



Impacts of sewage irrigation on soil properties of farmland in China: A review

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Abstract: Fresh water is a valuable nonrenewable resource and plays an important role of maintaining economic and social development. Sewage irrigation was taken a supplementary way to relieve water resource shortage in some areas (such as North China). With extensive implementation of sewage irrigation, serious pollution and destruction for farmland have gradually become a heated issue, impeding basic industries sustainable development in the near future. Here in this paper, some soil physical properties (soil bulk density, soil resistance to penetration and field capacity) and chemical properties (pH, soil organic matter, nitrogen, phosphorous, potassium, heavy metal and organic pollutants contents) and biological characteristics (soil microorganisms and enzyme activities) of farmland affected by sewage irrigation were systematically reviewed on the base of the current utilization status of China and some valuable suggestions were put forward to the future development prospects. 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

28 Introduction

29 Water is not only a valuable natural resource, which maintains people's survival and development,
30 but also constitutes the main constituent elements  environment (Bouwer, 1994; Gu et al., 2017;
31 Molles, 2008; Piao et al., 2010). China is rich in total water resources volume, where the total amount of
32 fresh water resources could reach $2.81 \times 10^{12} \text{ m}^3$ that accounts for about 6% of global water resources
33 (Thomas, 2008; Zhang and Wang, 2007). However, the per-capita water resources volume ($2.3 \times 10^3 \text{ m}^3$)
34 of China is quite limited, which equals to 25 percent of the world average level, making China to be one
35 of the poorest countries or regions (Fatta-Kassinos et al., 2011; JR, 1991; Wang et al., 2008). Even more
36 serious is that the water resource characteristics of regional and seasonal distribution in China, to some
37 extent, hinder the sustainable development of economic and social development in water shortage areas
38 (Piao et al., 2010).

39 As a vast agricultural country,  China has 70 percent of the total water being consumed in
40 agricultural production or irrigation (Qadir et al., 2010; Shi et al., 2014; Yang, 2000). At present, about
41 50 percent of total cultivated land areas could be irrigated, which produce about 75 percent of nation
42 grain output and more than 80 percent of cotton as well as more than 90 percent of vegetables in total
43 (Jin and Young, 2001a; Liu and Xu, 2002; Zeng and Zhu, 2004). With the rapid development of national
44 economy and continuous improvement of people's quality of life, water demand from its swelling urban
45 and industrial sectors exacerbates water resources scarcity, these shortfalls can be filled only by
46 diverting water from agriculture (Bouwer, 1994; Brown and Halweil, 1998; Vörösmarty et al., 2000). In
47 China, there is just about $3.0 \times 10^{10} \text{ m}^3$ of water in agricultural water shortage per year, resulting in a
48 reduction in grain yield of $2.5\text{-}4.0 \times 10^{10} \text{ kg}$ (Brown, 1995; Wang et al., 2010; Zhou, 2002). At the same
49 time, the total amount of wastewater discharged from industrial and urban areas is increasing, and the
50 discharge is relatively concentrated, which is not affected by seasonal change and flooding. Most of the
51 wastewater untreated or without necessary pretreatment is directly poured into rivers, lakes and

52 reservoirs, posing a potential threat to the environmental protection (Qadir et al., 2010; Rusan et al.,
53 2007).

54 Water resources depletion in agriculture promotes a large amount of sewage being used for
55 irrigation directly on a global scale, nearly $2.0 * 10^6 \text{ km}^2$ involved 50 countries are irrigated by sewage
56 (Abaidoo et al., 2010; Qadir et al., 2007; Wallach et al., 2005). By the end of 2009, China has $5.9 * 10^5$
57 km^2 irrigated farmland, accounting for 7.3 percent of the total area of irrigation farmland (Fang, 2011).
58 On the same time, sewage irrigation is using more at regions such as northern China where water
59 resources deficit is more serious. Application of sewage becomes to be an important supplementary way
60 to relieve agricultural irrigation water shortage water (Qadir et al., 2010; Rusan et al., 2007). Previous
61 studies reported that the main sewage irrigation area are Haihe river basin, Liaohe river basin, Yellow
62 river basin and Huaihe river basin, occupying approximate 85 percent of the sewage irrigation areas
63 (Liu and Xu, 2002).

