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Research Article

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The shallow groundwater pollution's assessment of west Liaohe plain (eastern)

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ABSTRACT

West Liaohe river plain is an important food base of China, and the groundwater is the main resource of water supply. Because of the effect of industrial and domestic pollution and the application of fertilizer and pesticide in agriculture, the groundwater has been polluted to a certain extent. This article analysis of carious methods of groundwater pollution evaluation, improves the method of single factor pollution, and proposes the single index pollution standard. The author carried out the survey in the west Liaohe plain, and collected 390 groundwater samples. Every sample is tested 79 indicators(including 7 live tests). According to the date's analysis , we choose 34 items evaluated , such as iron ,fluorine ,nitrogen and organic projects This article uses the single factor pollution index method to evaluate the groundwater pollution of the eastern west Liaohe plain and analyze the causes of groundwater pollution. According to the pollution's classification, the author classifies the pollution distribution range, and analyzes the reasons that led to groundwater pollution. This article solves the contrast between the evaluations of regional pollution problems, it can directly reflect the regional groundwater pollution, and provide a basis for management of groundwater pollution.

Keywords: West Liaohe River Plain, groundwater pollution, pollution assessment

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INTRODUCTION

With economic development, population increase and urban scale expansion in West Liaohe River Plain, contradiction between water supply and demand becomes increasingly prominent. In particular, rainfall decline has caused a serious lack of surface water over the years. Thus, groundwater resources are particularly important in the West Liaohe River Plain. However, underground water level falls gradually due to large-scale exploitation of groundwater. Especially centralized water supply in urban areas causes a large amount of groundwater exploitation. In addition, the groundwater has been polluted under the impact of industrial wastewater, domestic wastewater and agricultural irrigation. The pollution is more prominent in the eastern regions of West Liaohe River Plain with more concentrated urbanization, dense population and developed industry. In order to solve imbalance between water supply and demand in the survey area, Predecessors carried out hydro-geological work in different scales, such as 1:250000 regional hydro-geological survey, 1:200000 regional hydro-geological survey, 1:100000 hydro-geological investigation of water supply for agriculture and animal husbandry[1，2,3,4，5]. More geological survey results of hydrological engineering environment have been obtained and basic hydro-geological conditions are basically clear, but the work on groundwater pollution is still at a lower level, especially including the research on organic pollution. Therefore, it has an important theoretical and practical significance to rational development and utilization of groundwater, protection and scientific management of groundwater resources and even national economic development to carry out groundwater pollution assessment and identify characteristics of pollution in the survey area.

Different from groundwater quality, groundwater pollution mainly refers to water degradation arising from production and life of humans. There are a number of researches on groundwater quality assessment in China. The groundwater quality assessment is generally used to assess quality of water under existing conditions based on specific water quality standards. It is an assessment on suitability for some purpose. Groundwater pollution assessment is a pollution level assessment based on background value or pollution initial value[6]. Such assessment focuses on pollution status and needs long-term data collection. It usually can reveal cause or mechanism of changes in water quality, so it is the basis for water quality improvement and water environment protection.

General

Natural conditions

West Liaohe River Plain is located in the east of Inner Mongolia Autonomous Region and between southern mountains of Greater Khingan Range, Northern Hebei and Western Liaoning mountains. It is connected with Songliao Plain on the east and consists of alluvial plain formed by West Liaohe River and its tributaries and residual ancient sandy alluvial plain [7-9]. Eastern part of West Liaohe River Plain mainly refers to the basin of East Liaohe River and Liaohe River, mainly including Gongzhuling City, Lishu County and Shuangliao City in Jilin, Kezuohouqi in Inner Mongolia as well as Kangping, Faku, Changtu, Tieling and Kaiyuan in Liaoning, with a coverage area of about 30,000 km2. It is convenient in the transportation and No.102 National Highway is its traffic artery. In addition, it is agriculture-based.

