An Analysis on the Inter-annual Spatial and Temporal Variation of the Water Table Depth and Salinity in Hetao Irrigation District Inner Mongolia, China

Jun Du [a、b] Peiling Yang [a*] Yunkai Li [a] Shumei Ren [a] Xianyue Li [a] Yandong Xue [a]
Lingyan Wang [a] Wei Zhao [a]
a. College of Water Conservancy and Civil Engineering, China Agricultural University, Beijing 100081,China ; b. Bureau of Ningxia Farm，Yinchuan Ningxia 750001,China
dujun7927@163.com, yangpeiling@126.com （＊Corresponding author), liyunkai@126.com, renshumei@126.com, xueyandong1104@yahoo.cn, lxywater@yahoo.com.cn, wanglingyan@163.com

Abstract: Long-term Yellow River irrigation and the unique natural conditions in the Heitao Irrigation District (HID) Inner Mongolia, China, has led to serious environmental problems such as the shallower groundwater table and soil secondary salinization, etc. The conflicts among socio-economic development, water shortage and environmental degradation have become increasingly critical. By using the statistical methods, geo-statistical methods and ArcGIS9.0, we analyze the temporal and spatial variation of depth to water table (DWT) and groundwater salinity in the three different irrigation seasons in 2001, 2002 and 2003 respectively. The results show that DWT and groundwater salinity has formed a ribbon distribution after the long-term Yellow River irrigation. DWT is medium spatial correlative and the average spatial autocorrelation distance is 18.5km; the groundwater salinity is strong spatial correlative and the average spatial autocorrelation distance is 12.5km. The inter-annual distribution of DWT and groundwater salinity in 2001 is quite similar with it in 2002 and 2003. The DWT in western area, eastern area and a small part of middle area are shallower than other area in HID. The average DWT in March reached maximum and its minimum is in November each year. There are two high salinity degree zones (M>5000mg/l and even some other M>30000mg/l). The shallower groundwater salinity in the southeast and northwest are higher than that of in the middle part of HID. The shallower water table depth is, the higher the salinity of groundwater will be; the deeper water table depth is, the lower the salinity of groundwater will be.

Keywords: Hetao Irrigation District, Depth water table, groundwater salinity, spatial and temporal variation

1. Introduction

The HID (40°19′-41°18′ N, 106°20′-109°19′ E) is one of the three largest irrigation districts in China and be located the arid western part of Inner Mongolia Autonomous Region, China (Fig.1). The total land area of the HID is about 1.1×10^4 km^2, the irrigable land area is about 0.77×10^4 km^2, but due to salinity problems, the currently irrigated land area is only about 0.57×10^4 km^2. HID is in the mid-temperate zone with continental-monsoon arid climate. The weather is dry and hot during summer and severely cold with little snow in winter. From November to next March is a freeze-thaw period. Mean annual temperature is 6.3~7.7℃. During the winter the average air temperature are -10 °C and the soil freezing depths about 1.0 m. The average annual pan evaporation is about 2164 mm. Across HID, the average annual precipitation 168 mm recently 10 years. The the average ground slope is about 1/8000~1/4000 (from southwest to northeast). The ground elevation ranges from 1043 m to 1018 m. The main soil types are irrigation-warping soil and saline soil which was the non-zonal soils in HID. The average soil bulk density（0-100cm） is 1.45 g/cm^3 (Yang Jingyu, 2006).

The most common crops are sunflower, wheat, and corn. Flood irrigation is the most common irrigation method in the HID. The average depth of irrigation is 450 mm. Farmland is typically irrigated 7 times each year in 3 irrigating seasons. The 3 irrigation seasons are: summer irrigation (3 irrigation times, from April to June), the first-autumn irrigation (3 irrigation times, from July to September), and the second-autumn irrigation (1 irrigation times, from October to November). The summer and first-autumn irrigation are during the growing season of the crop. The purpose of the second-autumn irrigation period is to “bank” soil water and leach salt. From 1989 to 2005, the average annual water diversion of irrigation from the Yellow River is 5.2×10^9 m^3 by 1 main canal and 13 sub-main canals. Farmland recession water is drainage into the Wuliangsuhai Lake (Fig.1) by 1 main ditch and 10 sub-main ditches (Wang et al., 2004), and the average annual drainage amount was 0.5×10^9 m^3. The water diversion of irrigation in 2001, 2002 and 2003 was 4.89×10^9 m^3 ,5.08×10^9 $m^3$and 4.1×10^9 m^3 respectively. The salts which are brought by the irrigation water onto the farmland soil averages annually 235.5×10^8 kg, but the average annual discharged salt from the entire district by drainage is only 75.0×10^8 kg (Wang et al.,2004). For the period from 1987 to 1997, the average annual salt accumulation was estimated to be 3 mg/ha (Feng et al., 2003). About half of the irrigated cropland is saline-alkali soil (Feng et al., 2005). DWT is typically 1.0~1.5 m during the growing season and about 0.5 m following the second-autumn irrigation (from October to November) (Hao et al., 2008a).

Due to the arid climate, the water diversion from Yellow River is critical for agriculture in the HID. There are significant negative effects from flood irrigation and canal seepage. The resulting shallower DWT combined with intensive evaporation has produced a very high threat of soil salinization. About 18.8% of the total land area in the irrigation district has been abandoned because of the salinization problem, and about 43.0% of the irrigated area is significantly impacted salinization problem of various degrees (Qu et al., 2007). Geological structure, geographical conditions, and climate factors determine the hydrological cycle and the resulting potential for salinization. In HID, there are many factors affecting the salinity such as precipitation, evaporation, DWT, and water diversion irrigation from Yellow River (Wang et al., 2007; Yue et al., 2009). The geological structure determines that the major hydrologic pathway for groundwater loss away from the HID is through the phreatic evaporation (Hao et al., 2008a). And the accumulated salt in the deeper soil were dragged into the surface soil in this process. So, the process of groundwater discharge is the dominated factors related to the production, development, and evolution of the soil salinization in HID. Irrigation (precipitation), infiltration, drainage, and groundwater evaporation, create the natural-artificial surface water system that is the most important factor in hydrological cycle for the HID (Hao et al., 2008a).

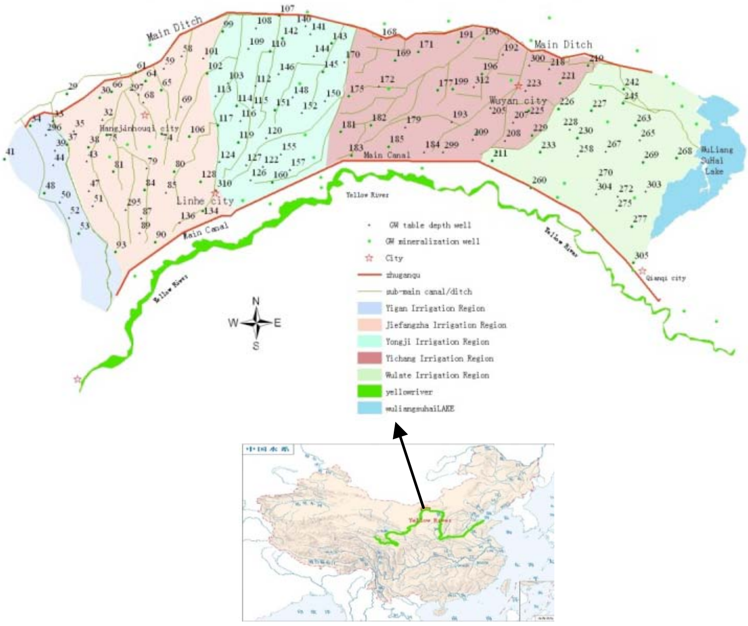

Fig.1 Map of Irrigation District located and observation wells distribution

A previous study showed that shallower groundwater had a significant effect on evaporation-transpiration and on soil water salinity. Evaporation exacerbated the surface soil water salinity, while the transpiration reduced the soil water salinity in the growth period of vegetation (Zhang et al., 2004). Climate condition and groundwater level fluctuation were the major environmental factors on the salinization of soil (Chen et al., 1997). Some studies on the salinity and DWT in HID showed that DWT is in 1.5m～2.0m contribute to the crops uptake the groundwater, but to minimize salinizion, DWT should be controlled below 2.0m from the soil surface (Kong，2009). When the water diversions from the Yellow River to the HID were reduced by 30%, there was resulting higher of DWT and reduction in salinity soil, but there was greater potential for soil water deficit and crop water stress. (Qu et al., 2007). Other researchers have reported on the soil salinization issues in HID such as: saline land improvement, the relationship between the soil salinization and the DWT, the distribution of salt in the soil profile, the salt balance, and the water balance (Yang et a1.,2003 ; Kong，et a1.,2004;Wang et a1., 2004; Jia et a1.,2006; Gao et a1., 2008a,b). But there are very few studies on the distribution of DWT and groundwater salinity in the entire HID. Therefore, this report is an analysis of the spatial and temporal variation of the DWT and groundwater salinity.

