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Effect of Sewage on Soil Properties, Essential Nutrient and Pollutant Element Status of Soils and Plants in a Vegetable Growing area near Jajamu Industrial area of Kanpur (U.P.)

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Abstract

Effect of continuous irrigation with sewage for more than three decades on soil physical, physico-chemical properties; and major, secondary and micronutrient with pollutant element status of soils and plants in Jajamu area of Kanpur city of Uttar Pradesh was ascertained. Long term alone use of sewage for growing crops, particularly vegetables, may result in the uptake of toxic metals by crop plants, with the chance of their access into the food chain. While the use of sewage with alternate irrigated with well water, the physical properties of soils were observed to be improved. An appreciable increase in organic carbon; available N, P, K, and micronutrients were recorded in the alternate with sewage and well water irrigated soils over that of the alone sewage irrigated soils. Electrical conductivity of alternate irrigated soils was much below the threshold limit of salinity. Long-term application of sewage water resulted in the accumulation of heavy metals in surface soil; the concentration of these elements is approaching the maximum permissible limits suggested. The mean content of total Fe, Mn, Zn, Cu, Ni, Cr and Pb in the soils irrigated with sewage water was 1.32, 1.15, 1.06, 1.09, 1.03, 1.11 and 1.01 times as compared to their content in the alternate irrigated soils, and the concentration of these metals in sugar beet grown on sewage-fed soils was higher by 1.05, 1.18, 1.11, 1.31, 1.67, 1.17 and 4.92 times, respectively. The relative availability of the metals was recorded in the order of Pb > Cu > Zn > Mn > Cr > Ni > Fe. The concentration of heavy metals in sugar beet plant grown on sewage was higher as compared to their tolerance level indicating their accumulation in plants. The results suggest that sewage irrigation improves soil physical properties and fertility status indicating its potential for use in agriculture. However, accumulation of heavy metals in soil and plant necessitates its safer use of alternate sewage with well water to safeguard soil health and reduce the risk of animal and human health hazard. Sugar beet was found more suitable in comparison to other vegetables under study and can be used for phytoremediation purposes to minimize the concentration of heavy metals in soil.

Key words: *Sewage, soil quality, heavy metals, sugar beet*

Introduction

Although soil acts as a physical filter due to its sieving action, a chemical filter due to adsorbing and precipitation of chemical substances and a biological filter due to decomposing the organic materials, it does not have infinite capacity to perform these functions. Since most of the soils possess buffering capacity it usually takes some time for the negative effects to become visible and then the soil can be considered polluted and the process as soil pollution. Soil pollution is not apparent immediately and

shows its effects only after many years. An indiscriminate land application of sewage effluents for long term may lead to such pollution problems. More than 450 cities in India generate more than 17×10^6 m³ of raw sewage per day (Bijay-Singh 2002). It is being increasingly used for irrigating especially the vegetables around most of the cities for last more than three to four decades on the same land which necessitates monitoring of these lands for the pollution hazards.

Utilization of water resources is crucial to agricultural production for meeting the ever-increasing demand of irrigation water for producing more and more food. Since resources are limited and large gap exists between available water supply and amount required, appropriate use of waste water of domestic origin can help in meeting part of increased demand of water for crop production. Moreover, the rising cost of commercial fertilizers have stimulated interest in the use of sewage water for irrigating agricultural crops in the vicinity of big cities because of its plant essential nutrient content which serves as a low analysis fertilizer. Research has shown beneficial effects of sewage irrigation on soil fertility. However, in the long-term use this may contaminate the soil with heavy metals which may pose serious human and animal health hazard. If the heavy metals are drawn into the soil-plant-animal continuum then their removal is not easy and since the curative strategies are expensive and very difficult, the preventive strategies need to be fixed in our country (Rattan *et al.* 2002). Since food chain contamination is one of the major routes for entry of metals into the animal system, monitoring the bio-available pools of metals in the contaminated soils is critical.

