Assessment Methods of Groundwater Overdraft Area and Its Application

DONG Yanan[1], XING Liting[1], ZHANG Xinhui[1], CAO Qianqian[1], LAN Xiaoxun[1]

[1] School of Resource and Environment, University of Jinan, Jinan 250022, China

e-mail: 791413427@qq.com

Abstract. Groundwater is an important source of water, and long-term large demand make groundwater over-exploited. Over-exploitation cause a lot of environmental and geological problems. This paper explores the concept of over-exploitation area, summarizes the natural and social attributes of over-exploitation area, as well as expounds its evaluation methods, including single factor evaluation, multi-factor system analysis and numerical method. At the same time, the different methods are compared and analyzed. And then taking Northern Weifang as an example, this paper introduces the practicality of appraisal method.

1. Introduction

With the increasing demand for water resources, people develop and utilize groundwater on a large scale for a long time, leading to the formation of groundwater over-exploitation areas and causing changes of ecological environment. As of 1995, all the 50 states in the United States caused surface subsidence due to over-exploited [1]. The Po Delta, Tokyo and Mexico also experienced severe ground subsidence due to over-exploited [2]. In China, the total area of over-exploited in the late 1990s was 180,000 km^2 [3]. In recent years, according to relevant statistics, over 100 large-scale groundwater descent funnels have formed, with the over-exploitation area covering an area of over 620,000 km^2 [4].

Over-exploitation of groundwater leads to a series of environmental and hydrogeological problems such as depletion of groundwater resources, ground subsidence, ground fissures, seawater intrusion, saltwater freshwater, karst collapse, slump in spring water flow, deteriorating groundwater quality, soil desertification and vegetation degradation.

The universality and growing severity of over-exploitation of groundwater have drawn the attention of the international community. As early as 1991, the IAWG meeting in Spain started to pay attention to the "aquifer over-exploitation" [5]. In recent years, with the further deterioration of environmental and hydrogeological issues, some cities in China have delineated the scope of their over-exploitation areas in order to better manage groundwater resources and put forward the governance objectives and requirements related to over-exploitation of groundwater [6-8]. However, due to the inconsistency of the division method or evaluation index of groundwater over-exploitation zone, the scope of over-exploitation zone is often not consistently demarcated. Therefore, to determine the scope of over-exploitation area reasonably is of great significance for developing and using groundwater scientifically, as well as preventing environmental and hydrogeological problems.

2. Connotation of groundwater over-exploitation area.

2.1. Concept of over-exploitation area

The Guidelines for the Evaluation of Groundwater Over-exploitation Area (SL286-2003) consider that the area where the amount of groundwater exploited exceeds the recoverable amount, and the groundwater level continues to decline, or the environmental geohazards or the deterioration of the ecological environment are caused by exploitation and utilization of groundwater are overdraft areas [9]. In t*he Technical Outline for Planning and Exploitation of Groundwater Resources in China* issued by the Ministry of Water Resources, the groundwater over-exploitation zone is defined as: the average annual groundwater exploitation exceeds the average annual groundwater recoverability, resulting in the depletion of groundwater resources, deterioration of water quality, land subsidence and other environmental geological problems in the area [10].

Many scholars have studied the concept of over-exploitation zone from many aspects. As early as the last century, the "temporal nature" of over-exploitation areas has been proposed. Since groundwater resources (or recoverable resources) vary with the level of groundwater extraction, over-exploitation also varies. Over-exploitation of groundwater is defined as the average exploitation of groundwater over the recharge for many year at a certain mining level [11]. With further research, Custodio raised the issue that when the amount of extraction was equal to or slightly less than the supply of resources, the river basins, springs and wetlands that were originally relied on groundwater recharge would tend to be depleted. That means this "non-over-exploitation" is meaningless if "groundwater extraction volume exceeds supply" is taken as the condition [12]. Therefore, the concept of overdrawn area is still controversial.

