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Saline-alkali land in the Yellow River Delta: amelioration zonation based on GIS

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Abstract: Soil salinization is one of the major land degradation types and has greatly influenced sustainable agricultural development. Zonation of saline-alkali land is the precondition for effective amelioration. The present situation of saline-alkali land is monitored by remote sensing image processing. Causes for land salinization are analyzed, especially the two key factors, ground water depth and its mineralization degree, are analyzed by using long-term observation data. Previously, zonation of saline-alkali soil was made descriptively and artificially. Based on the present situation of saline-alkali land, ground water depth and ground water mineralization degree, the zonation of saline-alkali land for amelioration in the Yellow River Delta was completed quantitatively. Four different types of saline-alkali land amelioration zones are delineated, namely, easy ameliorated zone, relatively difficult ameliorated zone, difficult ameliorated zone and unfavorable ameliorated zone. Countermeasures for ameliorating saline-alkali soils are put forward according to ecological conditions of different saline-alkali land zones.

Saline-alkali land in the Yellow River Delta: amelioration zonation based on GIS GUAN Yuan-xiu, LIU Gao-huan, WANG Jin-feng (State Key Laboratory of Resources and Environment Information System, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China) Globally, an estimated land area of 9.55×108 ha is affected by salinity and sodicity[1]. In the Yellow River Delta, saline-alkali land covers more than 70% of the total area. Soil salinization is the key factor that influences sustainable agricultural development. Geographic information system (GIS) is a powerful tool for spatial data analysis, which can be used to analyze data from different sources for saline-alkali land monitoring. Based on GIS, zonation of saline-alkali land can provide scientific basis for soil amelioration and sustainable agricultural development. 1 Study area ´Yellow River Delta´ is a fan-shaped landform with Ninghai at its tip, ranging from Taoer river mouth in the north to Zimai river mouth in the south[2]. The entire Dongying city was selected as study area which covers Hekou district, Lijin county, Kenli county, Dongying district and Guangrao county. Geographically, the area is coordinated from 36°55´ to 38°12´N and 118°07´ to 119°10´E. The area is topographically flat with a gentle slope. It is high in the south and west, low in the north and east. The highest elevation is 28 m in the southwest and the lowest is 1 m in the northeast. The natural gradient is 1/8000-1/12000. The Yellow River is the major builder of the Yellow River Delta. The micro-landforms of terraced uplands, coastal plain, flood plain, modern Yellow River Delta and sea shore are arranged in alternation due to frequent shifting of river course. The study area is located in a warm temperate zone with mean annual precipitation of 600 mm and mean annual evapotranspiration of 1944 mm. Ground water table is high and the water is poor in quality. Only the terraced uplands in south of the Xiaoqing river are covered with fresh water, the other part of the study area is covered with brackish water and salt water. From south to north and from inland to sea, the ground water table becomes shallower and shallower and the water mineralization becomes higher and higher[3]. Most of the areas are irrigated by the Yellow River. Owing to a gentle slope, Yellow River lateral seepage and sea water intrusion, the surface drainage is poor. Consequently, the land has greatly been salinized. Calcaric fluvisols and solonchaks calcaric are the major soil types. 2 Data and methodology 2.1 Data sources The following data was used for zonation of saline-alkali land in the Yellow River Delta: (1) Landsat TM data with Orbit 121-34 and acquired on June 25, 1999 was used for saline-alkali land monitoring. (2) Some 24 sheets of topographical maps at scale of 1:50,000 published in 1984 were used to register satellite data and for ground truth collection. (3) The analysis result of the topsoil acquired in September 1999 and the ground wat er long-term observation data from 1991 to 1997 were used as ancillary data (The ground water observation data was provided by Hydrogeology and Geology Engineering Institute of China). 