The agricultural land around Kanpur city is being continuously irrigated with city sewage water for many agricultural crops for more than last 30 years. Extent of contamination is better judged by making comparisons of metal contaminated soils with the adjacent non-polluted soils (Rattan *et al.* 2005). No investigation has been carried out in sewage irrigated soils of this peri-urban area. The influence of long-term use of sewage irrigation on soil physical, chemical and biological properties and plant essential nutrient status and heavy metal content in soils and plants under sewage irrigated soils and alternate sewage with well irrigated soils is ascertained in the present study.

Materials and Methods

The sewage water of Kanpur city which is discharged into Ganga river and is under long-term use for irrigating vegetables and other agricultural crops, has been collected at five discharge points. The sewage water at all discharge points was collected uniformly at the site where it was lifted by the farmers for its use. The major crops grown under sewage water in the area include Cabbage, Cauliflower, Brinjal, Tomato and Suga beet. The soil samples were collected at five sites in the Jajmau area from the cultivators' fields where the sewage water has been continuously used for irrigation for last 30 years.

The well water irrigated soil samples were also collected from the adjoining areas as the reference samples. At each site the soil samples from 0 to 20 cm depth were collected. An aliquot of 500 mL of sewage effluents and well water samples with 15 mL of HNO₃ was evaporated to near dryness on a hot plate. Then contents were digested with 15 mL of HNO₃ and 20 mL HClO₄ (70%) (Brar *et al.* 2000). The residue was taken in 15 mL of 6 N HCl and made to the volume (50 mL) and contents were filtered, the filtrate was then analyzed. The biological oxygen demand (BOD) of sewage water was estimated using Winkler method (Trivedy and Goel 1984) and chemical oxygen demand (COD) by using reflux method (APHA 1985). The other estimations for characterization of sewage effluents, soil properties, major and micronutrients were carried out by using standard procedures (APHA 1985). The total heavy metals were estimated by wet digestion (HNO₃ + HClO₄) and the

extractable heavy metals by using DTPA and measured by AAS (Page *et al.* 1982). The soil microbial count was estimated by dilution pour plate method (Chhonkar *et al.* 2007).

Results and Discussion

Characteristics of Sewage

The sewage effluents of five discharge site showed variability in chemical properties (Table 1). The pH of sewage was neutral to slightly alkaline (7.09 to 8.02) which is within safe limit of 6.0 to 8.5 as suggested by USSL (1954). The electrical conductivity (EC) of effluents was quite high and found to exceed the toxic limit as per the USSL (1954). The BOD ($81\text{--}212\text{ mg L}^{-1}$) was higher than the recommended maximum concentration of 100 mg L^{-1} (FAO 1985) and can be attributed to high content of suspended organic colloids in the sewage effluent. The COD values of effluents were quite above the ISI standard limit of 500 mg L^{-1} .

Table 1. Characteristics of sewage water

Sr. No.	Parameter	Range	Mean
1.	pH	7.09-8.02	7.56
2.	EC (d Sm^{-1})	0.88-2.18	1.53
3.	TDS (mg L^{-1})	340-1089	715
4.	DO (mg L^{-1})	2.45-3.18	2.82
5.	BOD (mg L^{-1})	81.4-212.4	146.9
6.	COD (mg L^{-1})	614-1118	866.5
9.	Ca (mg L^{-1})	3.49-12.98	8.24
10.	Mg (mg L^{-1})	1.34-5.93	3.63
11.	Na (mg L^{-1})	0.60-4.18	2.39
12.	K (mg L^{-1})	0.17-1.76	0.96
13.	CO_3 (mg L^{-1})	0.30-1.40	0.85
14.	HCO_3 (mg L^{-1})	1.64-5.05	3.35
15.	Cl (mg L^{-1})	3.68-14.9	9.31
16.	SO_4 (mg L^{-1})	1.12-6.48	3.80
17.	Fe (mg L^{-1})	0.88-3.85	2.37
18.	Mn (mg L^{-1})	0.82-3.77	2.29
19.	Zn (mg L^{-1})	0.33-1.97	1.15
20.	Cu (mg L^{-1})	0.59-2.39	1.49
21.	Ni (mg L^{-1})	0.18-0.89	0.54
22.	Cr (mg L^{-1})	0.79-1.95	1.37
23.	Pb (mg L^{-1})	0.04-0.39	0.21

