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Study on Quantification Method for the Risk of Surface Water Environmental Pollution Caused by Sewage Irrigation in Agriculture

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ABSTRACT

In agriculture, the risk of surface water environmental pollution caused by sewage irrigation is a very complicated problem. It depends on runoff pollution along rivers, lakes or estuary upper reaches and is non-point source pollution of water. In addition, it is a gradual process and its contributing reasons include many natural environmental factors, humanities, and social and economic conditions. While pointing out the mechanism of surface water pollution, this paper introduced the concept of "risk of surface water environmental pollution caused by sewage irrigation". It builds the quantitative model for the risk of pollution caused by sewage irrigation to surface water, in light of the inadequate study on the seriousness of pollution of farmland sewage irrigation caused to the surface water as well as based on such index assessment methods as single factor contaminant index, N.J. Nemerow pollution index and Ross water quality index. It also, through example application, indicates that this model can accurately reflect the degree of pollution caused by sewage irrigation to surface water.

INTRODUCTION

Nowadays, China is suffering from a serious shortage of water resources (Zhang et al. 2016). Irrigation is an excellent use for sewage effluent because it is mostly water with nutrients (Mladen et al. 2016). However, sewage irrigation is a double-edged sword. While lightening agricultural water crisis, it can cause pollution to farmland environment. If not properly controlled and managed, it can cause serious consequences (Bourazanis et al. 2016, Dawaki et al. 2015, Ines et al. 2016, Kayikcioglu 2012, Rezapour et al. 2012). Water pollution was formed gradually, caused mainly by the inappropriate behaviours of people during production activities (Zhao et al. 2016). Water pollution is deterioration of water quality caused by human activities which has adverse impacts on people's production and life or does other harms. In fact, water has certain ability to endure the pollutants discharged into it, which is just its purification capacity. However, when the pollutants discharged into water exceed the limit of environmental tolerance, the physical and chemical properties of the water will change, upsetting the original ecological system of the water. The water then cannot be used as the water supply source. Such water is called polluted water (Sun et al. 2016, Li et al. 2016). In this paper, surface water pollution caused by farmland irrigation with sewage refers to: After sewage irrigation, the nutrients in the sewage such as nitrogen and phosphorus flow into the surface water or the rivers flow through soil irrigated with sewage, carrying away the pollutants in it and causing water eutrophication. As a result, it becomes unable to meet environmental and ecological requirements.

In an earlier research on the pollution caused by sewage irrigation (Yu et al. 2002), researchers invariably reached their conclusions only by conducting relevant short-term tests and neither carried out adequate study on the seriousness of pollution caused by sewage irrigation to surface water, nor carried out in-depth quantitative analysis. This paper has built quantitative model for pollution of sewage irrigation caused to surface water, providing reference for sewage irrigation.

ESTABLISHMENT OF QUANTITATIVE MODEL

Surface Water Pollution Index

The effect of farmland sewage irrigation on surface water depends on runoff pollution along rivers, lakes or estuary upper reaches and is non-point source pollution of water. Specific research subject of water eutrophication should be studied based on a particular area. The effect of farmland runoff on surface water depends on the distance between the irrigated area and water, irrigated area farmland runoff distance and pollution degradation along its flowing area. Therefore, as far as an area irrigated with sewage is concerned, it is necessary to not only get some understanding of farmland runoff, but also evaluate the quality of surface water in the whole area.

Index assessment method is the earliest method used for water environment quality assessment (Zhang 2005).

Single factor assessment index:

$$I=\rho/S \quad ...(1)$$

Where, I is the environmental quality index of single factor, ρ is the concentration of pollutants in environment, and S is the degree of effect of such pollutants on human being.

Single factor superposition type, mean type, weighed mean type index: Such indexes are the most basic indexes in index assessment method. In an actual water environment quality assessment, specific index form should be selected according to the environmental conditions and environmental requirements of the evaluated area. During selection, reference should be made to the assessment cases of water environment at home and abroad and corresponding assessment technical specifications and standards. Common indexes of such type include, the superposition type index of the western suburb of Beijing, mean type index of the Tumen River, and weighed mean type index of the Nanjing water area. As to the superposition type index of the western suburb of Beijing, in $I=\sum_{i=1}^{n}\frac{\rho_i}{S_i}=\sum_{i=1}^{n}I_i$, ρ_i is the concentration of the i_{th} pollutant in environment, S_i is the degree of effect of the i_{th} pollutant on human being. As to the mean type index of the Tumen River, in $I=\frac{1}{n}\sum_{i=1}^{n}I_i$, I_i is the environmental quality index of the i_{th} pollutant. As to the weighed mean type index of the Nanjing water area, in $I=\frac{1}{n}\sum_{i=1}^{n}W_iI_i$, W_i is the weight of the i_{th} pollutant.

