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Theoretical Exploration of Risk Analysis of Sewage Irrigation in Farmland

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ABSTRACT

Sewage irrigation can provide water and fertilizer resource. However, sewage irrigation may lead to the accumulation of toxic and harmful substances in the soil and water source in some areas, which will be a serious threat to the human health in these areas. Risk of soil-crops, risk of surface water or underground water and risk of population health, which are greatly influenced by sewage irrigation, are selected to be research objects via analytic hierarchy process; evaluation indicators of degree of contamination of sewage irrigation to soil-crops, surface water or underground water and population health, and the computing method of the total risk degree are proposed, and the probability distribution of the risk of sewage irrigation is analysed. On the basis of theoretical study, combined with practical data, risk analysis of sewage irrigation in a given area is researched in this paper.

INTRODUCTION

China is water abundant in total water resources, but the usable water resources are very few. Water resources problem has become a choke point that blocks the rapid development of China's economic and society, especially the water shortage is more serious in agriculture. The agricultural water resource is an important natural resource and environmental condition for the sustainable development of agricultural economy and the construction of new socialist countryside. With the rapid development of national economy and the improvement of people's life, agriculture irrigating water is occupied by domestic water in cities, which causes the agricultural water shortage more and more serious; in addition, water pollution causes the water quality induced water shortage more and more serious, and the agriculture meets the serious challenge from water quality induced water shortage (Aregay et al. 2013, Liu et al. 2014). Therefore, a large amount of sewage irrigation has to be used in agriculture. The sewage irrigation is a double-edged sword, which simultaneously brings abundant water and fertilizer resources and a lot of harm (Yao et al. 2013).

The sewage studied in this paper refers to the sewage treated in accordance with national requirements for agricultural use. In this paper, focused on the environment problem of sewage irrigation, risk analysis theory of sewage irrigation in farmland is established, analytic hierarchy process is used in the risk identification in the sewage irrigation in farmland, several risk evaluation indicators are proposed, and stochastic method is used in the risk estimation, which achieves the transition from single field research to comprehensive research, from qualitative research to quantitative research of the risk of sewage irrigation, and provides reference and basis for sewage irrigation in farmland.

TOTAL RISK DEGREE OF SEWAGE IRRIGATION IN FARMLAND

Long-term of sewage irrigation in farmland will cause the noxious residual chemicals in the environment exceed the environmental capacity, and finally lead to abandonment of original environment or harm to human health. This is taken as the basis that sewage irrigation will cause hazards, and the degree of occurrence of environmental disasters caused by sewage irrigation is called the risk of sewage irrigation.

Risk Identification of Sewage Irrigation in Farmland

To decompose the risk caused by sewage irrigation via analytic hierarchy process can make scientific and objective understanding of this complex problem. It effectively reflect the real risks caused by sewage irrigation in farmland, and is the basis for the following research of risk (Chen et al. 2014, Zhou et al. 2013). According to the analysis result, main risks of all the risks caused by sewage irrigation is selected to analyse and research, which are risk of soil-crops (of the weight of 0.407); risk of surface water (of the weight of 0.238); risk of population health (of the weight of 0.133); risk of underground water (of the weight of 0.093).

Analysis of Environmental Risk of Sewage Irrigation to Soil-crops

Research method: At present, there are many researches on the environmental damages in irrigated area caused by sewage irrigation (Salakinkop & Hunshal 2014, Shi et al. 2014, Ye et al. 2015). In this paper, only the series of relations of pollutant concentration in sewage → pollutant content in soil → pollutant content in crops → prevalence rate in the sewage irrigation area are discussed, and on this basis, the irrigation concentration of acceptable risk and safety period of sewage irrigation are further studied.

