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Post-irrigation impact of domestic sewage effluent on composition of soils, crops and ground water—A case study

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Abstract

Long-term irrigation with sewage water adds large amounts of carbon, major and micro- nutrients to the soil. We compared the spatial distribution of N, P, K and other micronutrients and toxic elements in the top 0.6 m of an alluvial soil along with their associated effects on the composition of crops and ground waters after about three decades of irrigation with domestic sewage effluent as a function of distance from the disposal point. Use of sewage for irrigation in various proportions improved the organic matter to 1.24–1.78% and fertility status of soils especially down to a distance of 1 km along the disposal channel. Build up in total N was up to 2908 kg ha^{-1}, available P (58 kg ha^{-1}), total P (2115 kg ha^{-1}), available K (305 kg ha^{-1}) and total K (4712 kg ha^{-1}) in surface 0.15 m soil. Vertical distribution of these parameters also varied, with most accumulations occurring in surface 0.3 m. Traces of NO_3–N (up to 2.8 mg l^{-1}), Pb (up to 0.35 mg l^{-1}) and Mn (up to 0.23 mg l^{-1}) could also be observed in well waters near the disposal point thus indicating initiation of ground water contamination. However, the contents of heavy metals in crops sampled from the area were below the permissible critical levels. Though the study confirms that the domestic sewage can effectively increase water resource for irrigation but there is a need for continuous monitoring of the concentrations of potentially toxic elements in soil, plants and ground water.

Keywords: Sewage irrigation; Soil contamination; Long-term impacts; Ground water contamination; Plant composition

1. Introduction

Changing scenario with the economic development of the society towards large-scale urbanization and industrialization is leading to production of huge quantities of effluent in India. Industrial and domestic effluents are either used or disposed off on land for irrigation purposes that create both opportunities and problems.

Opportunities exist as sewage effluents from municipal origin are rich in organic matter and also contain appreciable amounts of major and micronutrients (Feign et al., 1991; Pescod, 1992; Gupta et al., 1998; Brar et al., 2000). Accordingly nutrient levels of soils are expected to improve considerably with continuous irrigation with sewage (Baddesha et al., 1986; Narwal et al., 1993; Brar et al., 2000). Again sewage effluents may contain variable amounts of heavy metals, which may limit the long-term use of effluent for agricultural purposes as a likelihood of phytotoxicity and environmental effects. In fact, the long-term impact of irrigation with poor quality waters on physico-chemical properties of soils has been reported to depend upon the interaction of several factors like the unique water quality limiting parameters and site-specific crop, soil and climatic conditions (Minhas and Gupta, 1992). Nevertheless, the opportunities for sewage availability usually decline with distance from the disposal site, such spatial effects of sewage use on soils and ground water have rarely been reported. Therefore, we attempted to monitor changes in soil properties and composition of winter crops and ground water at different distances from a disposal site for domestic sewage in Kurukshetra district.

2. Method and materials

To evaluate the impact of domestic sewage on soils and plants, a non-industrial town of Haryana, namely, Kurukshetra (76.4°N longitude and 29.6°E latitude), was