2. Materials and Methods

2.1 DWT measurement and water samples analysis

In this analysis, the HID was divided into 5 irrigated areas: Yigan, Jiefangzha, Yongji, Yichang and Wulate (Fig.1). There were 178 wells (Fig.2) distributed over the entire District. Seventy-five wells were used to observe the DWT, 42 wells were used to collect groundwater samples, while 61 well were used for both DWT and water samples.

The water quality analysis was performed at the Bayannur Water Conservancy-Science Institute Laboratory, Linhe, China. The constituent ions included: Na^+ and K^+ (determined by the flare photometer method), Ca^{2+} and Mg^{2+} (determined by EDTA titration), CO_3^{2-} and HCO^{3-} (determined by the acid titration), CL^- (determined by $AgNO_3$ titration method), SO_4^{2-} (determined by EDTA indirect titration method).

DWT was measured directly by a measuring tape with a detector at the end (Fig.2). The detector gave a signal when it reached the water surface and the length of the tape was recorded. Depth to groundwater table was calculated by subtracting the above ground wells' body height (L_1) from the recorded length of the tape. DWT calculate is given by:

$$DWT=L-L_1 \qquad (1)$$

Where DWT is the distance from the ground surface to the groundwater table. L is the distance from the well mouth to the groundwater surface. L_1 is the distance from the well mouth to the ground surface. DWT were measured once a week. Water samples for chemical analysis were collected at 15 in every month.

2.2 Typical years and typical irrigation period

Data from 2001, 2002 and 2003 years were analyzed to determine the inter-annual variation of DWT and groundwater salinity, which will continue in time and reflects the water diversion for irrigation into the HID. Also in this analysis, the March, July, and November was taken as typical period which was the fluctuation of DWT and the variation of the shallower groundwater salinity.

2.3 Sampling site data and processing

The value of DWT and groundwater salinity of 178 observation wells were used to develop the point file with ArcGIS9.0 and project the coordinate transformation to produced the distribution map for the geo-statistical analysis (Fig.1).Then of DWT and groundwater salinity from corresponding sampling points were entered into Arc GIS9.0 to form the attributive data to matched the geographic data of sampling points.

2.4 Correlation analysis

SPSS13.0 was used to analyze the change and relationship between DWT and shallower groundwater in March, July and November respectively. The data of DWT from 7 wells which less affected by the groundwater exploration were selected to analyzed the annual change of DWT each year (Fig.4, 5, 6). The data of 61 wells' DWT were as abscissa and with the corresponding salinity degree of groundwater as ordinate to make the relation curve to analyze the relationship between the groundwater salinity and DWT (Fig.25) in March, July, and November, respectively.

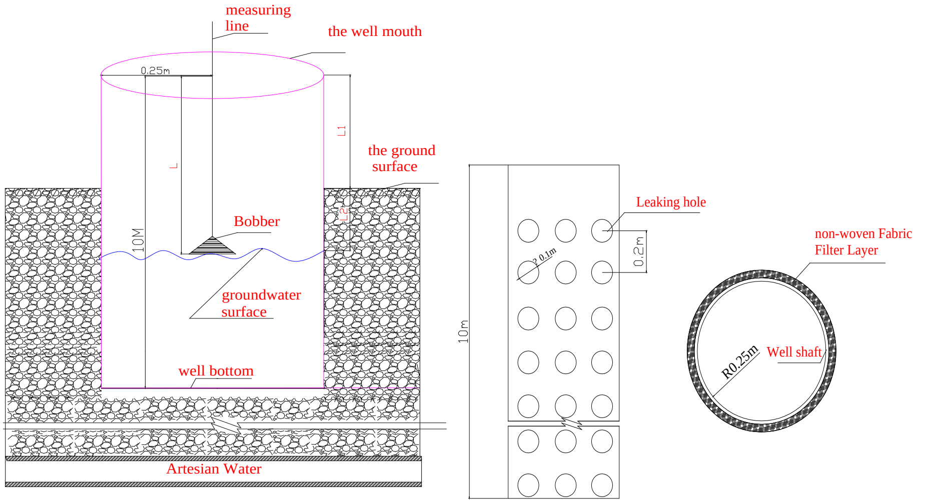

Fig.2 the observation wells' construction

2.5 Geo-statistical method and processing

Geo-statistical methods and ArcGIS9.0 were used to analyze the temporal and spatial variation of DWT and groundwater salinity from 2001 to 2003. Geo-statistical methods can be used to describe the spatial variability of environment and reveal the spatial heterogeneity and spatial pattern of natural phenomena (Pebesma et al.，1997). The semi-variogram model and Kriging interpolation are the two main geo-statistical methods used in this analysis (Jin et al.,1999; Sousa et al., 1999; Desbarats et al., 2002；Vijendra et al., 2004；Tong et al., 2007; Wang et al., 2007；Yue et al., 2009; Hu et al.2001, 2009； Husam,2010).

To get a better spatial estimation from sampling points, the variance of estimation error should be minimal. The Kriging method was used to obtain the variance of estimate. The advantage of Kriging is that it is the Best Linear Unbiased Estimator of the unknown fields (Journel and Huijbregts, 1992).The Kriging variance of estimate is independent of the actual measurements from the field. Ordinary Kriging interpolation at a point x_0 is given by:

$$Z^*\left(x_0\right)=\sum_{i=1}^{n} n\lambda_i Z\left(x_i\right) \tag{2}$$

Where $Z^*(x_0)$ is the estimated value, n is the number of points, $Z(x_i)$ is the measured value at point xi, and λ_i the Kriging weight. To calculate the Kriging variance, the semi-variogram is needed. The semi-variogram (usually called a variogram) is half the variance of measurement differences at all data pairs with the same distance (h). The Kriging variance is given by:

$$\gamma\ (h)=\frac{1}{2N_h}\sum_{i=1}^{N_h}[Z(x_i+h)-Z(x_i)]^2 \tag{3}$$

Where r(h) is semi-variogram, h is step length, namely the spatial interval of sampling points used for the classification to decrease the individual number of spatial distance of various sampling point assemblages, N(h) is the logarithm of sampling point when the spacing is h, and $z(x_i)$ and $z(x_i+h)$ are the values when the variable Z is at the x_i and x_i+h positions, respectively.

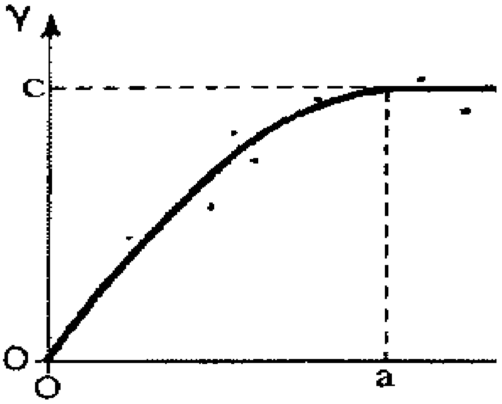

Fig. 3 experimental semi-variogram (dots) and fitted semi-variogram model

When computing the semi-variance (h) for different values of h, and when h is plotted versus (h), an experimental semi-variogram was obtained (Fig. 3. Sousa et al., 1999). However the experimental semi-variogram is not applicable in Kriging estimation because it cannot be represented by an equation. A semi-variogram model must then be adjusted to the experimental one, as exemplified in Fig.3 by the fitting of the Spherical equation. The best-fitted semi-variogram model has been used to produce the Kriging variance map. Selection of the best-fitted model was based on the condition that the root-mean-square was close to “0”,the average standard error is minimum, the mean standardized was close to the standard error and the root-mean-square standardized was close to “1” (Tang, 2007). Then GIS-Spatial Analyst tool in ArcGIS9.0 was used to produce a priority map and the best-fitted mode.

To obtain Kriging variance, construction of the variogram is needed. The variogram parameters are the sill, nugget, and the range. The nugget is the variogram value at the origin. Sometimes the nugget is different from zero due to measurement error. The range is the distance at which the variogram reaches the sill value. Three modules included Spherical model (Eq.4), Exponential model (Eq.5) and Gaussian model (Eq.6) were used in this study.

$$\gamma(h) = C_0 + C_1[1.5(h/a) - 0.5(h/a)^3] \qquad （4）$$

$$\gamma(h) = C_0 + C_1[1 - e^{-h/a}] \qquad （5）$$

$$\gamma(h) = C_0 + C_1[1 - e^{-(h/a)^2}] \qquad （6）$$

Where C_0 is nugget, which represents the spatial heterogeneity of the stochastic component. The sill value, ($C_0 + C$), is the attribute of the system or the maximum variation of the regional variables. The higher the sill value is, the larger the degree of the total spatial heterogeneity will be. The value of a is the range. Sill (C_0+C) and nugget (C_0) were used to describe the spatial heterogeneity. The ratio of nugget: sill (C_0/ C_0+C) reflected the total spatial heterogeneity (Li et al., 1995).

