The evolution of soil salinization in the Yellow River Irrigation District of Ningxia, China during the period of 1958 to 2007

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Abstract
Soil salinization is a real threat to agricultural systems, especially in oasis of the arid regions in the world. Hence, it is essential for the management of oasis agriculture to understand the spatial and temporal evolution of soil salinization. The combination of remote sensing image interpretation and the historical soil survey is an effective method for understanding of salt-affected soils. The three stages of soil salinization evolution in the Yellow River Irrigation District were studied during the period from 1958 to 2007. The area of salinized soil is generally decreasing, it reduced from 56.70% in 1958 to 33.52% in 2007. However, the degree of soil salinization in some areas such as downbend, lakes, fish ponds and sites with poor water drainage becomes more severe.

Key Words
Soil salinization, spatial and temporal evolution, agricultural sustainable development, Yellow River Irrigation district.

Introduction
Soil salinization is an important worldwide environmental problem, especially in arid and semi-arid regions (Wang *et al.* 2007). It is important to determine soil salinity as a parameter to environmental land management. Under arid or semi-arid conditions and in regions of poor natural drainage, there is a real hazard of salt accumulation in soils (Navarro *et al.* 2007). At the same time, soil salinization is one of the main types of land desertification and degradation and can negatively influence soil quality and sustainable agriculture (Eilers *et al.* 1997). Global total area of the salt-affected soils is about 950 million ha (Wang *et al.* 1993), accounting for 7.26% of the earth's land area. The area of the salt-affected soils is about 27 million ha in China. Of these about 6.7 million ha is farmland, accounting for 7% of the total farmland in China which mainly occurs in Xinjiang, Gansu, Ningxia, Inner Mongolia Autonomous Region and eastern coastal areas. The mitigation and control of soil salinity is one of the main challenges in the agriculture of the 21st century, in particular, where Irrigation is applied (Amezketa 2006). The effective management of the salt-affected soils requires understanding of not only the mechanism of soil salinization, but also the laws of space-time evolution. Some scholars have conducted many studies of soil salinization by remote sensing and other methods in arid regions (Metternicht and Zinck 2003; Mougenot *et al.* 1993; Metternicht 2001; Semih and Cankut 2008; Houk *et al.* 2006). This study analyses the data of historical soil survey mapping and the remote sensing image, aiming to find the trend of soil salinization and to provide a scientific method for soil improvement in the Yellow River Irrigation District of Ningxia, China.

Methods
Study area
The Yellow River Irrigation District of Ningxia, China, is located in the temperate arid zone with a continental climate at an average annual temperature of 9 ^{o}C (Figure 1). It covers an area of 7,790 km^2. The amount of annual rainfall totals is approximately 185 mm, most of which falls during the summer months between June and September. The annual evaporation is 1825 mm, nearly ten times more than the annual precipitation, and the drought index is 6.5. The annual average runoff in the Yellow River is 1030 m^3/s and the total volume of annual water flow through the Yinchuan Plain is 3.25×10^{10} m^3 (Zheng and Wang 2006). Soil salinization is a common feature in arid regions, and is particularly serious in the Yellow River Irrigation District of Ningxia in China. Soil salinization is not only the most important restricting factor for vegetation growth, but also the first barrier in the regional agricultural production. The Irrigation for agricultural purpose in China began since the Qin and Han dynasties, with the history of more than 2,000

years. In the meantime, the Irrigation played an important role in agricultural production year after year. However, the Irrigation water inevitably contains a certain amount of soluble salt, which leads to the rise of salt content in soil. Especially, the excessive Irrigation can usually cause the rise of the groundwater Table and make the soil more saline, which will reduce soil pore space and decrease soil capability for holding air and nutrients (O'Hara 1997). The soluble salt carried by Irrigation water can increase the soil salt content. Without proper drainage, the salts tend to accumulate in the upper part of soil profiles. Therefore, the formation of soil salinization is the result of many natural factors such as climate, hydrology, topography and geology and human activities.