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selected. Collection of sewage and its disposal from areas falling under Urban Estate of Kurukshetra is under the administrative control of the Public Health Department. A pumping station is located in the southwest part near the village Narkatari. The sewage is discharged into a lined channel that carries this water for a distance of about 3 km and ultimately joins a larger channel of the Saraswati river. Farmers owning land along this channel are making use of this sewage for irrigation purposes and the process is going on since about 30 years. Soils of the area are fine loamy mixed hyperthermic typic *Ustocrepts*. Soil samples from fields irrigated with sewage were collected from six locations at a depth interval of 0.15 m down to 0.6 m. These sampling sites (1 to 6) existed at a distance of 50, 250, 500, 1000, 2000 and 2000 m along the disposal drain and 25, 50, 500, 75, 100 m north and 125 m south of the channel, respectively. Water samples were also collected from the sewage disposal site (SW) and five tubewells (TW_1-TW_5) existing at a distance of 250, 500, 750, 1000 and 1000 m along the channel and 250, 250, 500, 500 m north and 600 m south of the channel, respectively. After collection, the sewage effluents and groundwater were stored in neutral plastic bottles. Several parameters were measured separately, pH and EC, by the procedure described by USSL (1954), DO, BOD, COD, TSS, cations—Ca^{2+} and Mg^{2+}, Na^+, K^+ anions—Cl^- and NO_3^-, and NH_4–N and P as per the method given by APHA (1992). Micronutrients and heavy metals like Fe, Cu, Mn, Zn, Pb, Cd and Ni were estimated after wet digestion with 1:4 mixture of $HClO_4$ and HNO_3, followed by measurement of respective concentrations with the help of atomic absorption spectrophotometer. Physicochemical properties of soils were determined by standard methods as described in Page et al. (1982). Total N was determined by Kjeldahl method. Total P was estimated after acid digestion of soil followed by spectrophotometric method, while total K was determined after HCl, $HClO_4$, and HNO_3 digestion followed by flame photometry. All the metallic concentrations in solution phase were determined by using atomic absorption spectrophotometer (AAS). Extractable metals were determined by AAS using DTPA as single extractant (Lindsay and Norvell, 1978). Plant samples of crops grown under sewage irrigated and non-sewage irrigated conditions were also collected from the soil sampling sites. After processing, these samples were digested with $HClO_4$–HNO_3–HCl acid mixture for determination of heavy metals with AAS.

Table 1
Characteristics of sewage (SW) and tubewell (TW^a) waters

Parameters	Units	SW	TW_1	TW_2	TW_3	TW_4	TW_5
PH		7.4	7.6	8.4	7.7	7.2	7.3
EC	($dS\ m^{-1}$)	1.74	1.02	1.01	1.12	1.02	1.46
TDS	($mg\ l^{-1}$)	900	1100	1300	560	510	700
DO	($mg\ l^{-1}$)	4	7.4	7.1	8	7.7	6.1
BOD	($mg\ l^{-1}$)	169	12	3	7	5	3
COD	($mg\ l^{-1}$)	382	ND	6.7	6.7	ND	ND
Na	($me\ l^{-1}$)	2.9	4.5	8.7	0.9	0.7	1.7
K	($me\ l^{-1}$)	0.6	0.1	0.3	1.1	0.3	0.2
Ca + Mg	($me\ l^{-1}$)	7.4	1.8	4.3	5	3.1	3
Cl	($me\ l^{-1}$)	2	3.8	4.8	0.6	0.6	1.2
CO_3	($me\ l^{-1}$)	2	ND	1.4	ND	ND	ND
HCO_3	($me\ l^{-1}$)	8.8	7.2	9.2	8.2	6	6.2
PO_4–P	($mg\ l^{-1}$)	26	1.0	ND	ND	ND	ND
NH_4–N	($mg\ l^{-1}$)	3.5	1.4	2.45	ND	ND	ND
NO_3–N	($mg\ l^{-1}$)	28	ND	1.05	1.4	2.8	2.4
Zn	($mg\ l^{-1}$)	0.07	0.04	ND	0.02	0.02	0.04
Fe	($mg\ l^{-1}$)	0.23	0.02	0.08	0.03	ND	0.05
Mn	($mg\ l^{-1}$)	0.66	ND	ND	0.12	ND	0.23
Cu	($mg\ l^{-1}$)	0.08	0.01	0.01	0.01	ND	ND
Cd	($mg\ l^{-1}$)	0.02	ND	ND	ND	0.02	ND
Pb	($mg\ l^{-1}$)	0.19	0.25	0.05	0.18	0.22	0.35
Ni	($mg\ l^{-1}$)	0.12	0.03	ND	0.07	ND	0.04
RSC	($me\ l^{-1}$)	3.4	5.4	6.3	3.2	2.9	3.2
SAR		1.5	4.74	5.93	0.57	0.56	1.39

ND—Not detected.

[a] TW_1, TW_2, TW_3, TW_4 and TW_5 exist at distances of about 250, 500, 750, 1000 and 1000 m along the channel and about 250, 250, 500, 500 and 600 m longitudinal to the sewage channel.

