Impacts of Sewage Irrigation on Soil Properties of Farmland in China: A Review

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Abstract: Fresh water is valuable nonrenewable resource and plays an important role of maintaining economic and social development. Condisering its large population and consumption potential, water resources deficit will certainly impede basic industries sustainable development of China in the near future. Application of sewage irrigation, to some extent, was regarded as an alternative way to solve the problem of agricultural irrigation water shortage in some areas (such as North China). However, accompanied with extensive implementation of sewage irrigation, some problems on sewage irrigation in agriculture are gradually obvious, especially serious pollution and destruction for farmland. In this paper, the effects of sewage irrigation on soil physical (soil bulk density, soil resistance to penetration and field capacity), chemical (pH, soil organic matter, nitrogen, phosphrous, patassium, heavy metal and organic pollutants) and biological characteristics (soil microorganism and enzyme activities) of farmland in China were systematically reviewed on the base of the current utilization status of China's farmland sewage irrigation and some feasible suggestions were put forward to the development prospect for the future. This review will be beneficial for promoting healthy development of sewage irrigation and providing theoretical support for reclamation and high efficiency of effluents in China.

Keywords: wastewater irrigation; soil characteristics; agriculture; pollution; China

Introduction

Water is not only the valuable natural resources, which maintains people's survival and development, but also constitutes the main constituent elements of environment [1-4]. China is rich in total water resources volume, where the total amount of fresh water resources could reach $2.81*10^{12}$ m^3 that accounts for about 6% of global water resources [5, 6]. Considering the large population base of China, however, the per-capita water resources volume is relatively limited, just only $2.3 *10^3$ m^3, which is only 25 percent of the world average level, becoming one of the poorest countries or regions of water resources per capita [7-9]. Even more serious is that the water resource characteristices of regional and seasonal distribution in China, to some extent, hinder the sustainable development of economic and social development in water shortage areas [2].

As a vast agricultural country, extensive quantities of water are being consumed in China's agricultural production and irrigation water accouts for more than 70% of the total water consumption [10-12]. At present, there are about 50 percent of total cultivated land that could be irrigated, and produces about 75 percent of nation grain output and more than 80 percent of cotton as well as more than 90% percent of vegetables [13-15]. With the rapid development of the national economy and the continuous improvement of people's quality of life, industrial and domestic water consumption increase continuously, which cause agricultural water is constantly being squeezed and irrigation water is not guaranteed and water scarcity is becoming increasingly serious[4, 16, 17]. In China, there are just about $3.0 * 10^{10}$ m^3 of water in agricultural water shortage per year, resulting in a reduction in grain yield of $2.5\text{-}4.0*10^{10}$ kg [18-20]. At the same time, the total amount of waste water discharged from industrial and urban areas is increasing, and the discharge is relatively concentrated, which is not affected by seasonal change and flooding. Most of the wastewater untreated or without the necessary pretreatment is directly poured into rivers, lakes and reservoirs, posing a potential threat to the ecological environment[10, 21].

Water resources depletion in agriculture promotes a large amounts of sewage being used for irrigation directly on a global scale and nearly 2.0* 10^5 km^2 involved 50 countries are irrigated by sewage [22-24]. There are 4.3*10^{10} km^2 of irrigated farmland by the end of 2009, accounting for 7.3 percent of the total irrigation area in China [25]. And sewage irrigation area show a rising trend and specially in northern China what was the main area of water resources deficit. Application of sewage in this area could solve the problem of agricultural irrigation water shortage, becoming an important alternative way [10, 21]. There are reports that sewage irrigation area mainly presently focused on Haihe river basin, Liaohe rive basin, Yellow river basin and Huaihe river basin, occupying approximate 85 percent of the sewage irrigation area [14]. For those developed countries, the techniques of sewage treatment and reutilization have matured and achieved the dual purpose of water conservation and pollution control [9, 22, 26]. Howver, for the current situation of China, sewage treatment techniques lag behind and water quality has not reached the standard for a long time, on the other hand, the sewage irrigation management and monitoring system are not sound [25]. More attention were paid to whether long-time sewage irrigation has affected soil properties of farmland in China [27-30].