In this study, “Histogram” and “Normal QQplot” were the geo-statistical modules used with ArcGIS9.0. These modules were applied to analyze the normality of the 178 wells data of DWT and groundwater salinity each month. The results shown that the mean data comply with lognormal distribution. The ordinary Kriging interpolation method was applied to optimal mathematical model, and set the values of “Lag size” and “Number of lags” etc. to get the optimal predication map (Fig.7～24) and the best-fitted model (Eq.4～6). Table 1～2 lists several models with their respective sill and nugget.

3 Results and Discussion

3.1 Analysis of the spatial structure of DWT and groundwater salinity

The ratio of C_0: (C_0+C) reflected the total spatial heterogeneity. A higher ratio indicates that the stochastic component was the main factor caused the spatial heterogeneity. The ratio of C_0: (C_0+ C_1) was in the range of 25%～75% of the spatial structure of DWT in the three years(Tab. 1). It shown that the spatial structure variation of DWT was not only affected by the structure factors but also by the random factors (the stochastic component). Due to the average annual precipitation is

168 mm and the irrigation water is the mainly recharge source of DWT. So the spatial structure variation of DWT was affected by the time and amount of the agricultural irrigation mainly during the irrigation season. The structure factors such as the terrain, landform and climate would be responsible for the variation of the spatial structure of DWT when the total water diversions of irrigation were reduced. For example, although the water diversions of irrigation in 2003 were reduced to 80% of the average annual water diversions of irrigation and the ratio of C_0: (C_0+ C_1) of the spatial structure of DWT in July and November decreased to 34.3 and 37.5 respectively, the distribution of DWT in July and November 2003 were similar to that of 2001 and 2002(Fig. 8, 11 and 14. Fig. 10, 12 and 15.). Therefore, the spatial structure of DWT was the moderate spatial correlation and the average corresponding distance was 18.5 km among the three years（Tab.1）. These result shown that the co-working of the structure factors and random factors were the mainly factor of the variation of the spatial structure of DWT in HID.

The table 2 shown that the ratio of C_0: (C_0+ C_1) of spatial structure of groundwater salinity varied from 0.3 to 45.7 in the three years. The spatial structure of groundwater salinity had the strong spatial correlation and the average corresponding distance was 12.1km. Since the salt which in the irrigation water (the Yellow River water salt content was 480 mg/l) were the mainly recharge resource of the shallower groundwater salinity, the different water diversions of irrigation would cause the variation of the shallower groundwater salinity. Meanwhile, the waste discharge of industries and civil life also enhanced the variation of it. This result shown that the groundwater salinity was affected by the random factors, such as irrigation water salt, field fertilization and waste discharge of industries and civil life in HID.

Table 1 the parameters of semi-variogram models for shallow groundwater table depth

Year	month	Model	Ran	Nug	Par	Sill	C_0/ (C_0+ C_1)
			km	C_0	C_1	C_0+ C_1	%
2001	Mar	Sph	22.7	0.15	0.11	0.26	58.2
	July	Exp	11.5	0.10	0.20	0.30	51.8
	Nov	Sph	13.4	0.24	0.09	0.33	73
2002	March	Sph	28.4	0.04	0.01	0.05	72
	July	Exp	19	0.05	0.06	0.11	46.6
	Nov	Sph	19	0.16	0.14	0.29	53.6
2003	Mar	Sph	22.7	0.03	0.02	0.05	52.7
	Jul	Gau	19	0.04	0.08	0.13	34.3
	Nov	Exp	10.7	0.14	0.24	0.38	37.5
mean			18.5	0.09	0.09	0.19	47.8

3.2 Analysis of temporal and spatial variation of the DWT

3.2.1 Temporal variation of DWT

The variation of DWT of 7 wells which without the affects of groundwater exploitation were similar among the three years (Fig 4, 5 and 6). Namely, the average DWT value was 2.0 m in January and reached the maximum value (2.5 m) in March, and then decreased to 1.5 m in May after the summer irrigation. Since the agriculture irrigation was gradually decreased from August to September, DWT increased to 2.2 m in September. Following the late autumn irrigation which the irrigation water amount were thirty percent of the total water diversion, the average DWT value rapidly decreased to 1.0 m in November. With the beginning of winter, the DWT gradually increased to 2.0 m by next January. Then, the fluctuation of the DWT completes the annual cycle. These peaks and valleys demonstrated that the time and amount of agricultural irrigation were responsible for the fluctuation of the DWT without the effect of irrigation exploitation in HID.

Table 2 the parameters of semi-variogram models for shallow groundwater salinity

year	month	Model	Ran	Nug	Par	Sill	$C_0/(C_0+C_1)$
			km	C_0	C_1	C_0+C_1	%
2001	Mar	Gau	11.1	0.05	0.68	0.72	6.4
	Jul	Sph	12.3	0.11	0.64	0.74	14.3
	Nov	Gau	9.5	0.18	0.53	0.71	25
2002	Mar	Sph	23	0.20	0.65	0.85	23.3
	Jul	Sph	13.5	0.35	0.42	0.77	45.7
	Nov	Gau	11.8	0.35	0.46	0.81	43.4
2003	Mar	Exp	7.9	0.04	0.79	0.83	4.7
	Jul	Exp	11.5	0.11	0.68	0.79	13.8
	Nov	Exp	8.4	0.00	0.69	0.69	0.3
	mean		12.1	0.16	0.61	0.77	20.1

3.2.2 Spatial variation of DWT in typical period

Owing to the temperature difference between the upper and under boundary of the freezing soil layer, the high absorption energy makes groundwater in air containing zone move towards the freezing layer so that the DWT value of 95% area of HID were in the ranged of 2～3 m in March each year (Fig.7, 10, 13) .

