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REUSE OF TREATED MUNICIPAL WASTEWATERS FOR IRRIGATION

Application of wastewaters to formlands has gained public acceptance with an aim for recycle and reuse of nutrients and organics contained in the wastewaters. This paper reports and discusses the use of treated municipal wastewaters for irrigation. The pretreatment system for wastewaters used in irrigation consisted of settling tanks, storage ponds, and irrigation ditches. Purification of wastewaters was reported using rice fields, lotus ponds, and aquatic plants with high removal efficiency of organic pollutants, ammonia, roundworm eggs, and bacteria. The problems associated with wastewater irrigation included surface and ground water pollution, increase in heavy metal concentration in crops, and salinity buildup in soils.

1. INTRODUCTION

Disposal of municipal wastewaters is a problem of increasing importance throughout the world. Application of wastes, including wastewasters to farmland with an aim for recycle and reuse of nutrients and organics present in the wastewasters, is gradually gaining public acceptance. Nutrients in the wastewaters can be utilized for raising crops and in some dry areas the water can reduce the soil water deficit that limits production.

Irrigation with low nutrient content wastewaters, especially municipal effluents, has been studied for various crops and under different climatic conditions [1] – [4] . Municipal wastewaters can pose problems when added to water systems, because they are frequently rich in nutrients and have a high oxygen demand due to the presence of soluble and suspended organic matter. The need to conserve and reuse water makes it mandatory that these wastewaters be utilized on potential cropland or by industry. However, depending on their industrial wastewater contributions, municipal wastewaters may contain high concentrations of heavy metals [5], [6]. Reported evidence has focused attention on such potential hazards as soil contamination, excessive concentration of heavy metals in food and feed crops, and deleterious effects on crop yields arising from the use of these wastewaters [7], [8]. This study was designed to report and to discuss the use of treated municipal wastewaters for irrigation in China.

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2. METHODS AND DISCUSSION

2.1. PRETREATMENT METHODS OF WASTEWATERS FOR IRRIGATION

There were different kinds of bacteria, parasite eggs, and polluting materials in municipal wastewaters. If they were used for irrigation without a certain degree of treatment, they definitely would cause some adverse effects. The water quality standard for municipal wastewater used for irrigation in China is shown in tab. 1, which lists maximum allowable levels of various quality parameters such as pH, suspended solids, and phenols [9]. To meet the water quality standard, wastewater has to be pretreated using physical and biological treatment methods such as settling tank, wastewater storage pond, and irrigation ditch.

Table 1
Water quality standard for municipal wastewater used for irrigation

Parameter	Maximum allowable level	Parameter	Maximum allowable level
pH	5.5–8.5	Pb	0.1
Water temperature	35°C	As	0.2
Suspended solids	300	Sulfides	5
Salts	800–1000	Cyanides	0.1
Chlorides	300	Cr	0.1
Phenols	5	Hg	0.005
Oil & grease	20–30	Cd	0.1
Total solids	1500		

Note: All units are in mg/dm^3 except pH (in pH unit) and water temperature (in °C).

The treatment performance of the settling tank of municipal wastewater treatment plants is summarized in tab. 2 [10]. Wastewaters were allowed to settle for 2.5 to 5 h in the tank before irrigating to the farmland. It was found that after the settling tank treatment the total solids, COD (chemical oxygen demand), roundworm eggs, and total bacteria cound in the water were removed in the range from 48 to 76%, 31 to 43%, 88 to 97%, and 33 to 71%, respectively. However, the level of nutrient in the treated wastewater remained relatively constant.

Wastewater storage ponds appeared to be quite effective in purification of municipal wastewaters for irrigation purposes. In the northeastern part of China the wastewater storage ponds also served as oxidation ponds. During the warm seasons the ponds have good treatment performance. During the cold winter, even if the pond water was frozen, the anaerobic degradation process would be operating and could still be helpful in purifying the wastewater. It has been reported that the removal efficiency of COD, BOD (biochemical oxygen demand), phenols, cyanides, suspended solids, and total bacteria count from the wastewater reached 59%, 50%, 50%, 50%, 76%, and 80%, respectively, using the storage pond treatment method [11].