Establishment of the model of risk of soil-crops caused by sewage irrigation: ***Heavy metal accumulation amount in soil:*** Since the variation of production volume of pollution sources is small, the variation of concentration of heavy metal in the local soil can be regarded as improving according to arithmetic progression. Under the conditions that the input volume of pollutant in the soil is hard to obtain, as well as the simulation experiment of local pots, Formula (1) can be used to predict the accumulation amount of pollutant within certain years (Zhang 2005):

$$W = N_w \cdot x + W_0,\ x = \frac{W_0 - B}{N_0} \quad ...(1)$$

Where, W denotes to the expected accumulation amount of pollutant in the soil within certain years, mg·kg^{-1} ; N_w denotes to the expected years of sewage irrigation; x denotes to the average annual increment of pollutant in the soil, mg·kg^{-1}; W_0 denotes to the accumulation amount of pollutant in the soil in the current year, mg·kg^{-1}; B denotes to the background value of soil environment, mg·kg^{-1}; N_0 denotes to the number of sewage irrigated years.

Computation method of content of heavy metal in main crops: There are many researches that show that there is certain relationship between content of heavy metal in crops and in soil in a specific area (Li et al. 2013, Wang et al. 2013, Kuerban et al. 2013). So in the analysis of content of heavy metal in main crops in sewage irrigation area, the linear dependence between monitoring results of contents of heavy metal in soil and main crops can be directly analysed.

Analysis of the risk of resident health caused by the heavy metal exposure in sewage irrigation area: Three indicators are used to represent the lifetime risk degree R of occurrence of chronic heavy metal poisoning in heavy metal contaminated area, which are heavy metal accumulation reference dose R_fD, actual human body heavy metal exposure dose I and prevalence of heavy metal poisoning A:

$$R = \frac{I}{R_f D} \times A \quad ...(2)$$

Because that the heavy metal exposure in sewage irrigation area is a chronic exposure process of gradually accumulation, I in formula (2) is replaced by lifetime heavy metal accumulation amount I_{lifetime} of resident in sewage irrigation area to analyse the risk of resident health caused by the heavy metal exposure in sewage irrigation area. Take the world's average lifetime 80 years as the lifetime of the resident in sewage irrigation area, and take it as the upper bound of evaluation time, the following formula is used to compute I_{lifetime}:

$$I_{\text{lifetime}} = I_{\text{food(lifetime)}} = \sum_{i=1}^{80} \sum_{j} Q_{(i,j)} \bullet c_{(i,j)} \quad ...(3)$$

Where, $I_{\text{food(lifetime)}}$ denotes to lifetime heavy metal exposure amount in food of residents in sewage irrigation area; $Q_{(i,j)}$ denotes to total food intake amount of the jth kind of food in the ith year kg·a^{-1}; $c_{(i,j)}$ denotes to the heavy metal content of the jth kind of food in the ith year mg·kg^{-1}.

Shang Qi et al. (2002) carried out the epidemiological investigation of As poisoning of population in As sewage irrigation area, the analysis of As accumulation exposure amount, and the curve fitting of the relationship between population As poisoning prevalence rate A (%) and As accumulation exposure amount I (mg), and obtained:

$$A = I^{1.843} / e^{12.694} - 2.866 (r^2 = 0.945) \quad ...(4)$$

Where, A denotes to the population As poisoning prevalence rate; I denotes to the As accumulation exposure amount (can be replaced by I_{lifetime}).

Based on analysing health risk of heavy metal exposure via above process, the risk analysis of pollution degree of soil-crops caused by heavy metal in current sewage irrigation area is carried out in this paper, the following formula is used:

$$D_s = R/[D] \quad ...(5)$$

D_s (soil) denotes to the risk degree of soil-crops in the sewage irrigation in farmland, if $D_s \geq 1$, the amount of one kind of heavy metal has exceeded the maximum environment capacity, which will lead to the soil-crops system unusable; if $D_s < 1$, the risk of soil-crops caused by sewage irrigation is acceptable.