Regional hydro-geological conditions

The survey area is divided into two hydro-geological units based on geographic location, hydro-geological structure and groundwater recharge, runoff and drainage, namely East Liaohe Hydro-geological Unit and the Lower Liaohe (Kangfa Hills) Hydro-geologic Unit. The survey area is based on hydro-geological conditions, Quaternary genetic type and structural features of basins and regions. Eastern part of West Liaohe River Plain mainly consists of East Liaohe groundwater systems, mainstream groundwater systems of Liaohe River, groundwater systems of Zhaosutai River, groundwater systems of Qinghe, groundwater systems of Lama River, groundwater systems of Xiushui River and groundwater systems of Liuhe River. The survey area is divided into four water bearing formations vertically based on litho-logy and hydro-geological conditions. The first water bearing formation is Quaternary loose unconfined water-bearing formation. It is a locally feeble confined and semi-confined aquifer with thickness of 3 to 55m and serves as an active cyclic alternating layer of groundwater. This formation is the aquifer mainly developed in the survey area. The second water-bearing formation is Neogene System one with roof burial depth of generally 7 to 46m. It is a confined aquifer. In the survey area, it is locally distributed and poor in the water quality, so its groundwater should not be developed. The third water-bearing formation is Cretaceous one with roof burial depth of 3.4 to 101m. Due to poor watery, it should not be developed. The fourth water-bearing formation is a weathered bedrock fissure water aquifer. Its groundwater mainly occurs in fissures and weathered cracks. Bedrock fissure aquifer has no focused mining value, but it plays an important role in recharge of groundwater in plain regions. In the research on underground water of eastern regions of West Liaohe River Plain, the first and second water-bearing formations are collectively known as shallow aquifer systems and major exploitation intervals while the third and fourth water-bearing formations are collectively known as deep aquifer systems which should not be developed.

Water sampling and testing

During the period from last ten-day of June to that of November in 2012, groundwater pollution survey was carried out in the survey area to select common motor-pumped wells and some water supply wells which are typical and easy to take sampling procedures by the principle of surface control and local refinement and based on sampling density of nearly 1.3 groups / 100 km2. 390 groups of shallow groundwater (confined and feeble confined groundwater) samples were taken. In accordance with the requirements of Specification for Geological Survey Assessment of Groundwater Pollution [10] of China Geological Survey Bureau, relevant protective agents were immediately added for collected samples based on testing indicators to prevent the testing indicators from physical or chemical reactions such as evaporation, oxidation and reduction. The samples were timely sent to Northeast Mineral Resources Supervision and Testing Center of Ministry of Land and Resources for analysis and testing. There are 79 testing indicators, including 7 physical and chemical site indicators, 35 inorganic indicators such as total hardness and TDS and 37 organic indicators such as halogenated hydrocarbons, chlorinated benzenes, monocyclic aromatics, organochlorine pesticides and polycyclic aromatic hydrocarbons.

Assessment method

There are a number of groundwater assessment methods at home and abroad, mainly including single factor pollution index method, comprehensive pollution index method, parameter grading score superposition index method, AHP method, statistical analysis method, gray system and fuzzy mathematical method. Comprehensive pollution index methods mainly include algebraic superposition method, geometric mean method, Nemerow pollution index method and RMS method. Their assessment results may suffer distortion or physical significance ambiguity. Due to shortcomings including large difference between background values (control value and detection limit) of pollution component and asynchronism of pollution component harms, the parameter grading score superposition index method may generate a harm of seriously polluted water lower than that of moderately polluted water. The AHP method has the shortcoming that data statistics quantity is large and the weight determination is difficult in case of more indexes. Statistical analysis method, grey system, fuzzy mathematics and other mathematical methods cannot directly reflect pollution characteristics. In short, the aforementioned methods have their own merits, but they are less feasible and difficult to popularize in the regional groundwater pollution assessment.

In contrast, the single factor pollution index method is widely used in China with a clear physical significance and simple calculation process. Due to large background value difference between the regions and between assessment indicators, pollution index cannot be compared so that overall groundwater pollution cannot be reflected. As heavy metals and organic indicators are taken into account, some assessment indicators have the natural background value of 0 so that the assessment method loses its mathematical significance. Therefore, it is urgent to find a practical groundwater pollution assessment method [11].