The characteristics of over-exploitation area makes it necessary to interpret the concept of itself in terms of forming conditions, natural properties and hazards of overdrawn area. Therefore, within a certain period of time, when groundwater exploitation exceeds a threshold value and the groundwater system, local geological environment, water quality or ecological environment have some damage or fission effects, they can be classified as groundwater over-exploitation area.

2.2. Natural and social attributes of over-exploitation area

2.2.1. Natural attributes of over-exploitation area

- The dynamic time-varying of the scope of over-exploitation area. The scope of overdraft area is not static. With changes in the amount of groundwater exploitation or groundwater recharge conditions, over-exploitation area increased or decreased. For example the area designated as over-exploitation area in Jiangsu Province in 2013 was reduced by 4.77% compared with that in 2005 [13].
- The differences of the type of over-exploitation area. According to the differences of groundwater aquifer medium, the over-exploitation area can be divided into the pore water over-exploitation area, fissure water over-exploitation area and the karst water over-exploitation area. According to aquifer burial conditions, it can be divided into diving over-exploitation area and confined water over-exploitation area. For example, there are both shallow pore water over-exploitation area and deep confined water over-exploitation area in Shandong and Hebei Provinces [14]. However, deep groundwater, which has weaker supply and renewal capacity, is often classified as a forbidden zone.
- The diversity of the hazards of the over-exploitation area. The hazards posed by over-exploitation are complex and diverse. First of all, over-exploitation leads to ecological problems, such as the decline of vegetation [15]; secondly, over-exploitation triggers geological and environmental problems such as land subsidence, karst collapse, ground fissures, etc. [16-18]; thirdly, over-exploitation leads to deterioration of water quality, stratigraphic pollution of aquifers, conventional ion composition increases, sea water intrusion have changed the quality of groundwater [19-20].

2.2.2. Social attributes of over-exploitation area

- The timing of evaluation index. The status of groundwater is affected by human activities. Therefore, there are some differences in evaluation indexes adopted in different periods. When a certain area has taken some measures to reduce groundwater exploitation, groundwater levels began to rise; in the process that water level has not yet recovered to the critical, if the same rate of decline of the water level was still to be used as an indicator, you will get conflicting results with the actual situation.
- The regional characteristics of evaluation index. Different hydrogeological conditions and different layout of groundwater exploitation and utilization have different thresholds for evaluating, and the different types of over-exploitation areas also determine the regional characteristics of evaluation indexes. For example, in Cangzhou, the area with the groundwater depth exceeding 10m is regarded as a shallow groundwater over-exploitation area [14], while Jining City determines that the area with a groundwater depth greater than 6m is a shallow pore water over-exploitation area [21].

3. Evaluation of over-exploitation area

3.1. Single factor evaluation method

- Single index numerical method. It mainly includes the evaluation methods based on the individual indexes of groundwater level declining rate, average annual groundwater over-exploitation coefficient, annual average spring flow decay rate and land subsidence rate [9].
- Statistics method. Groundwater over-exploitation caused many ground subsidence, ground cracks and other issues. Investigate and count hazard that has already been formed and evaluate according to the severity of the disaster. At present, for most evaluation, please refer to *The Guidelines for the Evaluation of Groundwater Over-exploitation Area* (SL286-2003) .

Although the single index numerical method or statistical method can directly evaluate the environmental geological problems or ecological deterioration caused by groundwater over-exploitation, it is usually only suitable for the evaluation of local over-exploitation and does not reflect the over-exploitation of groundwater in the area. Moreover, the groundwater system has integrity, so that a single evaluation index alone can not provide a comprehensive assessment of the groundwater system.

3.2. Multi-factor system analysis method

Multi-factor system analysis refers to the evaluation of overdrawn areas according to certain methods by selecting a variety of indicators , including analytic hierarchy process, gray clustering method and probabilistic neural network method [22-23].

Although the multi-factor system analysis method considers multiple evaluation indexes, its common defect is that the selection of indexes and weights is artificial, which will have a great impact on the evaluation results.