2.2 Methodology 2.2.1 Digital image processing The digital image processing has been widely used for saline-alkali land monitoring since the 1970s. Peng W. L. et al. proved that ´Tassled Cap´ transform can not only enhance the detectability of features, but also aid data compression [4]. Initially, Landsat TM digital data of 1999 was registered to topographical maps at scale of 1:50,000 through an image-to-map routine by identifying 25 pairs of GCP (ground control points). Subsequently, the digital data was resampled using a second order polynomial transform to a sub-pixel accuracy. The pixel size of the geo-referenced image is 30 m×30 m. ´Tassled Cap´ transform is a linear transformation of multi-spectral space. After ´Tassled Cap´ transforms, the former 3 dimensions of the geo-referenced image represent brightness, greenness and wetness. The brightness dimension contains information on soil, the greenness dimension is correlated to green plants, and the wetness dimension reflects soil water content. Soil salinization difference can be distinguished using brightness variable. The soil salinization degree is correlated to reflectivity. The higher the brightness variable value is, the more severe soil salinization and greater the brightness. Although the brightness and the wetness characteristics contain most information on saline-alkali soil, the greenness variable was referenced. The false color composite image was made by assigning RGB to brightness variable, greenness variable and wetness variable respectively. According to the relationship between the spectral response pattern as seen in image with ground truth and physio-chemical characteristics of saline-alkali soils established by field observation, the training samples were identified. The tidal flat is characterized with darkness, wetness and sparse vegetation cover; the areas like red and purple flowers indicate high reflectivity, low wetness and poor vegetation cover. These areas are heavily salinized-alkalized lands where the barren land accounts for more than half of the type of the land. Only Seablite and Chinese tamaris can survive there. The reflectivity of moderately salinized-alkalized land is lower than that of heavily salinized-alkalized land while the vegetation coverage on the former is higher than that on the latter. The moderately salinized-alkalized land is distributed alternately with arable land and grassland. About 50% of seedlings in moderately salinized-alkalized land can survive. The yellow areas in the image indicate common wetness and vegetation cover. These areas are lightly salinized-alkalized lands where 80% of the seedlings can survive; the bright green areas indicate high vegetation coverage and the bright red areas are newly harvested cornfields. These areas are arable land. Following tidal flat, heavily salinized-alkalized land, moderately salinized-alkalized land, lightly salinized-alkalized land and arable land, the vegetation coverage becomes higher and higher. The signature was completed until the cognition of training sample meets the desired classification accuracy. Subsequently, the decision rules are trained using the signature and the image is classified using the Maximum Likeliness Classification scheme. Accuracy assessment is a process to measure the accuracy attained using various classification schemes by comparing the classification result with the ground truth data. The method in common use is based on an error matrix[5]. An error matrix is a square array of numbers set out in rows and columns which express the number of sample units assigned to a particular category relative to the actual category as verified on the ground. The columns usually represent the reference data while the rows indicate the classification generated from the remotely sensed data. Since checking each classified pixel is not only impractical but also undesirable, one must use random sample. The supervised classification accuracy was assessed using stratified random sampling. Some 300 sample points were collected and each category was guaranteed to have more than 10 sample points. The visual interpretation results and data from fieldwork were used as ground truth data. The Dongying land-use map was used as ancillary data. The overall accuracy is about 91% (Table 1). Table 1 Error matrix of the supervised classification of the saline-alkali land in Yellow River Delta The classification result was generalized and changed into vector format. Then zonation of saline-alkali land in the Yellow River Delta was conducted (Figure 1). 2.2.2 The zonation model The development of salinity and alkalinity is governed, to a large extent, by re-distribution of salts in the soil profile brought about by fluctuation of ground water surface, which is a dynamic phenomenon and varies seasonally and annually. The saline-alkali land situation in the Yellow River Delta is the result of interaction of climate, geology, geomorphology, hydrology, hydrogeology, soil, sea tide, human activities and so on. The natural condition is the precondition for saline-alkali land formation. The rise of ground water table resulted from land-use change is the direct cause of soil salinization. The fundamental principle of saline-alkali land amelioration zonation lies in scientific and reasonable zoning by grasping leading factors. Long-term research and practice proved that the ground water depth has a close relationship with soil salinity or alkalinity. The approach of taking the critical buried depth of ground water table and quality as criterion to forecast, the occurrence possibility of soil salinization or alkalization has been accepted universally[6,7]. The sticking point of secondary salinization in the Yellow River Delta is high ground water mineralization degree and high ground water table. Based on the above analysis, the