 5.87 | 3.71  | 5.86               | 35.24 | 0.26 | 6.45     | 2.15     | 1.00                   |

It can be seen from table 2 that the average value of soil salt content in the study area is $5.87 \text{ g/kg} \pm 5.86 \text{ g/kg}$, showing severe salinization; the median value is $3.71 \text{ g/kg}$, the maximum value is $35.24 \text{ g/kg}$, and the minimum value is $0.26 \text{ g/kg}$; the kurtosis value is 6.45, the kurtosis value is high; the skewness value is 2.15, belonging to right skewed distribution, with strong dispersion; the coefficient of variation is 1.00, showing strong variability. Generally speaking, in spring, the soil salinization in Hekou District reached the level of severe salinization. This may be related to the lack of precipitation but high evaporation in spring, resulting in a large amount of salt accumulation on the surface.

3.2.2. Spatial characteristics of soil salinization. The spatial distribution of soil salinization in Hekou is shown in Figure 3, and the area and proportion of soil salinization in different degrees are shown in Table 3.

| Salinized soil | Non | Mild | Moderate | Severe | Saline | Total |
|----------------|-----|------|----------|--------|--------|-------|
| Area($\text{hm}^2$) | 2083 | 22360 | 55185 | 59463 | 87654 | 226744 |
| Proportion(%) | 0.92 | 9.86 | 24.34 | 26.22 | 38.66 | 100.00 |

As shown in table 3 and figure 3, the degree of soil salinization in Hekou is gradually increasing from southwest to northeast. Saline soil accounts for the largest proportion, with an area of $8.77 \times 10^4 \text{ hm}^2$, accounting for 38.66%. It is mainly distributed in the Northeast coastal lowlands, and in the Southwest near reservoirs, and in the Northwest and north of central areas. The area of severe saline soil is $5.95 \times 10^4 \text{ hm}^2$, accounting for 26.22%. It is mainly distributed in the northwest of Hekou District, Hekou, Liuhe town, Gudao and Xianhe town. The area of mild salinized soil is $2.24 \times 10^4 \text{ hm}^2$, accounting for 9.86%, distributed in 7, 10 and 11 Fenchang, DongCui and Laomiao villages in Liuhe town, Xinjian and Sanhe villages in Hekou town, and Caocang, Qianjia, Pojia villages in Yihe town, Beilou, Dongfeng villages in Xinhu town. The area of non-saline soil is $0.21 \times 10^4 \text{ hm}^2$, accounting for 0.92%, mainly distributed on both sides of the old Yellow River, Daying and Danghan villages in Yihe Town, Hanjia village in Xinhu Town. The distribution of moderate saline soil is between severe and mild.
3.3. Matching relationship between land use and salinization in Hekou District

3.3.1 Spatial matching relationship between land use and salinization. The salinization of land types is shown in figure 4. The degree of soil salinization in the study area is increasing from the southwest to the northeast, and the land use types are transiting from cultivated land to grassland, saline alkali wasteland, aquaculture water surface and salt field. The Southeast is close to the water source of the Yellow River, and there is a similar transition from south to north. This reflects the spatial matching relationship between land use and soil salinization. However, it can also be seen from Figure 4 that a large area of cultivated land is concentrated or scattered in the severe salinization or even saline soil area in the north. During field investigation, it is found that in the cultivated land in the northeast, there are some crops that are not salt tolerant and drought resistant, such as wheat. This reflects the mismatch between the two. Generally, the spatial distribution of land use and salinization is "overall matching, local mismatch".

