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Analysis on environmental safety issues caused by wastewater irrigation

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ABSTRACT

Irrigation with wastewater alleviated the shortage of agricultural water resources at the same time, also caused series of environmental security issues. The groundwater was polluted, farmland was polluted by some heavy metals and toxic substances), the quality and yield of agricultural products reduced in some irrigation zones. All of those will affect human health severely. The effective ways to improve the safety of sewage irrigation is to push forward the pretreatment technology of sewage, to promotion of irrigations with reclaimed water and to combine sewage treatment technology with suitable irrigation ways. Through these measures, the safe use of sewage recycle treatment will be realized, the ecological environment will be improved, and the food security will be ensured.

KEYWORDS

Wastewater irrigation; Environmental safety; Reclamation and reuse; Reclaimed water.

INTRODUCTION

With a severe shortage in water resource, China presents an increasing aggravation on the imbalance between supply and demand of water resource, mainly induced by the deterioration of water quality and rapid development of agriculture and industry. With the rapid development of the national economy and the improvement of the living standard of people, the wastewater discharges in cities and towns are increasing year by year. The total wastewater discharge in 2012 was 6.848×10^{10} t, presenting an increase by 3.7% compared with that in 2011[1]. China is a large agricultural country, and agriculture is the basis for national economy. Agriculture cannot develop without water conservancy and irrigation, and accordingly adequate water supply is a key factor to the increase in agricultural production. In 2012, a total of 3.8803×10^{11} m^3 water was used in agriculture in China, occupying 63% of the total water use of that year. As a kind of available resource, wastewater is becoming a major component of water used in agriculture.

DEVELOPMENT OF WASTEWATER IRRIGATION IN CHINA

Since the late 1950s and the early 1960s, wastewater irrigation has developed aiming at providing water and fertilizer for the development of agriculture and seeking a way for municipal wastewater disposal. Wastewater irrigation has experienced4 stages including spontaneous-, initial-, rapid-, and rational development stage[2].

With the development of wastewater irrigation, farmland irrigated with wastewater has been increasing gradually particularly in the suburban areas of many large and medium–sized cities. According to the statistics, farmlands irrigated by wastewater amounted to 1.15×10^4 hm^2 in 1957, and exceeded 130×10^4 hm^2 in 1980s, occupying approximately 20% in total discharges (3.70×10^{10}m3). Until 2000, the area of farmlands irrigated with wastewater had reached over 4.30×10^6 hm^2[3-4]. The development of farmlands irrigated with wastewater in China is shown in Figure 1.

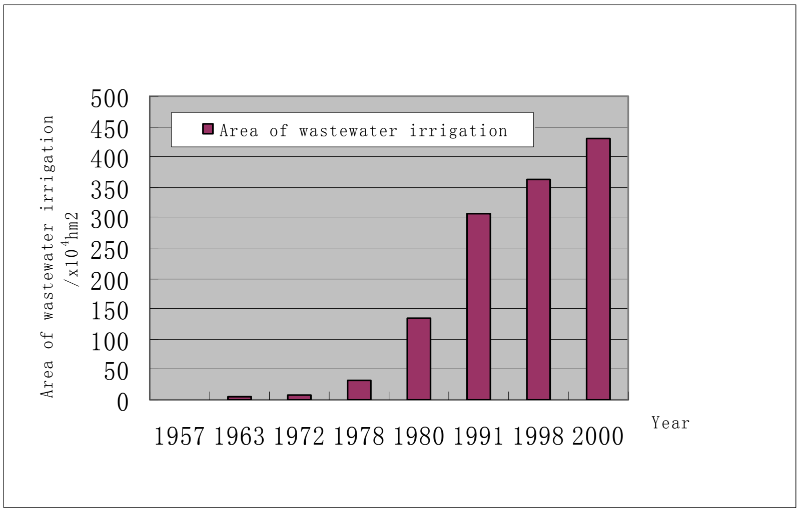

Figure 1 : The development of area of wastewater irrigation in China

ANALYSES ON THE ECO-ENVIRONMENTAL POLLUTIONS CAUSED BY WASTEWATER IRRIGATION

The nutrient elements of nitrogen (N), phosphorus (P) and potassium (K) in wastewater can provide necessary nutrients for the growth of crops. Therefore, wastewater irrigations exhibit certain positive effects on agricultural production. In 2012, the total amounts of N and P discharges in wastewater from cities and towns in China reached 4.5137×10^6 t and 4.888×10^5 t, respectively. Utilization of these wastewaters in farmland irrigation can improve soil fertility, reduce fertilizer usage, and save production cost. However, in early years, due to the outdated wastewater treatment technology and facilities, most wastewater used for irrigation had not been effectively treated or failed to meet the standard. Such wastewater contained certain amount of toxic materials, and thus long-term usage would not only exert negative effects on the growth of crops but also lead to a severe eco-environmental deterioration. The most direct influence was that the toxic substances in wastewater accumulated in soil, affecting the quality of soil and groundwater. Conclusively, wastewater irrigation can also indirectly impact the yield and quality of agricultural products and even human health.

