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Based on GMS management of shallow groundwater resource in Ningjin, China

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Abstract. Ningjin County is located the far end of Yellow River irrigation area which belongs to one of the serious lack of the water resources in Shandong province of China, in which water supplies mainly rely on groundwater, Yellow River division being as supplementary water supply. Now Ningjin is facing over exploitation of shallow groundwater in rural area and deep groundwater in the urban area. GMS software was used to simulate the groundwater dynamics of the whole county in the proposed four scenarios of reducing irrigation area by 20%, 30%, 40% and new water quantity of South-north Water Transfer as well as new Zhangweixinhe River water division under the current groundwater exploitation and allocated average annual amount of 52 million m3 of Yellow River water. The results showed that appropriate reduction of irrigation area and increase of passenger water introduction can effectively alleviate the overdraft of groundwater in Ningjin county.

1.Introduction

Ningjin county is located the far end of Yellow River irrigation area, which belongs to one of a severe shortage of water resources in Shandong province. The water resources amount per capita and per hectare are 167 m^3 . The groundwater as main water supply source plays an irreplaceable role in ensuring the sustainable development of economy and society of the whole county. With the development of social economy and the increase of population, the demand of water resources is increasing and contradiction between water demand and supply is sharp. It is vital significance that the change of groundwater development is analyzed, predicted under the condition of different scenarios and effective countermeasures by using groundwater numerical simulation method to ensure water safety, sustainable water resources use and ecological restoration in Ningjin County.

2.General situation of study area

Ningjin county is located in the northwest of Shandong province. The elevation in the southwest is about 20 m and in the northeast is about 9 m. It is 32.5 kilometers from east to west and 31 kilometers from north to south, with a total area of 833 km^2. The slope land is distributed in the central of Ningjin county, which accounts for 60.38% of the total area; the high flood land is mainly distributed in the northern and western regions along the Zhangweixinhe River, which covers 32.08% of the total area; the depression mainly consist of shallow flat depression and sandy channel, which is mainly distributed at the end of paleo-channel and depression, which covers 7.29% of the total area; and there are a small amount of sand dunes, accounting for 0.25% of the total area.

The climate in Ningjin is sub-humid or semi-arid warm temperate, and temperature varies seasonally with the annual average temperature is 12.3℃. The annual average rainfall is 580 mm; the precipitation in flood season (from June to September) is 460 mm, accounting for 80% of the total precipitation; the precipitation in non-flood period is 120.9 mm, accounting for 20% of the total precipitation, and the annual average evaporation is 1318.6 mm.

3.Current situation and existed problems of water resources development and utilization

The water resource is seriously shortage in Ningjin county. The total amount of annual average water resources is 117 million m^3 with available quantity of 83 million m^3, of which the surface water resource is 32 million m^3 with the available capacity is 0.17 billion m^3, and the groundwater resource is 85 million m^3 with the available capacity is 66 million m3. The amount of water resources per capita in the county is 250.5 m^3 (accounting for 1/8 of the amount of water resource per capita in China) and the average water resource per hectare in the county is 162.5 m^3 (accounting for 1/12 of the average water resource per hectare in China). The shallow groundwater resource is divided into 3 parts, namely, fresh water area, brackish water area and salt water area. The fresh water area (the total area of 525.9 km^2) is 30-50 m in depth of lower confining bed and 30-50 m in depth of phreatic surface, with less than 2 g/l of salinity, which is mainly distributed in the central and northern parts of Ningjin; the brackish water area (the total area of 197 km^2) is 10-30 m in depth of lower confining bed and 2-5 g/l in salinity, which is mainly distributed in west and east of Ningjin; the salt water area (the total area of 98.75 km^2) is less than 10 m in lower confining bed, with less than 5 g/l of salinity, which is mainly located in the south, southeast, west and north of Ningjin.