This paper systematically reviewed the effects of sewage irrigation on soil physical, chemical and biological characteristics of farmland in China based on the development and utilization of China's farmland sewage irrigation, putting forward suggestions to the development prospect in the near future. This specific objectives were to promote the sustainable development of sewage irrigation in China and provide theoretical support for reclamation and high efficiency of sewage.

1. History of sewage irrigation

Commonly sewage irrigation does not use production and domestic sewage directly, but is an engineering measure using appropriate treatment effluents that meet requirement of irrigation qualities to farmland, grassland landscape irrigation and groundwater recharge by taking advantage of soil self-purification ability purposefully, solving the lack of water resources and achieving sewage reclamation eventually [10, 14, 31].Many developed countries in the world have realized pretty early on that strategic significance of sewage reutilization. Western European countries has began to use sewage to irrigate farmland since the middle of the 16th century. In Germany, the world's largest and oldest sewage irrigation sites, where approximately 100 km^2 of marginal and low-productivity land have been irrigated by sewage since 1928 [32, 33]. The first large-scale utilization of sewage irrigation country is America, where a suit of water purification system was assembled in 1920 and some research and intensive utilization of sewage irrigation was conducted [34, 35]. Up to now, its wastewater treatment technology and application scope keep a leading place in the world. Japan has began to sewage recycling and implemented rural sewage treatment project since 1960s. About 2000 small sewage treatment plants on a national scale were implemented depending on small sewage treatment system for agricultural irrigation in the following 1970s [36, 37]. As one of the world's most severely water-deficient countries, Israel has established a comprehensive sewage system and sewage treatment projects in all its cities and settlements [38-40]. Almost all of the wastewater could be effectively processed and utilized [22]. More than 57% of the sewage after purification has been used in agriculture, garden, lawn irrigation, which accounts for about 20% of the total irrigation water, becoming a paragons of water resources efficient utilization countries [40]. Other countries, such as Tunisia, India, Jordan and Mexico, have also carried out relevant researches on wastewater irrigation and already accumulated a wealthe of experience[41-44].

For sewage irrigation safety, different countries and intenational organizations have created a set of standards in practice[45, 46]. In 1973, the World Health Organization (WHO) published a health guidelines for wastewater recycling of farmland irrigation and aquaculture, which claimed that sewage for farmland should be treated strictly. And the guidelines referring to some indexes were adjusted and new guidelines were published in 1989. However, those standards are too rigid and be of little practical value when popularized, resulting in not carried out by most countries and regions. The Food and Agriculture Organization (FAO) has also issued two technical reports about wastewater treatment and

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irrigation recycling and effluents quality controlling on the basis with the current situation of sewage irrigation utilization in the worldwide [47, 48]. The water quality requirements and sewage treatment methods for agricultural irrigation were also discussed and some guidance of sewage irrigation was proposed in view of the actual situation of the national development level.