3.3. Numerical method

With the progress of computer technology and groundwater flow simulation technology, the application based on numerical simulation is more and more widely. For example, the finite difference method is used to predict the evolution of groundwater over-exploitation area in the plain area of Tianjin [24]. The numerical method can reflect the complex hydrogeological conditions and complex groundwater flow regime in the area, and it is easier to solve the uncertainty and complexity in practical problems. Moreover, the numerical model can also evolve the groundwater movement and break the limitation of time. It can be seen that numerical simulation has a wide range of applications, and suitable for different hydrogeological conditions.

3.4. Discussion of evaluation methods

Although the single factor evaluation method has some shortcomings, it also highlights the significance of environmental hydrogeological problems. The hydrogeological significance of multifactor analysis method is not clear, and the numerical method can take the integrity of groundwater system into account. Therefore, in order to evaluate the over-exploitation area comprehensively and accurately, we must not only consider the importance of single elements of environmental hydrogeology, but also pay attention to the integrity of the groundwater system. Therefore, we can evaluate the groundwater overdraft area jointly by the regional groundwater numerical simulation and the local single factor indicator. Regional Numerical Simulation-Local Dynamic of Water Level Assessment, which uses numerical simulation to identify the entire groundwater system and uses the readily available groundwater table as an indicator to highlight the typical and representative hydrogeological problems, can be applied to improve the accuracy of valuation.

4. Application of method

The northern part of Weifang is the largest ultra-shallow groundwater over-exploitation area in Shandong Province. This paper evaluates the over-exploitation area of Weifang based on Visual modflow and using water level dynamic method.

4.1. Establishment of numerical simulation model

4.1.1. Source and sink data processing

The groundwater aquifer group in the study area is Quaternary pore water. The lithology is composed of fine sand, gravel, silt, clay and so on [25]. In the simulation area, the northern boundary is the Laizhou Bay coastline and set the head value to 0m; the eastern and western boundaries are administrative boundary of Weifang while the southern border is Quaternary pore water aquifer boundary (Figure 3-1).

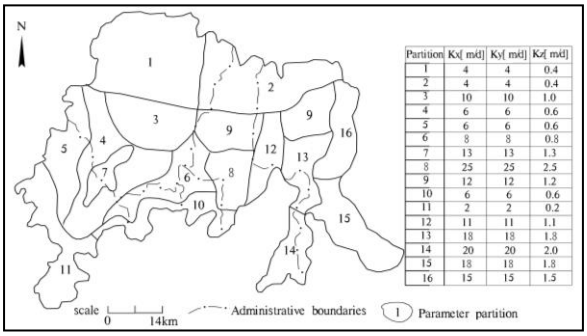
Select the 2010 (annual rainfall of 531mm), a flat-water period, as the simulation period with a duration of one month, using the water level in January 1, 2010 as the initial water level. At the same time, pumping wells was carried out, and no transpiration treatment was conducted here. Precipitation is treated as a surface recharge source, and the study area is zoned according to topography, hydrogeological conditions and other factors.

4.1.2. Determination of model parameters

According to the hydrogeological conditions, the initial values of the parameters are given. After inputting the corresponding source, sink data and the initial values of the parameters, the values of the adjustment parameters, the source and sink items are run repeatedly according to the model operation results, so that the calculated water level of the observation point and the actual observed water level are fitted. The final model parameters and values are shown in Figure 3-1.

4.1.3. Results of model operation fitting

Figure 3-2 shows the fitting curve between the calculated groundwater level and the actual monitored water level. The goodness of fit can be seen from the figure: the standardized mean square error (RMS) is 2.628%, and the correlation coefficient is 0.992. The result shows that the fitting result of the model reaches the precision requirement. Then delineating the over-exploitation area is based on the flow field map in January 1, 2011 (Figure 3-3).