Single factor pollution standard index assessment method

Based on various influence factors, the single factor pollution index method is modified and renamed single factor pollution standard index method. This method takes into account Class III standard value of Groundwater Quality Standards (GB/T14848-1993) [12] and Sanitary Standard for Drinking Water (GB5749-2006) [13], that is, standard exceeding is considered to better reflect human influence. In addition, this method also can be used for comprehensive pollution assessment, that is, the pollution can be controlled effectively based on groundwater pollution indicators determined in accordance with single factor pollution assessment results.

Calculation formula $P_{ki}=（C_{ki}-C_{0i}）/C_{IIIi}$ (1)

Where, P_{ki} – pollution index of the i^{th} indicator for k water sample;
C_{ki} - test result of the i^{th} indicator for k water sample;
C_{0i} - background value of the i^{th} indicator in the region of k water sample
C_{IIIi} - Class III index limit of the i^{th} indicator in the Groundwater Quality Standards.

Single factor pollution standard index Pki of each water sample point is calculated by Formula (1) and pollution is graded based on pollution grading standard in Table 1 to obtain single factor pollution grading results of water samples.

As known from the results, Class I indicators no pollutant detected, Class II, Class III and Class IV indicate the defected pollutants are not out of limits while Class V and Class VI indicate standard exceeding.

Table 1 Single Factor Pollution Standard Index Grading Standard

Pollution category	No pollution	Light pollution	Moderate pollution	Less serious pollution	Serious pollution	Extremely serious pollution
Pollution grading	I	II	III	Ⅳ	V	Ⅵ
Index range	$P\leq0$	$0<P\leq0.2$	$0.2<P\leq0.6$	$0.6<P\leq1.0$	$1.0<P\leq1.5$	$P>1.5$

Assessment index classification

Hazardous substances closely related to human activities are selected for the groundwater pollution assessment indicators, including inorganic indicators and organic indicators. The assessment indictors can be classified five types, namely inorganic indicator, three-nitrogen indicator, toxic heavy metal indicator, volatile organic compound indicator and semi-volatile organic compound indicator (Table 2).

Table 2 Classification of Groundwater Pollution Assessment Indicators

Indicator category	Indicator name
Inorganic indicator	Total iron, fluorine, etc.
Three-nitrogen indicator (three items)	Nitrate - nitrogen, nitrite – nitrogen and ammonium nitrogen
Toxic heavy metal indicator (five items)	Arsenic, cadmium, chromium, lead and mercury
Volatile organic compound indicator (21 items)	Benzene, ethylbenzene, toluene, xylene, methylene chloride, trichlorethylene, 1,2 - dichloroethane, chloroform, tetrachlorethylene, 1,1,1 - trichloroethane, carbon tetrachloride , 1,2 - dichloropropane, 1,1,2 - trichloroethane, trichlorethylene, 1,1 - dichloroethylene, bromoform, 1,2 - dichloroethylene, styrene, o-dichlorobenzene, chlorobenzene and dichlorobenzene
Semi-volatile organic compound indicator (5 items)	Total hexachlorocyclohexane (HCH), γ-BHC (benzene hexachloride), total DDT (double-chlorophenyl trichloroethane), hexachlorobenzene and benzo (a) pyrene

Control value determination

There are a number of methods to calculate groundwater background values, but their calculation results are not ideal and have a large deviation from actual conditions. Calculation methods are selected based on provinces. Investigation of Chemical Background Value for Groundwater in Jilin Province is taken as the basis for calculation method selection of Jilin while the 1:200000 report in the early 1980s is the basis for Liaoning and Inner Mongolia. If no complete previous data, mathematical statistics can be conducted for inorganic sample testing results by the following mathematical formula based on the Report for Survey and Assessment of Groundwater Resources and Environmental Problems in West Liaohe River Plain and chemical testing data obtained in the work, thus getting the control value.

$$Y = X \pm 2S, \quad S = \sqrt{\frac{\sum \left(Xn - \overline{X} \right)^2}{n-1}} \qquad (2)$$

Where, Y is control value;
X is arithmetic mean value of tested component concentration for multiple points;
Xn is tested component concentration for single point;
S is standard deviation;
n is number of item.

