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Study on Quantification Method for the Risk of Groundwater Environment Pollution Caused by Sewage Irrigation

Xin Huang and Lin Qiu
School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, Henan, 450045, China

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ABSTRACT

Pollution by sewage irrigation of groundwater environment is slow and imperceptible. The pollution risk accumulated gradually, and the reasons for it are very complicated. Pollutants enter the underground aquifer through the leakage, leaching and other ways, and cause groundwater environment pollution. This paper presents the theory and quantification method for the degree of groundwater environment pollution caused by sewage irrigation, based on the study of the way and approach of groundwater environment pollution caused by sewage irrigation, critical content evaluation and current situation evaluation. By establishing the index model of the pollution degree of the groundwater environment, the study makes a quantitative description of the pollution risk of the groundwater environment. Finally, it analyses the study area, and the results show that: its pollution degree is 0.365, which means that the long-term sewage irrigation in the area has less risk to the groundwater environment.

INTRODUCTION

With the increase of the discharge of industrial and agricultural wastewater, the environmental pollution of shallow groundwater has been very serious (Wei et al. 2014, Wilkin et al. 2014). According to the survey of 20 irrigation districts in the north and south of China, the groundwater environment in most of the irrigation districts is polluted. With the sustainable development of sewage irrigation, the groundwater environment pollution will be an important issue. Pollutants enter the underground aquifer through the leakage, leaching and other ways, and cause groundwater environment pollution. The pollution degree of groundwater environment in sewage irrigation area is closely related to soil texture and groundwater level (Jiang et al. 2016). The sewage irrigation area with groundwater depth less than 7 m is more likely to cause groundwater pollution. Especially in the sandy soil irrigation district, because of the low soil absorption capacity, irrigation water can penetrate faster and more easily cause groundwater pollution. The main super-standard items in the polluted groundwater include total hardness, ammonia, sulfide, total bacteria, *Escherichia coli*, organic compounds, etc. (Jiang et al. 2013). Especially, the pollution problem of NO_3^--N in sewage irrigation region is becoming more and more serious. For example, the ammonia nitrogen content in shallow groundwater in the Kuihe river sewage irrigation region was significantly higher (Sun & Fu 2014), and the nitrate content in groundwater in Mexico area was also generally high. In this paper, the risk of groundwater environment pollution caused by sewage irrigation refers to the NO_3^--N, NH_3-N, etc. in the sewage seeping into groundwater, and causing groundwater quality not suitable for drinking or irrigation, thus making it not meet the requirements of environment and ecology.

In the current research on the risk of groundwater pollution by sewage irrigation, researchers only conducted a purposeful experiment and came to the conclusions (Kulikowska & Gusiatin 2015). There were few researches on the serious degree of the groundwater environment pollution risk caused by sewage irrigation, and no more profound quantitative analysis was done. Based on the present situation evaluation of groundwater environmental quality, this paper establishes a quantitative model for the risk of groundwater environmental pollution, and provides a reference for sewage irrigation.

ESTABLISHMENT OF A QUANTITATIVE MODEL OF THE RISK OF GROUNDWATER ENVIRONMENT POLLUTION BY SEWAGE IRRIGATION

The influence of sewage irrigation on groundwater environment is affected by many factors, such as sewage irrigation condition, the types and properties of pollutants, types and properties of soil, the amount and condition of water entering the soil, the regional topography and geomorphology, and hydrogeological conditions. These factors must be investigated and tested in the field, so their influence on the groundwater environment can be summarized, analysed and determined.

Ways and Means of Sewage Irrigation on Groundwater Pollution

Groundwater pollution can be divided into two ways: direct and indirect pollution (Jefimova et al. 2014). Direct pollution is characterized by the direct entry into the aquifer, in the process of this type pollution, the nature of the pollutant does not change, such as phenol, cyanide, oil and other pollution. The characteristic of indirect pollution is that, groundwater pollution is not caused by the direct entry of pollutants into the aquifer. It is because of the pollutants acting on other substances, producing some other components, causing groundwater contamination. For example, the increase of groundwater hardness due to pollution, which may produce a large amount of soluble calcium and magnesium in the soil of pollution area, so as to enhance the soil mineralization. At the same time as the replacement of potassium and sodium ions in the sewage, the contents of calcium and magnesium in groundwater would increase. Still another example, because of the existence of oxygen consumption substances, the dissolved oxygen in water would reduce. The processes of the indirect pollution are more complex, and the cause of pollution is easy to cover up, and it is more difficult to find out the source and way of pollution.

Critical Content Assessment of the Effect of Sewage Irrigation on Groundwater Environment

Many investigations have revealed that when the sewage irrigation is not correct, the groundwater environment of the irrigation area is often polluted or urban drinking water sources are polluted (Song et al. 2006, Sheng et al. 2006). In the process of the determination of the water quality standard, the soil environmental quality standard and the soil environmental capacity, because the potential of sewage irrigation on groundwater environment pollution has become a limiting factor, therefore, it is necessary and important for the rational development of sewage irrigation to understand the influence of sewage irrigation on the groundwater environment and control the pollution of the groundwater.