Table 2

Treatment performance of the settling tank of municipal wastewater treatment plant

Sample No.	Flow rate dm^3/s	Flow velocity mm/s	Detention time h	pH		Total solids		
				Infl	Effl.	Infl. mg/dm^3	Effl. mg/dm^3	% Removal
1	33.7	1.84	3.5	6.9	6.9	–	–	–
2	23.5	1.28	5.1	5.9	6.1	758	330	56
3	30.4	1.65	3.96	6.0	6.0	582	310	46.7
4	48.9	2.66	2.46	6.1	6.1	810	380	53.1
5	31.8	1.73	3.78	6.1	6.3	1444	354	75.5

Sample No.	Oxygen consumption			Roundworm eggs			Total bacteria count 10^6 cell/cm^3		
	Infl. mg/dm^3	Effl. mg/dm^3	% Removal	Infl. egg/dm^3	Effl. egg/dm^3	% Removal	Infl.	Effl.	% Removal
1	25.5	15.8	38.0	3072	96	96.9	5.4	3.6	33.3
2	27.3	18.9	30.8	2240	120	94.6	0.68	0.24	64.7
3	35.2	20.0	43.2	1720	208	87.9	4.76	1.84	61.3
4	46.0	30.9	32.8	720	48	93.3	3.98	1.14	71.4
5	49.8	32.5	34.7	406	16	96.1	13.7	9.0	34.3

The performance of the irrigation ditch for wastewater pretreatment was also studied. It was found that in a ditch of 6 km in length, with discharge of 0.4 m^3/s, and flow velocity of 0.56 m/s, removal of phenols and sulfides through natural oxidation process amounted to ca. 40%, whereas that of the suspended solids, to 46% [11]. However, the contents of *E. coli* and pathogens in the wastewater had remained unchanged during the irrigation ditch treatment.

2.2. PURIFICATION OF WASTEWATER THROUGH IRRIGATION

Ways of purifying municipal wastewaters by rice field, lotus pond, and aquatic plants are listed below.

1. Purification of wastewater by rice field. The municipal wastewater pretreated in settling tank (detention time: 2.46 to 5.1 h) was supplied to the rice field for a period of 2 to 4 days. Table 3 [10] shows the performance of rice field in municipal wastewater purification. The contents of BOD, NH_3–N, TKN (total Kjeldahl nitrogen), and bacteria count in the wastewater were drastically reduced. After 2 days of irrigation treatment, 98% of NH_3–N, 88.4% of TKN, 78.6% of BOD, 96.6% of roundworm eggs, and 98.3% of bacteria were removed from wastewaters.

2. Purification of wastewater by lotus pond. Table 4 [12] shows the purification performance of lotus pond for municipal wastewater treatment. It was noted that after 3.6 days of lotus pond treatment, BOD, bacteria count, and *E. coli* were removed at removal efficiency of 86%, 78%, and 95%, respectively. After 8.7 days of treatment, the removal efficiency of NH_3–N, BOD, bacteria, and *E. coli* from wastewaters had reached 88%, 95%, 99%, and 100%, respectively.

Table 3

Purification performance of rice field for municipal wastewater treatment

Parameter	Before irrig.	2 days after irrig.		4 days after irrig.	
	Value	Value	% Removal	Value	% Removal
Total solids mg/dm^3	659	253	61.6	112	83.0
TKN mg/dm^3	13.14	1.52	88.4	1.42	89.2
Ammonia mg/dm^3	10.86	0.22	98.0	0.10	99.1
BOD mg/dm^3	18.76	4.02	78.6	3.0	84.0
Dissolved oxygen mg/dm^3	2.07	4.8	0	6.64	0
pH	7.5	7.2	–	7.0	–
Roundworm eggs egg/dm^3	1664	56	96.6	–	–
Total bacteria count 10^6 $cell/cm^3$	11.54	0.193	98.3	–	–

Table 4

Purification performance of lotus pond for municipal wastewater treatment

Parameter	Detention time day			
	0.71	3.6	6.0	8.7
Hydraulic loading $m^3/ha \cdot day$	1300	261	155	106
BOD loading $kg/ha \cdot day$	2420	480	290	198
NH_3–N				
Influent (mg/dm^3)	31.5	31.5	31.5	31.5
Effluent (mg/dm^3)	33.0	30.4	16.4	3.8
% Removal	0	3.5	47.9	87.9
BOD				
Influent (mg/dm^3)	186	186	186	186
Effluent (mg/dm^3)	38.1	26.1	12.4	9.0
% Removal	79.5	86.0	93.3	95.2
% Removal of total bacteria count	56.7	78.4	98.2	99.1
% Removal of *E. coli*	83	95.4	97.4	100