Control values of groundwater pollution assessment indicators such as fluoride, nitrate - nitrogen, nitrite – nitrogen, ammonium nitrogen and total iron are determined based on full analysis and research (Table 3).

Table 3 Zoned Contrast Value of Some Assessment Indicators

Province	Ground water type	Distribution area	Groundwater control value (mg / l)				
			Fluoride ion	Ammonium ion	Nitrate	Nitrite	Total iron
Jilin	Confined or feeble confined	Low plains	0.93	0.2	10	0.001	0.320
		High plains	0.32	0.2	10	0.001	0.218
		Valley plain	032	0.2	10	0.001	0.930
Liaoning	Confined	Liuhe groundwater systems	0.354	0.02	15	0.02	0.35
		Liaohe River alluvial fan groundwater system	0.01	0.02	3	0	1.0
		Zhaosutai River groundwater system	0.01	0.01	1.0	0	1.0
		Qinghe groundwater systems	0.01	0.02	1.0	0	0.3
		groundwater system of the upper reaches of Liaohe River	0.01	0.01	2.0	0.02	1.5
		Xiushuihe groundwater system	1.0	0.05	1.0	0	1.0
Inner Mongolia	Confined	Some regions of Kezuohouqi	0.34	0.05	1.0	0	0.2

Under normal circumstances, there are few organic matters and toxic heavy metals such as cadmium, chromium, lead and mercury in primitive environment. Human activities are the main way to groundwater pollution. Therefore, control value of organic matters and toxic heavy metals is set to 0 in the groundwater pollution assessment.

Regiongal groundwater pollution assement

As shown from assessment and analysis based on the sample testing data, eastern part of West Liaohe River Plain suffers pollution and its groundwater is polluted seriously. Unpolluted samples of Class I account for only 8.9% of total samples, light pollution samples of Class II account for 29.9%, moderate pollution samples of Class III account for 34.9%, less serious pollution samples of Class IV account for 10.6%, serious pollution samples of Class V account for 3.6% and extremely polluted samples of Class VI account for 12%.

Inorganic component

There is a high content of iron and manganese in the entire region. Fluorine is out of limits mainly in the eastern part of Kezuohouqi and middle part of Shuangliao County. Main cause for exceeding of iron, manganese and fluorine is the primitive environment with a higher hydro-geochemistry background value. But the above elements with a higher content in the groundwater do not affect the pollution assessment.

Three-nitrogen

Shallow groundwater in the eastern part of West Liaohe River Plain suffers serious three-nitrogen pollution distributed in sheets. The groundwater in the entire region suffers three-nitrogen pollution and is seriously polluted groundwater – based. Nitrite - nitrogen, nitrate – nitrogen and ammonium nitrogen reach the over-limit ratio of 35.93%, 16.99% and 7.24%. Main causes for three-nitrogen pollution include long-term application of pesticides and fertilizers in the West Liaohe River Plain as a agricultural commodity grain base, stacking and leaching of household wastes in the intensive living areas and industrial three-nitrogen in surface discharge ditches of industrial enterprises. With precipitation leaching and surface water recharge, three-nitrogen ions increase in the groundwater to cause increase of over-limit points in the entire region.

Heavy metals
Heavy metals in the groundwater such as arsenic and lead have a higher detection rate and are distributed in spots. 8.66% of shallow groundwater in the survey area suffers heavy metal pollution. Lead pollution is the most serious, with the over-limit ratio of 10.86%. Chromium (hexavalent), mercury and cadmium are detected. Arsenic content of shallow groundwater is higher in some areas, with the over-limit ratio of 4.18%. As shown from the analysis, the arsenic is mainly generated from native geological environment and affected by geological conditions of deep structure and recharge zone. Heavy metal pollution is distributed mainly in spots and lines, more around urban areas and industrial and mining enterprises. The pollution is serious especially in the sewage irrigation area around urban areas. Disordered discharge of sewage from urban areas and industrial and mining enterprises, poor waste management and illegal sewage discharge in the energy resource development are important causes for heavy metal pollution of groundwater.