Partition	Kx[m/d]	Ky[m/d]	Kz[m/d]
1	4	4	0.4
2	4	4	0.4
3	10	10	1.0
4	6	6	0.6
5	6	6	0.6
6	8	8	0.8
7	13	13	1.3
8	25	25	2.5
9	12	12	1.2
10	6	6	0.6
11	2	2	0.2
12	11	11	1.1
13	18	18	1.8
14	20	20	2.0
15	18	18	1.8
16	15	15	1.5

Fig.1 Study area overview and parameter zoning map

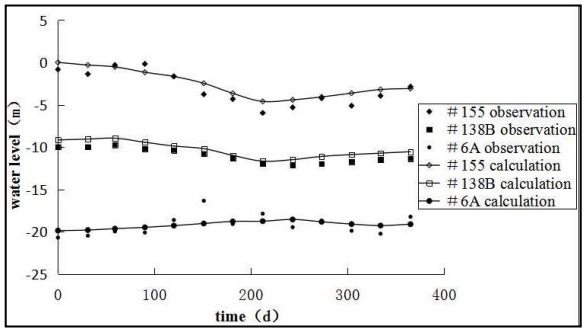


Fig.2 The water level fitting curve of groundwater observation well

4.2. Application of water level dynamic method

Taking the lack of observation data in observation wells into account, we selected the data with more continuous and complete observation data from December 1, 2008 to December 1, 2014. In this long-term series the groundwater level generally decreases and the rainfall is generally in an average state. According to the observation data, the over-exploitation area distribution map was drawn based on the descending rate of groundwater level (Figure 3-4).

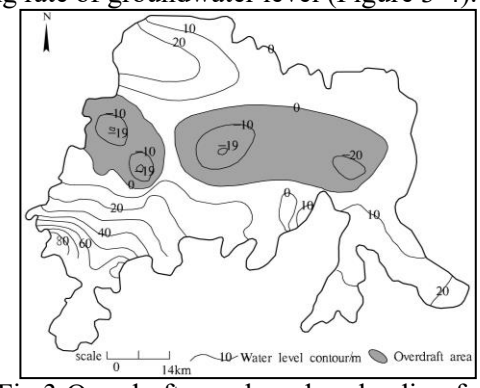


Fig.3 Overdraft area based on landing funnel

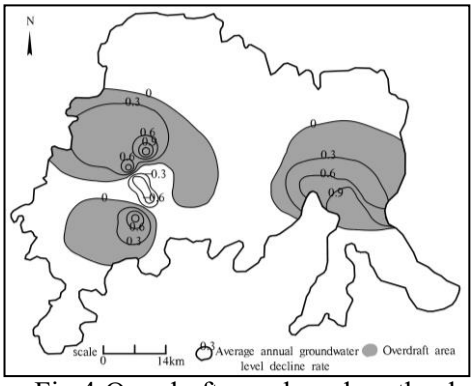


Fig.4 Overdraft area based on the decreasing rate of groundwater level

5. Conclusion

- Over-exploitation area refers to the area where groundwater exploitation exceeds a certain threshold and has some damage or fission on the groundwater system or local geological environment, water quality or ecological environment within a certain period of time.
- There are many evaluation methods for over-exploitation area, each method has its advantages, disadvantages, and applicable conditions. Different research purposes, different regions and the degree of mastery of data affect the choice of evaluation system, and we should select evaluation system according to the actual situation.

References

[1] Bertoldi GL. Where do we go from here: a new initiative for subsidence research in the United States[A]. Annual Meeting of the symposium on land subsidence[C]. Califmia: Califomia institute of technology press, 1995.

[2] Andrew Sowter, Moh Che Amat, Francesca Cigna, et al. Mexico City land subsidence in 2014-2015 with Sentine-1 IW TOPS:results using the Intermittent SBAS (ISBAS) technique[J]. International Journal of Applied Earth Observations and Geoinformation, 2016, (52): 230-242.

[3] Qiao Shishan. Advice on enhancing groundwater over-pumping areas rehabilitation[J]. China Water Resources, 2008, (23): 37-39.