Analyses on the agricultural soil pollutions caused by wastewater irrigation

The purification ability and buffering capacity of soils are limited. Due to the long-term usage of wastewater which failed to meet the irrigation standard, the contents of organic pollutants, heavy metals and suspended solids are beyond the holding capacity of soils and absorption by plants, which would inevitably lead to soil pollutions. As presented in many studies, years of unreasonable wastewater irrigation have caused severe organic pollutions and heavy metal pollution in soils. According to the survey on wastewater irrigation zones throughout China by the Ministry of Agriculture, in the wastewater irrigation zones covering approximately.40×10^6 hm^2, 64.8% of the soils were polluted by heavy metals, in which 46.7%were slightly polluted, 9.7% were moderately polluted, and unfortunately 8.4% were severely polluted[5].

TABLE 1 : Major heavy metals contaminating the soils in wastewater irrigation zones among different provinces[6-14]

province	major heavy metals
Tianjin	Cd、Hg、As
Beijing	Zn、Cd、Hg、Pb
Liaoning	Cd、Hg、Pb、Ni
Shanxi	Hg、Cd、As
shaanxi	Ni、Hg
Hunan	Cd、As、Hg、Pb
Guangdong	Cd、Cu、Ni
Guangxi	As、Pb、Cd、Zn

Heavy metal pollution in soils is one of the most extensive eco-environmental pollution issue caused by wastewater irrigation. The results of lots of surveys show that due to the differences in the development of industry and economy among different provinces, the major heavy metals contaminating the wastewater irrigation zones are different, as shown in TABLE 1.

Heavy metal pollutions in soils are characterized by the excessive accumulations of heavy metal, which are mainly distributed in the plough layer.

Wastewater irrigation can also bring about organic pollutants in some irrigation zones. For example, in eight large irrigation zones from Liaoning, the detection rate of polycyclic aromatic hydrocarbon (PAH) is up to 89.1%[15]. PAH is also detected in various wastewater irrigation zones from Beijing, Tianjin, Henan and Shanxi[16-19]. More seriously, nine endocrine disruptors are detected to be at pollution levels in three typical wastewater irrigation zones from Hebei[20].

Wastewater irrigation can also result in deteriorations of soil physical and chemical properties, the hardened soils, the reduced fertility, the imbalance of soil structure and function, and the damaged soil ecological balance. Moreover, the soil environment gets worse, combined with the deteriorative soil biological community structures, the decreased diversity, and thus eco-environmental problems emerge.

By analyzing the soils in the wastewater irrigation zones from Ningxia, Sun *et al*[21]. found that the original good structure of soils was destroyed by pollutants in the wastewater. Consequently, the soils were hardened, soil salinization was exacerbated, i.e., the soils were contaminated, and soil quality decreased significantly.

A wastewater irrigation experiment on calcareous drab soil for consecutive 9 years was carried out by Li *et al*[22]., and the results indicate that long-term wastewater irrigations would lead to a soil secondary salinization, while total salt content and the contents of ions such as Na^+, Mg^{2+}, and Cl^- increased fairly greatly.

Analyses on the groundwater contamination caused by wastewater irrigation

During wastewater irrigation, some major anions and cations in wastewater can easily move downwards through the soils and enter the shallow groundwater, leading to the pollutions in the shallow groundwater. Lots of studies suggested that NH^{4+} in wastewater can participate in ion exchange reactions with Ca^{2+} and Mg^{2+} on soil colloid surface. Subsequently, the hardness of groundwater goes up and soil N content rises. Ammonium in soils can be transferred to go $NO^{3-}$by a nitrification process, exacerbating groundwater pollutions in a short time. Nitrate is also readily leached to deeper soil layers or to the groundwater, and consequently the amount of NO^{3-} in the groundwater exceeds the standard value. Tang *et al*[23]. took groundwater samples from typical irrigation zones with decades of wastewater irrigation histories in the suburbs of Shijiazhuang City and analyzed them. The results revealed a higher NO^{3-} concentration in the groundwater of wastewater irrigation zones than that in groundwater of zones irrigated with groundwater.

