Trend prediction of regional groundwater level with GIS-FEFLOW model in Beijing Mihuaishun plain, China

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Abstract: A three dimensional finite element model (FEFLOW) has been used for regional groundwater flow modeling of Mihuaishun plain located in the south of Beijing, China. The numerical groundwater flow model is developed considering recharge components (precipitation infiltration, river leakage, and irrigation return flow). GIS interface is created for each source of recharge. Hydraulic conductivities and storage coefficient have been calibrated by the steady state model using the recorded data from 2007 to 2009. The model results is useful to identify the aquifer characteristics and to analyze the groundwater dynamics. The groundwater level monitoring network will be improved by analyzing groundwater levels. The future development scenarios are proposed to predict the trend changes of groundwater levels.

1. Introduction
The integrated and sustainable management of the limited water resources constitutes a significant issue due to increased demand for water, water deficiency and ecological problems caused by overuse of available water [1]. Integrated approaches in geographic information system (GIS) and groundwater model play an increasing role in the field of hydrology and water resources management. Using GIS as preprocessor and postprocessor, the time in developing a distributed parameter model can be considerably saved. Moreover, within a GIS framework, the powerful functions of visualization, statistics and analysis can help to check, manipulate and analyze a large amount of modeling data which is time consuming and tedious if it is done manually. It provides suitable alternatives for efficient management of large and complex databases developed in different model. Such models have been applied to investigate a wide variety of hydrology and water resources management problems. For the decades, various studies have been conducted by using finite element model (FEFLOW) and GIS [2-7].
The study area, MiHuaiShun plain, is located at the south of Beijing, capital of China, where exist two primary water sources, the 8th water source plant and HuaiRou emergency water sources, they supply water to the urban areas. The extensive groundwater exploitation for agricultural, industrial and drinking water supplies has led to a substantial decline in the potentiometric surface in the study area. In the present work, a 3D finite element flow model, coupled with a GIS, was explored to estimate the evolution of the flow system and to quantitatively assess the response of the groundwater system under different scenarios of groundwater management. A three-dimensional regional numerical groundwater flow model, calibrated under transient conditions has been developed and used to predict the drawdown for the period from 2010 to 2020 under two different groundwater extraction schemes.

2. Materials and Methods

2.1 Study area

MiHuaiShun plain is located at the south of Beijing, between 40.17º - 40.43º N and 116.57º - 116.83º E. With a value of around 33 km from east to west and 32 km from south to north, the total area is about 621 km². The outlined location of study area is represented in Fig. 1.

Fig. 1. Location of the study area

From the hydrogeological point of view, the study area represents a Quaternary alluvium and proluvial system. The storage of water resource decreases from the west to the east as well as from the north to the south. The thickness of the Quaternary deposits varies from tens to hundreds of meters. Due to the variability of lithology and discontinuities, the hydrogeological formation of the study area is based on both lithology and hydrogeological properties. From the alluvial fans to the plain, the sediment thickness increases and grain size decreases, while the aquifer systems change from a single sandy gravel aquifer to multi-sand and clay layers.

2.2 Methodology

Integration of GIS with groundwater modeling provides an effective way of analyzing and monitoring temporal changes in groundwater and its associated environment [1]. It provides suitable alternatives for efficient management of large and complex databases developed in different model environments. With advances in 3D modelling software and visualization tools over the last few years, as well as the increasing 2.5D and 3D GIS applications, digital subsurface information of local to regional scales has become more applicable and available [8]. A 3D groundwater flow software, FEFLOW, has been used in this study.

3. Numerical modelling

FEFLOW [11] was selected as simulation code because of its advanced capabilities to simulate groundwater flow in complex aquifer conditions, and is the most sophisticated software packages available for the modeling of flow and transport processes in porous media under saturated and unsaturated conditions. The finite element method, which is employed in FEFLOW and other codes, addresses many of the shortcomings of the finite difference method and is often applied in more
complex settings. The finite element method uses more sophisticated numerical solution algorithms resulting in more stable, faster solutions, which help modeling in complex geologic areas [9, 10, 11].