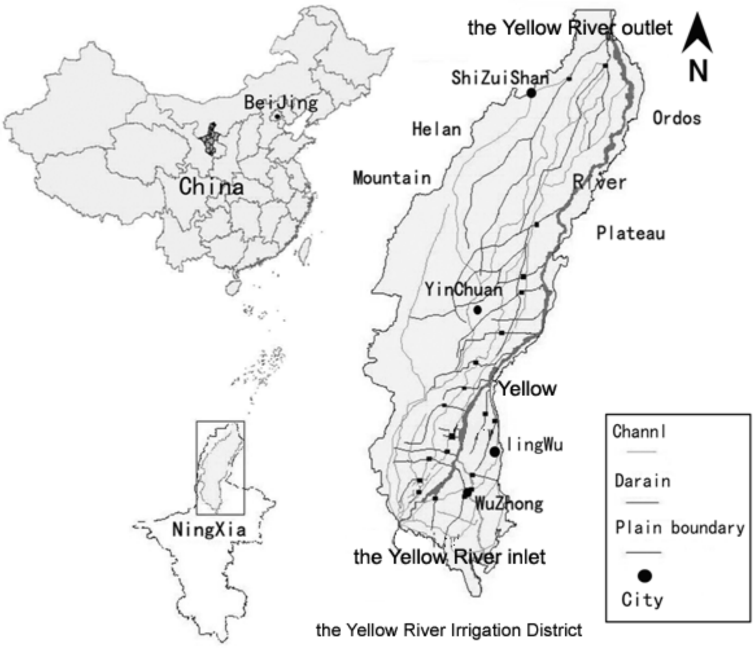

Figure 1. Location of the Yellow River Irrigation District of Ningxia, China.

The historical survey of soil salinization in the study area

In order to understand the developing trend of salt-affected soils, the surveys of soil salinization by the Government of Ningxia Autonomous Region were conducted for five times from 1958 to 2005. The data of the first three stages was based on the soil survey map; that of the last two stages was based on the remote sensing image interpretation.

Remote sensing image interpretation

The satellite images were taken on April 24, 2007 by the CBERS-02B satellite and downloaded from the China Centre for Resource Data and Application (CRESED), which are the second level products of CCD camera.

Table 1. Classification of soil salinization and the key to interpretation.

Contents	Non-salt-affected soils	Salt-affected soils		
		Lightly salt-affected soils	Moderately salt-affected soils	Heavily salt-affected soils
Soil total salt (%)	<0.15	1.5-3.0	3.0-6.0	6.0-10
Salt spots ratio	<1/10	1/10-1/3	1/3-1/2	>1/2
Groundwater level (m)	>1.5	1.5-1.8	1.2-1.5	>1.0
Salinity (g/L)	<2.5	2.5-3.0	3.0-4.0	>4.0
surface features	With dense vegetation, no or few salt crusts on the surface	With dense vegetation, and 1-5cm salt crusts on the surface	With sparse vegetation, and a less than 5cm salt crusts on the surface	With bare vegetation and a 10-20cm salt crust on the surface

They contain four spectral bands with a resolution of 20×20m per pixel for each. The data acquired by CBERS-02B CCD camera has five spectral bands, which are blue band (0.45~0.52μm), green band (0.52~0.59μm), red band (0.63~0.69μm), near infrared band (0.77~0.89μm) and short infrared band (0.51~0.73μm). In this study, the pseudo-colour composite of band 432 is used, and the specific contents of remote sensing image interpretation signs are established for each type of soil salinization (Table 1).

Results

The results (Figure 2) showed that the evolution of soil salinization has gone through three stages (1958-1962, 1962-1997 and 1997-2007) in the Irrigation district.