The study by Liu et al[24]. demonstrated that after long-term wastewater irrigation, the amount of Cl^-, total hardness and TDS of the groundwater in a wastewater irrigation zone from Jiaozuo City were at pollution levels. The investigation by Zhang[25], Fang[26] *et al.* showed that long-term wastewater irrigation could cause organic pollutants of the groundwater in some irrigation zones to various degrees. Wastewater irrigation also leads to pathogenic microorganism pollutions in the groundwater. Han *et al*[27]. indicated higher detection rates of total amount of bacterial, coliform and intestinal tract pathogenic bacteria of the groundwater in the wastewater irrigation zones were higher than those in the clean-water irrigation zones in the suburb of Chifeng City.

Effects of wastewater irrigation on crop quality

The toxic substances in wastewater are readily absorbed by crops and moreover, reserved in crops, which will bring about not only the decrease of crop yields or even suffering great losses from pollutions, and also the declines of crop quality to a different degree.

Wastewater irrigation can also inhibit the growth and development of crops such as rice and corn, accompanied with decreased yields[28-29]. Wastewater irrigation also leads to a large amount of nitrite far exceeding the standards in vegetables. Heavy metals such as Pb and Cd even exist in some corn seedlings, crop grains and vegetables, which implies that the transfer of heavy metals from soil to agricultural products would pose great potential threatsto human health[30-31].

THE REASONS FOR ENVIRONMENTAL SAFETY ISSUES INDUCED BY WASTEWATER IRRIGATION

Lack of safety awareness in wastewater irrigation

The soil-plant system exhibits certain purification capacity for wastewater. The removal rate of biological oxygen demand (BOD)can be as high as 94-99%, while the removal rates of total N and total Pcan be up to 67-84% and 44-99%, respectively. To reduce the amount of wastewater flowing into rivers, lakes and seas, and alleviate the pollution load of natural water bodies, wastewater irrigation was regarded as a means of wastewater disposal in early years in China. Resultingly, many irrigation waters have exceeded standard caused by long-term irrigations with untreated wastewater

Low wastewater treatment rate and outdated wastewater treatment techniques

The discharge volume of wastewater in China is tremendous. Until 2012, wastewater discharge had increased by 43% from 3.73×10^{10} t in 1995 to 6.592×10^{10} t. It is predicted that the annual wastewater discharge will be increased to $8.5\text{-}10.6\times10^{10}$ m^3 in 2030. Unfortunately, the drainage facilities and wastewater treatment facilities in most cities of China have been lagging behind, resulting in low wastewater treatment rate. Currently, most treated wastewater in China flows into surface water like rivers. The length of the drainage pipelines and number of wastewater treatment facilities in China, as listed in TABLE 2 for the past decade, affect the surrounding eco-environment of cities significantly.

TABLE 2 : Length of drainage pipelines and number of wastewater treatment facilities in China for the past decade

Year	Length of drainage pipelines in cities (km)	Number of wastewater treatment facilities (set)
2003	198645	65128
2004	218880.9	66252
2005	241055.7	69231
2006	261379	75830
2007	291933	78210
2008	315220	78725
2009	343892	77018
2010	369553	80332

As shown in TABLE 2, in early years, the wastewater treatment facilities were far from perfection and the drainage pipelines were insufficientfor most cities in China, leading to a low wastewater treatment rate. According to the statistic data, the wastewater treatment rate in 1998 was less than 30% and that in 2010 was only 77.4%. Figure 2 shows the daily wastewater discharge and daily wastewater treatment capacity in cities.

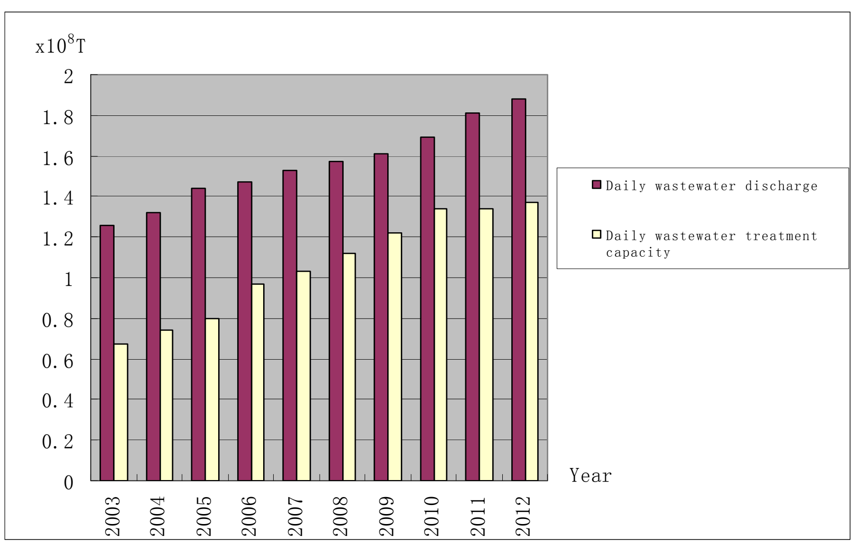

Figure 2 : Daily wastewater discharge and daily wastewater treatment capacity in cities of China