Safety period of sewage irrigation, concentration analysis of acceptable risk sewage irrigation of heavy metal pollutant in soil, and risk degree: In a given sewage irrigation area, the safety period should be: when applying sewage irrigation with a specific concentration, within the safety period, the residents' health risk degree caused by heavy metal exposure in the sewage irrigation is below [*D*]. Accordingly, acceptable risk sewage irrigation concentration is the allowable maximum concentration of heavy metal in sewage when the residents' health risk degree caused by heavy metal exposure in the sewage irrigation is below [*D*]. It is worth noting that the acceptable risk sewage irrigation concentration is not fixed, it depends on the requirements of irrigation safety period.

Analysis of Environmental Risk of Sewage Irrigation to Surface Water or Underground Water

The influence of farmland pollutant on surface water in sewage irrigation area depends on pollutant runoff along the river, lake or in upper reaches area, and it is the land non-point source pollution of the water body. The influence of farmland runoff on surface water also depends on the distance between irrigation area and water body, the length of farmland runoff flow path, and attenuation of pollutant. For an irrigation area, not only the farmland pollutant runoff should be known, but also the water quality of the surface water in the whole area should be evaluated.

There are many investigation reports that reveal the underground water or urban drinking water source polluted caused by improper sewage irrigation (Bourazanis et al. 2016, Schacht & Marschner 2015). In the determination of water quality standard of sewage irrigation, soil environment quality standard and the soil environment capacity, because that the pollution potential of sewage irrigation to underground water has been a limiting factor, in order to rationally develop sewage irrigation, it is necessary to understand the influence of sewage irrigation on underground water and control the pollution of sewage irrigation to underground water.

In this paper, the following idea is applied to establish the pollution degree evaluation indicator D_w of sewage irrigation to surface water or underground water, which provides a method to evaluate the potential impact of sewage irrigation on surface water or underground water.

$$D_w = \begin{cases} \dfrac{PI}{\max\{PI_0\}} \ or \ \dfrac{\max\{PI_0\} - PI}{\max\{PI_0\}}, & 0 \le PI < \max\{PI_0\} \\ 1 \ , & PI \ge \max\{PI_0\} \end{cases} \quad ...(6)$$

Where, D_w denotes to the pollution degree of surface water or underground water; $\max\{PI_0\}$ denotes to the comprehensive quality index classification reference value.

It is easy to know that D_w shows the pollution degree of surface water or underground water after sewage irrigation, and $0 \le D_w \le 1$. If $D_w = 0$, the surface water or underground water is not polluted, and there is no risk of sewage irrigation; if $D_w = 1$, the surface water or underground water does not confirm to the water quality requirement, and the risk degree is 1; the larger the D_w is, the larger pollution degree of surface water is.

Analysis of Population Health Risk

Basic conception of population health risk evaluation: Population health risk evaluation is the emphasis of the narrow sense environment risk evaluation which was arisen after 1980s. It takes risk degree as evaluation indicator, connects the environment pollution and human health, and quantitatively describes the risk of the harm of pollution to human health.

The sewage irrigation has been used for decades, for example, to irrigate farmland, park, golf course, landscape water and industrial water. When applying sewage irrigation, there are plenty pathogenic bacteria, parasites and intestinal viruses in the raw water, which is the source of population health risk.

If using untreated or incompletely treated sewage to irrigate farmland, the causative agent will transfer from soil to the surface of crops during irrigation, and cause serious health problems. If people engaged in farm production and others directly touched them during farm production or product processing and consumption, there will be potential risk of pathogen infection.

Risk of population pathogen infection caused by sewage irrigation: According to new evidence of epidemiological and technical aspects, such standard was recommended for using sewage to irrigate raw vegetables: there is an average of 1000 coliforms per 100mL sewage, and there is less than one parasitic ovum per liter sewage. Accordingly, focused on the health evaluation of viruses, bacteria and other microorganisms, Rose proposed different dose response models for different bacteria (Regli et al. 2013).