3. Results and discussion

3.1. Quality of sewage effluent and ground water

The quality of sewage and well waters was assessed for irrigation with respect to their pH, EC, BOD, contents of Na^+, Ca^{2+}, Mg^{2+} and some of the heavy metals (Table 1). All the waters were alkaline in reaction. The pH of the sewage water (7.4) was lower than the ground water as collected from different tube wells in the nearby area (7.3–8.4) while its salt content (EC 1.74 $dS\ m^{-1}$) was considerably higher than those of well waters (1.01–1.46 $dS\ m^{-1}$). As expected, the dissolved oxygen (DO) was monitored to be the minimum in sewage water (4 $mg\ l^{-1}$) whereas it ranged between 6.1 and 8 $mg\ l^{-1}$ in ground water samples. The effect of DO was reflected on BOD of the samples. Its value was quite high in raw sewage water (169 $mg\ l^{-1}$), whereas it ranged between 3 and 12 $mg\ l^{-1}$ in ground water. Raw sewage water showed very high COD value (382 $mg\ l^{-1}$) while it was nil in three of the ground water samples and two samples showed only negligible amount of COD ($\sim$ 7 $mg\ l^{-1}$). On the basis of BOD and COD, the raw sewage water was rated as unsuitable for irrigation purposes when compared with the prescribed limits of 100 and 250 $mg\ l^{-1}$ for BOD and COD, respectively.

The concentration of almost all the nutrient elements tended to be higher in sewage, with NO_3–N (28 $mg\ l^{-1}$) content being 10–20 times the content in well waters (1.05 to 2.8 $mg\ l^{-1}$). NO_3–N in the sewage water though falls into the slight to moderate category of degree of restriction of use as per FAO guidelines (Pescod, 1992), its concentrations in well water about 250 m from disposal point do indicate towards initial stages of ground water contamination as a consequence of sewage irrigation. Content of NH_4-N in sewage water was 3.5 mg l^{-1} whereas only two of the ground water samples showed the presence of NH_4-N (1.4 and 2.45 mg l^{-1}). Phosphorus content in sewage was also quite high (26 mg l^{-1}), whereas it was not detected in any of the ground water samples. As per the cationic composition sewage, water was of Ca + Mg–Na–K type. Anionic composition was of HCO_3-CO_3-Cl type, whereas ground water samples were of HCO_3-Cl type. SAR vis-a-vis Na content in most of the water samples including raw sewage water was within the limits prescribed for irrigation as per FAO guidelines (Pescod, 1992). The residual sodium carbonate (RSC) of these waters ranged between 2.9 and 6.3 me l^{-1}. Thus, the long-term use of these waters is expected to induce alkalinity problem in soil.

The analysis for micro/trace element and/or heavy metals in raw sewage and in ground water samples shows that Zn, Mn, Fe, Cu, Pb, Cd and Ni are well within the limits as per the standard prescribed for land disposal and should not pose any serious hazard. In general, concentrations were four times higher in sewage than in the ground waters. However, the contents of Cd, Ni, Pb and Mn were on the higher side, which could prove to be toxic to some crops. Water sample from TW_5 existing at 2 km from the disposal point showed a higher amount of Mn (0.23 mg l^{-1}) and TW_4 showed a slightly higher amount of Cd (0.02 mg l^{-1}). High contents of Cd and Ni have earlier been reported in sewage water contaminated with effluent discharge from electroplating industries (Saini and Kansal, 1990; Singh and Kansal, 1985a,b; Narwal et al., 1990). It may be pointed out here that the drinking water for human and animals living around the fields irrigated with sewage water and along the drain is usually drawn from the ground water. Since some quantities of NO_3-N, Cd and Mn were traced in some of the samples, there is a matter of concern that further increase in their contents may be hazardous.