The total dissolved solids (TDS) in the effluents ($340\text{ to }1089\text{ mg L}^{-1}$) were higher at most points as compared to the permissible limit of 450 mg L^{-1} as per FAO (1985). However, still the values of TDS are well below the recommended maximum concentration of 3000 mg L^{-1} for irrigation water as per criteria of FAO (1985) and 2100 mg L^{-1} as suggested by ISI specifications (ISI 1982) for city effluents composition suggested for effluents to be discharged on land.

Among the basic cations, Na^+ was dominant in sewage effluents ($0.60\text{ to }4.18\text{ me L}^{-1}$) which was higher than 3 me L^{-1} as per the guidelines of FAO (1985). The chlorides ($3.68\text{ to }14.9\text{ me L}^{-1}$) were higher than recommended level of 4 me L^{-1} (FAO 1985). The bicarbonate content was quite

high in the effluents (0.30.1 to 1.40 me L⁻¹) suggesting that these levels are toxic since they exceed 1.5 me L⁻¹ recommended level (FAO 1985). The higher bicarbonates, sodium, chlorides and sulphates have also been observed by Maiti *et al.* (1992) in Calcutta city sewage effluents.

Table 2. Recommended maximum concentration of heavy metals for use of waste water in agriculture

Heavy metals	*Recommended maximum concentration
Fe (mg L ⁻¹)	5.0
Mn (mg L ⁻¹)	0.2
Zn (mg L ⁻¹)	2.0
Cu (mg L ⁻¹)	2.0
Ni (mg L ⁻¹)	0.01
Cr (mg L ⁻¹)	0.1
Pb (mg L ⁻¹)	0.2

*National Academy of Sciences (19720); FAO (1985)

The concentration of micronutrients (Fe, Mn, Zn and Cu) was higher in sewage indicating that they are good source of plant essential micronutrients which may help in mitigating emerging problems of their deficiency that are otherwise overcome by application of costly chemical fertilizers. However, their concentrations are high and were beyond recommended maximum concentration given by FAO (1985) (Table 2). The concentration of Mn, Ni, Cr and Pb in sewage effluents was higher than the recommended maximum concentration suggested by FAO (1985) indicating that they can chromium to contamination of soil and may be potentially toxic for plants, human and animal health.

Physical Properties of Soils

Sewage water irrigation becomes most important source of irrigation in Jajmau areas. It will improve the soil physical properties like infiltration, BD, and porosity. Rattan *et al.*, (2005) indicated that fields irrigated sewage irrigation water around the peri urban areas of Keshopur Sewage treatment plant had sandy loam were recorded. Out of 50 samples analyzed, 7 samples belong to loamy sand and 23 samples were classified as sandy loam. It clearly depicts that increased clay content in the soil. Kharche *et al.* (2011) reported that use of sewage irrigation recorded certain improvement in soil physical properties like bulk density, water retention, hydraulic conductivity, organic carbon and build up of soil N, P, K, micronutrients, heavy metals providing the proper aerated conditions. The bulk density of soils irrigated with sewage water was low (1.03 to 1.30 Mg m⁻³) as compared to those for the alternate sewage and well water irrigated soils (Table 3). Mathan (1994) recorded significantly lower bulk density and increased hydraulic conductivity in sewage farm soils with sewage irrigation for 30 years. This can be attributed to improvement in total porosity and aggregate stability in the sewage-irrigated soils due to addition of organic matter which plays an important role in improving soil physical environment. Otis (1984). This can be justified as the organic suspended solids may impede water transmission initially by temporarily plugging soil surface and by clogging of pores; however, the effect of organic matter addition through sewage on aggregation improves soil structure and enhances water transmission. The soil moisture retention of sewage-irrigated soils was also slightly higher as compared to that of sewage-free soils which can be ascribed to addition of organic matter through sewage. Rattan *et al.* (2001) observed enhanced available water content in the soils due to continuous application of sewage effluents.