Hereby, the risk degree D_p (people) of population infected by pathogen in sewage irrigation can be denoted as

$$D_p = S \times P_i = \frac{D_p^{'}}{[D]} \quad ...(7)$$

Where, D_p denotes to the risk degree of influence or harm of a pathogen; *S* denotes to the severity degree of influence or harm of that pathogen; P_i denotes to the probability of occurrence of the influence or harm of the pathogen; D_p' denotes to the current risk of pathogen; [*D*] denotes to the acceptable annual risk threshold considered by USEPA.

For viruses, bacteria and other microorganisms, USEPA considered that the acceptable annual risk threshold was 1×10^{-4} (Qiu & Wang 2003).

Total Risk Degree of Sewage Irrigation

We define that the total risk degree of all the risks caused by sewage irrigation in farmland is:

$$D = \sum_{i=1}^{n} W_i D_i \quad ...(8)$$

Where, D denotes to the total risk degree of sewage irrigation in farmland; W_i denotes to the weight of each risk caused by sewage irrigation in farmland; D_i denotes to the risk degree of each risk; n denotes to the number of risks.

Considering the specific research situation in this paper, the weight W_1 of atmosphere risk degree caused by sewage irrigation and the weight W_5 of social and personal property losses caused by sewage irrigation is small, they are ignored here.

RESEARCH ON PROBABILITY OF THE RISK OF SEWAGE IRRIGATION IN FARMLAND

Without regard to non-sewage irrigation, the probability distribution of the risk caused by sewage irrigation in farmland is studied and discussed.

In this sector, the idea of Pearson P-III type parameter estimation is firstly introduced, then the relationship formula between total risk degree of sewage irrigation and precipitation is deduced based on the whole production function of the moisture and moisture production function, which is:

$$D(R) = \begin{cases} A\cdot(1-\frac{W_C}{W_N})^2 + B\cdot(1-\frac{W_C}{W_N}), & 0 \le W_C \le W_N \\ 0, & W_C > W_N \end{cases} \quad ...(9)$$

Non-parametric test method is used to analyse the probability distribution of the risk caused by sewage irrigation to obtain its probability distribution function and numerical characteristics, and so that the quantitative estimation of the probability and the consequence of the risk of sewage irrigation in farmland can be obtained (Huang et al. 2008).

CASE STUDY AND APPLICATION

Computation of Comprehensive Risk Degree of Sewage Irrigation

Basic information: The climate in sewage irrigation area is subtropical transitional climate, and the area has been irrigated for 20 years with detailed monitoring data. Its topsoil depth is 20～50cm, the irrigation water volume is 5 $100 m^3 \cdot hm^{-2} \cdot a^{-1}$, the soil environment quality background value of mercury (Hg) is 0.12 $mg\cdot kg^{-1}$, arsenic (As) is 10.6 $mg\cdot kg^{-1}$, lead (Pb) is 24.8 $mg\cdot kg^{-1}$, copper (Cu) is 32.2 $mg\cdot kg^{-1}$, chrome (Cr) is 59.0 $mg\cdot kg^{-1}$, and cadmium (Cd) is 0.19 $mg\cdot kg^{-1}$. The main crop in the irrigation area is rice, the whole growth duration is from May to September, the probability of irrigation P=90%. The main application of the water body in this area is that, 30% for drinking 40% for irrigation, 30% for industrial cooling.

Risk degree of soil-crops: Here we take heavy metal As for example to compute risk degree of soil-crops.

Computation of concentration of As in soil in sewage irrigation area over the years: The background value of As in the soil in sewage irrigation area is B=10.6 $mg\cdot kg^{-1}$, suppose the variation of the concentration of As in soil is arithmetic progression, the area has been irrigated for 20 years, the irrigation water volume is 5 $100 m^3 \cdot hm^{-2} \cdot a^{-1}$, and the accumulation amount of As in soil in 2015 is 19.20 $mg\cdot kg^{-1}$, thereby the average annual increment of pollutant in soil x:

$$x = \frac{W_0 - B}{N_0} = \frac{19.20 - 10.6}{20} = 0.43 \quad mg \bullet kg^{-1}$$