3.2. Irrigation impact on soil properties

The analysis of soil samples (Table 2) reveals higher salt content of surface 0.15 m soil at site-1 which was just 50 m from the disposal outlet, while the minimum salts were observed at the last site (no. 6) which was at about 2 km distance along the disposal channel. Most of the salts were accumulating in surface than the underlying soil layers. Sodium was also concentrating in surface layers but site 3 did show accumulation of Na in deeper layers as well. Build-up of Na as indicated by SAR was highest in soil irrigated only with tubewell water (site-3). Due to residual alkalinity in ground water, the soils have been rendered slightly alkaline (pH 8.2–8.7) and the pH increased with the depth. Slight reduction in soil pH was

Table 2
Physico-chemical properties of soils irrigated with sewage and tubewell water

Site No.	Distance (m)		Soil depth (m)	pHs	ECe (dS m^{-1})	O.M. (%)	Available (kg ha^{-1})			Total (kg ha^{-1})		
	Along the channel	Longitudinal to channel					N	P	K	N	P	K
Site-1	50	25	0 – 0.15	8.1	1.68	1.73	91.6	24.6	268	2891	1771	4236
			0.15 – 0.30	8.4	0.83	0.94	64.8	37.3	248	2240	1410	3968
			0.30 – 0.45	8.4	0.51	0.52	48.0	21.2	256	1220	1202	4152
			0.45 – 0.60	8.6	0.27	0.40	32.3	18.4	265	410	917	3970
Site-2	250	50	0 – 0.15	8.4	1.96	1.78	95.1	58.2	239	2908	2015	3788
			0.15 – 0.30	8.6	0.64	0.82	69.3	32.3	234	2219	1506	3627
			0.30 – 0.45	8.5	0.32	0.51	48.4	24.4	237	1216	1109	3745
			0.45 – 0.60	8.6	0.28	0.33	26.4	22.0	246	718	821	3961
Site-3	500	500	0 – 0.15	8.5	0.81	0.97	66.9	25.4	238	1348	471	3696
			0.15 – 0.30	8.5	0.54	0.62	46.4	19.7	196	628	541	3136
			0.30 – 0.45	8.6	0.62	0.47	22.9	20.2	221	316	410	3532
			0.45 – 0.60	8.7	0.33	0.28	24.1	16.8	216	224	392	3541
Site-4	1000	75	0 – 0.15	8.3	1.46	1.68	89.6	64.4	305	2688	1866	4712
			0.15 – 0.30	8.6	0.91	0.87	64.8	40.4	268	2240	1506	4206
			0.30 – 0.45	8.7	0.58	0.72	46.0	29.6	257	1344	1084	4112
			0.45 – 0.60	8.2	0.52	0.49	29.8	24.3	274	710	427	4439
Site-5	2000	100	0 – 0.15	8.6	1.12	1.18	71.7	36.9	249	1623	1072	3996
			0.15 – 0.30	8.6	0.68	0.84	57.0	21.6	224	918	610	3673
			0.30 – 0.45	8.5	0.37	0.59	26.4	19.4	241	481	438	3928
			0.45 – 0.60	8.4	0.36	0.36	22.8	16.8	237	296	421	3840
Site-6	2000	125	0 – 0.15	8.3	0.99	1.24	74.6	34.0	235	1608	1171	3673
			0.15 – 0.30	8.4	0.72	0.92	56.4	19.8	216	1201	719	3507
			0.30 – 0.45	8.5	0.41	0.45	24.3	16.9	227	479	420	3730
			0.45 – 0.60	8.6	0.28	0.36	22.7	18.3	230	308	387	3758

observed at sites receiving higher proportions of sewage for irrigation. High load of organic matter (BOD) in sewage water has resulted in an improvement in organic matter; available and total nutrients in soils over the years as compared to tubewell water irrigated soils. The organic matter content of surface 0.15-m layer ranged between 1.68% and 1.78% in sewage irrigated soils, whereas it ranged between 0.97% and 1.18 % in soils irrigated with tubewell water and/or occasionally with sewage water. As the loading rates with sewage declined towards the tail end of disposal channel and along the longitudinal distance from this channel, reduced build-up of OC was observed especially beyond the distance of 1 km from the disposal site. Similarly, Narwal et al. (1993) observed that the continuous use of sewage water for irrigation increases soil EC and OC, whereas it decreases soil pH and Singh and Verloo (1996) reported lower pH and higher OC in soils irrigated with sewage water as compared to those irrigated with ground water.