[4] Yang Guoqiang, Meng Jingying, Su Xiaosi,et al. A briefly review of evaluation index and method of groundwater overdraft[J]. Water Saving Irrigation, 2011, (8): 34-38.
[5] Villarroya F.. Regulatory issues mainly about aquifer over exploitation within the scope of sustainable development[C], 1994.
[6] Guo Xiuhong, Zhao Hui.Delimitation of groundwater over-exploitation area[J]. China Water Resources, 2015, (1): 41-43.
[7] Le Feng, Fang Rui, Zhu Li, et al. Environmental geological problems and countermeasures of Nantong groundwater overdrawn Area[J]. Ground Water, 2014, 36(4): 95-108.
[8] Li Jie. Analysis on the effect of groundwater pressing in Cangzhou City[J]. Water Conservancy Science and Technology and Economy, 2015, 21(12): 4-6.
[9] SL286-2003. The guidelines for the evaluation of groundwater over-exploitation area[S]. Beijing: China Water Conservancy and Hydropower Press, 2003.
[10] Ministry of Water Resources.Technical outline for planning and exploitation of groundwater resources in China[R].Beijing:Ministry of Water Resources,2003.
[11] Hu Zhirong, Cao Wanjin, Ren Qingchao, et al. Groundwater overdraft and its environmental impact[J]. Water conservation, 1995, (2): 37-41.
[12] Custodio E.. Aquifer over-exploitation : what does it mean?[J]. Hydrogeology Journal, 2002, 10(2): 254-277.
[13] Huang Xiaoyan, Feng Zhxiang, Li Lang. Analysis on the changing tendency of groundwater over mining area in Jiangsu Province[J]. Ground Water, 2014, 36(4): 53-86.
[14] Liu Zhenduo, Wang Chunqiao, Wu Xingguo. Approved and ban mining area, limited mining area of groundwater overdraft area in Cangzhou City[J]. Water Conservancy Science and Technology and Economy, 2011, 17(9): 65-75.
[15] Sun Xianchun. Groundwater effect on the growth of the vegetation in the yinchuan plain[J]. GEOSCIENCE, 2008, 2(22): 320-324.
[16] Ge Chunlan. Analysis of ground subsidence caused by the decrease of groundwater level[J]. Inner Mongolia Coal Economy, 2012, (04): 36-37.
[17] Zhang Renquan. Basis of hydrogeology[M]. Sixth Edition.Beijing: Geological Publishing House, 2011: 166-168.
[18] Wang Zhecheng, Zhang Yun. Advances of research on the earth fissure induced by groundwater over-exploitation[J]. Hydrogeology & Engineering Geology, 2012, 39(2): 88-93.
[19] Lin Zhixiang. Environmental Geological problems caused by decreasing groundwater table[J]. Heilongjiang Science and Technology Information, 2016, (12): 2.
[20] Cao Bin, Tang Peijun, Jiao Yufei. An analysis of hydro-chemical characteristics of groundwater in over-exploited area of northern Weifang[J]. China Rural Water and Hydropower, 2017, (3): 85-95.
[21] Chen Guohao. The zonation of groundwater over Exploitation in Jining City[D]. Nanjing: Hohai University, 2007.
[22] Zhao Min. Stuy on delimitation of groundwater overdraft area sand evaluation of reducing groundwater exploitation effect based on AHP[D]. Taiyuan: Taiyuan University of Technology, 2016.
[23] Hao Jie. Study of Xian over-exploited groundwater area and the amount of ecological restoration[D]. Xian: Changan University, 2011.
[24] Xu Haizhen, Li Guomin, Li Ming, et al. Analysis on over-exploited area evolution of groundwater in Tianjin city based on numerical simulation[J]. Journal of Geotechnical Investigation & surveying, 2011, 39(11): 35-40.
[25] Diao Weijie, Feng Zhonglun, Liu Xishen, et al.Optimal allocation of Weifang based water resource in North of on Visual Modflow[J]. Water Resources and Power, 2017, 35(4): 25-28.