Table 3. Mean values of physical and chemical properties of sewage and well- irrigated soils

Properties	Texture	BD	PD	Porosity	pH	EC	OC	CEC
Sewage irrigated soil								
Min	sl	1.03	2.64	51.25	6.80	0.64	0.68	20.06
Max	sl	1.30	2.66	60.99	7.73	1.15	1.44	41.30
Mean	sl	1.19	2.65	55.60	7.24	0.72	1.05	33.42
Alternate irrigated with well water								
Min	sl	1.10	2.64	51.48	6.65	0.40	0.72	23.44
Max	sl	1.29	2.66	58.36	7.47	0.98	1.28	39.14
Mean	sl	1.18	2.65	55.36	7.03	0.62	1.00	31.68

Chemical Properties of Soils

The pH of soils irrigated with sewage effluents was not much influenced (Table 3) as compared to that under alternate use of sewage use. The electrical conductivity in sewage-irrigated soils was high due to salt content of sewage water of domestic origin (Khurana *et al.* 2004). However, it was below the threshold limit to cause salinity hazard to the soil. The lower calcium carbonate content in sewage-fed soils can be attributed to the low pH and acidic components of domestic sewage water.

The mean organic carbon content in sewage- irrigated soils was higher and it was 0.68 and 1.44 per cent, alone use sewage water the organic carbon per cent was high which is ascribed to the addition of organic matter through long-term application of sewage effluents. Thus sewage application to soils is a carbon building/ sequestering and soil quality sustaining practice (Rattan *et al.* 2001). The improvement in soil quality is also evident from the improved physical properties of sewage-fed soils. This also corroborates the farmers view in this peri-urban area who express that the sewage water application is useful for improving soil quality, good crop growth and higher crop yields in absence of addition of any organic manures in these soils. The carbon sequestration resulting due to increase in soil organic carbon (SOC) on long-term use of sewage water is thus beneficial not only in mitigating the greenhouse effect but also in improving the soil quality (Rattan *et al.* 2001). While the alternate use of sewage with well water of assistance the consequence as sustainability of soil, environment and human.

All the exchangeable cations (Ca^{2+} , Mg^{2+} , Na^{+} and K^{+}) in sewage-irrigated soils were higher and the exchangeable Na^{+} was slightly increased in the soil. The cation exchange capacity of the soils is in general higher variation due to inherent character of dominant smectitic mineralogy of the soils. However, due to organic matter addition through sewage it might have further increased due to continuous use of sewage irrigation.