64 Techniques of sewage treatment and reutilization have achieved the dual purpose of water
65 conservation and pollution control for some developed countries (Angelakis et al., 1999; Fatta-Kassinos
66 et al., 2011; Wallach et al., 2005). For China, sewage treatment techniques lag behind and most of water
67 quality for irrigation has not reached the standards for a long time, on the other hand, the sewage
68 irrigation management and monitoring system are not sound (Fang, 2011). More subjects were paid
69 attention to whether long-time sewage irrigation has affected soil properties of farmland in China (Khan
70 et al., 2008; Liu et al., 2005; Meng et al., 2016; Tang et al., 2004).

71 This paper systematically reviewed the effects of sewage irrigation on soil physical, chemical and
72 biological characteristics of farmland in China based on the development and utilization of China,
73 putting forward suggestions to the development prospects in the near future. The specific objectives
74 were to promote the sustainable development of sewage irrigation in China and provide theoretical
75 support for reclamation and high efficiency of effluents. 

76

77 **1. History of sewage irrigation**

78 In fact, sewage irrigation does not use production and domestic sewage directly, but it is an
79 engineering measure adopting appropriate treatment effluent which meets irrigation quality requirement
80 for farmland, grassland landscape and groundwater recharge. It makes full use of soil self-purification
81 ability purposefully and solves the lack of water resources and achieves sewage reclamation eventually
82 (Liu and Xu, 2002; Qadir et al., 2010; Xia and Wang, 2001). Many developed countries in the world
83 realized early on the strategic significance of sewage reutilization. Several western European countries
84 used sewage irrigation since the middle of 17 century. Berlin, Germany is the oldest sewage irrigation
85 sites in the world where approximate 100 km² of marginal and low-productivity land has been sewage
86 irrigated since 1870 (Hass et al., 2012; Lottermoser, 2012). The first large-scale utilization of sewage
87 irrigation country is America, where a suit of water purification system was assembled in 1920 and
88 some research and intensive utilization of sewage irrigation were conducted (Chen et al., 2000; Sabol et
89 al., 1987). Up to now, its wastewater treatment technology and application scope keep a leading place in
90 the world. As one of the world's most severely water-deficient countries, Israel has established a
91 comprehensive sewage system and sewage treatment projects in all its cities and settlements (Chen and
92 Zhou, 2001; Heukelekian, 1957; Jueschke et al., 2008). Almost all of the wastewater could be
93 effectively processed and utilized (Wallach et al., 2005). More than 57 percent of sewage after
94 purification has been used in agriculture, garden and lawn irrigation, which accounts for about 20
95 percent of the total irrigation water, becoming a paragon of water resources efficient utilization
96 countries (Chen and Zhou, 2001). Other countries, such as Tunisia, India, Jordan and Mexico, have also
97 carried out relevant researches on wastewater irrigation and already accumulated a wealth of
98 experience (Abu-Sharar et al., 2010; Bouri et al., 2008; Siebe and Fischer, 1996; Singh et al., 2012).

99 For sewage irrigation safety, different countries and international organizations have created a series
100 of standards in practice (EPA, 1992; FAO, 1985). In 1973, the World Health Organization (WHO)
101 published health guidelines for wastewater reclamation of farmland irrigation and aquaculture, which

102 claimed that the significance of sewage irrigation for farmland me indexes in the guidelines were
103 reset and new guidelines published in 1989. However, when those standards were popularized
104 throughout the world, few countries and regions adopted because of overly strict criteria (EPA, 1992).
105 The Food and Agriculture Organization (FAO) has also issued two technical reports about wastewater
106 treatment and irrigation reclamation and sewage quality controlling based on the current sewage
107 irrigation utilization in the worldwide (Pescod, 1992; Wescott, 1997). The water quality requirements
108 and sewage treatment methods for agricultural irrigation were also discussed and some guidance of
109 sewage irrigation was proposed in view of the actual situation of the national development level.