3. Purification of wastewater by aquatic plants. The municipal wastewater was firstly treated in settling tanks, then introduced into the field of aquatic plants. The performance of aquatic plants in purification of pretreated wastewater is listed in tab. 5 [13]. It was found that the Chinese aquatic plants, jiaobai and chigu, removed BOD and NH_3–N from wastewaters with the respective efficiencies exceeding 50% and 82%. Under conditions of lower temperature, wet season, and shorter detention time, the performance of aquatic plants in wastewater purification was less effective.

Table 5

Purification of settled wastewater effluent by aquatic plants

Parameter	Plant jiaobai			Plant chigu		
	Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
Water temp. (^oC)	27.3	25.5	20.5	37.3	25.5	20.5
Irrig. rate (m^3/h)	223.6	248	145	187.2	216	87.1
Water depth (cm)	13.8	15	14.2	5.65	5.02	6
Detention time (day)	6.26	6.5	10.6	2.97	2.35	7.08
BOD						
Influent (mg/dm^3)	150.8	150	188.4	149.9	138.5	181
Effluent (mg/dm^3)	19.7	17.8	16.8	21.8	25	18.12
% Removal	86.9	88.1	91.1	85.5	81.9	90.0
NH_3–N						
Influent (mg/dm^3)	33.8	46.6	66.5	35.4	45.7	56.0
Effluent (mg/dm^3)	12.2	23.2	24.7	17.6	25	21
% Removal	63.9	50.2	62.9	50.3	45.3	62.5

2.3. PROBLEMS ASSOCIATED WITH WASTEWATER IRRIGATION

1. Pollution of surface water by wastewater irrigation. Municipal wastewaters were pretreated in settling tank and oxidation tank, were used for irrigation in the rice field. The same water was then discharged to the creeks. Water samples collected from the creeks were analyzed for both control zone and wastewater irrigated zone. Table 6 [13] shows the pollution of surface water

Table 6

Pollution of surface water by wastewater irrigation

Parameter	pH	Chlorides mg/dm^3	Dissolved oxygen mg/dm^3	Oxygen consumption mg/dm^3	BOD mg/dm^3	NH_3–N mg/dm^3	Nitrite mg/dm^3	Total bacteria count 10^4 cell/cm^3
Wastewater irrigation zone (avg. of 6 districts)	7.43	69.7	0.99	11.85	3.77	1.06	0.053	0.36
Control zone (avg. of 2 districts)	7.49	62.5	1.29	10.9	2.93	0.1	0.005	0.186

by irrigation of treated wastewater. It is noted that the levels of NH_3–N and nitrite increased about 10 times; BOD, total bacteria count, COD, and chlorides in the wastewater irrigated zone increased by 29%, 94%, 9%, and 12%, respectively, compared to those of the control zone.

2. Pollution of ground water. Table 7 [14] shows the pollution of shallow well water by wastewater irrigation. Well 4, the control well, was 300 m away from the wastewater irrigation ditch. Wells 1, 2, and 3 were 45 m, 55 m, and 120 m away from the ditch. It is noted that the contents of chlorides, nitrate, as well as total hardness in water from the wells 1 and 2 were much higher than those in well 4, suggesting that ground water pollution has to some extent resulted from wastewater irrigation. The contents of chlorides and nitrates, as well as the hardness in well 1 were higher by 37%, 33%, 8%, and 68%, when compared with those in the control well. There was a little change in oxygen consumption indicating that organic pollutants may be removed by microorganisms present in well water.