![Figure 3. Spatial distribution of soil salinization](image)

![Figure 4. Degree of salinization in different land types](image)

3.3.2 Quantitative matching relationship between land use and salinization. The area and proportion of different types of salinization in Hekou District are shown in Table 4.

| Land type              | Salinized soil | Non | Mild | Moderate | Severe | Saline | Total |
|------------------------|---------------|-----|------|----------|--------|--------|-------|
|                        | Area(hm²)     |     |      |          |        |        |       |
| Cultivated land        | 380           | 7998| 30352| 9324     | 5979   | 54034  |
|                        | 0.70          | 14.80| 56.17| 17.26    | 11.07  | 100.00 |
| Construction land      | 20            | 2610| 9247 | 6625     | 13864  | 32367  |
|                        | 0.06          | 8.06 | 28.57| 20.47    | 42.83  | 100.00 |
| Grassland              | 46            | 2028| 4702 | 6737     | 3346   | 16859  |
|                        | 0.27          | 12.03| 27.89| 39.96    | 19.84  | 100.00 |
| Saline alkali wasteland| 972           | 1848| 6973 | 8946     | 11727  | 30467  |
|                        | 3.19          | 6.67 | 29.43| 33.48    | 30.30  | 100.00 |
| Garden land            | 22            | 1235| 5446 | 6196     | 5076   | 18506  |
|                        | 0.12          | 6.67 | 29.43| 33.48    | 30.30  | 100.00 |
| Total                  | 1442          | 15718| 56721| 37829    | 40523  | 152233 |
|                        | 0.95          | 10.33| 37.26| 24.85    | 26.62  | 100.00 |

Seeing from the proportion of saline soil area of different degrees in each type, the proportion of severe salinization and saline soil in the cultivated land is as high as 28.33%, and that of moderate is more than half, indicating that the problem of cultivated land salinization is serious. It is found that some cultivated land can’t be used because of serious salinization and lack of irrigation. At the same time, due to soil erosion, rising evaporation of underground saline water, climate drought and tide, the quality of cultivated land is degraded. According to the statistical data of Hekou in 2018, the utilization rate of cultivated land is about 65.63%, which also shows that although the amount of cultivated land is large, the utilization rate is not high. More than 60% of the construction land is moderately salinized land, indicating that the
construction site selection is conducive to the protection of mild and moderate land, but some construction land is located in mild and moderate areas, which needs attention. 60% of the grassland is distributed in severe salinization area. 67.85% of the saline alkali wasteland is severe, and the remote location and lack of water resources make it unsuitable for agricultural development. In terms of quantity, the relationship between land use and salinization also exists overall matching and local mismatching.

3.4. Suggestions on sustainable land use in Hekou District

3.4.1. Strengthen the protection of cultivated land. It is necessary to strictly control the cultivated land occupied by construction in mild and moderate saline areas. We should strengthen the management and protection, constantly improve the farming and fresh water irrigation conditions. In order to ensure the quality of supplementary cultivated land, fresh water irrigation sources and facilities should be ensured for land consolidation of newly developed cultivated land.

3.4.2. Developing characteristic garden and animal husbandry. We should attach importance to the construction and protection of characteristic gardens, actively develop woodland, vigorously develop grassland, and construct production bases on the premise of maintaining ecology, so as to promote the development of picking, forest timber and animal husbandry.

3.4.3. To explore multi-functional utilization of saline alkali land resources. We should strengthen the research on the sustainable utilization of saline alkali land resources, explore the multi-functional utilization of saline alkali land resources, and promote the improvement of ecological environment and sustainable development in saline alkali areas. For saline alkali wasteland, in the case of lack of sufficient water resources, we should try to develop it as little as possible and even not develop it, give full play to its natural ecological function, and take practical measures to maintain and improve the ecology of natural reserves.

4. Conclusion
The spatial characteristics of land use in Hekou District are obvious. Cultivated land is concentrated in the southwest and southeast, a little in the middle. Aquaculture water surface and saline wasteland are concentrated in the northeast and northwest coastal area. Construction land is concentrated in the south, and salt pan fields are mainly distributed in the northwest. The spatial distribution of soil salinization in Hekou District increased from southwest to east and north in spring, showing strong variability. The spatial distribution and quantity of land use and salinization are in the relationship of "overall matching and partial mismatch". Land use should be adjusted according to the characteristics of salinization and land demand. Hekou District should strengthen the protection of cultivated land, develop characteristic gardens and animal husbandry, explore the multi-functional utilization of saline land resources, and promote regional ecological improvement and sustainable development.

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