three leadin g factors of current saline-alkali land conditions, buried depth of ground water and mineralization were taken to conduct saline-alkali land amelioration zonation. In the Yellow River Delta, the soil texture is mainly sandy clay loam. The evapotranspiration is much higher than precipitation. The water need for evapotranspiration is provided by ground water continually. Consequently, the shallower the ground water depth is, the stronger the evapotranspiration and soil salinization. In the case with similar ground water depth and soil texture, the higher the ground water mineralization degree is, the stronger the soil salt accumulation is. The stronger the soil salinization is, the more difficult the soil amelioration is. Based on the water and salt movement law and saline-alkali land situation, we assigned weights to influencing factors of ground water depth, ground water mineralization and saline-alkali land using the Delphi process (Table 2). The Delphi process is a popular decision-by-committee approach. Each person in the committee assigns weights. These weights are averaged to create the final weighting scheme. The scores and weights in Table 2 were debugged until they were proved to be suitable for amelioration zonation in the Yellow River Delta. Table 2 Weight assignment for the factors of saline-alkali land The ground water observation data is in the form of random points. In order to classify and zonalized ground water, value of each cell should be estimated using observation data. That is assigning a measurement point to a representative area. Traditionally, the cell value was interpolated artificially using the measurement. Kriging is a geological statistical method. It comes of mineral resources prediction and becomes popular in the realm. Recently, it is used to analyze the variability of geological space and ground water observation data. Kriging is a statistical technique for interpolating unknown values using a moving search window and weights are assigned based on distance. GIS grid was made by interpolating ground water depth and mineralization using Kriging method on the ARC/INFO platform. Then contour maps were made using grid-to-line transformation. According to Table 2, zones of ground water depth (Figure 2) and zones of ground water mineralization degree (Figure 3) were created. Figure 2 Zones of ground water buried depth in the Yellow River Delta Figure 3 Zones of ground water mineralization degree in the Yellow River Delta Superposition analysis of ground water buried depth, ground water mineralization and saline-alkali land was made with weights. The process can be expressed as a mathematical 3-D matrix. In order to simplify the problem, the 2-D matrix is illustrated as follows (Tables 3 and 4): According to the result of superposition analysis, the zonation model was set up as follows: (1) where P represents polygons of the superposition analytical result; j represents the number of influencing factors; I represents score; and W represents weight. Table 3 Superposition analysis of ground water buried depth and mineralization degree Table 4 Superposition analysis of ground water buried depth, mineralization degree and current saline-alkali land conditions The amelioration zonation was conducted using the above-mentioned model and the zones of saline-alkali land amelioration in the Yellow River Delta were identified (Figure 4). 3 Results and discussion 3.1 Saline-alkali land situation Besides the terraced uplands in the south and the Yellow River course (accounting for 15%), the other parts of the Yellow River Delta were salinized or alkalized to different degrees. The salt marsh is distributed along the coastline with an elevation of less than 2 m above the sea level. Heavily salinized-alkalized land accounts for 28%. It is crosscut the Yellow River like two belts. One is on the inner side of the salt marsh, and the other is along the coastline of the year 1855. The distribution pattern of the heavily salinized-alkalized land is consistent with the geographical distribution of highly mineralized ground water. It is proved that not only ground water buried depth and quality but also sea and the Yellow River influence the salt content of soils. Besides salt marsh and heavily salinized-alkalized land, most of the areas to the north of the Yellow River are moderately salinized-alkalized land which accounts for 17% of the total area. Lightly salinized-alkalized land accounting for 22% is distributed near the Yellow River estuary and on the inner side of heavily salinized-alkalized land. All in all, the distribution of saline-alkali land in the Yellow River Delta looks like two overlapped fans. The Yellow River is the axis of the two fans and the 1855 coastline is their interface. From the edge to the inner, from the axis to the wing, soil salinization becomes increasingly severe. The spatial distribution pattern of saline-alkali land in the Yellow River Delta embodies the environmental characteristics of a river estuary influenced jointly by river and sea. 3.2 The ground water situation The ground water is determined to a great extent by the geomorphologic conditions. From