110 **2. Application of sewage irrigation in China**

111 Compared with some developed countries, the source of sewage irrigation in China mainly comes
112 from untreated or raw domestic and industrial wastewater (Pedrero et al., 2010). Though there has been
113 a long history for peasants using human wastes to fertilize farmland in many parts of China, sewage
114 irrigation development emerged later given the development level of economic and urbanization (Liu et
115 al., 2005; Zeng et al., 2007; Zhang, 2014). Three periods could be divided in accordance with the
116 development scale and stage: the first period is classified as spontaneous irrigation stage using sewage
117 effluents (Liu and Xu, 2002). Peasants lived in the suburban of Beijing began to mix domestic and
118 industrial effluents for farmland irrigation in the 1940s. But the emission load of sewage is relative
119 limited on a small scale, the national sewage irrigation area was just only $1.16 * 10^2$  km^2 (Li and Luo,
120 1995; Zhang, 2014). The second period is served  preliminary development stage from 1957 to 1972.
121 In 1957, the Chinese government constructed sewage irrigation projects and the ministry of construction
122 engineering, agriculture and health jointly processed sewage irrigation into national scientific research
123 projects, prompting its preliminary development and forming a certain scale. And the first pilot scheme
124 for sanitary management of sewage irrigation was promulgated four years later (Zhang, 2014). pping
125 into 1970s, especially the implementation of reformation and opening policy and household contract
126 responsibility system accelerated rural enterprise development, sewage irrigation entered a

127 fast-developing period and had to face with unprecedented historical challenges. Firstly, some problems
128 of water resources shortage were gradually emerging and sewage irrigation areas increase dramatically.
129 More than $3.62 * 10^4$ km² of farmland in China was irrigated using sewage effluents at the end of the
130 20th century (Wang and Lin, 2003). Although the Chinese government brought out and revised a series
131 of irrigation water quality standards which were applied to surface water, groundwater, aquaculture
132 treated wastewater and farmland irrigation water from agricultural production effluents in 1979, 1985
133 and 1992, respectively. Some standards for organic pollutants controlling were also increased and these
134 standards became national mandatory standards (Shi et al., 2008). However, just like many laws and
135 regulations in China, these standards existed in name only (Fang, 2011; Jin and Young, 2001b). And the
136 industrial and domestic sewage quality changed dramatically, toxic and harmful organic pollutant
137 species increased continuously (Weber et al., 2006). Only current water quality indicator standards
138 could not meet to the requirement of sewage irrigation, has the Chinese government come to realize the
139 hazards of sewage irrigation for agricultural production (Liu et al., 2005; Shi et al., 2006). A file of work
140 arrangement based on soil environmental protection and comprehensive adjustment in later period was
141 finally reported by General Office of the State Council in 2013. That was the first time for authority to
142 express explicitly prohibition of using wastewater containing heavy metals, refractory organic pollutants
143 and sludge, dredging of sediment, tailings that were untested or safety disposal for agricultural
144 production. Unfortunately, the relevant standards or guidelines of wastewater irrigation applied to new
145 conditions have been slow to appear due to various economic benefits.

146

147 **3. Influence of sewage irrigation on soil properties**

148  is not merely the base supporting plant growth and breeding, but also the foundation of human
149 agricultural production (Killham, 1994; Molles, 2008). All kinds of human agricultural production
150 activities conduct in soil and abundant agricultural products acquire directly or indirectly from soil. Soil
151 is located in the interface of atmosphere, lithosphere, hydrosphere, and biosphere, participating a variety

152 of processes involved physics, chemistry, biochemistry and becoming the crucial place of material
153 circulation and energy exchange (Huang, 2000; Killham, 1994). Its existence provides a relatively stable
154 survival and procreation environment for aboveground vegetation and underground microorganism (Li
155 et al., 2000).

156 In China  peasants always use untreated sewage for farmland irrigation in agricultural production
157 directly. For substances dissolved in sewage, there are mainly four approaches of transference after
158 migrating into the soil (Wang and Lin, 2003; Zeng and Zhu, 2004). Some would gradually be reduced
159 by soil self-purification; some would be adsorbed and retained in the soil layer; some could be absorbed
160 by crops and the rest would enter aquifers along with water infiltration (Keesstra et al., 2012; Qadir et
161 al., 2010). Although soil has a certain capability of clearance and degradation of pollutants via
162 metabolism and transformation, increasing some nutritive element contents and enriching soil,
163 long-term irrigation by sewage which does not conform water quality standards induces organic
164 pollutants, heavy metals, solid suspended particles and bacteria microbes into the soil easily
165 (Fatta-Kassinos et al., 2011; Meng et al., 2016; Rusan et al., 2007; Zeng et al., 2007). Furthermore, the
166 worse thing is that these contents have been far beyond the ability of soil self-purification, causing
167 serious soil pollution and giving rise to some changes of soil physical, chemical and biological
168 characteristics.