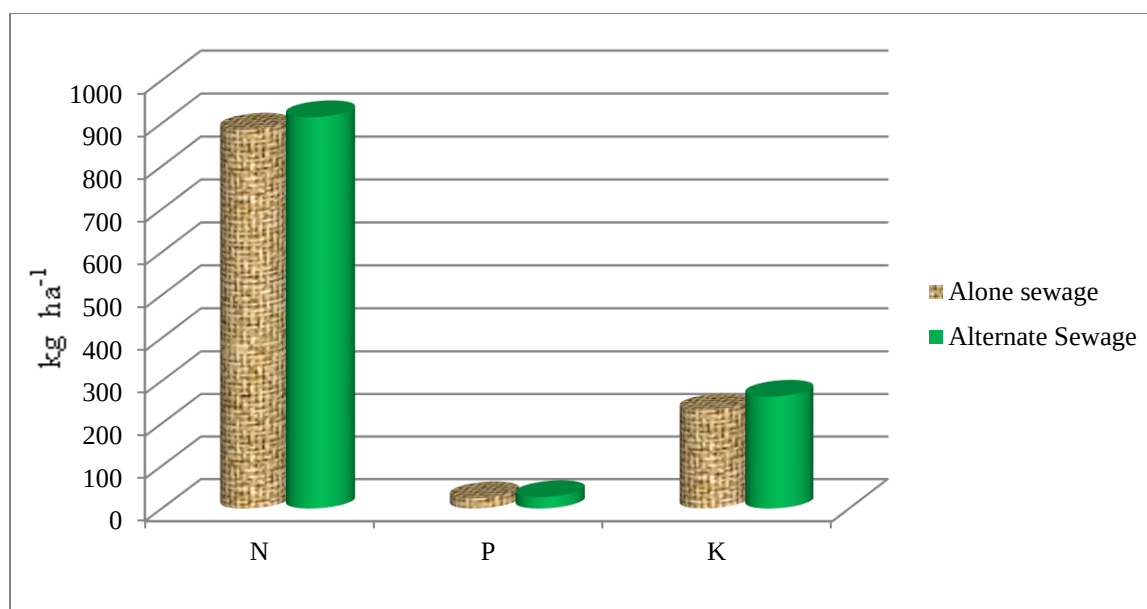


Figure 1. Effect of sewage irrigation on N,P and K build-up in soils

Plant Essential Nutrients and Heavy Metal Status of Soils

The sewage-irrigated soils recorded higher total N, P, K, Fe, Mn, Zn Cu, Ni and Pb (Tables 4,5) indicating their significant addition through sewage suggesting use of alternate sewage with well water as a low grade cheap fertilizer in agriculture which can markedly reduce the cost due to substitution of chemical fertilizers. The alternate sewage-irrigation with well water resulted in an increase of N,P, and K availability of about 1.03, 1.10 and 1.02 time more compare to alone use of sewage water shows in figure 1. The total accumulation of nutrient content was observed very high in alone use of sewage.

The total content of micronutrients and other trace elements were higher in the sewage-fed soils (Table 5). The mean total content of Fe, Mn, Zn, Cu, Ni, Cr and Pb in

Table 4. Mean and range of N, P and K content of alone and alternate of sewage with well water-irrigated soils

Particular	Total nutrient (kg ha ⁻¹)			Available nutrient (kg ha ⁻¹)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Sewage irrigated soils						
Min	4200	389	16383	580	15.3	199.9
Max	8963	875	24704	1238	34.4	257.6
Mean	6408	616	20414	885	24.2	231.0
Alternate irrigated with well water soils						
Min	NA	NA	NA	630	17.0	226
Max	NA	NA	NA	1251	35.2	289
Mean	NA	NA	NA	914	26.8	263

sewage-irrigated soil was 1.13, 1.16, 1.01, 1.02, 1.01, 1.07 and 1.03 times more their content in soils alternate irrigated with well water. The corresponding mean values of alone and alternate use sewage irrigated soil was 11301, 423.3, 543.9, 205.6, 291.6, 226.2, 276.2; and 9926, 363.7, 538, 202, 288.7, 211.7, 268.7 mg kg⁻¹, respectively. The overall decrease in total Fe, Mn, Zn, Cu, Ni, Cr and Pb content in alternate use of sewage with well water irrigated soils was 11.4, 11.6, 10.1, 10.0, 10.1,

10.6 and 10.2% respectively. This indicates that the heavy metals accumulate in sewage irrigated soil which happens to be toxic effect on rooting depth for most of the vegetable crops.