The shortage of water resources, less rainfall and large industry and agriculture and and domestic water consumption result in the groundwater overexploitation in Ningjin county. The shallow overexploitation area is located at Yellow River flood plain in the north of Ningjin county, which extents from Xiangya county in the west to Changgong county in the east of Ningjin county, with the overexploitation of 471.8 km^2 and average annual overexploitation of 29.14 million m^3. And the confined water was exploited in the whole Ningjin county, which induced a series of problems (Land subsidence, Water quality deterioration and Land desertification).

4. Numerical simulation

4.1 Conceptional model

The study area is the whole Ningjin county with the area of 833 km^2. Zhangweixinhe River as the boundary in the west and north of Ningjin along the horizontal direction, and administrative boundaries of Ningjin county as the flow boundary in the other regions. Geological stratification is carried out vertically, and the whole county will be roughly divided into 2 zones. The shallow fresh water area(zone 1) is 20-40 mm in depth of lower confining bed with the area of 130 km^2, and under the fresh water area, there is salt water area; the shallow and deep part of the zone 2 are fresh water area, with the lower confining bed depth of 50 m and the area of 700 km^2. The entire region's aquifer is generalized into a single layer structure, and the groundwater occurrence in Ningjin county is shown in figure 1.

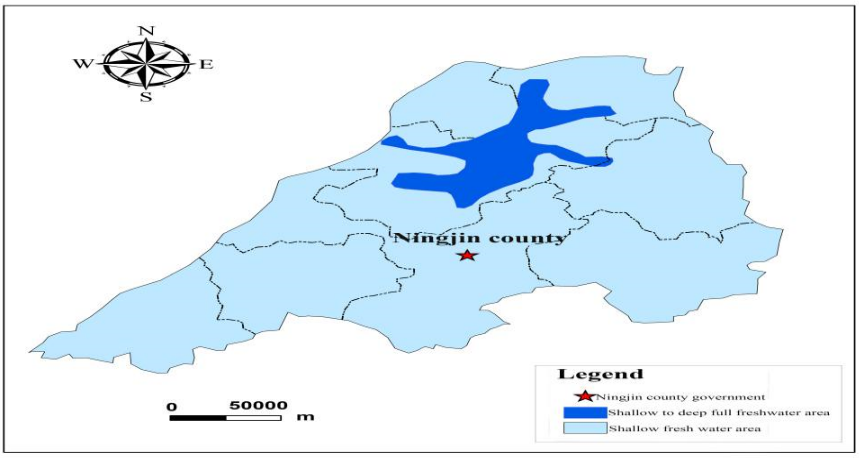

Figure 1. Groundwater occurrence in Ningjin county

4.2 Mathematical model

According to the generalized condition of hydrogeology in Ningjin county, the underground flow is generalized into a two-dimensional homogeneous unsteady underground flow system[2]. The equations are listed as follows:

$$\frac{\partial}{\partial x}\left[K(h-B)\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K(h-B)\frac{\partial h}{\partial y}\right]+\varepsilon_1(x,y,t)-\varepsilon_2(x,y,t)=\mu\frac{\partial h}{\partial t}....(x,y)\in D, t\geq 0$$

$$h(x,y,0)=h_0(x,y)..(x,y)\in D$$

$$h(x,y,t)\Gamma_1=h_1(x,y,t)..(x,y)\in\Gamma_1, t\geq 0$$

$$K(h-B)\frac{\partial h}{\partial n}|\Gamma_1=q(x,y,t)...(x,y)\in\Gamma_2, t\geq 0$$

Where B is the aquifer floor elevation (m); H is the aquifer water level (m); h_0 is the initial water level (m); h_1 is the first type boundary water level (m); ε_1(x, y, t) is the aquifer recharge intensity (m/d); ε_2 (x,y,t) is the aquifer discharge intensity (m/d); q(x, y, t) is single wide flow the second type of boundary; μ is the phreatic aquifer storage coefficient; K is the permeability coefficient (m/d);

5. GMS model simulation

5.1 Discretization of model area

Based on the spatial discretization of model area the mesh generation of area (833 km^2) is carried out by using the mode of 3D-grid in GMS; the conceptual model is translated into grid model by using the mode of map to modflow; and the gride is given some parameters such as boundary condition, aquifer thickness, permeability coefficient and source-sink term and so on[3].