Wastewater was not treated until recently in most cities and towns of China. At the early stages, most of wastewater-treatment plants only have the first-class enhanced treatment technologies and outdated wastewater treatment facilities, due to technical and economic limitations. Not many wastewater treatment plants have the second-class enhanced treatment technologies. With the rapid development of economy and industry, the quality of municipal sewage and industrial wastewater in China has developed greatly. Wastewater contains all kinds of detrimental organic substances that are difficult to degrade and toxic heavy metals, which originated from industries such as printing and dyeing, pesticide, chemical industry, and petroleum. The pollutants in wastewater are complex, and thus the traditional wastewater treatment technologies cannot be satisfactory. Some wastewater treatment plants are not equipped with the sterilization devices for water discharge. As a result, the microbial index of water cannot meet the water quality requirement for farmland irrigation[32-35].

Gap between water quality criteria for farmland irrigation and wastewater discharge criteria

Currently, wastewater discharge in cities and towns of China follows Pollutant Discharge Criteria for Wastewater Treatment Plants in Cities and Towns (GB18918-2002)and Comprehensive Criteria for Wastewater Discharge (GB8978-1996). The major pollutants described in these criteria are organic substances, N, P and special pollutants produced by certain industries. The performed criteria for farmland irrigation are Water Quality Criteria for Farmland Irrigation (GB5084-2005) and Water Quality for Farmland Irrigation and Recycle of Municipal Sewage (GB20922-2007). When wastewater is used for farmland irrigation, heavy metal pollutants and harmful organic substances in it readily accumulate in soils. Therefore wastewater irrigation must be strictly controlled. As N and P are key nutrients which are necessary in agriculture, water quality criteria for farmland irrigation and *wastewater* treatment plants should be objective-dependent, as indicated in Figure 3.

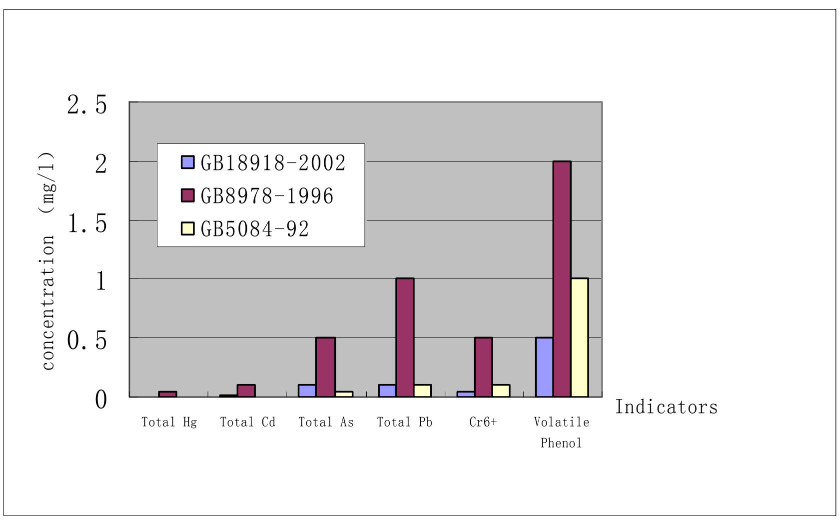

Figure 3 : The difference of control index among three kinds of standard

After treated by plants, the wastewater can meet the related criteria and then be used in farmland irrigation, which will generate potential soil heavy-metal contamination risks.

CONCLUSION

Wastewater irrigation provides solutions for municipal sewage discharge and water shortage in agricultural production. However, it also causes a series of issues such as soil heavy metal pollution, groundwater contamination and the decline of yield and quality of crops in wastewater irrigation zones, which has become one of the important factors influencing eco-environmental safety and constraining the sustainable development of agriculture.

The wastewater treatment facilities in cities and towns need to be improved. Higher requirements, specifically, higher wastewater treatment rates and treatment levels, should be achieved in key watershed regions and in cities along many big rivers. Additionally, it is suggested that related departments should pay more attentions to the protection of agricultural ecosystem, crop production safety and human health when making urbanization development schemes and accelerating the economy development.

Based on actual situations in China, we should make efforts to adopt positive and effective strategies and scientific attitudes, and explore economically effective and technically feasible wastewater irrigation methods. The quality of wastewater used in irrigation should be frequently monitored, and reclaimed water irrigation should be emphasized. The irrigation amount of reclaimed water should be strictly controlled; and scientific and reasonable irrigation regime and crop planting system should be developed for farmland irrigation with reclaimed water, by which the eco-environmental safety and human health are guaranteed, and the agricultural development is promoted.

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