Table 5. Range and mean of total and DTPA extracted heavy metal content (mg kg⁻¹ soil) of sewage and well-irrigated soils

Particular	Fe	Mn	Zn	Cu	Ni	Cr	Pb
Total Content							
Sewage-irrigated soils							
Max	9201	379.8	506.2	152.5	181.1	189.2	165.8
Min	12425	466.8	584.8	257.9	399.4	265.1	386.5
Mean	11301	423.3	543.9	205.6	291.6	226.2	276.2
DTPA-extractable content							
Sewage-irrigated soils							
Max	66.3	30.5	53.7	20.9	4.8	2.6	54.1
Min	180.0	78.2	120.4	77.2	11.4	11.1	133.2
Mean	106.0	56.5	89.9	49.6	8.3	7.3	92.6
Relative availability							
@#	0.93	13.34	16.52	24.12	2.84	3.22	33.52
Total Content							
Soils alternate irrigated with well water							
Max	8224	326.9	502	150	180.0	179.2	162.1
Min	10893	400.8	579	253	397.0	247.1	376.9
Mean	9926	363.7	538	202	288.7	211.7	268.7
DTPA-extractable content							
Soils alternate irrigated with well water							
Max	50.6	28.6	53.3	19.0	5.27	2.45	55.7
Min	135.8	66.9	112.8	70.1	10.97	9.75	129.7
Mean	80.5	49.3	84.5	45.5	8.03	6.55	91.4
Relative availability							
@#	0.81	13.55	15.70	22.52	2.78	3.09	34.01

The DTPA extractable heavy metal content was also higher in sewage-irrigated soils and the mean value of DTPA extractable Fe, Mn, Zn, Cu, Ni, Cr and Pb in sewage irrigated soil was 1.32, 1.15, 1.06, 1.09, 1.03, 1.11 and 1.01 times higher than alternate well water irrigated soils except (negligible) Pb which showed least distinction by 1.01 times Rattan *et al.* (2005) reported that sewage irrigation for 20 years resulted into significant build-up of DTPA extractable Zn, Cu, Fe, Ni in sewage-irrigated soils over adjacent alternate irrigation with well water soils. This may be attributed to the decrease in pH associated with increase in organic carbon as a result of long-term use of sewage effluents. The higher content of extractable heavy metals in surface layer indicated low mobility of these metals in the soil (Brar *et al.* 2000; Khurana *et al.* 2004).

Relative Availabilities of Heavy Metals

Relative availability of the metals was recorded in the order of Pb > Cu > Zn > Mn > Cr > Ni > Fe shows in figure 2. It is due to low amount of Pb and to high of Fe and the soil which statistically compacted these reverse high and low in case of Pb and Fe due to Fe abundant in soil in effluent and high redox potential in that areas. In comparison to alone and alternate use sewage with well water irrigated soils, had high relative availability in alternate irrigated soil due to better soil physical and chemical properties. In most of the cases concentration of micronutrient in winter then those of

during the summer (Mitra and Gupta 1999) Williams (1980), Patel *et al.* (2004) for Gujarat soils, the relative availability are high due to fine texture soil of Jajmau *i.e.* near the bank of Ganga.