5.2 Initial and boundary conditions

Boundary conditions: the north and west part of the county is bounded by the Zhangweixinhe River. The rest area are bounded by the administrative districts of Ningjin county and they are regarded as the flow boundary.

The average annual rainfall of Ningjin county is 580 mm. According to the pumping tests of different layers, it can be inferred that the rainfall infiltration recharge coefficient is 0.15, the water supply degree is 0.06, and the River infiltration recharge coefficient is 0.29. Based on the field survey and measurement, the data of the elevation all points, the pumping and irrigation flow of the well and the water level of the monitoring well are obtained.

5.3 Source and sink

From 2010 to 2015, the county's total annual average water supply was 1.371×10^8 m^3, and the irrigation water consumption was 1.173×10^8 m^3, of which the amount of water from Yellow River in irrigation water was 6.4×10^7 m^3, and the field infiltration recharge was 5.8×10^7 m^3. The annual runoff of Zhangweixinhe River, Ningbeihe River and Ningnanhe River reached 1.165×10^8 m^3, and the River infiltration replenishment was 3.38×10^7 m^3. The average annual rainfall was 580 mm and the amount of rainfall infiltration recharge was 3.31×10^7 m^3.

The discharge of groundwater is mainly from the underground water extracted by agriculture, life and ecology, of which the demand of agricultural water is 1.171×10^8 m^3, the demand of domestic water is 1×10^7 m^3, and the demand of ecological water is 6869 m^3. According to the above calculation, the total amount of groundwater replenishment was 1.056×10^8 m^3, and the total discharge was 1.271×10^8 m^3, the groundwater is under the overexploitation state.

5.4 Scenarios of groundwater mining and replenishing

There are four scenarios. Plan 1: the area of cultivated land is reduced by 20%; Plan 2: the area of cultivated land is reduced by 30%;Plan 3: the area of cultivated land is reduced by 40%; Plan 4: The amount of water from Yellow River, Zhangweixinhe River and Yangtzi River will be increased by 1×10^8 m^3.

5.5 Model parameter calibration and test

5.5.1 Parameter calibration basis and fitting

In the identification of the model, the water level map in 2014 is initial flow field, and the input of the model is based on the replenishment and output calculated by water balance, and the change of monitoring underground water level is the standard of model identification. Based on the fitting analysis of the calculated and the actual water level, the fitting parameters are constantly adjusted to fit the calculated water level and the monitoring water level to the maximum extent. Parameters calibration is shown in Table 1.

Table 1. Parameters calibration

Rainfall infiltration recharge coefficient	Specific yield	River infiltration recharge coefficient	Field infiltration recharge coefficient
0.15	0.05	0.3	0.20

5.5.2 Model identification

According to the observation data of the underground water level from 2010 to 2015, there are 26 observation wells, and the water level of 4 monitoring wells selected is used to simulated the water level every year. Compared the calculated water level and measured level, the fitting effect is better. Based on the identification and verification of the model and the fitting of the parameters, the establishment of the model is confirmed to be in line with the actual situation, which can be used to study the groundwater balance scheme in this area. The fitting lines of monitoring wells are shown in Figure 2.