Evaluation of the effect of phenol and cyanide on groundwater environment: It is a complex issue whether the wastewater will pollute groundwater environment by downward infiltration and how much the critical concentration of irrigation is, when using wastewater containing phenol and cyanide for farmland irrigation (Juana et al. 2014). It is not possible to make the correct conclusion using some laboratory tests not carried out in depth or with shorter time. It is decided by a lot of factors that whether the pollutants in farmland sewage irrigation can be infiltrated into the underground aquifers and enough to cause the pollution of groundwater. Under the condition of soil water infiltration to the underground water, the concentration of pollutants, soil properties and structure will affect the amount of groundwater seepage to the groundwater. Under normal circumstances, if the content of phenol and cyanide in the sewage of irrigation area does not exceed the standard of farmland irrigation water quality, the groundwater environment will generally not be contaminated.

Assessment of the potential impact of heavy metals in different soils on the groundwater environment: Heavy metals usually do not cause pollution to the groundwater environment. Since the heavy metals can easily be adsorbed by the soil. Heavy metals in sewage are mainly accumulated in the topsoil or upper soil during sewage irrigation, which will not pollute the groundwater environment. But, some studies considered that with the time going, when the accumulation of heavy metals reaches to a certain extent, it is possible to move down the layer by layer, and will affect the groundwater environment (Jing et al. 2014). This problem can be solved according to the research results of the soil environmental capacity in China. Because the soil dynamic capacity is the amount of soil that is allowed to enter per hectare soil each year, if it is proved that the quantity value does not make the soil accumulated more than the soil environment quality standard, that sewage input less than this value (or converted to concentration), which cannot cause intolerable accumulation of heavy metals in soil. Therefore, it is not necessary to consider the heavy metal excessive accumulation and pollute the groundwater environment. In addition, if it is proved that the metal content in the soil is equivalent to the critical content of soil, irrigation water still does not make the metal through the topsoil or 1m soil layer, water seepage concentration reaches the standard of groundwater quality, so that the capacity value (or converted for irrigation concentration) will not cause the pollution of groundwater environment.

Since China has been developed, environmental (dynamic) capacity of these elements in different soils, so the critical concentration or standard of sewage irrigation water quality (C) without causing groundwater pollution can be calculated in accordance with the local irrigation or add some factors, which is calculated as:

$$C = \frac{Q - R - F}{Q_w} \quad ...(1)$$

In the formula, Q is the variable capacity of soil element ($g \cdot hm^{-2} \cdot a^{-1}$), R is the amount of an element drag-in by precipitation and water-spray ($g \cdot hm^{-2} \cdot a^{-1}$), F is the amount of an element drag-in by fertilization, Q_w is the irrigation water amount. Where, R and F are very small, can be ignored, so that C of the regions can be calculated only according to their irrigation water amount Q_w.

Status Evaluation of Groundwater Environmental Quality

Evaluation procedure: The main steps of the status evaluation (Wong & Hu 2014) of groundwater environmental quality include groundwater environment present situation investigation and data collection, groundwater monitoring, exploration and test, selection of evaluation factors and evaluation criteria of groundwater environmental quality, determination of evaluation model and evaluation method of groundwater environmental quality, and expression of assessment results of groundwater environmental quality.

Evaluation method: At present, there are many methods to evaluate the groundwater quality in China. Those include mathematical statistic method, groundwater quality model simulation and forecast method, single factor index method, comprehensive index method, fuzzy comprehensive evaluation method, grey system method, environmental hydrogeological mapping method, etc. The following are the methods recommended by the national standard "Groundwater Quality Standards" (GB/T14848-93).

Classification of the quality of individual components according to the measured concentration in accordance with the standards: Groundwater quality is classified into five classes in "Groundwater Quality Standards" (GB/T14848-93), according to the present situation of groundwater quality, human health reference value and groundwater quality protection, and with reference to the highest water quality requirements of drinking water, industrial and agricultural water.

Class I: Mainly reflect the natural low background content of groundwater chemical composition, suitable for various purposes.

Class II: Mainly reflect the natural background content of groundwater chemical composition, suitable for various purposes.

Class III: Based on the human health reference value, mainly applied to the centralized drinking water source and water for industry and agriculture.

Class IV: Based on the requirements of agricultural and industrial water. In addition to suitable for agriculture and some industrial water, it can be used as drinking water after suitable treatment.

Class V: Not suitable for drinking, other water usage can be selected according to the intended use.

At the same time note, when the standard values of different classes are the same, select good does not choose bad.

Determine the evaluation scores of individual components according to different classes: Firstly, carry out evaluation of each individual component, classify component quality categories of each category, determine single component evaluation score F_i according to Table 1 for each class respectively. Note: The project participating in the rating should not be less than the national standard of the monitoring project, but does not include bacteriological indicators.