169

170 **3.1 Effect on soil physical characteristics**

171 Long-term sewage irrigation upsets the balance of nature, causing ecological deterioration of
172 farmland (Wiel-Shafran et al., 2006). For the effects of sewage irrigation on soil physical properties, the
173 most direct performance is structural damage, functional disturbance and soil hardening (Wang and Lin,
174 2003). Soil bulk density is one of the important indicators measuring soil physical properties. It reflects
175 the degree of compaction to a certain extent, which has a great influence on soil aeration, soil

176 water-holding quantity and absorption capacity, infiltration, soil erosion resistance ability and solute
177 migration (Huang, 2000). The porosity of soil is subjected to changes in soil density (Neves et al., 2003).
178 A study on the consecutive irrigation in calcareous soil of China showed that long-term sewage
179 irrigation changed soil structure significantly (Li, 2001). Soil porosity and bulk density had a close
180 correlation with sewage irrigation time. As time goes on, the soil porosity decreased while the bulk
181 density increased. Furthermore, irrigation by effluents containing high salinity made soil secondary
182 salinization easily and enhanced total alkalinity and sodium alkalinity sharply, causing soil hardening
183 and soil permeability decrease (Li et al., 2003; Li et al., 2006). There are also reported that some organic
184 matter, microorganism, fibers and sediments from sewage deposited in the soil surface exerted an
185 negative impacts on soil physical traits, which would result in soil permeability degradation and soil
186 compaction occurrence (Siebe and Fischer, 1996).

187 The most conspicuous phenomenon of soil hardening is soil resistance to penetration, which is an
188 important index measuring crop roots elongation resistance (Barber, 1994; Mullins et al., 1994).
189 Generally, it is related to soil aggregate characteristics and soil particular spatial arrangement (Ahmed et
190 al., 1987; Franzluebbers et al., 2000). A study in Weihe River irrigation area by Hu found that the
191 topsoil of farmland within 10 cm irrigated by sewage directly was loose and resistance to penetration
192 was less than 500 kPa in this layer, which did not affect the crop root growth (Hu, 2010). However, the
193 value of resistance to penetration could be raised drastically with increase in soil depth, ranging from
194 415 kPa in 10cm to 1473 kPa in 45cm (Hu, 2010). Higher compaction in the deep soil layer shed a light
195 that there existed a thinning trend of unconsolidated for topsoil layer, which would compress thickness
196 of soil layer that was suitable for crop roots growth and increased the sensitivity of crop to
197 environmental changing. Problems like soil compactness cannot be neglected in future agricultural
198 production (Hernández et al., 2015).

199 Field capacity refers to the maximum amount of water maintained by soil without being affected by
200 the groundwater and becomes the upper limit of available moisture for vegetation (Daniel, 1980; Qin,

201 2003). It is controlled by soil structure and soil texture, playing a vital role in farmland water balance
202 controlling, irrigation and drainage, drought and moisture conservation (Shao et al., 2006). A research
203 reported that the field capacity of loam would be greater than that of sand in normal conditions (Jia and
204 Fan, 2007). When irrigated by sewage, the organic matter would be into the soil and increase the 
205 particles viscosity, thus increasing field capacity (Lan et al., 2010). Some similar research has confirmed
206 that irrigation adopting eutrophic or untreated aquaculture wastewater did increase soil particles
207 viscosity and enhanced field capacity (He, 2012; Wang and Lin, 2003).

208

209 **3.2 Impacts on soil chemical characteristics**

210 The ects of sewage irrigation on soil chemical properties are reflected in soil acidity-alkalinity
211 firstly, which is one of the important factors affecting soil fertility (Bao, 2000). The formation and
212 change of soil acidity-alkalinity depends on the relative strength of base substances leaching and
213 accumulation process (Dheri et al., 2007). And the degree of acidity or alkalinity can be most
214 conveniently expressed by pH value (Huang, 2000). Soil has a certain buffering function, thus the pH
215 level is relatively stable (Masto et al., 2009). Once the value varies drastically, the soil chemical
216 properties would be changed accordingly, which affects existing form, transformation and availability of
217 soil nutrients directly (Ma and Zhao, 2010). Soil pH changes are related to irrigation water types and
218 soil category (Wan et al., 2015). He et al.(2012) showed that the value of pH in soil would decrease with
219 the increase of irrigation times when using wastewater from pig farms to irrigate the yellow clay. While
220 an opposite conclusion was drawn that the value would increase if irrigated by effluents from
221 paper-making factories to moderately degraded saline-alkali soil (Xia et al., 2011). It is also found that
222 there was no obvious effect on vegetable field pH when sewage came from livestock breeding (Zhang et
223 al., 2011). The reason for fluctuation of pH could be explained by the different degrees of ammoniation
224 and nitrification of soil organic matter, anaerobic decomposition of organic matter, enrichment and
225 release of metal ions (Dheri et al., 2007; Rusan et al., 2007).