2. Application of sewage irrigation of China

Compared with some deveolped countries, the source of sewage irrigation mainly comes from untreated or raw domestic and industrial wastewater [49]. Though there has a long history for peasants using human wastes to fertilize farmland in many parts of China, sewage irrigation development emerged later given the level development of economic and urbanlization [27, 50, 51]. Three periods could be divided in accordance with the development scale and stage: the first period is classified as spontaneous irrigation using of sewage effluents [14]. Peasants lived in the suburban of Beijing began to mix domestic and industrial effluents for farmland irrigation in 1940s. But considering the emission load of sewage is relative limited on a small scale, the national sewage irrigation area was just only $1.16*10^2$ km^2 [51, 52]. The second period is regarded as preliminary stage of development from 1957 to 1972. In 1957, the Chinese government constructed sewage irrigation project and the ministry of construction engineering, agriculture and health jointly processed sewage irrigation into national scientific research project, prompting its preliminary development and forming a certain scale. And the first pilot scheme for sanitary management of sewage irrigation was promulgated four years later[51]. Stepping into 1970s, especially the implementation of reformation and opening policy and household contract responsibility system accelerated urban and rural enterprises development, sewage irrigation entered a fast-developing period and had to face with unprecedented historical challenges. Firstly, some problems of water resources shortage are gradually highlighted and sewage irrigation areas increase dramatically. More than $3.62*10^4$ km^2 of farmland in China was irrigated using sewage effluents at the end of the 20th century [53]. Although the Chinese government brought out and revised a series of irrigation water quality standards which were applied to surface water, groundwater, aquaculture treated wastewater and farmland irrigation water come from effluents that were mainly agricultural products as raw material in 1979, 1985 and 1992, respectively. Some standards for organic pollutants controlling were also increased and these standards became national mandatory standards[54]. However, just like many laws and regulations in China, these standards existed in name only in practice [25, 55]. And with the rapid development of national economy, the industrial and domestic sewage water quality changed dramatically, toxic and harmful organic pollutant species increased continuously [56]. Only current some indicators of water quality standards could not adapt to the requirement of sewage irrigation, has the Chinese government come to realize the hazards of sewage irrigation for agricultural production [27, 57]. A file of work arrangement on soil environmental protection and comprehensive adjustment for the near time was finaly issued by General Office of the State Council on January 28, 2013, which was the first time for authority to explicitly forbid to use wastewater containing heavy metals, refractory organic pollutants and sludge, dredging of sediment, tailings that were untested or safety disposal for agricultural production. But so far, the relevant standards or guidelines of wastewater irrigation applied to new conditions have been delayed due to various economic benefits.

3. Influence of sewage irrigation on soil properties

Soil is not merely the base supporting plant growth and breeding, but also the foundation of human agricultural production [1, 58]. All kinds of human agricultural production activities are mainly carried out in soil and abundant agricultural products acquired directly or indirectly from soil. Soil is located in the interface of atmosphere, lithosphere, hydrosphere, and biosphere, participating a variety of processes involved physics, chemistry, biochemistry and becoming the crucial place of material circulation and energy exchange [58, 59]. Its existence provides a relatively stable survival and procreation environment for aboveground vegetation and underground microorganism [60].

In China, untreated sewage is often used for farmland irrigation in agricultural production directly. For substances dissolved in sewage, there are mainly four approaches of transference after migrating

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into the soil [13, 53]. Some of them would gradually reduced by the soil self-purification; some of them would be adsorbed and retained in the soil layer; some of them could be absorbed by crops and the rest would enter aquifers along with water infiltration[10, 61]. Although soil, to some extent, has the capacity to clearance and degradation of pollutants via metabolism and transformation, increasing some nutritive element contents and fertility in the soil, long-term irrigation using sewage that does not conform water quality standards makes organic pollutants, heavy metals, solid suspended particles and bacteria microbes into the soil [9, 21, 29, 50]. But the worse thing is that these contents has been far beyond the ability of soil self-purification, causing serious soil pollution and giving rise to some changes of soil physical, chemical and biological characteristics.

3.1 Effect on soil physical characteristics

Long-term sewage irrigation damages the balance of nature, causing ecological deterioration on farmland [62]. For the effect of sewage irrigation on soil physical properties, the most direct performance is structural damage, functional disturbance and soil hardening [53]. Soil bulk density is one of the important indicators measuring soil physical properties. It reflects the degree of compaction to a certain extent, which has a great influence on soil aeration, soil waterholding and absorption capacity, infiltration, soil erosion resistance ability and solute migration [59].The porosity of soil is subjected to changes in soil density[63]. A study on the consecutive irrigation in calcareous soil of China showed that long-term sewage irrigation changed soil structure significantly. Soil porosity and bulk density had a close correlation with sewage irrigation time. As time goes on, the soil porosity decreased while the bulk density increased [64]. Furthermore, irrifation by effluents containing high salinity made soil secondary salinization easily and enhaced total alkalinity and sodium alkalinity sharply in the soil, causing soil hardening and soil permeability decrease [65, 66]. There are also reported that the organic matter, microorganism, fiber and sediment from sewage deposited in the soil surface exerted an negative impacts on soil physical traits, which resulted in soil permeability degradation and soil compaction occurrence [44].