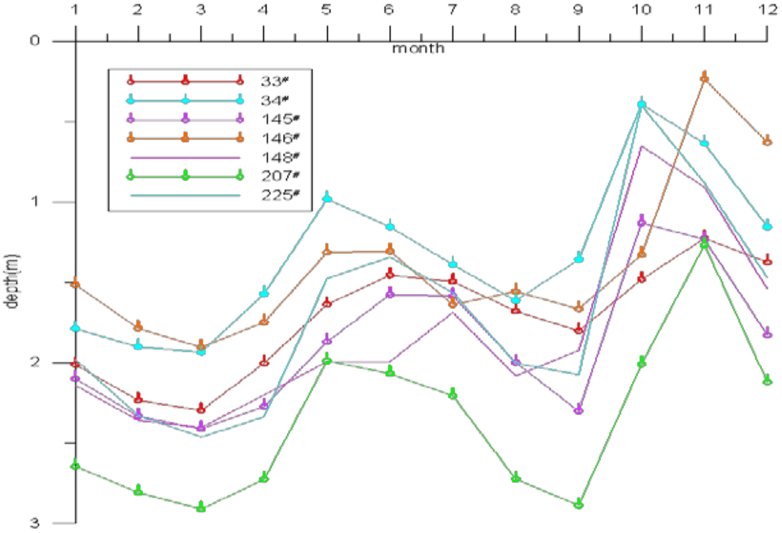

Fig.4 Map of DWT variety，2001

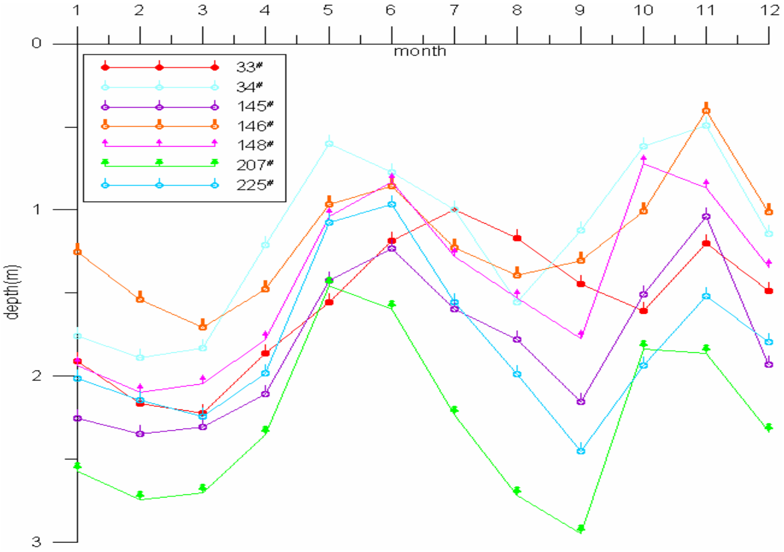

Fig.5 Map of DWT variety，2002

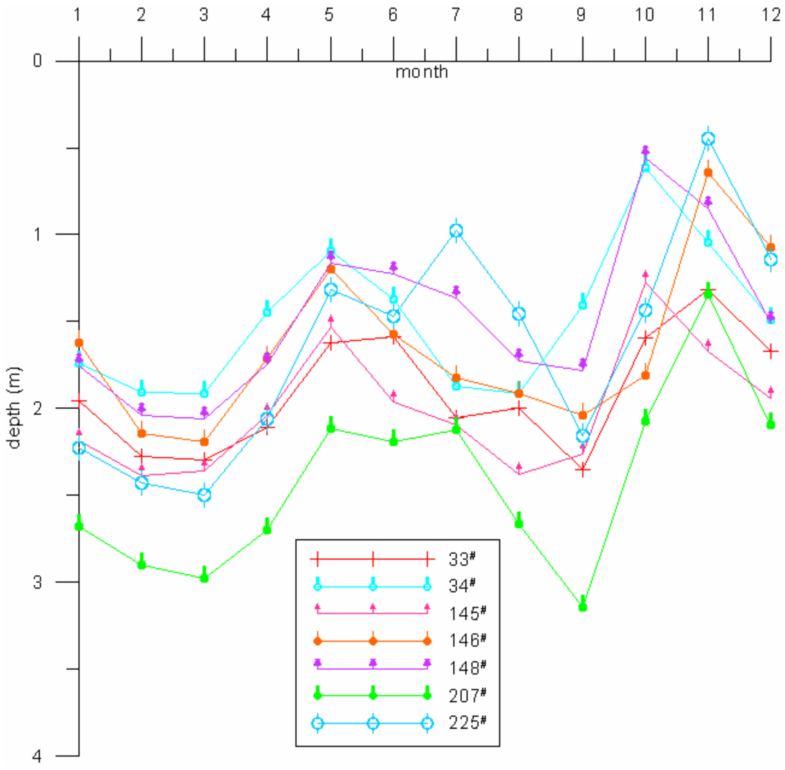

Fig.6 Map of DWT variety，2003

Because the water diversions of irrigation were reduced to 80% of the average annual water diversions of irrigation (52×10^{9} m^{3}) in 2003, and the irrigation water amount were reduced during the summer irrigation season. Therefore, the DWT value of 80% area of HID were in the range of 1.5～2.0 m, and the regions of DWT in the range of 2～3 m were continuously in July 2003(Fig.14). Although the DWT of 80% area of HID were also in the range of 1.5～2.0 m in July 2001, the regions of the DWT in the range of 2.0～3.0 m were scattered over the southwest in HID(Fig.11). In 2002, the total water diversions of irrigation were more than that of other two years. And the DWT value of 50% areas of HID were in the range of 1.0～1.5 m in 2002(Fig.8). It can be drawn into conclusion that the distributional-variation of the water diversions of irrigation among years caused the distributional-variation of DWT in the entire HID. In other word, the more the water diversions of irrigation were, the shallower DWT in HID would be.

In additional, the figure 8, 11 and 14 shown that the shallower DWT region distributed in Yigan, southwestern part of Jiefangzha, minor area of Yongji and Wulate irrigation region. These regions were the agricultural areas with little in groundwater exploitation and lower terrain. While the deeper DWT regions distributed in the northeastern part of Jiefangzha, major part of Yongji and Yichang irrigation region. These regions were the agricultural areas with the higher terrain and cities-towns. And an amount of the groundwater exploitation were used to meets the demand of the domestic water, public facilities and urban greening in cities-towns.

Take $310^{\#}$, $223^{\#}$ and $305^{\#}$ well as example, the average annual DWT were 3.7 m, 3.5 m and 3.5 m from 2001 to 2003, which were located around the city of Linhe, Wuyuan and Qianqi respectively. In second-autumn irrigation season, there was 1 irrigation-time in HID, and the irrigation amount was 30% of the total water diversions of irrigation. And the terrain slopes gently, the average ground slope is about 1/8000~1/4000 (from southwest to northeast). Therefore, the DWT of the entire HID were in the two ranges ,namely, 0.5～1.0 m and 1.0-1.5 m in November. The range of 0.5～1.0 m distributed in Yigan, Yongji and Wulate irrigation region, and the range of 1.0～1.5 m distributed in Jiefangzha and Yichang irrigation region (Fig. 9, 12, 15).