226 Organic matter is a significant component of soil and its content was usually be regarded as an
227 important index measuring soil fertility (Rattan et al., 2005). The accumulation of soil organic matter is
228 not only closed related to natural environment conditions, but also depends on the input of organic
229 matter by all means (Qin, 2003; Shao et al., 2006). Sewage irrigation could solve water shortage in
230 actual agricultural production and increase soil fertility as well, which is the comprehensive reflection
231 of water and fertilizer. But the amplitude of increase showed the significant of differentiation in
232 different regions (Xue, 2012). A paddy field irrigated by eutrophic sewage displayed that soil organic
233 matter contents of sandy soil and loam increased significantly, the value from loam increased by 97.1%
234 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
235 g/kg (Lan et al., 2010). Comparable differences also existed the degree of improvement in soil organic
236 matter with different soil layers. Extremely significant effects on soil organic matter were easily
237 discovered within 20 cm of topsoil, while the increase extent was significantly reduced with the
238 deepening of soil layers (Hu, 2010). Furthermore, more efforts in maintaining global carbon balance
239 have focus on the soil organic matter, which are considered as an irreplaceable role of affecting the
240 global warming in the worldwide. The accumulative effect of soil organic matter from sewage irrigation
241 has become one of inputs of soil organic carbon in farmland and participated in the global carbon
242 circulation (Rattan et al., 2005; Zhang et al., 2008b).

243 Nitrogen is an essential nutrient for crop growth, and the abundance and supply of nitrogen of soil
244 affects crop growth and development (Masto et al., 2009). A study of irrigation using agriculture
245 wastewater for a long time displayed that nitrogen accumulation in soil increased significantly and the
246 nitrogen content in soil for more than 12 years' irrigation was significantly greater than that of untreated
247 farmland (Zhang et al., 2011). There existed an obvious feature of eutrophication when farmland was
248 irrigated by sewage over a long period of time, alkali-hydrolysable nitrogen content increased
249 significantly in each soil layers, especially in the soil surface, its content could reach the level of 8.26
250 mg kg⁻¹, much higher than the average (Hu, 2010). In the meantime, the nitrogen accumulation of soil

251 profile was significantly affected by nitrogen mobility and irrigative infiltration (Wiel-Shafran et al.,
252 2006). The accumulation of NO_2^- and NO_3^- downward migration easily with water eluviation when
253 polluted water was adopted for irrigation, causing groundwater pollution in a shallow layer of water
254 (Zhang et al., 1996). Sewage irrigation had a lesser impact on NH_4^+ existing in deep soil and
255 groundwater, but for the NO_3^- concentration, great influence was emerged for long-term sewage
256 irrigated soil, causing groundwater pollution for deep soil layer easily (Liu and Lu, 2002).

257 Phosphorus is one of the three essential nutrients for plants. Not only it constitutes the components
258 of many important compounds in plants, but also participates in various plant metabolic processes by all
259 means (Dalai, 1977; Marschner et al., 2007; Redding et al., 2002). The study on farmland and forest
260 land found that the total phosphorus had significantly increased in the soil surface and most of them
261 could be kept in the topsoil within 40 cm when using pig farms' wastewater irrigation for a long-term
262 (Hu et al., 2010; Hu et al., 2012). Comparable concentrations were found in the farmland with piggery
263 wastewater irrigation that the phosphorus mainly accumulated in the plowing layer (0-40cm) and
264 increased with the increase of irrigation time (Yu, 2009). Redding et al (2005) discovered that the
265 available phosphorus and total phosphorus content were significantly higher than that of controlling
266 irrigated by piggery wastewater after anaerobic digestion and the phenomenon of excessive
267 accumulation of phosphorus appeared in the top soil layer within 5 cm.