The most conspicuous results of soil hardening is soil resistance to penetration, which is an important index measuring crop roots elongation resistance[67, 68]. Generally, it is related to soil aggregate characteristics and soil particular spatial arrangement [69, 70]. A study in Weihe River irrigation area by Hu found that the topsoil of farmland within 10 cm irrigated by sewage directly was loose and resistance to penetration was less than 500 kPa in this layer, which did not affect the crop root growth. However, the problem of resistance to penetration became obvious as the soil layer deepen, ranging from 415 kPa in 10cm to 1473 kPa in 45cm. Soil deep compactness shed new light that there existed a thinning trend of unconsolidated topsoil layer, which compressed thickness of soil layer that was suitable for crop roots growth and increased the sensitivity of crop to environmental change. Problems like soil compactness cannot be neglected in future agricultural production [71].

Field capacity refers to the maximum amount of water maintained by the soil without being affected by the groundwater and becomes the upper limit of available moisture for vegetation [72, 73]. It is controlled by soil structure and soil texture, playing a vital role in farmland water balance controlling, irrigation and drainnage, drought and moisture conservation [74]. The field capacity of loam would be greater than that of sand in normal conditions [75]. When irrigated by sewage, the organic matter would be into the soil and increase the soil particles viscosity, thus increasing field capacity [76]. Some similar research has confirmed that irrigation adopting eutrophic or untreated aquaculture wastewater did increase soil particles viscosity and enhanced field capacity [53, 77].

3.2 Impacts on soil chemical characteristics

The effects of sewage irrigation on soil chemical properties is reflected in soil acidity-alkalinity firstly, which is one of the important factors affecting soil fertility [78]. The formation and change of soil acidity-alkalinity depends on the relative strength of base substances leaching and accumulation process [79]. And the degree of acidity or alkalinity can be most conveniently expressed by the pH value [59]. Soil has a certain buffering function, thus the pH value is relatively stable [80]. Once the pH value varies drastically, the soil chemical properties would be changed accordingly, which affects existing form, transformation and availability of soil nutrients directly [81]. Soil pH changes are related to the types of irrigation water and soil category [82]. He et al.(2012) showed that the soil pH value would decrease with the increase of irrigation times using wastewater from hoggery to irrigate the yellow clay. While an opposite conclusion was drawn that the value of pH in soil increased if irrigated by effluents from paper-making factories to moderately degraded saline-alkali soil [83]. It is also found that there was no obvious effect on vegetable field pH when sewage came from livestock breeding [84]. The reason for fluctuation of pH value could be explained by the differnent degrees of ammoniation and nitrification of soil organic matter, anaerobic decomposition of organic matter, release and enrichment of metal ions [21, 79].

Organic matter is a significant component of soil and its content was usually be regarded as an important index mearsuring soil fertility [85]. The accumulation of soil organic matter is not only closed related to natural environment conditions, but also depends on the input of organic matter by all means [72, 74]. Sewage irrigation could solve water shortage in actual agricultural production and increase soil fertility as well, which is the comprehensive reflection of water and fertilizer. But the amplitude of increase showed huge agrotype and spatial difference [86]. A research irrigated by eutrophic sewage displayed that soil organic matter content of sandy soil and loam increased significantly, the value from loam increased by 97.1% from 2.73 g/kg to 5.38 g/kg, while the value from sandy soil increased by 36.5% from 0.85 g/kg to 1.16 g/kg [76]. Comparable differences are also existed the degree of soil organic matter increment with different soil layers. Extremely significant effects on soil organic matter were easily discovered within 20 cm of topsoil, while the increase leel was significantly reduced with the depth of soil layers [87]. Furthermore, more efforts in maintaining global carbon balance have focus on the of soil organic matter, which is considered as an irreplaceable role of affecting the global warming in the worldwide. The accumulative effect of soil organic matter from sewage irrigation has become one of input of soil organic carbon in farmland and participated in the global carbon circulation [85, 88].