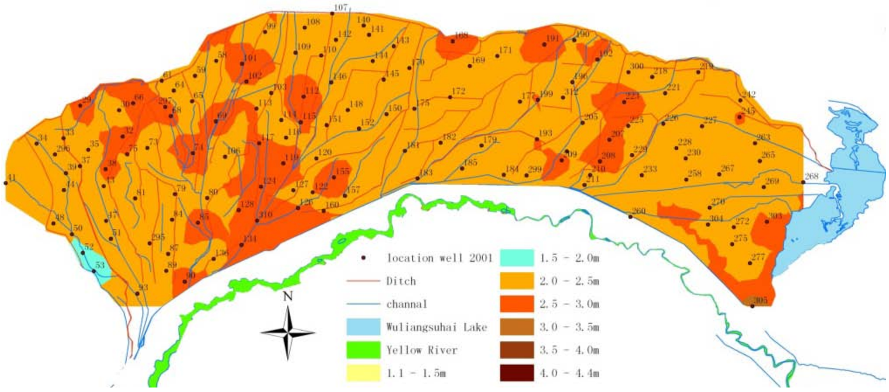

Fig.7 Distributing map of DWT in March, 2001

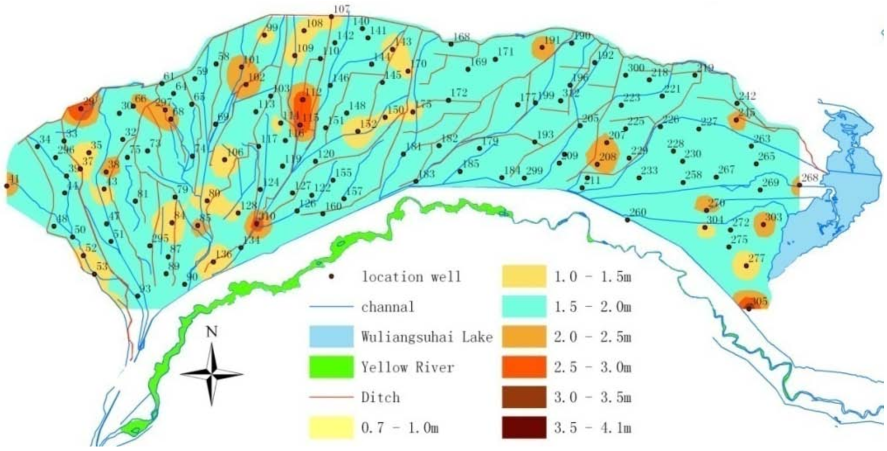

Fig.8 Distributing map of DWT in July, 2001

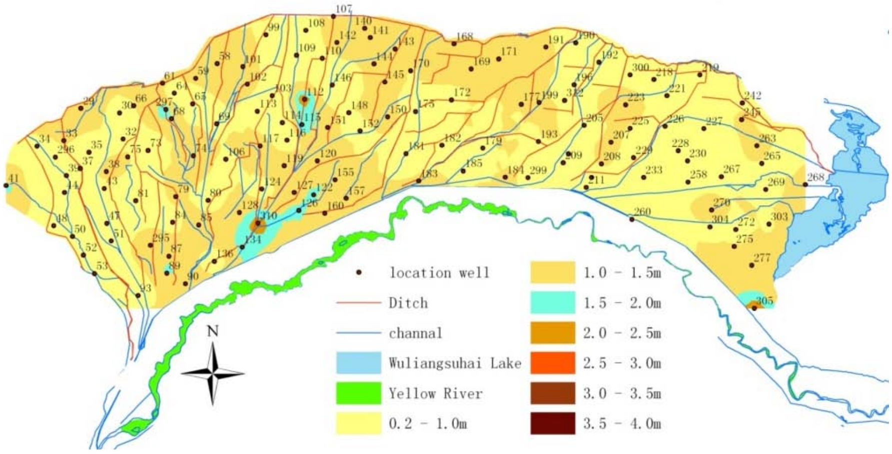

Fig.9 Distributing map of DWT in November, 2001

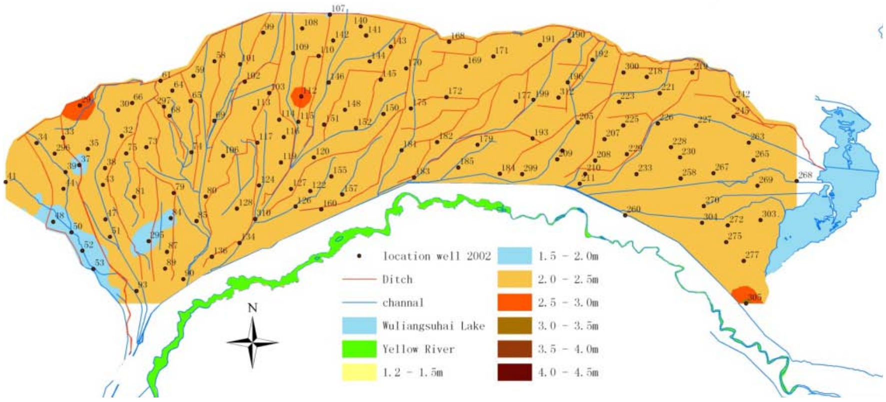

Fig.10 Distributing map of DWT in March, 2002

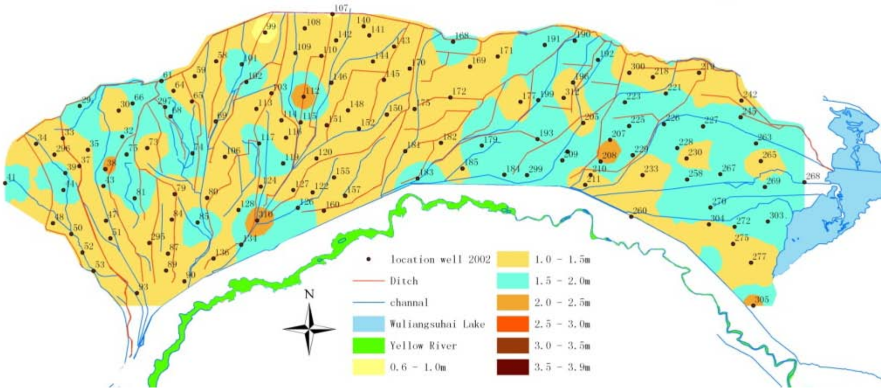

Fig. 11 Distributing map of DWT in July, 2002

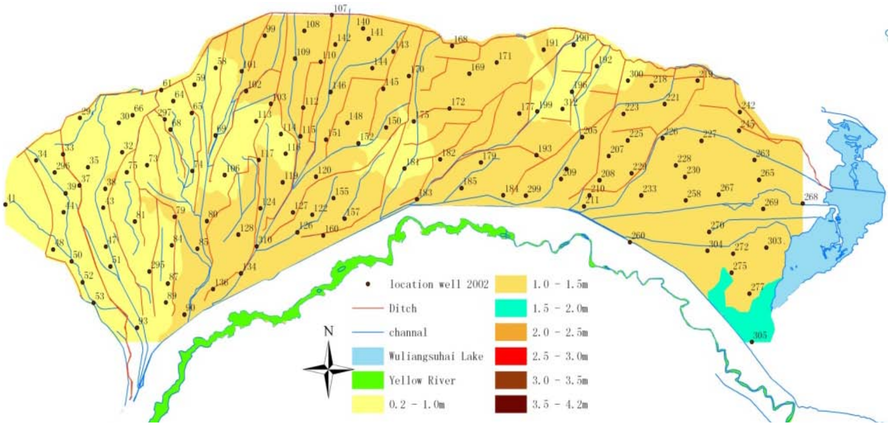

Fig.12 Distributing map of DWT in November, 2002

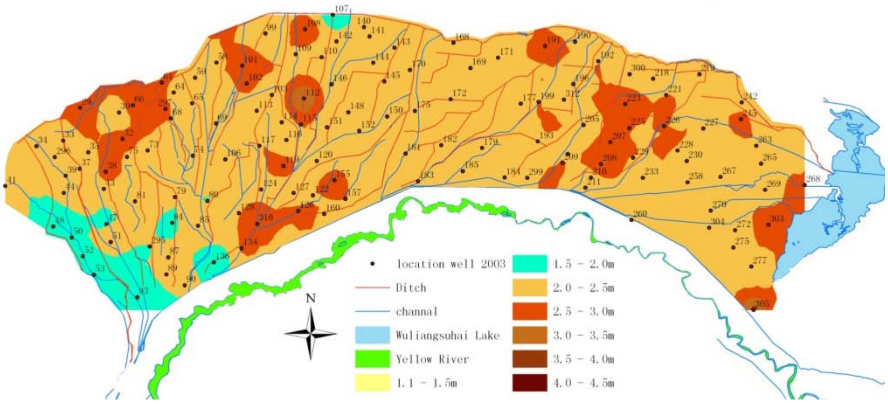

Fig.13 Distributing map of DWT in March, 2003

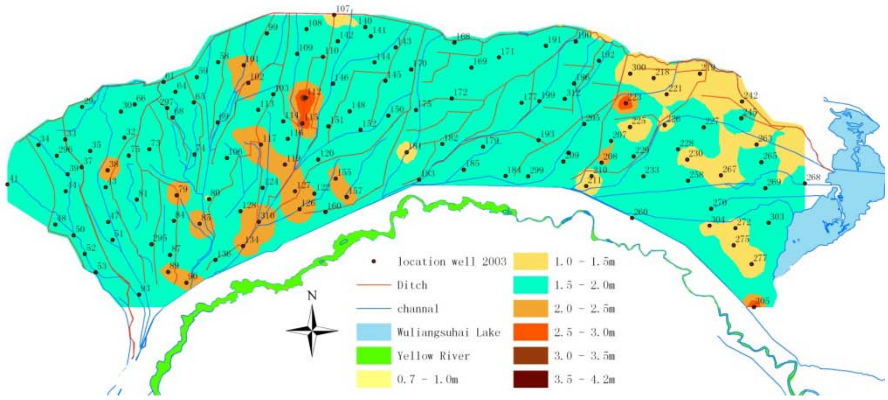

Fig.14 Distributing map of DWT in July, 2003

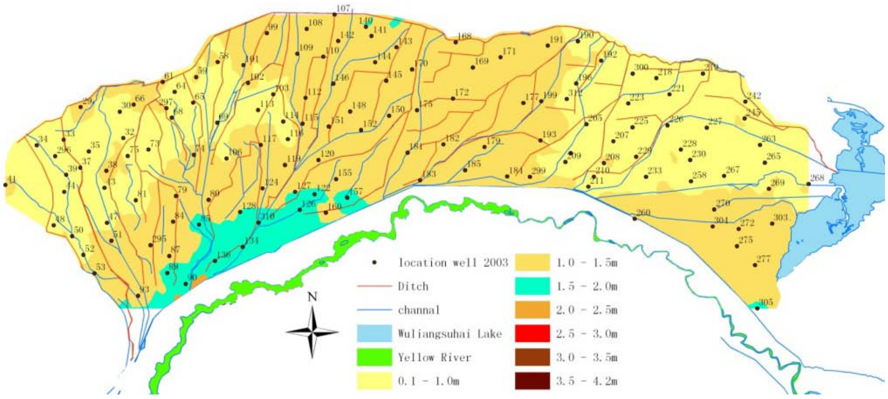

Fig.15 Distributing map of DWT in November, 2003

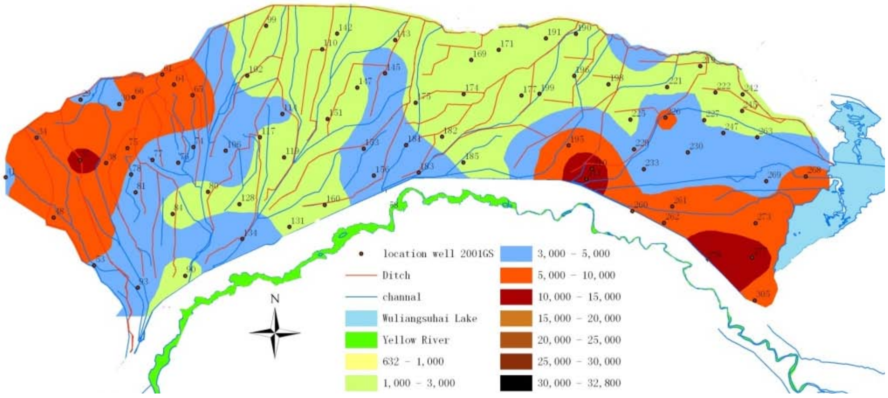

Fig.16 Distributing map of groundwater salinity in March, 2001

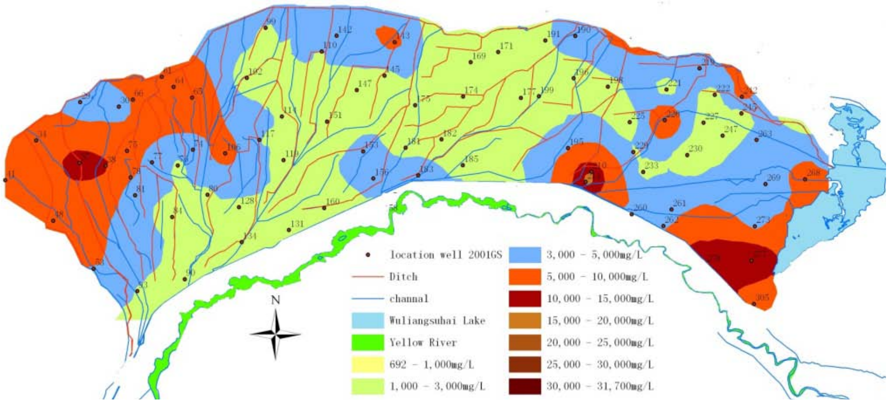

Fig.17 Distributing map of groundwater salinity in July, 2001

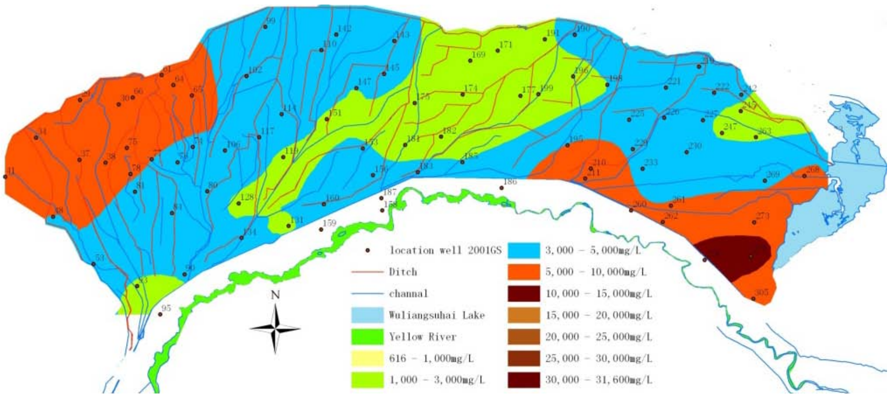

Fig.18 Distributing map of groundwater salinity in November, 2001

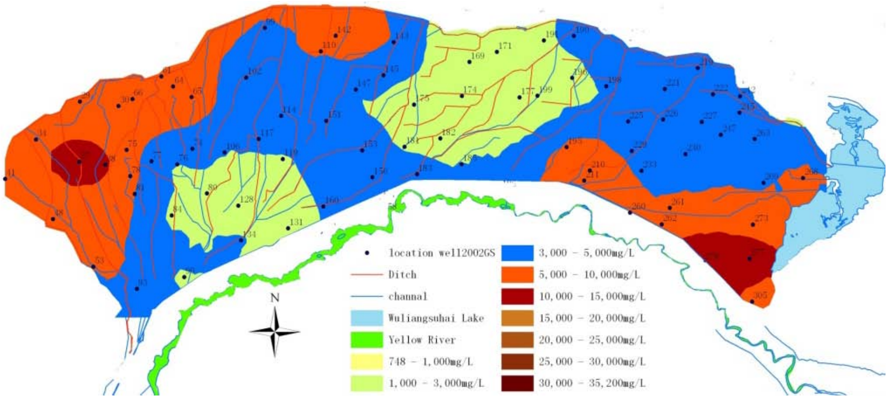

Fig.19 Distributing map of groundwater salinity in March, 2002

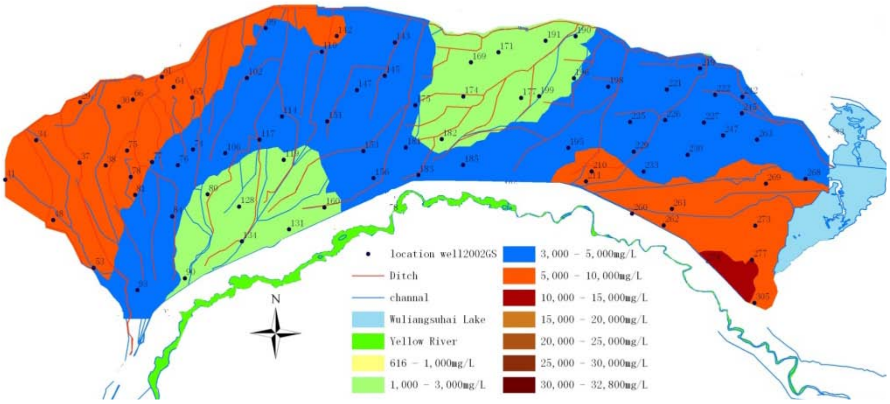

Fig.20 Distributing map of groundwater salinity in July, 2002

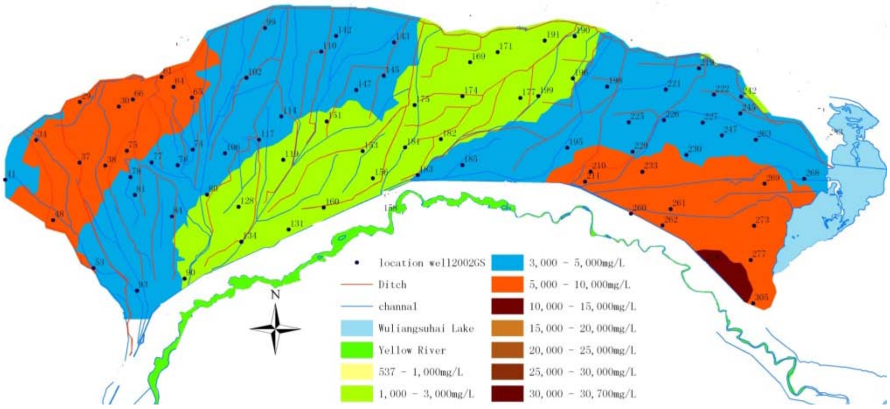

Fig.21 Distributing map of groundwater salinity in November, 2002

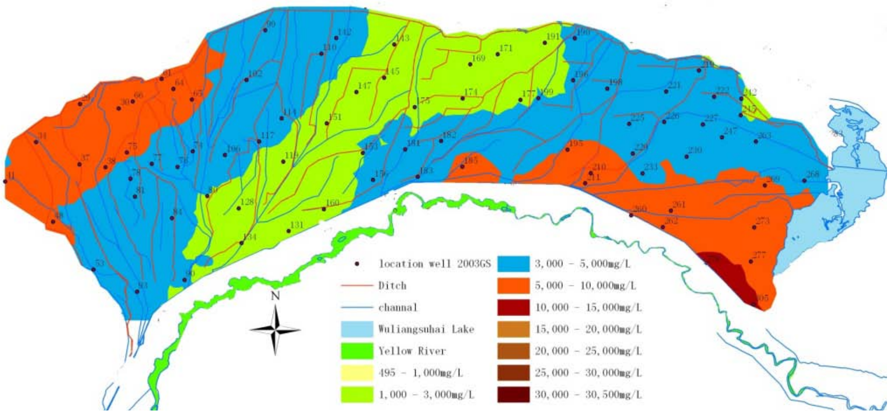

Fig.22 Distributing map of groundwater salinity in March, 2003

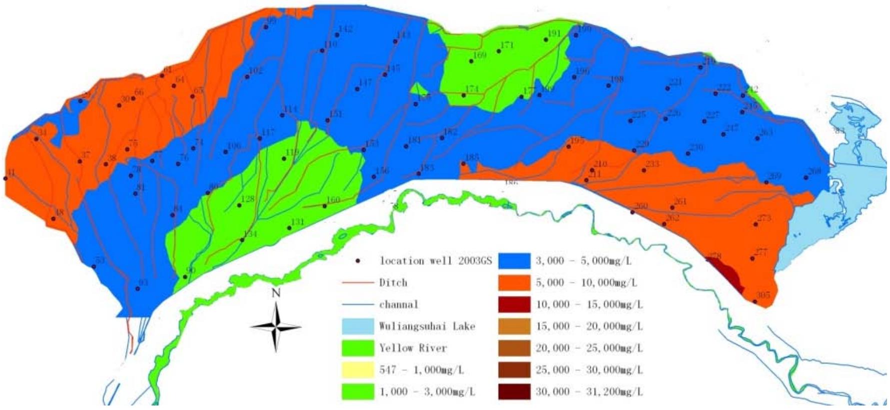

Fig.23 Distributing map of groundwater salinity in July, 2003

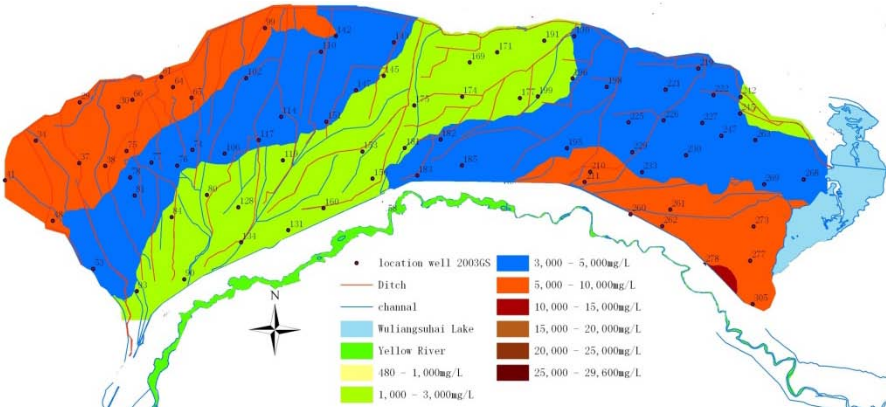

Fig.24 Distributing map of groundwater salinity in November, 2003

3.3 Analysis of temporal and spatial distribution of the groundwater salinity

The temporal and spatial distribution of the groundwater salinity was quite similar among the three years (Fig. 16～24). There were two salinity degree zones in the northern and southern of HID, which the salinity degree was more than 5000 mg/l (red regions) and even, in some local areas, the salinity degree was more than 10000 mg/l. The northern zone was from Dashuwan (west) to Fenzidi (east), the southern zone was from Xishanzui extended to Chengnan and Shulinzi. The groundwater salinity of the major area of Hetao in March and November was M<3000 mg/l and M>4000 mg/l, respectively. The reasons caused these results were followed:

(1) Because the southwest elevation (1043 m) was higher than that of the northwest (1034 m) and the southeast (1018 m). The groundwater horizontal movement was from southwest toward the northwest and southeast. An amount of salt accumulated into the soil and penetrated into groundwater of the northwest and southeast area of HID. Therefore, the groundwater salinity in southeast and northwest were higher (M>5000 mg/l) than that of (M<3000 mg/l) the middle area of HID.