Poisonous and harmful organic matters
Pollution features of poisonous and harmful organic matters include more detected pollutant types, more sampling well points of defected pollutants, more types of organic pollutants detected in a single point, low concentration of organic pollutants and no over-limit. Volatile organic compounds play a larger influence on groundwater. The groundwater polluted by volatile organic compounds account for 15.38% of total sampling points, including 14.82% for light pollution and 0.56% for moderate pollution. Semi-volatile organic compounds almost have no influence on groundwater. Only benzo (a) pyrene can cause light pollution. The groundwater polluted by semi-volatile organic compounds account for 19.28% of total sampling points. Poisonous and harmful organic matter pollution is mainly caused by production, processing, storage and use of the poisonous and harmful organic matter products by petrochemical enterprises. Groundwater of the area around solid waste of petrochemical enterprises and along sewage discharge canals also suffers the pollution.

Analysis of groundwater pollution causes
Since the 1980s, social and economic development has become rapid with fast urbanization, urban size increase and population expansion in the eastern part of West Liaohe River Plain. With intensification of human activities, increase of unreasonable disposal for oil pollution, urban garbage as well as production and sanitary sewage, extensive application of pesticides and fertilizers in agricultural production and delay of environmental legislation and management, groundwater pollution becomes increasingly aggravated. Its main performances include:

1) Seasonal rivers become pollutant-containing rivers to cause decline of groundwater quality. Most rivers in the survey area are seasonal. Due to construction of water conservancy projects in the upstream and dry trend, the majorities of rivers is dry or have no flow so as to become pollutant-containing canals of towns and industrial and mining enterprises along them, mainly including Zhaosutai River, Qinghe and Shahe. Due to nearby discharge of industrial wastewater and urban sewage, most rivers are polluted seriously.

2) There are medium and large-sized feeding farms such as chicken farms and pig farms in towns and villages within the range of survey area. Stacking of animal manure and fodders pollutes groundwater of surrounding areas.

3) A large number of industrial and domestic wastewater is discharged in the rural-urban fringe zone. Due to low processing rate, the wastewater causes pollution to groundwater. In particular, extensively distributed township enterprises discharge unprocessed wastewater to underground and surface area via seepage pits, seepage wells and sewers so as to dot and linear pollution of rivers, soils and groundwater.

4) Household waste yard is not provided with anti-seepage measures so as to cause serious dotted pollution of groundwater. Waste plastics, waste paper, metal and coal ash in urban household wastes include more sulfates, chlorides, ammonia, organic impurities and corrupted organic matters. They can generate high pollution leachate under precipitation leaching. Due to no anti-seepage measure, the high pollution leachate pollutes groundwater by wastewater recharge.

5) Excessive application of fertilizers and pesticides in agriculture production directly affects groundwater quality. A large number of excessively used fertilizers and pesticides enter soils and groundwater via farmland runoff, drainage and underground seepage to cause pollution during the rainfall or irrigation.

6) A large number of insecticides are used in villages suffering plague of insects within the range of survey area. They enters groundwater with leachate in the rainy season to cause groundwater pollution.

CONCLUSION

Single factor pollution standard index method is used to systematically assess groundwater pollution of West Liaohe River Plain. As shown from assessment results, shallow groundwater in 70.1% of sampling points in the eastern part of West Liaohe River Plain has been polluted and serious pollution – based; deep groundwater is also polluted, but it is not a major issue in the research. The single factor pollution standard index method can basically achieve comparison of pollution indicators between regions, directly reflect regional groundwater pollution and provide a basis for targeted groundwater pollution control.

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