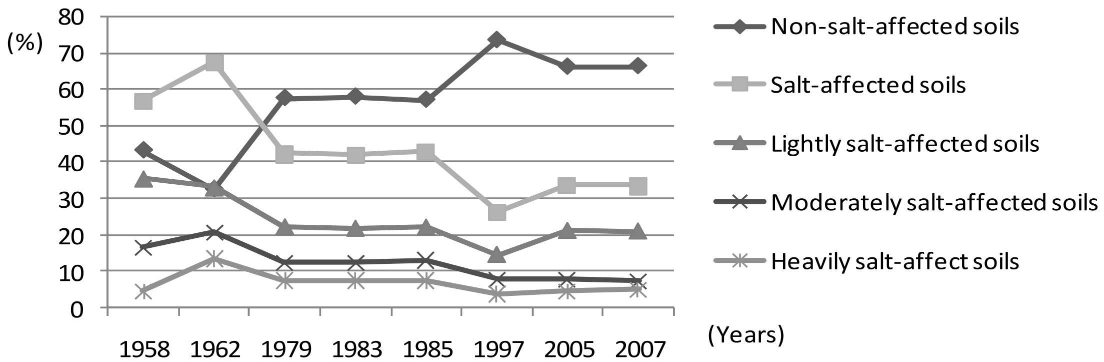

Figure 2. The evolution of soil salinization of the Yellow River Irrigation District from 1958 to 2007.
a. The total value (percent) is a sum of non-salt-affected soils and salt-affected soils; the value (percent) of salt-affected soils is a sum of lightly salt-affected soils, moderately salt-affected soils and heavily salt-affect soils.
b.The data from 1958 to 1985 is from Ningxia Soil, P410.
c. The data in 1997 is from Ningxia Hui Autonomous Region Eco-Environmental Remote Sensing Investigation Report, P9 and P31.
d. The data in 2005 is from cultivated land soil survey and salt-tolerant plant breeding in the Yellow River Irrigation District of Ningxia, Ningxia People's Publishing House. 2006. P74.
e. The data in 2007 is the result of remote sensing image interpretation in this study.

The first stage (1958-1962)

The proportion of salinized soils increased from 56.7% in 1958 to 67.39% in 1962 (Figure 2), with the soil salinization areas of 16.22×10^4ha and 19.27×10^4ha, respectively. At this stage, the natural disaster took place for three consecutive years in New China's history. In order to solve the problem of severe food shortage throughout the country, the rapid expansion of rice cultivation area was an inevitable choice in Irrigation district. The quantity of the water diversion from the Yellow River ranged from $4.61\times10^8m^3$ to $5.26\times10^8m^3$. The quantities of the water discharge, meanwhile, were $12.3\times10^8m^3$ and $16.5\times10^8m^3$, respectively. The activities eventually lead to the hazard of water discharge and the rise of groundwater Table, which intensified soil salinization in the Irrigation district.

The second stage (1962-1997)

The local government learned a lesson and built the five major drainage systems including the Red Flag Canal, the Sier Drain Ditch, the Yinxin Drain Ditch and the Yonger Drain Ditch to desalinate the soils by drainage. The establishment of agricultural infrastructure is an effective measure to control and lower groundwater Table in the Irrigation district in the stage. The groundwater depth was maintained between 1.65 to 1.8 meters. At the same time, the government made strict polices control the area of paddy fields in the northern Irrigation district as an additional measure. As a result, the percentage of soil salinization area fell from 67.39% in 1962 to 26.37 % in 1997. However, the distribution of soil salinization within the Irrigation district was imbalance due to the differences in hydrological and geological conditions. The southern areas with excellent drainage conditions accounted for 14.44%; the central areas accounted for 25.69%; the northern areas accounted for 42.37% due to the poor drainage.

The third stage (1997-2007)

During the past decade, the overall degree of soil salinization in the Irrigation has been generally low. However, the degree of soil salinization in some areas with higher groundwater Table and poor drainage has been elevated to some extents. In general, the area of the heavily and moderately salinized soils continues to decline, while that of the lightly is still increasing. By 2007, the degree of soil salinization in the district is as follows.