The concentration of As in soil in sewage irrigation area in the given year is W, and the variation rule of concentration of As in soil is:

$$W = N_w \cdot x + W_0 = 0.43 N_w + 10.6$$
$$(N_w(\text{years of sewage irrigation}) = 1,2,3,\cdots)$$

Computation of content of As in main crops in sewage irrigation area: Local residents mostly take rice as the main food, so we choose rice as the main research object in this area. According to monitoring data of content of As in rice and in soil of each monitoring point in sewage irrigation area, we can obtain the dependent equation between the content of As in rice and in soil, as:

$$Y = 0.0079X - 0.0489 \quad (R^2 = 0.9816)$$

Where, X denotes to the content of As in soil ($mg\cdot kg^{-1}$); Y denotes to the content of As in rice ($mg\cdot kg^{-1}$); R denotes to correlation coefficient.

Risk degree of health caused by As exposure: The computation of accumulated rice consumption of population: the standard average rice consumption of residents (adult (above 18-year old)) in sewage irrigation area is 502.2g, annual rice consumption is $Q = 502.2g \times 365 = 183.3kg$. According to the "Recommended dietary allowance" revised by Chinese Society of Nutrition, average annual consumption of juveniles is 0.669 times of that of adults.

Computation of accumulated As exposure amount in food: Take average content of As in rice for 20 years as the content of As in rice, we can obtain c=0.131 mg·kg^{-1} according to the dependent equation between the content of As in rice and in soil. So As exposure amount in food of residents in sewage irrigation area in 2015 is:

$$I_1 = Qc = 183.3 \times 0.131 = 24.012\text{mg}$$

$$I_2 = 0.669 I_1 = 16.064\text{mg}$$

For residents with different age, because that the time of As exposure is different, the lifelong As exposure amount is different. For current residents, if take 2015 as the resent year, the risk degree of health of residents born in 2015 caused by As exposure is the largest. According to above analysis, for these residents, their lifelong exposure amount from food is:

$$I_3 = 0.669 \cdot \sum_{i=2015}^{2032} I_{\text{In food}\ (i)} + \sum_{j=2033}^{2094} I_{\text{In food}\ (j)} =$$

$$0.669 \times 24.012 \times 18 + 24.012 \times 62 = 1777.744\text{mg}$$

For residents that have lived in sewage irrigation area for more than 20 years, their largest risk degree occurred in their adulthood during these 20 years, therefore,

$$I_{\text{now}} = 20 \times 24.012 = 480.24\text{mg}$$

The US EPA hold that there is no adverse chronic poisoning when intaking 200～250 μg As per day, so 200μg/d is determined as R_fD. Then according to the relation between population As poisoning prevalence rate A (%) and As accumulated exposure amount I (mg), which was proposed by Shang Qi, we can obtain that the As poisoning prevalence rate in 2015 in this area is A=1%.

Risk degree of health of residents born in 2015 in sewage irrigation area caused by As exposure is:

$$R_{\text{lifelong}} = \frac{I_3}{R_f D} \times A = \frac{1777.744}{200 \times 10^{-3} \times 365 \times 80} \times 1\% = 0.003$$

Since beginning sewage irrigation in the area, current risk degree of health of residents caused by As exposure is:

$$R_{\text{now}} = \frac{I_{\text{now}}}{R_f D} \times A = \frac{480.24}{200 \times 10^{-3} \times 365 \times 80} \times 1\% = 0.0008$$

According to US EPA's information, we can know that the risk is acceptable when R<2×10^{-3}, namely [D] =2×10^{-3}. Thereby, current comprehensive risk degree of soil-crops caused by sewage irrigation is:

$$D_s = \frac{R_{\text{now}}}{[D]} = \frac{0.0008}{0.002} = 0.400$$

For residents born in 2015 in sewage irrigation area, the lifelong risk degree of soil-crops caused by sewage irrigation is D_s=R/[D]=1.5>1. If we do not take environmental protection measures, sewage irrigation will cause harm to the residents in the area.