Nitrogen is an essential nutrient for crop growth, and the abundance and supply of nitrogen of soil affect crop growth and development[80]. A study of irrigation using aquaculture wastewater for a long time displayed that nitrogen accumulation in soil increased significantly and the nitrogen content in soil for more than 12 years was significantly greater than that of untreated farmland [84]. There existed an obvious feature of eutrophication when farmland was irrigated by sewage over a long period of time, alkali-hydrolysable nitrogen content increased significantly in each soil layers, especially in the soil surface, its content could reach the level of 8.26 mg kg^{-1}, much higher than the average [87]. In the meantime, the nitrogen accumulation of soil profile was significantly affected by nitrogen mobility and irrigative inflitration [62]. The accumulation of NO_2^- and NO_3^- downward migration easily with water eluviation when polluted kratos water was adopted for irrigation, causing groundwater pollution at shallow layer [89]. Sewage irrigation had a lesser impact on NH_4^+ existing in deep soil and groundwater, but for the NO_3^- concentration, great influence was emerged for long-term sewage irrigated soil, easily causing groundwater pollution for deep soil layer [90].

Phosphorus is one of the three essential nutrientsd for plants. Not only it constitutes the components of many important compounds in plants, but also participates in various metabolic processes in plants by all means [91-93]. The study on farmland and forest land found that the total phosphorus had significantly increased in the soil surface soil and most of them could be kept in the upper soil (0-40 cm) using horrgey wastewater f a long-term wastewater irrigation [94, 95]. Comparable concentrations were found in the farmland with swine wastewater irrigation that the phosphorus accumulated in the plowing layer (0-40cm) and increased with the advance of irrigation time [96]. Reddling et al (2005) discovered that the available phosphorus and total phosphorus content were significantly higher than that of controlling irrigated by piggery wastewater after anaerobic digestion and the phosphorus appeared the phenomenon of excessive accumulation in the top soil layer within 5 cm.

Potassium is also a major nutrient in higher plants, which together with nitrogen and phosphorus is known as the three essential factors of plant nutrition. Among them, the available potassium refers the potassium that is easily absorbed by the plant and becomes the main diagnostic index of soil fertility [59, 72]. After sewage irrigation, the soil available potassium content has increased greatly, that is mainly because there contains a lot of nutrients in the sewage, making available potassium enrichment in the soil surface [80, 87]. The content of total potassium in soil could be also improved for sewage irrigation, the appliaction of molasses alcohol water water has significantly increased the soil total potassium content ,improving soil fertility [97].

In general, heavy metals from sewage effluents could be adsorbed by soil particles and most heavy metal ions are concentrated in the soil, resulting in soil heavy metal pollution, which has become the most serious problem for human health [27, 82, 98]. According to the bulletin of soil pullution published by Chinese government in 2014, 39 of 55 surveyed area irrigated sewage existed soil contaminated. There were 26.4% exceeded the maximum permitted levels of total 1378 soil points and the main pollutants were cadmium, arsenic and polycyclic aromatic hydrocarbons. And these metal distribution are homogeneous ,but heavy metal spatial distribution existes some differences [27, 28, 99]. A broad distinction of vertical distribution of heavy metal pollution element could be drawed in soil profile and concluded that heavy metal element mainly concentrated in the soil within 50cm and its vertical distribution varied with soil texture [100]. Heavy metal content was related to the lithology structure in soil vadose zone. The silt was not favorable for heavy metal accumulation, the sandy soil took the second. The highest content was found in loam, becoming the main enrichment of heavy metals in soil [53]. The degree of heavy metals enrichment in soil is also closely related to wastewater irrigation time and concentration of heavy metal ions in sewage [27, 85]. Wang et al found that long-term excessive irrigation by sewage exceeded standard posed a threat to soil, Cu, Pb, Zn, Cd, As, Hg, Cr and other harmful substances have been serious exceeds the limits of soil capacity. The five toxic metals (Cd, Cr, Cu, Zn, Pb) increased during the sewage irrigation on the farming area of Beijing and Shenyang and that pollution with Cd, Cu, Zn, and Pb was exacerbated in soils [101, 102]. Ultimately, these heavy metal are dangerous to human health through various food chains[103] .