3.1 Spatial and temporal discretization
The model domain is spatially discretized into triangle grid with 27912 elements and 44620 nodes. The observation boreholes are set on the nodes. Forward/Backward Euler automatic time step is used for the temporal discretization in the model. The model layers were developed from point data using Akima’s bivariate interpolation method.

3.2 Model calibration and verification
In this study, the duration of the transient model is from 2007 to 2010. The stress period of one month was chosen which coincides with the observation interval of the groundwater heads. 48 time-dependent stress periods were specified.

The initial head of each layer in the model was obtained from the steady-state head solutions, which was formulated using the hydrological year of 2007. The application of model-generated head values guarantees that the initial water head and the model inputs and parameters are consistent.

A qualitative and a quantitative evaluation are performed to validate the model. One can see from Fig. 2 that the model output reasonably reproduces the observed values, and that the correlation coefficient of computed and observed values is close to one and within both sides of the 95% confidential lines.

Fig. 2 Observed versus computed water heads for a transient state model

4. Scenario development
The calibrated model was applied to predict future scenarios considering the variations of affecting factors and parameters related to groundwater utilization schemes in the study area. Two scenarios are proposed considering the present and future water exploitation plans.

4.1 Trends change of groundwater level under the present situation
According to the decade’s observation history of hydrology and meteorology resource prediction from 1999 to 2010, generally it can be concluded that a reduction in precipitation occurred during these ten years. The aforementioned findings reflect the future trends to some extent, therefore, the future trend of water resources variation can be forecasted representatively in some degree.

The change of groundwater level during 2010-2019 can be predicted using the previously established groundwater flow numerical model taking into account the present exploitation. Due to excessive groundwater exploitation, the groundwater resources of the study area have been in a negative balance, and the groundwater level is continuously decreasing. It is remarkable in the south, with a predicted average drop in groundwater level, 13.5 m. Until 2019, the drawdown of groundwater level in the northern Xitiangezhuang monitoring well reaches 8 m, leading to an average annual decline of 0.8 m. In 2013, the first large depression cone is expected to appear in the vicinity of eight
water plant due to excessive exploitation. This dewatering phenomenon will then be observed in Fangezhuang, Hu Ying, north of small business, North Taipingzhuang as shown in Fig. 4.

4.2 Trend change of groundwater level with no exploitation of groundwater

South-to-North Water Transfer Project has been initiated since 2003 for the runoff water scheduling principle and sustainable water resources development, and with the purpose of protecting environment, and it is proposed in the proposal of Central Line Project of South-to-North Water Diversion, to cease and limit the overexploitation of groundwater and to protect groundwater resources. Based on this principle and the actual condition of the study area, abstraction will not be permitted in Huairou emergency water source water and 8th water plant to study the groundwater level variations.

As the abstraction in the area of Huairou emergency water and eight water plant stopped for many years, the average groundwater exploitation and supply were observed to be kept in balance. In the groundwater flow field under the action of phreatic water aquifer of groundwater level, it was observed that the northern groundwater levels decreased slightly, while the water level in the eight water plant shows an increasing trend, with a value about 0.3 - 8 m as shown in the right part of Fig. 3.

5. Conclusions

In the present study, numerical groundwater flow modeling was integrated in GIS environment to identify and analyze the groundwater spatial-temporal behavior in Mihuaishun plain. The main findings have been obtained: 1) Vertical downward flow is confirmed by groundwater levels at multiple piezometers within several aquifers, showing that the groundwater level decreased; 2) The groundwater in the deep confined aquifers is mainly recharged by the linkage of shallow aquifers; 3) due to the small leakage rate, groundwater withdrawal from the deep aquifers has resulted in the depression cone; 4) single aquifer exists in the North-West boundary extending down to East-South boundary with multi-aquifers separated by the aquitard, and these results in the variation of water level in different layers. Flow directions were conceptualized from the boundary to the depression cone.

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