the terraced uplands in the south to the northern shore of the deltaic plain, the ground water depth varies from more than 10 m to less than 1 m and the contents of soluble salts in the ground water increase by 2 g/l to 30 g/l. The ground water buried depth in most parts of the Yellow River Delta is less than 2 m. The shallow ground water buried area accounts for 75%. Even if the salt content of the ground water is low, soil salt accumulation will occur in shallow ground water buried areas. So only the ground water table be regulated to below the critical depth can soil salinization be avoided. Chloride water is the major water type in the Yellow River Delta. Fresh water (<2 g/l) accounts for 23.6%, which is distributed in the terraced uplands and areas far from the sea. From the inland to the seaside, the ground water mineralization degree increases gradually. The g

round water mineralization degree in the southeast is more than 50 g/l and even reaches up to 100 g/l in some areas. 3.3 Countermeasures The zonation of saline-alkali land for amelioration in the Yellow River Delta was completed using the zonation model. Four different saline-alkali land amelioration zones were delineated, namely, easy ameliorated zone, relatively difficult ameliorated zone, difficult ameliorated zone and unfavorable ameliorated zone. The countermeasures for ameliorating saline-alkali soil were put forward according to ecological condition of different salinity-alkality zones. The easy ameliorated zone is distributed in the terraced uplands in the southern part, flooded plain in the western and the Yellow River flood land, which covers an area of 161,389.1 ha and accounts for 21%. In most of these areas, ground water depth is more than 5 m and ground water mineralization degree is less than 2 g/l. The natural condition of this region is suitable for agricultural development. Soil salinization will not happen if irrigation practice is properly done. Relatively difficult ameliorated zone is distributed on the outer side of easy ameliorated zone. The altitude of these areas is relatively high. Lightly salinized-alkalized soil and moderately salinized-alkalized soil are the major types of this area, which cover an area of 277,492.9 ha and account for 36%. Most of the secondary salinized soil is found here. The regional environment is fragile. The ground water depth of most of the areas is less than 1 m and the ground water mineralization degree ranges from 2 g/l to 10 g/l. The stabilization of the Yellow River channel and prevention of sea water intrusion are the preconditions for agricultural development. Soil amelioration profit from water control is the core problem. The water and soil resources should be developed, managed and harnessed through engineering, biological and agronomic measures. The detailed zonation strategy should be made and the land use scale, structure, and allocation should be adjusted. Land unsuitable for crop growing should be turned into grassland or forestland. Consequently, the eco-agriculture will be developed. The difficult amelioriated zone covers 149,661.5 ha and accounts for 20%. The ground water is characterized by very high water level and salt content. Salt content in the whole soil profile is overmuch. Soil amelioration is a long-term task, any undue haste should be avoided. Water and salt observation network should be built as soon as possible. Engineering projects should be constructed. According to the law of salt and water movement, ground water should be rationally controlled and regulated to prevent soil salinization. In addition, integrated development and management measures should be worked out. With natural leaching and artificial flooding, desalination of soil and ground water will take place gradually. The unfavorable amelioration zone distributed in salt marsh and heavily salinized-alkalized land covers 177,814.0 ha. The soil salt content in these areas is more than 2 g/l. The ground water depth is less than 1 m and mineralization degree is more than 30 g/l. In the near future, these areas will be unfavorable for amelioration because they are still affected by tides and storm surge. 4 Conclusions Previously, the zonation of saline-alkali soil was completed descriptively and artificially on topographic maps[8]. Both the objectivity and effectivity is too poor to meet the need of up-to-date and reliable information. In this paper, the zonation of the Yellow River Delta was established according to current situation of saline-alkali land. The two key factors, ground water depth and mineralization were taken into account. Based on GIS, the zonation was made quantitatively. Not only processing speed but accuracy was improved. This is a pilot study. Weight was tentatively assigned to factors that influence soil amelioration. In soil zonation, saline-alkali land conditions, ground water buried depth and mineraliztion were considered. In the years to come, micro-geomorphology, irrigation system, drainage system, farming system and so on should be taken into account to work out operational countermeasures. References

关键词： GIS; the Yellow River Delta; saline-alkali land; zonation