Except for heavy metal pollution in soil, there existed various degrees of organic pollutants in some sewage irrigation areas [10]. Organic pollutants, such as aromatic hydrocarbons, phenols, organic chlorine are easily discovered in industrial wastewater [104]. A research by collecting seven different depths of soil samples irrigated wastewater in Taiyuan, Shanxi Province found that the constituent parts in sewage diversified and extremely complicated, main pollutants as plasticizer, such as the phthalate esters, skatole, sterols, polycyclic aromatic hydrocarbons and so on. The most serious pollution of polycyclic aromatic hydrocarbons is found in soil. This substance has penetrated into the groundwaterand also detectd in the nearby shallow groundwater [105]. A survey involved Shenyang and Fushun sewage irrigation area, the China's largest oil wastewater irrigated area showed that the accumulation of toxic substances irrigated by petrochemical industrial sewage was serious, among which the aromatic hydrocarbons were quite a proportion, and the carcinogens benzene and pyrene were severely exceeded [106]. The sensory indicators of rice produced in this region are extremely poor with strong smell from oils and aromatic compounds [25].

3.3 Influence of soil microorganism and enzyme activities

Soil microorganism, as an important part of maintaining soil quality, participates in most all of soil biological and biochemical activities and is sensitive to reflect the change of soil quality health[107]. The quantity, composition and activity of soil microbial population are dynamic processes with environmental change and the number of microbial living cells is regarded as one of the most sensitive biological indicators [108]. Sewage irrigation would cause a change of microhabitat to some extent, having a great effect on soil microbial activities [88]. Soil bacteria, fungi and actinomycetes are the three essential types of microorganisms that can be used to reflect the total amount of soil microorganisms and play a significant role of soil organic matter and inorganic materials transformation

[109]. The number of bacteria and actinomycetes in the soil showed a descending trend after long-term sewage irrigation, while the number of fungi increased slowly [110]. Similar results in Shenyang and Fushun sewage irrigation region were found that sewage irrigation changed the content of soil nutrient and multiring hydrocarbon and then had a direct effect on the microbial populations, which total nitrogen were very significant positive and significantly positively correlation with bacteria, nitrogen-fixing bacteria and phosphorus bacteria, respectively [111, 112]. In the meantime, the way of sewage irrigation also affects the number of soil microorganisms [113]. A series of studies by Oron et al displayed that soil surface humidity affected the total number of soil bacteria under the circumstance of sewage irrigation. When subsurface or underground drip irrigation was adopted, the total number of bacteria of subsurface drip irrigation is much higher than that of the underground. The most likely explantation would appear to be that soil played a role of secondary filters in the process of sewage infiltration, reducing contact probability between sewage and aboveground vegetation part [114, 115].

Soil enzymes is a catch-all term of active substance found in the soil, primarily coming from the soil microbes and plant root secretion and enzymes released by the decomposition of animal and plant residues [116, 117]. Common enzymes mainly includes oxidoreductases, hydrolytic enzymes, crack enzymes and transferation enzymes, all of which participate in and promote a large proportion oforganic substances transformation and material circulation by various of soil ecological processes [84]. Some relevant research has produced evidence to suggest that irrigation by petroleum processing wastewater could stimulate aerobic heterotrophic bacteria and fungi growth in the soil, and soil dehydrogenase, catalase, polyphenol oxidase activity showed positive correlation with the total petroleum hydrocarbon content, while soil urease activity had a significant negative correlation with the total petroleum hydrocarbon content in the soil [118]. Other observations were found that soil enzyme activities were dually influenced by soil nutrient and multiring hydrocarbon pollution after long term irrigation by petroleum processing wastewater, as well as the soil organic carbon and total phosphorus content showed a significantly relation with dehydrogenase, polyphenol oxidase and urease activity respectively,

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the content of multiring hydrocarbon were significantly positive correlated to dehydrogenase and urease activities respectively, while it was significantly positively related topolyphenol oxidase activities [111, 112]. Similar studied the relationship between sewage irrigation soil polluted by heavy metal Pb, Cd and the soil enzyme activity in heavy industry city, Baoding, Hebei Province have also proven that soil urease and hydrogen peroxide enzyme activities increased with the increase of soil Pb, Cd content [119].There are problems with many studies concerning indirect influence caused by sewage irrigation such that soil secondary salinization in calcareous drab soil lead to enzyme activities constrained, causing soil environment quality decline [64].