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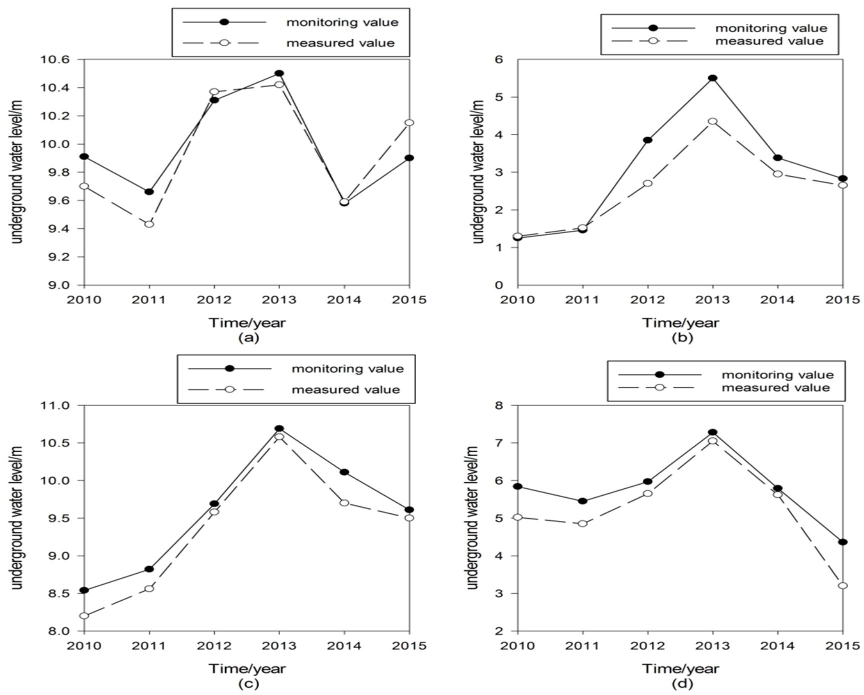

Figure 2. Fitting line of monitoring wells underground water level ((a)No. 70 monitoring well underground water level; (b) No.72 monitoring well underground water level; (3) No. 83 monitoring well underground water level; (d) No. 87 monitoring well underground water level)

5.6 Forecast and results

Scheme 1: under the conditions of current groundwater exploitation, when the irrigation area is reduced by 20%, the total amount of groundwater replenishment is 93.87 million m^3, and the total discharge is 103.71 million m^3. The groundwater is in the state of overexploitation.

Scheme 2: under the conditions of current groundwater exploitation, when the irrigation area is reduced by 30%, the total amount of groundwater replenishment is 88.3 million m^3, and the total discharge is 91.97 million m^3. The groundwater is in the state of overexploitation.

Scheme 3: under the condition of current groundwater exploitation, when the irrigation area is reduced by 40%, the total amount of groundwater replenishment is 82.14 million m^3, and the total discharge is 80.26 million m^3. The groundwater is in the state of replenishment.

Scheme 4: under the conditions of current groundwater exploitation, when the introduction amount of guest water (including Yellow River, Yangtze River and Zhangweixinhe River) is increased to a total of $1x10^8$ m^3, the total amount of groundwater replenishment is 135.6 million m^3, and the total discharge is 127.1 million m^3. The groundwater is in the state of replenishment.

The reliability analysis of simulated underground flow field and actual underground flow field is carried out. According to the forecast of Ningjin county, the total water demand of Ningjin county is 181.65 million m^3 and the available water supply is 182.5 million m^3 in 2020, which can meet the water demand of various industries.

6.Conclusions

The groundwater lever is monitored and different exploitation and recharge of groundwater schems are presented by using GMS software. The following conclusions can be drawn from the results.

(1) Under the condition of current groundwater exploitation, the groundwater is still in over-mining state when the cultivated land area is reduced by 20%; when the cultivated land area is reduced by 30%, the groundwater is still in overdraft state, but the rate of overdraft has slowed down; when the cultivated land area is reduced by 30%, it can effectively alleviate the situation of over-exploitation of groundwater; under the conditions of the current groundwater exploitation and the cultivated land

irrigated area unchanged, the water from Zhangweixinhe River, Yangtze River and Yellow River is used to increase the amount of groundwater replenishment. As a result, it can greatly alleviate the over-exploitation of groundwater.

(2) Ningjin county should further implement the project of groundwater recharge and make full use of the foreign water resources (Yellow River water and Yangtze River water) and precipitation to restrict the exploitation of deep groundwater. Meanwhile, Government should speed up the construction of water rights market, and rationally allocate shallow freshwater resources, only in this way, can it provide scientific basis for the sustainable utilization and development of groundwater resources in Ningjin county.

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