The surface soil was also richer in nutrients than the underlying layers at all the sites. Availability status of N, P and K in soils improved with the loads of sewage being received, e.g. soils (sites 1, 2 and 4) receiving higher amounts accumulated more of these nutrients than sites 5 and 6. However, more interesting to note was the very high build-up in the total N, P and K contents in sewage irrigated soils. The total N, P and K contents of surface layers of these soils were as high as 2908, 2015 and 4712 kg ha^{-1}, respectively, whereas the contents in tubewell water irrigated site (no. 3) were 1348, 471 and 3696 kg ha^{-1}. The contents of DTPA extractable micronutrients and heavy metals were also improved considerably in sewage water irrigated soils (Table 3). Higher build-up was observed in surface than lower layers except for Cd. Singh et al. (1991) and Bansal et al. (1992) had earlier reported the micronutrients like Zn, Mn and Fe to distribute well in the profile, while Jayabaskaran and Sree Ramulu (1996) observed greater movement of metals in sewage irrigated light textured soils than in heavy textured soils. It may be pointed out that the build-up of heavy metals like Cr, Ni and Pb warrants towards their continuous monitoring and suitable measures are needed before these become toxic.

3.3. Changes in mineral composition of plants

Changes in nutrient contents of soils also reflected in uptake by winter (wheat, berseem) and summer (rice, sorghum) crops growing at these sites (Table 4). Higher contents of N, P, K and Na were monitored in their shoots when grown on soils irrigated with sewage water and there was constant decline in their concentrations in samples drawn from fields lying at a distance from the disposal point and from the channel. Higher accumulation of micro-

Table 3
DTPA extractable micro-nutrients and heavy metals in soils irrigated with sewage and tubewell water

Site No.	Distance (m)		Soil depth (m)	Zn	Cu	Fe	Mn	Pb	Cd	Cr	Ni
	Along the channel	Longitudinal to channel		(mg l^{-1})							
Site-1	50	25	0–0.15	2.65	2.59	22.69	7.22	1.65	0.01	6.77	3.28
			0.15–0.30	1.71	1.74	13.53	9.54	1.26	0.02	4.16	2.36
			0.30–0.45	1.22	1.25	6.43	9.65	1.24	0.02	2.13	1.98
			0.45–0.60	0.69	1.15	4.53	10.81	0.78	0.04	1.92	0.94
Site-2	250	50	0–0.15	2.46	2.76	23.33	7.26	1.91	0.01	5.79	3.13
			0.15–0.30	1.63	2.15	16.31	8.14	1.73	0.02	5.10	1.98
			0.30–0.45	0.89	1.99	8.40	9.12	1.01	0.02	3.26	0.84
			0.45–0.60	0.65	0.82	5.12	10.40	0.77	0.03	1.42	0.72
Site-3	500	500	0–0.15	0.89	1.25	16.50	5.05	0.83	ND	1.34	0.80
			0.15–0.30	0.40	0.64	6.40	6.32	0.58	ND	0.62	0.24
			0.30–0.45	0.18	0.52	5.36	7.21	0.32	ND	0.38	0.19
			0.45–0.60	0.12	0.38	4.12	7.06	0.17	ND	ND	0.12
Site-4	1000	75	0–0.15	2.80	2.55	24.12	7.51	1.60	ND	6.43	3.67
			0.15–0.30	2.01	1.87	17.16	8.78	1.16	0.02	4.13	1.87
			0.30–0.45	1.64	1.23	13.43	9.24	0.87	0.02	2.24	0.99
			0.45–0.60	0.57	0.74	5.46	10.23	0.63	0.02	0.96	0.67
Site-5	2000	100	0–0.15	1.04	1.47	18.53	5.79	0.98	ND	2.30	3.02
			0.15–0.30	0.54	0.84	9.46	7.15	0.79	0.01	1.96	1.23
			0.30–0.45	0.42	0.74	7.32	7.68	0.51	0.02	0.92	0.67
			0.45–0.60	0.22	0.49	5.10	8.41	0.28	0.01	0.42	0.24
Site-6	2000	125	0–0.15	0.99	1.45	17.82	5.84	0.99	ND	2.18	2.42
			0.15–0.30	0.37	0.82	8.37	7.46	0.74	ND	1.24	0.98
			0.30–0.45	0.22	0.68	6.12	6.98	0.53	0.01	0.64	0.68
			0.45–0.60	0.16	0.51	4.98	7.53	0.32	0.01	0.42	0.32

ND—Not detected.