N. L. Nemerow pollution index:

Index model:

$$PI_j=\sqrt{\frac{1}{2}\left[\left(\max\left\{\frac{\rho_i}{S_{ij}}\right\}\right)^2+\left(\frac{1}{n}\sum_{i=1}^{n}\frac{\rho_i}{S_{ij}}\right)^2\right]} \quad ...(2)$$

Wherein, PI_j is the N.L. Nemerow pollution index of the j_{th} water application, p_i is the measured concentration of the i_{th} pollutant, and S_{ij} is the water quality standards of the j_{th} water application of the i_{th} pollutant.

Classification of N.L. Nemerow pollution indexes according to application:

Class I: PI_1 of human's contact with water, including drinking, swimming, beverage process, etc.

Class II: PI_2 of human's indirect contact with water, including fish farming, industrial food preparation, agricultural use, etc.

Class III: PI_3 of human's noncontact with water, including industrial cooling water, water for public entertainment, shipping, etc.

***Parameter selection*: ** Generally, factors that greatly affect human health and can objectively reflect water quality are taken as assessment parameters. For sewage of agricultural use, N.L. Nemerow pollution index method takes the following as the parameters for calculation of water quality index: nitrate nitrogen, COD, BOD_5, temperature, suspended matter, pH, dissolved oxygen, alkalinity, total nitrogen, As, Hg, sulphate, Fe, Mn, coliform count, etc.

***Calculation method*:** First, figure out the classified indexes of water for different uses, and then figure out the total water quality indexes according to the method of weighted stack.

The comprehensive water pollution index form is as follows:

$$PI=W_1\cdot PI_1+W_2\cdot PI_2+W_3\cdot PI_3 \quad ...(3)$$

Wherein, PI is N.L. Nemerow pollution index; W_1, W_2 and W_3 are the weights of water for three purposes. The meaning of other symbols are the same.

***Classification of pollution classes*:** Classify the level of pollution of the comprehensive quality index PI to surface water. The relationship between pollution class and PI is as given in Table 1 (Ding 2006).

Ross water quality index:

***Parameter selection*:** In 1977, Ross from the UK selected BOD_5, ammonia nitrogen, suspended solid and DO as the parameters of water quality assessment, on the basis of previous work. Among them, DO is calculated respectively, with concentration ($mg\cdot L^{-1}$) and saturation (%) as the unit (Ross 1977).

***Grading according to parameter concentration*:** Grade the

Table 1: Relationship between pollution class and PI.

PI Pollution Class	0~0.6 Cleanliness	0.6~1.0 Light cleanliness	1.0~2.6 Light pollution	2.6~5.0 Middle level pollution	> 5.0 Serious pollution
Grade of quality of corresponding surface water	Class I	Class II	Class III	Class IV	Inferior Class IV

Table 2: Relationship between pollution level of surface water and D_{sw}.

D_{sw}	0	(0, 1.0)	1.0
Pollution situation	not polluted	polluted	Serious pollution
Risk level	0	0~1	1

above-mentioned parameters according to their concentrations, as well as take them as the grading standard for each parameter of the water quality index.

***Specified parameter weight coefficient*:** The parameter weight coefficients are BOD, 3; ammonia nitrogen, 3; suspended solid, 2, and dissolved oxygen, 2.

***Calculation formula for water quality index*:**

$$WQI = \frac{\sum P_i}{\sum W_i} \quad ...(4)$$

Wherein, *WQI* is the Ross assessment index, P_i is the grade of each parameter, and W_i is the weight of each parameter.

***Grading of water quality indexes*:** Ross divided the water quality of river into 11 levels according to the value of *WQI*. The higher the value is, the better the water quality is. For example, the value "10" indicates no pollution, "8" slight pollution, "6" moderate pollution, "3" serious pollution, and "0" poor water quality.

Assessment Index for Degree of Pollution Caused by Sewage Irrigation to Surface Water

Although most of the studies on the regional water non-point sources are conducted through water pollution survey, restrictions on the runoff of farmland pollutants and evaluation of their effects, is still a problem to the solved by the research field of sewage irrigation. This paper creates an evaluation index for pollution caused by sewage irrigation to surface water i.e., D_{sw} (surface water) by adopting the following, to provide a method for assessment of the effects that sewage irrigation has on the surface water.

$$D_{sw} = \begin{cases} \dfrac{PI}{\max\{PI_0\}} \text{或} \dfrac{\max\{PI_0\} - PI}{\max\{PI_0\}}, & 0 \le PI < \max\{PI_0\} \\ 1 \ , & PI \ge \max\{PI_0\} \end{cases} \quad ...(5)$$

Wherein, D_{sw} is the surface water pollution degree and $\max\{PI_0\}$ is the comprehensive quality index grading reference value (Table 2).