1. The area of lightly salt-affected soils makes up about 21.12% of the farmland in the Irrigation district, which is mainly distributed in the upland, with groundwater Table of 1.5 to 1.8 meters in depth in the counties of Pingluo and Linwu, whose capability of land production is moderate.
2. The area of moderately salt-affected soils makes up about 7.37% of the farmland in the Irrigation district, which is mainly distributed in lowland and blocked areas in Huinong, Helan and Pingluo counties, with lower capability of production.
3. The area of heavy salt-affected soils makes up about 5.03% of the farmland in the Irrigation district, mainly distributed in Helan, Huinong and Pingluo. It is in a depression with difficulty in water drainage or the new low farmlands without a drainage system, with the lowest capability of production.

Conclusion

Soil salinization brings an increasing environmental hazard, especially in arid Irrigation areas. This study has elucidated the stages of soil salinization evolution in Yellow River Irrigation District. The overall level of soil salinization in Irrigation area is alleviated. The level of soil salinization has gone through a tortuous process from lightly affected to heavily affected, then from heavily affected to lightly affected and finally from lightly affected to heavily affected. However, the overall trend is going down. The rate of soil salinization is reduced from 56.70% in 1958 to 33.52% in 2007. The non-salt-affected soils soil increases from 43.30% in 1958 to 66.48% in 2007. The soil salinization in some Irrigation areas tends to become more severe, which is mainly distributed in downbend, lakes, fish ponds and other places with poor water drainage. Most canals in the Irrigation district are in poor condition, which leads to sideway leaking and results in the rise of groundwater Table in the nearby area. Meanwhile, it becomes more difficult for water drainage in the district because most pumped wells are deserted and some stopped working due to the lack of funds. The surface water and groundwater in the northern Irrigation district are flowing to the south, which is one of the reasons for the increase of soil salinization in parts of the old Irrigation areas.

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References

Amezketa E (2006) An integrated methodology for assessing soil salinization, a pre-condition for land desertification. *Journal of Arid Environment* **67,** 594-606.

Houk E, Frasier M, Schuck E (2006) The agricultural impacts of Irrigation induced waterlogging and soil salinity in the Arkansas Basin. *Agricultural Water Management* **85,** 175-183.

Metternicht G (2001) Assessing temporal and spatial changes of salinity using fuzzy logic, remote sensing and GIS. Foundations of an expert system. *Ecological Modelling* **144,** 163-177.

Metternicht GI, Zinck JA (2003) Remote sensing of soil salinity: potentials and constraints. *Remote Sensing of Environment* **85,** 1-20.

Mougenot B, Pouget M, Epema G (1993) Remote sensing of saltaffected soils. *Remote Sensing Reviews* **7,** 241-259.

Navarro PJ, Jordan MM, Melendez PI, Gomez I, Juan P, Mateu J (2007) Eestimation of soil salinity in semi-arid land using a geostatistical model. *Land degradation and development* **18,** 339-353.

Eilers RG, Eilers WD, Fitzgerald MM (1997) A salinity risk index for soils of the Canadian Prairies. *Hydrogeology Journal* **5,** 68-79.

O'Hara SL (1997). Irrigation and land degradation: Implications for agriculture in Turkmenistan, central Asia. *Journal of Arid Environments* **37,** 165-179.

Semih E, Cankut O (2008) Estimating soil salinity using satellite remote sensing data and real-time field sampling. *Environmental Engineering Science* **25,** 981-988.

Wang YG, Xiao DN, Li Y, Li XY (2007) Soil salinity evolution and its relationship with dynamics of groundwater in the oasis of inland river basins: case study from the Fubei region of Xinjiang Province, China. *Environ Monit Assess* **140,** 291-302.

Wang ZQ, Zhu SQ, Yu RP (1993) 'Saline soil of China.' pp. 1. (Science press Publishing: Beijing) (in Chinese)

Zheng J, Wang Y (2006) Research on the Bearing Capacity of Water Resources in Yinchuan Plain. *Journal of Ningxia University (Natural Science Edition)* **27,** 80-83. (in Chinese)