Analysis of As irrigation concentration of acceptable risk in soil and safety period of sewage irrigation: According to annual irrigation water volume in sewage irrigation area and average annual increment of pollutant in soil, we can obtain that the average concentration of As in sewage for irrigation in this area of 20 years is 0.190 mg·L^{-1}, which will cause different degree of health risk to people born in 2015. Taking 2015 as the recent year, if the health risk degree of As exposure of residents born in 2015 is lower than 2×10^{-3}, using backward deducing according to analysis procedure used in risk evaluation, we can obtain that As irrigation concentration of acceptable risk for residents born in 2015 is 0.143 mg·L^{-1}. According to above analysis, when the As concentration is controlled below 0.143 mg·L^{-1}, current health risk degree of all the residents in sewage irrigation area caused by As exposure will be lower than 2×10^{-3}, the safety period of sewage irrigation will be at least 80 years.

To study the requirements of different safety irrigation period (s) to irrigation concentration of acceptable risk (C_{As}), we can directly compute the corresponding irrigation concentration of acceptable risk according to the analysis procedure of irrigation concentration of acceptable risk for residents born in 2015.

With increment of safety period s of sewage irrigation, irrigation concentration C_{As} of acceptable risk will stabilized as 0.143 mg·L^{-1}. In the actual management and planning of sewage irrigation, we can predict the As concentration and safety period of sewage irrigation according to this relationship, thus we can protect the health and environment in sewage irrigated area. For example, current average As concentration in sewage for irrigation in each year is 0.190 mg·L^{-1}, if we use it to irrigate, the safety period can be obtained according to correlation diagram, as s =39.7 years. It should to take more strict measures in this sewage irrigation area to achieve long safety period.

Risk degree of surface water: Here the proportions of water body for different application are taken as bases to determine weight W_1,W_2,W_3, namely:

W_1= 0.3,W_2= 0.4,W_3= 0.3

Therefore, comprehensive pollution water quality indicator PI is:

$$PI = W_1 \cdot PI_1 + W_2 \cdot PI_2 + W_3 \cdot PI_3 =$$

$$0.3 \times 4.44 + 0.4 \times 2.37 + 0.3 \times 1.36 = 2.79$$

Its relative evaluation indicator of degree of surface water pollution D_w is:

$$D_w = \frac{PI}{\max\{PI_0\}} = \frac{2.79}{5.0} = 0.558$$

Here the surface water in this area has been seriously polluted.

Risk degree of underground water: According to the monitoring data of quality of underground water in this area, each single component is evaluated, and we can obtain that its relative evaluation indicator of degree of underground water pollution D_w is:

$$D_w = \frac{F}{\max\{F_0\}} = \frac{2.63}{7.2} = 0.365$$

Risk degree of population health: For the evaluation of risk degree of population health, the data from the epidemiological investigation is the most reliable.

As of May, 25th, 2005, there are 42 epidemic outbreaks of diseases, such as cholera, dysentery, typhoid and paratyphoid intestinal infectious diseases and infectious diarrhoea.

Suppose all the epidemic outbreak of intestinal infectious diseases in 2005 are near the sewage irrigation, and caused by sewage irrigation. Currently, the agricultural population in this area is 2.2403 millions, we can obtain the risk d of epidemic outbreak of intestinal infectious diseases via math scaling method, as:

$$d = \frac{\text{number of cases}}{\text{total population}} = \frac{42\,\text{cases}}{2.2403\,\text{million}} = \frac{1\,\text{case}}{53\,\text{thousand}}$$

$$= 0.187 \times 10^{-4}$$

We can know that $d < 1 \times 10^{-4}$ (acceptable annual risk threshold proposed by USEPA), and the actual risk degree D_p' $<d$, for calculating conveniently, scaling method is applied, and D_p' $=d=0.187 \times 10^{-4}$.