(2) The soil water was in the cycle process of the irrigation recharge and evaporation-transpiration in summer irrigation and first-autumn irrigation season. These resulted in soil salinization and high degree of groundwater salinity. Under the action of the high evaporation and transpiration, a large amount of the salt of which accumulated in deeper-soil and dissolved in groundwater were moved toward and accumulated into the surface later soil. But the accumulated salt in the surface later soil dissolved adequately into the shallower groundwater again during the second-autumn irrigation period. So, the groundwater salinity of the major area of HID in November was M>4000 mg/l. With the lateral seepage of soil water and the horizontal movement of groundwater, a lot of salt of which dissolved into soil-water and shallower groundwater was moved away HID during the period from November to the next March. Then, the groundwater salinity of the major area of HID was M<3000 mg/l in March.

3.4 Relationship between the table depth and salinity of groundwater

Under arid or semi-arid conditions and regions of poor natural drainage, there was increasing potential for hazardous accumulation of salts in soils. The salinity was important index that reflected the degree of human activities on the water quality influence of the groundwater. Meanwhile the salinity also reflected the distributing characteristics and change trend of the chemical composition of the groundwater in some regions. DWT was important as it determines the distance that contaminants had to travel before reaching the groundwater. Deep groundwater was less vulnerable than shallow aquifers. In HID, due to the agricultural irrigation water resource was mainly Yellow River water, and the average annual salinity degree of the irrigation water was 480mg/l. So, the agricultural irrigation time and amount was the mainly factors to affected the variation of the groundwater salinity. At the same time, the agricultural irrigation water were also the mainly resource to recharged the groundwater. Therefore, there was maybe certain correlation between DWT and groundwater salinity in a given temporal and spatial range. Fig.25 (here was given the relation curve in March 2001 only, since other years' regression correlation results were similar to it.) shown that Linear regression between DWT and the groundwater salinity indicated that there were other factors than water table depth that influenced salinity of groundwater.

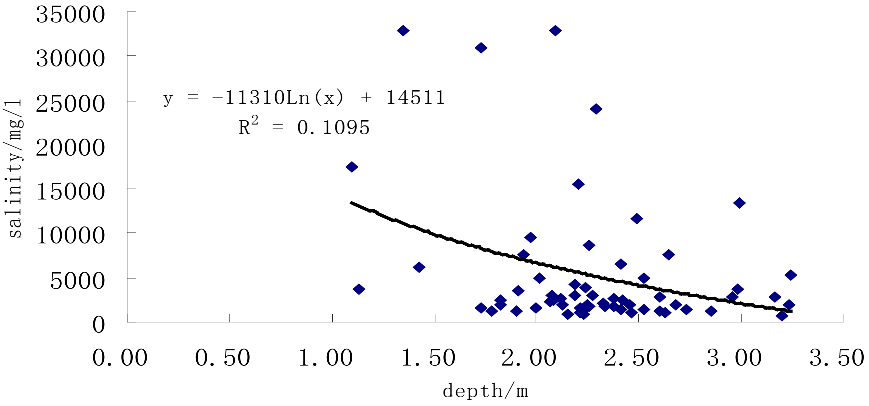

Fig.25 Relationship between DWT and groundwater salinity in March，2001

The figure 7～24 shown that the special relationship between them in some special regions. The first relationship existed around the wetland and the lower terrain region. For example, the average annual DWT of wells 37# and 38#was 0.97 m and 1.01 m, and the corresponding salinity degree values were 14500 mg/l and 12800 mg/l respectively. Both wells were installed nearby Dashuwan and Daxian Lake (saline lake), respectively. The average annual DWT of wells 106# was 0.89 m and the corresponding salinity degree values were 8000 mg/l which was installed in nearby the wetland. The average annual DWT of wells 277# and 278# was 0.90 m and 0.87 m, respectively, and the corresponding salinity degree values was 31700 mg/l and 31000 mg/l. Both of which were installed in nearby Xian Lake (saline lake).