4 Implications for sewage irrigation development in future

For the current development of sewage irrigation in China, governors must clearly realize that wastewater discharge itself is guarantee of water scarcity for grain production and huge population demands for food security in China, on the other hand, the adverse effect brought by the sewage irrigation was removed completely. Therefore, any research and development involves sewage irrigation need to consider the actual situation in China carefully. And four aspects should be taken into account on the road toward achieving safe and efficient utilization of farmland wastewater irrigation in China.

4.1 Regulate pollution sources strictly and perfect supervision system

At present, the first question for sewage irrigation in China is to solve the quality problem gradually. Starting from the sewage source, the water quality monitoring should be strengthened and the water quality of the wastewater entering the farmland should be strictly controlled [10, 11, 120]. Contaminated water that is seriously exceeded is forbidden from discharging and utilization . In addition, in the view of the current situation that governors always adopt an attitude towards removing responsibility of supervision and administration of sewage in practical work, so the management system of the sewage irrigation should be established and implemented urgently, realizing the explicit responsibility and embodiment in different stages of the sewage dischage, disposal and irrigation [12, 13]. For the companies and individuals in the wastewater irrigation area, awareness of environmental protection should be increased. For those enterprise illegal discharges sewage behavior, the amounts of punishment need to be much greater than its illegal profit. For the individual, the health risks of sewage irrigation should be extensively published, enchacing awareness of environmental and human health [82, 85].

4.2 Optimize mode of sewage irrigation and avoid irrigation on a single type sewage for a long time

China has summarized some effective methods for sewage irrigation techniques through several decades of practice, which including oxidation pond purifying wastewater treatment and mixed irrigation between wastewater and clear water [121]. However, the flood irrigation mode is the most common adopted in the vast area of sewage irrigation. It , on the one hand, wastes a lot of valuable sewage resources, and on the other hand causes serious soil pollution [122]. Thus the current model of sewage irrigation should be changed and optimized, combining agricultural water-saving irrigation with sewage pretreatment and developing underground aerated drip sewage irrigation. Considering the different crop growth stage, edible parts and contaminants in wastewater irrigation,sewage irrigation time and quantity need to be allocated reasonably, reducing the effect of sewage irrigation on crop growth and human health [114, 115].

4.3 Conducting sewage irrigation adjusted measures to local conditions and protecting groundwater resources

Because of unmatched irrigation facilities, improper irrigation methods, unscientific irrigation systems and low management level, there existed some problems that the field irrigation efficiency was low and the percolation towards deep soil layer was serious [14]. Sewage irrigation misoperation or irrigation by untreated sewage easily gave rise to pollutants infiltration in soil, endangering the security of drink water and even forming inverse funnel of sewage, which posed a threat to deep groundwater. Once groundwater is contaminated, it will be difficult to recover, and the consequences will be severe. It seems reasonable to assume that it is not suitable for sewage irrigation for some inadaptable wastewater irrigation areas such as strong soil permeability, high underground water level, aquifer outcrop and centralized drinking water sources, which easily lead to groundwater pollution and be unfavorable to our human health [10, 19]. Therefore, it is appropriate to adjust measures to local conditions for sewage irrigation and reduce the environmental risks caused by sewage irrigation.

4.4 Adsorption and degradation of soil harmful substances by some plant and microbe characteristics of selective absorption

In the technical field of heavy metal contaminated soil repair, phytoremediation is highly favored for its advantages such as excellent reinforced effect, low cost and high environmental benefit [123]. At the same time, microorganisms could either fix heavy metal ions through their metabolic functions or convert toxic heavy metal ions into non-toxic or low-toxic prices[124]. Hyperaccumulators could be introduced to repair the soil contaminated by sewage irrigation adopting their own strong absorption ability for some heavy metals and anti-heavy metal toxicity. Furthermore, the function of microbial selective absorption was jointly utilized to establish the system of plant-microbial repairment, improving the efficiency of the heavy metal pollution soil restoration [125].

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