Effect of irrigation by untreated sewage effluents on the micro and potentially toxic elements in soils and plants

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Abstract

In Indian Punjab, industry is still discharging the untreated effluents in the sewage system. Being a cheap source of irrigation, farmers are applying this water to their fields. The composition of these waters varies depending upon the nature of industry. For example, the concentrations of Cd, Ni and Co were higher in sewage water of industrial area manufacturing metallic products than from textile, dye and wool industry. High Cd concentration was observed in sewage water of electroplating industry and Cr content was high in sewage water of leather industry. The Cr content was found to be 140 times higher than the maximum tolerance limit for discharge of effluents on land. In comparison to groundwater, the sewage water had 4 to 2300 times' higher content of different elements. Soil samples collected from sewage and non-sewage irrigated fields, at different times, from three major cities of Punjab, India showed a build up of elements in fields irrigated by effluent containing sewage water. The accumulation was observed up to 30 to 60 cm depth. The plant samples collected from the same fields also showed higher concentration of most of these elements in different parts. However, the build up in plants was not proportional to the build up in soils, indicating that most of the potentially toxic elements are still being retained by the soils. The accumulation within the crops also varies, in some crops such as cauliflower the accumulation in edible parts was higher as compared to no-edible parts, whereas in other crops such as potato and tomato the reverse trend was observed. The sewage water of non-industrial towns can safely be used directly for irrigation, if it meets the other requirements such as salinity and pH etc. There is a need to pre-treat the effluents of industrial cities/areas before their disposal in the sewage system and also to continuously monitor the status of these elements in soils as well as in crops to prevent any health hazard to human/ animals consuming food grown on such soils.

Keywords: sewage effluents, potentially toxic elements, soils, crops

Introduction

Land application of wastewater is centuries old practice. This practice was introduced in US more than one hundred years ago but general interest on the subject waned after the turn of the century in favour of more mechanized method of waste treatment and disposal (Jewell and Seabrook, 1979). It allows disposal of the sewage effluents and fulfills the increasing demand of water for agricultural purposes In India, too, the land application of raw sewage and sludge is an old practice. The first sewage farm in the country started in 1895 at Ahmadabad. There are more than 200 sewage farmers in the country (Jurwarkar *et al.,* 1991) covering an area of about 50,000 hectares. Currently, more than 450 class I and II cities in India generate about 17.4 million cubic meters of raw sewage per day. However, due to limited facilities, only 35.6% in Class I cities and 13.5% in Class II cities is being collected, the rest being thrown into low lying areas, water bodies or along the road sides. About 22.2 and 4.5 per cent of the collected sewage in Class I and Class II cities, respectively, have a provision of primary treatment, while secondary treatment is provided to less than 10% of the collected sewage. If whole of the generated sewage is collected and treated to primary level, about 4000 tones of sludge will be available for enriching the soils with organic matter and essential nutrients.

The cost of constructing, operating and maintaining a land treatment facility is generally considered to be lower than corresponding conventional waste water treatment system (Badger and Thomason, 1987). In the UK, treatment and disposal of sewage sludge from biological water plants accounts for approximately 50% of the total cost of sewage treatment, and the major US sludge disposal route is land application (Lake 1987). Due to the fact that toxic substances are concentrated in the solid phase during wastewater and sludge disposal, the sludge management can be more risky than irrigation with wastewater particularly in developing countries with economic and administrative constraints. In Morelos, Mexico, large quantities of sludge from a wastewater treatment plant containing pathogens and toxic substances as ionic aluminum have been deposited in open areas, causing damage on soils and problems to the inhabitants (Qrtiz-Hernandez *et al.,* 1993).

The reuse of domestic wastewater to irrigate agricultural land seems to be a practical option for under developed world including India. One of the most important problem in the Municipal Corporation areas of cities like Ludhiana, Jalandhar, Amritsar in Punjab, India are that industries are not confined to industrial parks rather most of the small to medium industries are running in the residential area. The owners of these small to medium industries are unable to install their treatment plants, and they are disposing their effluents in the domestic sewage system of the city, which is carried forward to rural areas through open sewage drains and farmers with fields adjoining to these drains irrigate purely or mixing it with underground irrigation water.