The second relationship was exists around the cities and towns. In the cities and towns regions, due to the recharge and exploration of groundwater balanced the fluctuation of DWT and slow down the salt accumulation in the shallower groundwater. For example, the well 310$^{\#}$(Linhe city), 223$^{\#}$(Wuyuan city) and 305$^{\#}$(Qianqi city) which the average annual DWT were 3.82 m, 3.76 m and 3.64 m and the corresponding salinity values was 1550 mg/l, 1200 mg/l and 2900 mg/l, respectively.

There were many factors which influence the variation of the table depth and salinity of groundwater such as terrain, climate condition, soil types, quality and time of irrigation water and the terrain of HID, etc. Although the linear relationship between the DWT and groundwater salinity were not significant, the distribution of DWT could reflected the distribution of the groundwater salinity in the certain regions. Namely the shallower DWT was, the higher the salinity degree of groundwater would be. The deeper DWT was, the lower the salinity degree of groundwater would be.

4 Conclusions

Due to insufficient data coverage, the shallower groundwater salinity studies often require interpolation or extrapolate from a few observation points into large areas. This was especially critical for groundwater aquifers with complex and extensive hydro-geological heterogeneities at extremely varying scales. The geo-statistics methods and Arc GIS were very useful for DWT and groundwater salinity studies in HID Inner Mongolia, China. The spatial structure of DWT was controlled by the terrain, landform and climate more than the random factors such as the waste discharge of industries and civil life, the time and amount of the agricultural irrigation. Therefore, DWT was the medium spatial correlation and the average corresponding distance was 18.5km in three years. The variation of the spatial structural of the groundwater salinity was mainly affected by the random factors, and it is the strong spatial correlation and the average corresponding distance was 12.1km in three years.

There were remarkable differences in the temporal and spatial variation of the recharge rate and salinity of groundwater in different irrigation regions, since their agricultural planting structure and water diversions of irrigation were different. Meanwhile, massive groundwater exploitation of living and industrial enhanced the disparity of temporal and spatial variation. However, the temporal and spatial distribution of DWT and groundwater salinity was quite similar between years (from 2001 to 2003) in HID Inner Mongolia. DWT in western, eastern area and a small part of middle area were shallower than other area in Hetao. The average annual DWT in March reached the maximum and that of in November reached its the minimum within one year. The shallower depth region of groundwater distributed in the agricultural area, and the deeper depth region of the groundwater distributed in cities and towns with higher terrain.