D_{sw} represents the degree of pollution caused by sewage irrigation to surface water, $0 \le D_{sw} \le 1$. When $D_{sw} = 0$, it indicates that the surface water is not polluted and sewage irrigation does not pose any threat, and the risk level is 0. When $D_{sw} = 1$, it indicates that the surface water does not comply with the requirements for the quality of water, and the risk level is 1. The higher the value of D_{sw} is, the more the surface water is polluted. Therefore, the formula above can be used to assess the pollution level of surface water.

EXAMPLE

The data about the sewage irrigation area of a province in China are used to introduce the application of quantitative model for risk of pollution of sewage irrigation to surface water. Located in a hill agriculture section, this sewage irrigation area is under the influence of subtropical transitional climate with abundant rainfall and mean annual precipitation over 1,000 mm. The terrain here is complicated with undulating hillocks and slopes as well as mounds and dykes. The annual sown area of the irrigation area is nearly 440,000 hm^2, and the multiple crop index is around 2.2. The irrigation area has an irrigation history of over 30 years and detailed monitoring data about it is available. Its topsoil depth is 20-50 cm, irrigation water volume is about 5,100 $m^3 \cdot hm^{-2} \cdot a^{-1}$, soil environment quality background value of Hg is 0.12 $mg \cdot kg^{-1}$, As is 10.6 $mg \cdot kg^{-1}$, Pb is 24.8 $mg \cdot kg^{-1}$, Cu is 32.2 $mg \cdot kg^{-1}$, Cr is 59.0 $mg \cdot kg^{-1}$ and Cd is 0.19 $mg \cdot kg^{-1}$. The staple crop in the irrigation area is rice. The main usages of water in this area are: 30% for drinking, 40% for agricultural irrigation and 30% for industrial cooling. The measured concentration of each pollutant and water quality standards of different usages of water are provided in Table 3.

Here, the percentages of water in different usages are taken as the basis for determining W_1, W_2 and W_3. $W_1 = 0.3$, $W_2 = 0.4$, $W_3 = 0.3$. Therefore, the comprehensive water pollution index *PI* is:

$$PI = W_1 \cdot PI_1 + W_2 \cdot PI_2 + W_3 \cdot PI_3 = 0.3 \times 4.44 + 0.4 \times 2.37 + 0.3 \times 1.36 = 2.79$$

It can be seen that the pollution level of the water is moderate pollution. Its relative surface water pollution degree assessment index is $D_{sw} = \frac{PI}{\max\{PI_0\}} = \frac{2.79}{5.0} = 0.558$. This can more intuitively show that the pollution degree of water is above average.

CONCLUSION

According to the analysis and study of examples, long-term irrigation of farmland with sewage will have great negative

Table 3: Pollutant measured concentration, N.L. Nemerow water quality standards of different water usages and N.L.Nemerow index calculation.

Item	COD_{Mn} ($mg\cdot L^{-1}$)	TN ($mg\cdot L^{-1}$)	Suspended Soil ($mg\cdot L^{-1}$)	TP ($mg\cdot L^{-1}$)	Fe & Mn ($mg\cdot L^{-1}$)	Mean Value	Maximum Value	PI_j
Water quality standard of class I usage S_{i1}	15	0.5	-	0.1	0.35			
Water quality standard of class II usage S_{i2}	20	1.0	10	0.2	0.4			
Water quality standard of class III usage S_{i3}	30	1.5	500	0.3	25.5			
Measured value ρ_i	8.2	2.5	24	0.53	0.9			
ρ_i/S_{i1}	0.55	5	-	5.3	2.57	3.355	5.3	4.44
ρ_i/S_{i2}	0.41	2.5	2.4	2.65	2.25	2.042	2.65	2.37
ρ_i/S_{i3}	0.27	1.67	0.048	1.77	0.04	0.760	1.77	1.36

Note: "-" refers to "under discussion"; j refers to N.L. Nemerow water pollution index for the j_{th} water usage.

effects on surface water environment. In order to reduce and gradually eliminate the serious negative effects of sewage irrigation on surface water environment and really achieve sustainable development of farmland sewage irrigation, relevant departments should adopt strict countermeasures. Research on the risks of sewage irrigation started relatively late and so far there still has been no systematic research method. Studying such risks is very complicated. They occur slowly and cannot be easily perceived; what is more, many factors contribute to them, including numerous natural environmental factors such as meteorological conditions (e.g. rainfall, temperature, humidity), hydrological data (e.g. surface water, ground water), agricultural conditions (e.g. soil, crop), physiognomy and geology, as well as humanities, social and economic conditions. The theory and model discussed in this paper solved the problem of quantification of degree of pollution caused by sewage irrigation to surface water environment. Through this model, the pollution of surface water environment can be described quantitatively. However, the model proposed by this paper only touches upon this field. In the future, it is necessary to develop more scientific methods to describe the risks, perfect the assessment indexes for pollution degree of surface water environment, and establish grading standards for it, so that the pollution level can be well known.

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