Table 1: Individual component evaluation score F_i.

Category	I	II	III	IV	V
F_i	0	1	3	6	10

Calculation of comprehensive evaluation score: Select Nemero index to calculate comprehensive evaluation score F:

$$F = \sqrt{\frac{\overline{F}^2 + F_{\max}^2}{2}}, \overline{F} = \frac{1}{n}\sum_{i=1}^{n} F_i \quad ...(2)$$

In the formula, $F_{\max}$ is the maximum of single component evaluation score F_i; $\overline{F}$ is the average score of F_i, n is number of items.

Determining the grade names: According to F, the groundwater quality level is classified on the basis of the Table 2.

Analysis Standard:

1. Drinking water quality standards: China's Ministry of Health "Water Quality Standard for Drinking Water Source CJ3020-93" was used.
2. Irrigation water quality standards: China's Ministry of Water Resources, "Water Quality Standard for Irrigation GB5084-2005" was used.
3. Environmental water quality standards: China's Environmental Protection Bureau "Environmental Quality Standard of Surface Water GB3838-2002" was used.

Assessment Index of Pollution Degree of Groundwater Environment by Sewage Irrigation

In this paper, the following ideas are used to establish the assessment index (D_{gw} (ground water)) of the pollution degree of groundwater environment by sewage irrigation, which provides the assessment method for the potential impact of groundwater environment by sewage irrigation.

$$D_{gw} = \begin{cases} \dfrac{F}{\max\{F_0\}}, & 0 \le F < \max\{F_0\} \\ 1 \;, & F \ge \max\{F_0\} \end{cases} \quad ...(3)$$

In the formula, D_{gw} is the groundwater pollution degree; $\max\{F_0\}$ is the comprehensive quality index classification reference value.

Table 2: Classification of groundwater quality.

Grade	Excellent	Good	Normal	Poor	Very Poor
F	<0.80	0.80~2.50	2.50~4.25	4.25~7.20	≥7.20

Table 3: Quality category and evaluation score of each individual component.

Item	NH_3-N	NO_3^--N	Total hardness	Sulphate	Cadmium
Measurement result ($mg \cdot L^{-1}$)	0.08	4.5	330	170	0.001
Category	III	II	III	III	II
F_i	3	1	3	3	1

It is easy to know that the meaning of D_{gw} is the contamination degree of groundwater environment after sewage irrigation, $0 \le D_{gw} \le 1$. When $D_{gw}=0$, there is no environmental pollution of groundwater, sewage irrigation did not cause the risk, and the risk degree is 0. $D_{gw}=1$, indicates that the groundwater environment cannot meet the various quality requirements, and the risk degree is 1. The larger D_{gw} indicates that the degree of pollution of groundwater environment is bigger. Hence, the formula above can be used to evaluate pollution degree of groundwater environment.

CALCULATION EXAMPLE

According to the monitoring data of groundwater quality in the study area, evaluate each individual component; classify component quality categories, and the results are shown in Table 3.

Use Nemerow index to calculate comprehensive evaluation score F:

$$F = \sqrt{\frac{\overline{F}^2 + F_{\max}^2}{2}} = \sqrt{\frac{\left[\frac{1}{5}(3+1+3+3+1)\right]^2 + 3^2}{2}} = 2.63 \quad ...(4)$$

According to the standard of F value classification, the groundwater quality of the area is normal, and its relative pollution degree of groundwater environment D_{gw} is:

$$D_{gw} = \frac{F}{\max\{F_0\}} = \frac{2.63}{7.2} = 0.365 \quad ... (5)$$

This can be more intuitive to reflect the degree of water pollution is lighter.

CONCLUSIONS

According to the studies and analysis of the groundwater environment pollution assessment in the studied area, long-term sewage irrigation in the area is less risk to the groundwater environment. Relevant departments should still take strict control measures to alleviate and gradually solve the pollution problem of sewage irrigation on groundwater environment, and truly achieve the sustainable development of sewage irrigation. The research on the risk analysis of sewage irrigation started relatively late, and there is still no systematic research method. The risk of groundwater environment pollution caused by sewage irrigation is a very complicated problem. It happens slowly and is not easy to detect. It is also a process of accumulation, and the cause of its formation is very complex, not only with many natural environmental factors such as precipitation, temperature, hydrologic condition, soil, crop and landform and geological conditions, but also related to cultural, social and economic conditions. The theory and model method proposed in this paper can solve the problem of the quantification of groundwater environment pollution degree by sewage irrigation. By using the model, the quantitative description of the pollution risk of the groundwater environment can be made. Actually, this model proposed in the paper has only made some superficial work in this area, and in the future it is necessary to seek a more scientific method to describe the risk, to improve the evaluation index of risk degree of groundwater pollution and to work on classification standards of groundwater environment pollution risk by sewage irrigation, so that the degree of environmental pollution can be clearly understood.

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