Due to the geological structure and geographical conditions, a large of salt accumulated into the soil and penetrated into groundwater of the northwest and southeast area of HID. In northwest and southeast area, the groundwater salinity were M>5000mg/l and even, in some local areas, M>10000mg/l. Meanwhile, the special irrigation seasons and climate made the maximum and minimum of groundwater of HID appeared in the specific period of September and March, respectively. The groundwater salinity of the major area of HID was more than 4000mg/l in November. With the lateral seepage of soil water and the horizontal movement of groundwater, some of the accumulated salt was drained away HID. The groundwater salinity of the major area of HID was less than 3000 mg/l except the northwest and southeast area in March.

There were many factors which influence the variation of the table depth and salinity of groundwater such as climate condition, soil types, quality and time of irrigation water and the terrain of HID etc, and the temporal and spatial variation of these factors was high in the different area. Therefore, the linear relationship between DWT and groundwater salinity were not significant. In some special areas, however, the distribution of DWT could reflect the distribution of the groundwater salinity. Namely the shallower DWT was, the higher the groundwater salinity degree would be. The deeper DWT was, the lower the groundwater salinity would be.

In this study, we get the characteristics of the temporal and spatial distribution of DWT and shallower groundwater salinity. We can make the rational agriculture planting structure according with these characteristics. For example, planting the crop which are the salt-resistant and drought tolerant in the high salinity areas in order to reduced the amount of the salt which were brought by the irrigation water, and to increased the amount of irrigation water in the second-autumn period to leach more soil salt. This is quite important to maintain the eco-environmental balance in HID.

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References

Chen Yaxin：Dynamic simulation of the relationship between water table and salinization of soil．Journal of Hydrulic Engineering. 5:77-84（1997）

Chen Rongyan：Change of the shallow groundwater quality by human activities influence in lower reaches of Panlongjiang River．Journal of Water Resources Water Engineering. 18(5)：47-51（2007）

Desbarats, A.J., Logan, C.E., Hinton M J, et al.：On the Kriging of water table elevations using collateral information from a digital elevation model. Hydrology, 255: 25-38（2002）.

Feng Zhaozhong,Wang Xiaoke, Feng Zongwei, et al.：Influence of autumn irrigation on soil salt leaching of different farmlands in HID of Inner Mongolia. Rural Eco-environ. 19 (3), 31-34（2003）

Feng Zhaozhong, Wang Xiaoke, Feng Zongwei：Soil N and salinity leaching after the autumn irrigation and its impact on groundwater in HID, China. Agricultural Water Management. 71:131-143（2005）

Finke, P.A., Brus, D.J., Bierkens, M.F.P., et al.：Mapping groundwater dynamics using multiple sources of exhaustive high resolution data. Geoderma, 123: 23-39(2004)

Gao Hongyong, WU Jingwei, Duan Xiaoliang:The Impact of Water-table on The Ecological Environment of Hetao Irrigation Area. Journal of Arid Land Resources and Environment. 22(4):134-138(2008)

Hao Fanghua, Ouyang wei, Yue yong, Yang Zhifeng:Analysis of water cycle characteristics and soil water movement in the agricultural irrigation area in Inner Mongolia．Acta Scientiae Circumstantiae28 (5): 825-831(2008a)

Hao Fanghua, Ouyang Wei, Li Peng, et al.:Temporal and spatial variability of nitrogen in soil in the Wulate irrigation districtof theHetao irrigation area in Inner Mongolia．Acta Scientiae Circumstantiae, 28(5): 845-852(2008b)

Hu Kelin, Li Baoguo, Cheng Deli: Spatial Variability of the Regional Shallow Groundwater Depth and Water Quality．Advances in Water Science，11（4）：408－414.

Hu Kelin, Chen Hailing, Zhang Yuanpei et al., 2009. Spatial distribution of shallow groundwater depth, total dissolved solid and nitrate pollution．Transactions of the CSAE, 25(Supp.1):21-25(2000)

Husam Baalousha, Assessment of a groundwater quality monitoring network using vulnerability mapping and geo-statistics: A ca：se study from Heretaunga Plains, New Zealand. Agricultural Water Management, 97:240-246(2010)

Jia Xianyan, Wu Hongyu, Li Xia, FU Bingzhe, Study on Floristics component of saline-alkali land in HID.Journal of Inner Mongolia Agricultural University. 27(4):76-80(2006)

Jin Menggui, Zhang Renquan, Sun Lianfa, Gao Yunfu: Temporal and spatial soil water management: a case study in the Heilonggang region, PR China. Agricultural Water Management 42: 173-187(1999)

Kong Fanrui: Experimental Research on the Effect of Different Kinds of Groundwater Buried Depth on Soil Water, Salinity and Crop Growth. China Rural Water and Hydropower, 5：44-48(2009)

Kong Dong，Shi Halbin，Huo Zaihang，et a1.: Effects on Growth of Sunflower under Different fine soils in the Hetao Irrigation Area. Journal of Shenyang Agricultural University,35(5—6)：414-416(2004)

Lasserrea, F., Razacka, M., Banton, O.: A GIS-linked model for the assessment of nitrate contamination in groundwater. Hydrol, 224, 81–90(1999)

Lee Jinyong, Song Sungho:Evaluation of groundwater quality in coastal areas: implications for sustainable agriculture. Environ Geol 52:1231–1242(2007)

Lee Jinyong, Hahn JS:Characterization of groundwater temperature obtained from the Korean national groundwater monitoring stations: implications for heat pumps. Hydrol 329:514–526(2006)

Li Habin, Reynolds, J.F.: On definition and quantification of heterogeneity. Oikos, 73: 280—284 (1995)

Mouser, P. J., Hession, W.C., Rizzo D M, et al.: Hydrology and Geo-statistics of a Vermont, USA Kettlehole Peat land. J Hydrology, 301: 250-266(2005)

Pebesma E J, Kwaadsteniet J W: Mapping groundwater quality in the Netherlands. Hydrology, 200: 364-386(1997)

Qu Zhongyi, Chen Yaxin, Fan Zehua, Zhang Yiqiang: The Prediction of Water and Salt Regime and Effect Evaluation of Water-Saving Reform Project in Large-Scaled Irrigation District China Rural Water and Hydropower, 8:27-41(2007)

Tang Guoan:Geographic information system spatial analysis experiment and course. Beijing, Science press: 363-428(2007)

Tong Ling, Kang Shaozhong, Zhang Lu:Temporal and spatial variations of evapor-transpiration for spring wheat in the Shiyang river basin in northwest China. Agricultural Water Management 87:241-250(2007)

Vicente Sousa, Luis Santos Pereira:Regional analysis of irrigation water requirements using Kriging Application to potato crop at TraÂs-os-Montes. Agricultural Water Management 40, 221-233(1999)

Vijendra K. B., Gerrit H., James E.H., et al.:Agricultural water use estimation using geospatial modeling and a geographic information system. Agric Water Manage, 67: 185-199(2004)

Wang Xusheng, Yue Weifeng, Yang Jinzhong:Analysis on Water Cycling in GSPAC System of Hetao irrigation District in InnerMongolia, China. Journal of Irrigation and Drainage,23(2):3-6(2004)

Wang Xuequan, Lu Qi, Gao Qianzhao: Study on the Volumes of Water Diverted from the Yellow River to the Irrigated Area in the Great Bend of the Yellow River. Arid zone research. 22(2):146-151(2005)

Wang Weiguang, Xue Xuzhang, Di Wei, 2007.Spatial Variability of Water Level in HID Inner Mongolia and Their Estimations by the Kriging． Journal of Irrigation and Drainage. 26(1): 18-21．

Webster, M.A. ,Oliver.: Geostatistics for Environmental Scientists/2nd Edition Xiao Duning, Li Xiaoyu,2007.Temporal and spatial dynamical simulation of groundwater characteristics in Minqin Oasis． Sci China Ser D-Earth Sci,50(2): 261-273(2007)

Yan Jinfeng, Chen Xi, Luo Geping, Guo Quanjun:Temporal and spatial variability response of groundwater level to land use/land cover change in oases of arid areas． Chinese Science Bulletin. 51(Supp. I): 51-59(2006)

Yang Jingyu, Qu Zhongyi:Determination and Evaluation on Soil Water Retention Curve Model in Hetao Irrigation District. Journal of Arid Land Resources and Environment. 28(5):155-159(2006)

Yue yun, Hao Fanghua, Ma Guifeng:Spatial Variability of GWS in HID Inner Mongolia. Journal of Environmental Sciences Inner Mongolia, 21(4):97-90(2009)

Zhang Deqiang:Study on the variation and influence factor of soil2water mineral degree in shallow groundwater areas .Journal of Engineering Geology, 1:52-56(2004)

Yang Luhua,Shen Rongkai,Cao Xiuling:Scheme of groundwater use in Hetao irrigation district in Inner Mongolia. Transactions of the CSAE. 19(4):56-59(2003)