268 Potassium is also a major nutrient in higher plants, which together with nitrogen and phosphorus are
269 known as three essential factors of plant nutrition. Among them, the available potassium refers to the
270 potassium what is easily absorbed by the plant and becomes the main diagnostic index of soil fertility
271 (Huang, 2000; Qin, 2003). After sewage irrigation, the soil available potassium content has increased
272 greatly, the foremost reason is that there contains a lot of nutrients in the sewage, making available
273 potassium enrichment in the soil surface (Hu, 2010; Mastro et al., 2009). The content of total potassium
274 in soil could be also improved for sewage irrigation, previous studies reported that the application of
275 alcohol wastewater has significantly increased the soil total potassium content, improving soil fertility

276 (Xu, 2007).

277 In general, heavy metals from sewage effluents could be adsorbed by soil particles and most heavy
278 metal ions are concentrated in the soil, resulting in soil heavy metal pollution, which has become
279 most serious problem for human health (Liu et al., 2005; Mapanda and Mangwayana, 2005; Wan et al.,
280 2015). According to the bulletin of soil pollution published by Chinese government in 2014, 39 of 55
281 surveyed areas irrigated sewage existed soil contamination. 26.4 percent of investigation soil points in
282 total exceeded the maximum permitted levels and the main pollutants were cadmium (Cd), arsenic (As)
283 and polycyclic aromatic hydrocarbons (PAHs). Some heavy metal types were same, but heavy metal
284 spatial distribution existed heterogeneity (Hu et al., 2006; Khan et al., 2008; Liu et al., 2005). A broad
285 distinction of vertical distribution of heavy metals could be discovered in soil profile and it had been
286 recognized for many years that heavy metals are mainly concentrated in the soil within 50cm and these
287 vertical distribution varied with soil texture (Cao, 2004). Heavy metal contents corresponded to the
288 lithology structure in soil vadose zone. The silt was not favorable for heavy metal accumulation, the
289 sandy soil took the second. The highest content was found in loam, becoming the main enrichment of
290 heavy metals in soil (Wang and Lin, 2003). Besides, the degree of heavy metals enrichment in soil was
291 also closely related to sewage irrigation time and concentration of heavy metal ions in sewage (Liu et al.,
292 2005; Rattan et al., 2005). Wang et al found that long-term excessive irrigation by exceeded standard
293 sewage would pose a threat to soil, copper (Cu), lead (Pb), zinc (Zn), cadmium, arsenic, mercury (Hg),
294 chromium (Cr) and other harmful substances had been serious exceeded the limits of soil capability.
295 Five heavy metals (Cd, Cr, Cu, Zn, Pb) increased gradually during sewage irrigation in the farming
296 areas of Beijing and Shenyang and some elements like Cd, Cu, Zn, and Pb were excessive accumulation
297 in soil (Sun et al., 2006; Wang et al., 2006). Ultimately, these heavy metals are dangerous to human
298 health through various food chains (Loska et al., 2004) .

299 Except for heavy metal pollution in soil, various degrees of organic pollutants were existed in some
300 sewage irrigation areas (Qadir et al., 2010). Organic pollutants, such as aromatic hydrocarbons, phenols,

301 organic chlorine are easily discovered in industrial wastewater (Tian et al., 1993). A research by
302 collecting seven different depths of soil samples irrigated by wastewater in Taiyuan, Shanxi Province
303 found that the constituent parts in sewage were diversified and extremely complicated, main pollutants
304 were plasticizer, such as the phthalate esters, skatol, sterols, polycyclic aromatic hydrocarbons and so on.
305 The most serious pollution came from polycyclic aromatic hydrocarbons in soil. These substances could
306 penetrate into the groundwater and relevant studies have documented in the nearby shallow
307 groundwater (Du et al., 2010). A survey involved Shenyang and Fushun sewage irrigation area, the
308 China's largest oil wastewater irrigated area, showed that the accumulation of toxic substances irrigated
309 by petrochemical industrial sewage was serious, among which the aromatic hydrocarbons were quite a
310 proportion, and carcinogens benzene severely exceeded (Zhang et al., 2003). The sensory indicators of
311 rice produced in this region are extremely poor with strong smell from oils and aromatic compounds
312 (Fang, 2011).