Thereby the risk degree of population health caused by sewage irrigation D_p is:

$$D_p = D_p' / [D] = 0.187 \times 10^{-4} / 1 \times 10^{-4} = 0.187$$

Comprehensive risk of sewage irrigation: Normalize the weights of risks analysed in this paper, new respective weights can be obtained as:

$$w_s = 0.467,$$

$$w_{w\,(\text{surface water})} = 0.276,$$

$$w_p = 0.153,$$

$$w_{w\,(\text{underground water})} = 0.1070$$

So the current comprehensive risk degree D of sewage irrigation in this area is:

$$D = w_s D_s + w_{w(\text{surface water})} D_{w(\text{surface water})}$$

$$+ w_p D_p + w_{w(\text{underground water})} D_{w(\text{underground water})}$$

$$= 0.467 \times 0.400 + 0.276 \times 0.558 + 0.153 \times 0.187$$

$$+ 0.107 \times 0.365 = 0.408$$

We can know that the degree of the risk caused by sewage irrigation in this area is middle risk, appropriate prevention and control should be carried out to change the current situation of environmental pollution and reach the target of sustainable development of sewage irrigation in this area.

Probability Distribution

Main crop in the irrigation area is rice, according to the analysis of water resources balance, when probability of irrigation P=90%, it is difficult for local rainfall runoff to meet the requirements of irrigation water, thereby irrigation is needed. According to 10 years of local meteorological, hydrological and geological data, we select data of whole growing period (May to September) of rice, which is: C_v=0.15, C_s =0.30, $X_{average}$=1359mm. Soil initial water storage capacity is 86.4mm; the required water volume of whole growing period of rice is W_N=600mm.

Via 10 years of rainfall data during whole growing period, 10 data of risk degree caused by sewage irrigation can be obtained, the results are shown as in Table 1.

To carry out the W test to risk degree caused by sewage irrigation, it is considered that the local risk degree caused by sewage irrigation can be seemed as obeying the normal distribution. Estimating the parameters via maximum likelihood estimation method, the result is: risk of sewage irrigation $\sim N$ (0.275, 0.015).

CONCLUSION

The research of the analysis of risk caused by sewage irrigation was started late, and there is no systematic research methodology up to now. In this paper, Risk of soil-crops, risk of surface water or underground water and risk of population health, which are greatly influenced by sewage irrigation, are selected to be research objects via analytic hierarchy process; evaluation indicators of degree of contami-

Table 1: The series of risk degree by sewage irrigation.

1	2	3	4	5	6	7	8	9	10
0.058	0.153	0.216	0.237	0.251	0.281	0.298	0.337	0.390	0.531

nation of sewage irrigation to soil-crops, surface water or underground water and population health are proposed, which are D_s,D_w,D_p, and the computation method of total risk degree caused by sewage irrigation is proposed via composite of all the risk evaluation indicators, thereby a completed theory system of analysis of risk caused by sewage irrigation is formed, and the probability distribution of risk caused by sewage irrigation is studied; on the basis of theoretical study, combined with actual data of sewage irrigation area, the risk analysis is studied, and we obtained that its comprehensive risk degree D =0.408, and the probability distribution obeys the normal distribution, the irrigation pollutant As concentration of acceptable risk is 0.143 mg·L^{-1}, and the relationship between safety period (s) of sewage irrigation and As concentration (C_{As}) of acceptable risk in soil.

The theory and methods proposed in this paper is only simple work in the research on risk analysis of sewage irrigation, the concept of risk theory of sewage irrigation need to be deepen to seek more scientific methods to describe in future; the evaluation indicators of all the risks in sewage irrigation in farmland should be improved; all the risks caused by sewage irrigation should be classified and studied more intensively, every sensitive elements should be specified to reflect the essential of the risk; the criterion of classification of risk degree of sewage irrigation should be established for a clear understanding of the degree of environmental hazards.

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