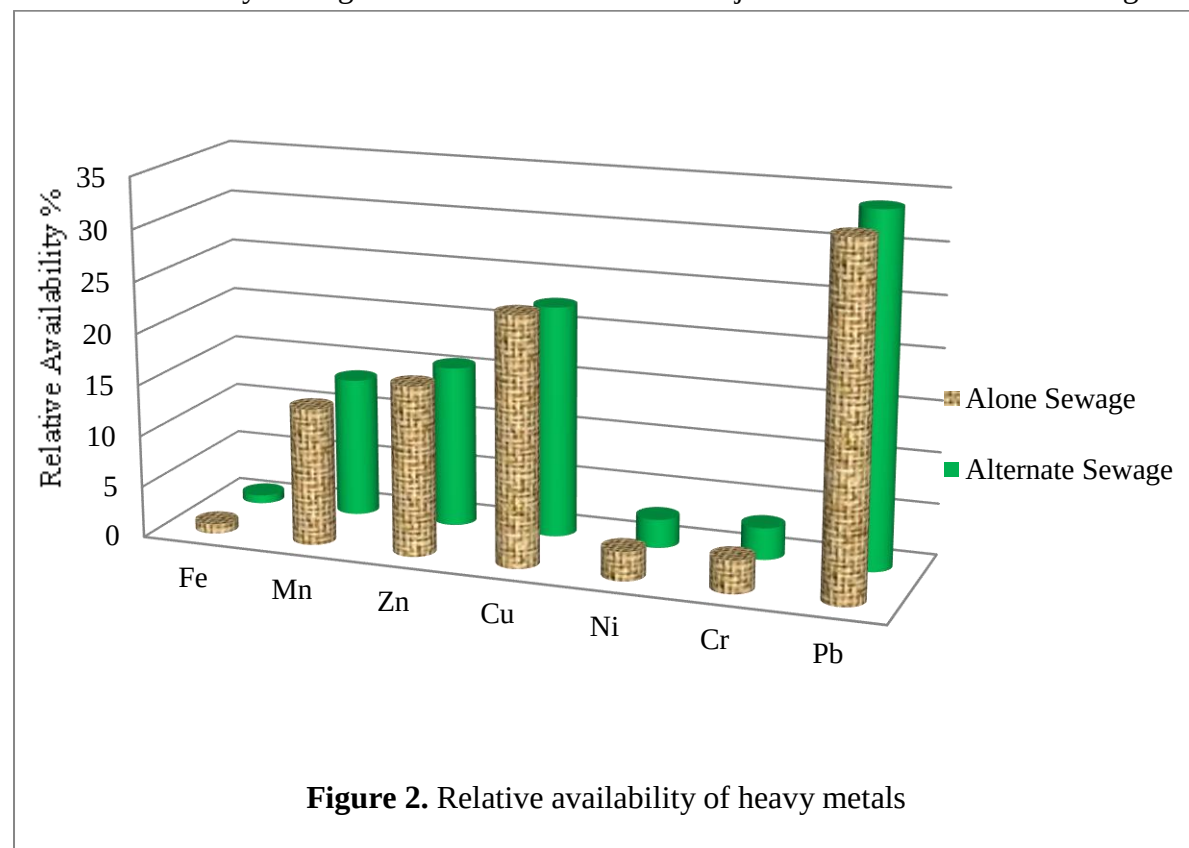


Figure 2. Relative availability of heavy metals

Table 6. Suggested Critical soil concentration values (mg kg^{-1} soil) for phyto-toxicity of heavy metals

Element	Kabata and Pendias (1992)	Department of Environment (1980)	Ontario, Canada by Seto and Deangelis (1978)
Mn	1500-3000	-	1500
Zn	70-400	450	216
Cu	60-125	200	100
Ni	100	110	32
Cr	-	400	-

Although, the concentration of total heavy metals in the sewage-irrigated soils is below the maximum permissible limits as given by Kabata and Pendias (1992) and Department of Environment (1989), but it can be observed that these soils are expected to approach these critical concentrations in few years from now and may become toxic on accumulation of these metals by continuous use of sewage (Table 6). In addition, if rather strict criteria of Ontario Canada (Seto and Dengelis 1978) are considered for categorizing soils in polluted category, most of the soils fall under contaminated category with respect to these heavy metals.