313

314 **3.3 Influence of soil microorganisms and enzyme activities**

315 Soil microorganisms, as an important part of maintaining soil quality, participate in most of soil
316 biological and biochemical activities and are sensitive to reflect some changes of soil quality health
317 (Stenberg, 1999). The composition and activities of soil microbe are dynamic processes with
318 environmental change and the number of microbial living cells is regarded as one of the most sensitive
319 biological indicators (Li et al., 2005a). Sewage irrigation would cause micro-environmental change to
320 some extent, having a great effect on soil microbial activities (Zhang et al., 2008b). Soil bacteria, fungi
321 and actinomycetes are the three essential types of microorganisms that can be used for reflecting the
322 total amount of soil microorganisms and playing a significant role of soil organic matter and inorganic
323 materials transformation (Aleem et al., 2003). The number of bacteria and actinomycetes in the soil
324 showed a descending trend after long-term sewage irrigation, while the number of fungi increased
325 slowly (Ge et al., 2009). Similar results in Shenyang and Fushun sewage irrigation region were found

326 that sewage irrigation changed the contents of soil nutrient and PAHs and then had a direct effect on the
327 microbial populations, among which total nitrogen had a high significant positive and significant
328 positive correlation with bacteria, nitrogen-fixing bacteria and phosphorus bacteria, respectively (Zhang
329 et al., 2007; Zhang et al., 2008a). In the meantime, adoption of sewage irrigation equipment also
330 affected the number of soil microorganisms (Heidarpour et al., 2007). A series of studies by Oron et al.
331 displayed that soil surface humidity affected the total number of soil bacteria under the circumstance of
332 sewage irrigation. When subsurface or underground drip irrigation was adopted, the total number of
333 bacteria by subsurface drip irrigation is much higher than that of the underground. The most likely
334 explanation would appear to be that soil played a role of secondary filter in the process of sewage
335 infiltration, reducing contact probability between sewage and aboveground vegetation part (Oron et al.,
336 1999; Oron et al., 1995).

337 Soil enzymes are the catch-all term of active substances found in the soil, primarily coming from the
338 soil microbes and plant root secretion and enzymes released by decomposition of animal and plant
339 residues (Burns and Dick, 2002; Cao et al., 2003). Common enzymes mainly include oxidoreductases,
340 hydrolytic enzymes, crack enzymes and transferase, all of which participate in and promote a large
341 proportion of organic substances transformation and material circulation by various of soil ecological
342 processes (Zhang et al., 2011). Some relevant research has produced evidence to suggest that irrigation
343 by petroleum wastewater could stimulate aerobic heterotrophic bacteria and fungi growth in soil, and
344 soil dehydrogenase, catalase, polyphenol oxidase activities showed a positive correlation with the total
345 petroleum hydrocarbon content, while soil urease activities had a significant negative correlation with
346 the total petroleum hydrocarbon content in soil (Li et al., 2005b). Other observations were found that
347 soil enzyme activities had been dually influenced by soil nutrient and PAHs pollution when irrigated by
348 petroleum processing wastewater for a long time. The soil organic carbon and total phosphorus contents
349 showed a significant relation with dehydrogenase, polyphenol oxidase and urease activities respectively,
350 the content of PAHs were significant positive correlated to dehydrogenase and urease activities

351 respectively, while it was significantly positively related to polyphenol oxidase activities (Zhang et al.,
352 2007; Zhang et al., 2008a). Similar studied of the relationship between soil heavy metal pollution by Pb
353 and Cd and the soil enzyme activities in a heavy industry city of Baoding, Hebei Province had also
354 proven that soil urease and hydrogen peroxide enzyme activities increased with the increase of Pb and
355 Cd in soil (Liu, 1996). There were problems with many studies concerning indirect influence caused by
356 sewage irrigation such that soil secondary salinization in calcareous drab soil, leading to enzyme
357 activities constrained, causing soil environment quality decline (Li, 2001).

358

359 **4 Implications for sewage irrigation development in the future**

360 For the current development of sewage irrigation in China, government officials must clearly realize
361 that wastewater discharge itself is a guarantee of water scarcity for grain production and huge
362 population demands for food security in China. On the other hand, we have to face the adverse effects
363 brought by the sewage irrigation and find solutions instead of complaints. However, any research and
364 development involve sewage irrigation need to consider the actual situation in China carefully. Four
365 proposals have been made for achieving safe and efficient utilization of wastewater irrigation in
366 farmland of China.