Table 4
Effect of sewage irrigation on the chemical composition of crop plants

Crop/Site		N	P	K	Zn	Cu	Fe	Mn	Pb	Cd	Cr	Ni
		(%)			(mg kg^{-1})							
Wheat (boot leaf stage)												
Site	1	2.64	0.23	2.43	275	13	56	44	26	ND	ND	13
	2	2.71	0.44	2.38	304	12	100	13	11	1.0	ND	15
	3	2.46	0.54	2.02	261	10	38	6	ND	ND	ND	4
	4	2.27	0.25	1.63	293	4	122	49	ND	ND	ND	29
	5	2.40	0.34	1.35	270	9	119	13	ND	ND	ND	28
	6	2.04	0.23	1.70	180	9	79	15	ND	ND	ND	13
Egyptian clover (third cut)												
Site	1	3.42	0.39	1.84	277	13	164	60	22	ND	ND	16
	2	3.19	0.43	1.59	295	33	153	71	25	ND	ND	34
	3	2.48	0.17	1.66	228	23	109	18	ND	ND	ND	12
	4	3.23	0.40	2.40	294	18	188	72	26	ND	ND	39
	5	2.80	0.30	2.01	317	20	190	72	ND	ND	ND	28
	6	2.96	0.28	1.70	232	15	168	43	ND	ND	ND	12
Rice (milk ripe stage)												
Site	1	2.80	0.21	2.24	121	12	138	68	4	ND	2	6
	2	2.86	0.24	2.32	98	18	129	72	2	0.4	4	7
	3	2.54	0.18	2.08	56	8	52	29	ND	ND	ND	2
	4	2.78	0.26	2.29	84	21	98	46	6	ND	5	5
	5	2.67	0.22	2.13	78	10	102	39	1	ND	ND	2
	6	2.72	0.16	2.18	69	14	76	53	ND	ND	ND	3
Sorghum (jointing stage)												
Site	1	3.52	0.46	1.82	56	15	226	54	2	ND	6	4
	2	3.76	0.38	1.90	62	11	232	46	3	ND	3	2
	3	2.98	0.26	1.71	24	9	146	34	ND	ND	ND	2
	4	3.48	0.34	1.84	49	12	192	39	3	ND	2	3
	5	3.12	0.35	1.68	43	10	178	46	ND	ND	ND	1
	6	3.04	0.28	1.72	36	8	180	32	1	ND	ND	3

ND—Not detected.

nutrients and heavy metals in plants was also observed in sewage water irrigated crops, but by and large the contents of Pb, Cd, Zn, Mn, Cu, Fe and Ni were within the critical limits prescribed for phytotoxicity of these metals (Pescod, 1992). The contents of heavy metals also declined with distance of sampling from the disposal pump. Thus this analysis shows that the soils irrigated with different proportions of sewage and ground waters at the site have still not been inflicted to levels of heavy metals which may prove to be toxic in spite of the irrigation being practiced since about three decades. Dutta et al. (2000) have earlier reported similar observations for soils irrigated with domestic sewage from IARI.

4. Conclusions

The results from the site under study where sewage from municipal is being used for about three decades showed the enrichment of soils with both organic matter and nutrients without excessive accumulation of any toxic elements in soils and plants. Thus, the efficient use of such domestic sewage can effectively increase water resource for irrigation and may prove to be a boon for agricultural production. However, traces of some of the toxic ions like Ni, Cd and Pb were noticed in plants and that NO_3 in some well waters should be a matter of concern and indicate the need for continued monitoring or treatment of sewage water before it is let into disposal channel for irrigation. Moreover, it may be pointed out that health hazard emerging from the use of sewage, though not assessed here, can pose restriction on its use if applied for irrigation without the appropriate remedial measures.

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