Table 7

Pollution of shallow well by wastewater irrigation

Parameter	Well 1	Well 2	Well 3	Well 4 (control well)
Distance from wastewater irrig. ditch (m)	45	55	120	300
pH	7.5	7.3	7.5	7.5
Total hardness (CaO)	40.7	42.4	30.8	24.2
Chlorides (mg/dm^3)	254	230	165	185
Oxygen consumption (mg/dm^3)	1.60	1.80	1.47	1.58
Nitrate (mg/dm^3)	250	211	161	57

3. Effects of wastewater irrigation on crops. Contents of arsenic and chromium in crops, i.e., rice, wheat, potato, cabbage, tomato, etc., were determined. Results indicated that the AS level has increased by about 2 times, from 0.02 to 1.0 mg per kg of vegetable, and Cr level has increased by nearly 4 times, from 110 to 260 mg per kg of vegetable, when the crop land was irrigated by wastewaters [13]. The effect of wastewater irrigation on farm crops was also investigated in terms of the parasite egg. It was found that the number of parasite eggs was closely related to the detention time of wastewater irrigation. For example, in one case study, the number of parasite eggs was 20 eggs per 100 g of vegetable before wastewater irrigation. One day after wastewater irrigation, the number of parasite eggs drastically increased to 50 eggs per 100 g of vegetable, then gradually decreased to 40–20 eggs after 7 to 21 days of wastewater irrigation.

4. Effects of wastewater irrigation on soil. Wastewaters usually have high content of dissolved salts. If they were used for irrigation, they could affect composition of the soil. In one area, one year after wastewater irrigation, the white looking salts started to appear in the soil. The salt content in the soil reached 300 to 1200 mg/dm^3. In other areas, because of salt excess being deposited in the soil, which resulted from wastewater irrigation, the productivity of rice was significantly reduced.

3. CONCLUSIONS

1. In China, the wastewaters used for irrigation should be pretreated using physical and biological treatment methods such as settling tanks, wastewater storage ponds, and irrigation ditches.

2. Wastewater storage pond removed 59% of COD, 50% of BOD, 76% of suspended solids, and 80% of total bacteria from municipal wastewaters.

3. Rice fields irrigated with pretreated municipal wastewaters removed 98% of NH_3–N, 78.6% of BOD, 96.6% of roundworm eggs, and 98.3% of bacteria from wastewater. Lotus ponds removed 86% of BOD, 78% of bacteria, and 95% of *E. coli*. Fields of aquatic plants removed 50% of NH_3–N and 82% of BOD.

4. Problems associated with wastewater irrigation included surface and ground water pollution, increase in heavy metal concentration in crops, and salinity buildup in soil.

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WYKORZYSTANIE OCZYSZCZONYCH ŚCIEKÓW KOMUNALNYCH DO NAWADNIANIA

Zastosowanie ścieków do upraw zyskało akceptację społeczną. Ścieki użyte w tym celu są recyrkulowane, a zawarte w nich składniki odżywcze i organiczne wykorzystywane przez rośliny. Artykuł opisuje zastosowanie oczyszczonych ścieków do nawadniania. Układ wstępnego oczyszczania ścieków użytych do irygacji składa się z osadników, zbiorników i rowów irygacyjnych. Oczyszczanie wody odbywa się na polach ryżowych, w stawach lotosowych i uprawach roślin wodnych, które mają zdolność efektywnego usuwania zanieczyszczeń organicznych, amoniaku, jaj glist i bakterii. Problemy związane z nawadnianiem ściekami obejmują skażenia wód powierzchniowych i gruntowych, zwiększenie stężenia metali ciężkich w plonach oraz wzrastające zasolenie gleb.

ИСПОЛЬЗОВАНИЕ ОЧИЩЕННЫХ КОММУНАЛЬНЫХ СТОЧНЫХ ВОД ДЛЯ ИРРИГАЦИИ

Применение сточных вод для культур получило общественную акцептацию. Употребленные для этого сточные воды являются рециркулированными, а содержащиеся в них питательные и органические составные элементы используются растениями. Настоящая статья описывает применение очищенных сточных вод для орошения. Система предварительной очистки сточных вод, употребленных для ирригации, состоит из отстойников, вместилищ и ирригационных канав. Очистка воды происходит на рисовых полях, лотосных прудах и культурах гидрофитов, которые способны эффективно удалять органические загрязнения, аммиак, яйца аскаридов и микробы. Проблемы, связанные с орошением сточными водами, охватывают заражение поверхностных и грунтовых вод, повышение концентрации тяжелых металлов в плодах, а также повышающуюся засоленность почвы.