367 **4.1 Strict control of pollution sources and reasonable management system**

368 At present, the first question for sewage irrigation in China is to solve the quality problem gradually. 
369 Starting from the sewage sources, water quality monitoring should be strengthened and water quality of
370 wastewater entering the farmland should be strictly controlled (Engineering, 2000; Qadir et al., 2010;
371 Yang, 2000). Excessive contaminated water is forbidden for discharging and utilization. In addition, in
372 the view of the current situation that governors always adopt an attitude towards removing supervision
373 responsibility and administration of sewage in practice, so scientific management system of sewage
374 irrigation should be established and implemented urgently, realizing explicit responsibility and
375 embodiment in different stages of sewage discharge, disposal and irrigation (Shi et al., 2014; Zeng and

376 Zhu, 2004). For companies and individuals in the wastewater irrigation areas, awareness of
377 environmental protection should be increased. For those enterprises that have illegal discharges sewage
378 behaviors, the amounts of punishment need to be much greater than its illegal profit. For individual, the
379 health risks of sewage irrigation should be extensively published, enhancing awareness of
380 environmental and human health (Rattan et al., 2005; Wan et al., 2015).

381 **4.2 Optimization mode of sewage irrigation and avoiding irrigation by single type sewage for a** 382 **long time**

383 China has summarized some effective methods for sewage irrigation techniques through several
384 decades of practice, which including oxidation pond purifying wastewater treatment and mixed
385 irrigation between wastewater and clear water (Hong et al., 2011). However, the flood irrigation mode is
386 the most common adopted in the vast area of sewage irrigation. It , on the one hand, wastes a lot of
387 valuable sewage resources, and on the other hand causes serious soil pollution (Zhang et al., 2005).
388 Therefore the current model of sewage irrigation should be changed and optimized, combining
389 agricultural water-saving irrigation with sewage pretreatment and developing aerated drip sewage
390 irrigation. Considering different crop growth stages, edible parts and contaminants in wastewater
391 irrigation, sewage irrigation time and quantity need to be allocated reasonably, reducing the adverse
392 effects of sewage irrigation on crop growth and human health (Oron et al., 1999; Oron et al., 1995).

393 **4.3 Conducting sewage irrigation adjusted measures to local conditions and protecting** 394 **groundwater resources**

395 Because of unmatched irrigation facilities, improper irrigation methods, unscientific irrigation
396 systems and low management level, there existed some problems that field irrigation efficiency was low
397 and percolation towards deep soil layer was serious (Liu and Xu, 2002). Improper use of sewage
398 irrigation equipment or irrigation by untreated sewage easily gave rise to pollutants infiltration in soil,
399 endangering security of drinking water and even forming inverse funnel of sewage, which would pose a
400 threat to deep unground water. Once groundwater is contaminated, it will be difficult to recover, and the

401 consequences will be severe. It seems reasonable to assume that it is not suitable for sewage irrigation
402 for some inadaptable wastewater irrigation areas such as strong soil permeability, high underground
403 water level, aquifer outcrop and centralized drinking water sources, which easily lead to groundwater
404 pollution and be unfavorable to our human health (Qadir et al., 2010; Zhou, 2002). Therefore,
405 developing corresponding scheme in line with local conditions was an appropriate measure to reduce
406 the environmental risks caused by sewage irrigation.

407 **4.4 Adsorption and degradation of soil harmful substances by preferential absorption from plant** 408 **and microbe**

409 In the remedy technology of heavy metal contaminated soil, phytoremediation is highly favored for
410 its advantages such as excellent reinforced effect, low cost and high environmental benefit (Nie et al.,
411 2016). At the same time, microorganisms could either fix heavy metal ions through their metabolic
412 functions or convert toxic heavy metal ions into non-toxic or low-toxic prices (Li et al., 2015).
413 Hyperaccumulators could be introduced to repair contaminated soil by adopting their own strong
414 absorption abilities for some heavy metals and anti-heavy metal toxicity. Furthermore, the function of
415 microbial selective absorption was jointly utilized to establish the system of bioremediation, improving
416 the remediation efficiency of heavy metal pollution (Rajkumar et al., 2010).

417 **5. Conclusion**

418 The biggest challenge now facing the Chinese government is how to meet the soaring water demand
419 of its expending urban and industrial portions without decreasing its own agriculture needs. In
420 consideration of world food security, sewage irrigation on a mass scale indeed is an alternative way for
421 water scarcity in some areas of China. However, the effects of inappropriate sewage irrigation on soil
422 physical, chemical and biological characteristics of farmland should be paid attention to in practice.
423 Some relevant matched irrigation facilities, proper irrigation methods, scientific irrigation systems from
424 agriculture and water resources departments and high sewage management level together with clear
425 reward and punishment from government are worthy of been put forward, popularized and applied in

426 line with local conditions, promoting reclamation and high efficiency of effluents in China.

427

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431

432 **References**

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