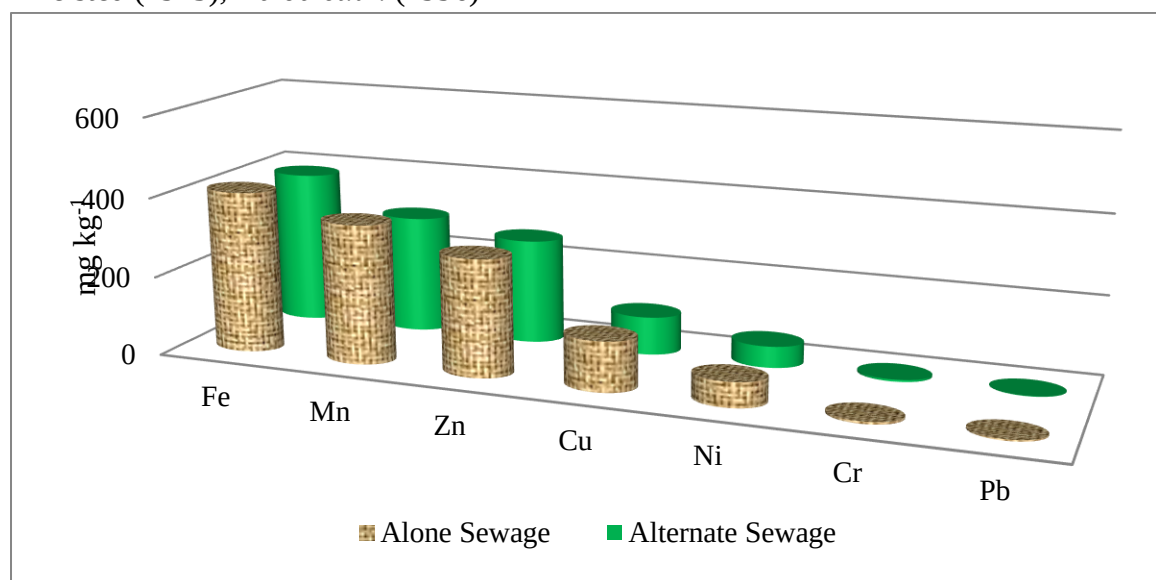
Essential Nutrients and Heavy Metal Content of Sugar beet

The higher concentration of heavy metals was observed in the sugar beet plant grown on these alone sewage- and alternate with well irrigated soils (Table 7 and Figure 3). The mean concentration of Fe, Mn, Zn, Cu, Ni, Cr and Pb in sugar beet grown on sewage-fed soils was about 1.05, 1.18, 1.11, 1.31, 1.67, 1.17 and 4.92 times their content under alternate sewage

Table 7. Mean heavy metal contents in Sugar beets plant grown on alone sewage and alternate with well water irrigated soils

Heavy metals	Concentration (mg kg ⁻¹)		Suggested tolerance level* (mg kg ⁻¹)
	Alone sewage irrigated	Alternate sewage and well water irrigated	
Fe	290-532 (407)	318-465 (388)	750
Mn	283-410 (351)	270-321 (297)	300
Zn	215-367 (295)	213-312 (264)	300
Cu	59-182 (126)	10-130 (96)	150
Ni	37-89 (63)	33-78 (54)	50
Cr	2.69-9.09 (5.78)	2.16-7.25 (4.94)	2.0
Pb	2.06-5.11 (3.54)	3.09-0.85 (0.72)	3.0

*Melsted (1973); Naidu *et.al.* (1996)

**Figure 3.** Heavy metal content of Sugar beet

with well water irrigated soils, respectively. The concentration of heavy metals in sugar beet is higher as compared to the suggested permissible tolerance levels (Table 8) as by council for Agricultural Science and Technology (1976), Melsted (1973); Naidu *et.al.* (1996). Sugar beet was found more suitable in comparison to other vegetables under study and can be used for phytoremediation purposes to minimize the concentration of heavy metals in soil.

Conclusions

Alternate use of sewage with well water irrigated soils recorded improvement in soil physical properties like bulk density, water retention, hydraulic conductivity, organic carbon and build-up of soil available N, P, K, and micronutrient status. The sewage-irrigated soils had higher electrical conductivity and organic carbon as compared to the alternate use of sewage- irrigated soils. The

electrical conductivity although increased due to alternate sewage use with well water, it was within the tolerance limit to cause any soil salinity hazard. The heavy metals like Fe, Cr, and Pb were found to be accumulated in surface soil and plant due to long-term use of sewage irrigation. This warrants the potential hazard to soil and plant health suggesting necessity of their safe use after pre-treatment or alternate use with well water in order to make use of sewage effluents as a cheap potential alternative source of plant nutrients in agriculture.

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