The 93 towns in Punjab generate about 113.4 million litters per day of raw sewage (Kansal and Randhawa, 1993). In addition to domestic effluents, a number of industries too produce large volume of effluents requiring their proper disposal. May times, industries produce highly toxic effluents which can neither be thrown into water bodies nor used for agricultural purposes as the toxic elements are likely to enter food chain through plants, animals and fish. However, effluents of some industries have useful characteristics and, therefore, have the potential to improve the productivity of soils. The land management of such wastes thus, not only brings the economic benefits but also protect the fragile ecosystem from degradation.

A long-term project with the following objectives is continuing in the Department of soils, Punjab agricultural University, Ludhiana. I. To determine the elemental composition of sewage water drains mostly containing a mixture of domestic sewage and effluents of various industries II. To determine the nature of effluents discharged by the different industries dealing with manufacturing of different products III. To study the effect of irrigation of fields with sewage waters containing untreated effluents on their build up in soil IV. To study the effect of effluent containing sewage water irrigation on the elemental composition of plants and V. To study the effect of irrigation by these waters on the soil-plant-human/animal health. The results of the part of the project are summarized and discussed inthe present paper.

Materials and Methods

In order to study the extent of elemental pollution, three major industrial towns of Punjab namely Jalandhar, Ludhiana and Amritsar and two non-industrial town namely Abohar and Malerkotla were selected. Ludhiana is a big town and is commonly known as industrial hub of Punjab where machine tools, electroplating, bicycles and woolen and hosiery manufacturing unit's discharge their industrial effluents directly or through sewage into fresh water tributary. The daily disposal of such waters, which are both of industrial and domestic origin, is quite high. Jalandhar is one of the important industrial cities of Punjab where different types of industries such as hand tools, sports, pipe fittings, rubber and leather are located. Amritsar is another Industrial City of Punjab where electroplating, fertilizer and woolen industries are dominated. The polluted water released from these industries without treatment, together with wastewater of domestic origin find its way into respective drains. Abohar and Malerkotla is non-industrial town where sewage drain carries only domestic sewage.

The samples of effluents were collected either from different site of a sewage drain or from proximity to different industries dealing with the manufacture of different products from exit points of the sewage line where it was thrown into the main sewage drain. Five ml of nitric acid was added in each sample to suppress any microbial activity during refrigeration. Soil samples were collected from fields irrigated by wastewater and under ground water. Plant samples were collected from respective fields and were analyzed for different elements.

Results and Discussion

Elemental composition of sewage effluents

The composition of the effluents is dependent on various factors such as time of sampling, site of sampling, location of industries, nature of industrial products manufactured by the industry etc.

Time of sampling

In early studies to standardize the time of sampling, two types of the industries were selected (Azad *et al.,* 1984). First categories of industries were dealing with manufacture of bicycle and its spares and sewing machines and second categories were dealing with manufacture of textile and woolen goods including dying units. To see the variations in composition over the period the samples were collected in the morning, noon and evening hours. The high contents of elements were observed in the evening time sampling, indicating that these industries are storing their effluents in small sores during the day and discharge them into sewage in the evening. Thus evening time sampling was suggested, however, evening time irrigation with sewage effluents should be avoided as it contains higher content of pollutants. The higher content of element in wastewaters of metallic industries indicated that the effluents discharged by the textile industry are safe as compared to effluents of metallic industries.

Composition of effluents in industrial and non-industrial cities

The variation in the composition of non-industrial and industrial cities of Punjab is evident from the data reported in Table 1. The content of trace elements was higher in wastewater of industrial towns of Jalandhar and Amritsar as compared to non-industrial town of Abohar. The wastewaters of Abohar thus can very safely be used for irrigation purposes. It also contains a lot of organic matter along with essential nutrients with only negligible amounts of toxic elements (Singh and Kansal 1985).

Table 1 Content of trace elements in sewage water of non-industrial and industrial cities of Punjab.

Location	Elements Concentration (μg ml^{-1})					
	Fe	Mn	Zn	Cu	Pb	Cd
Non Industrial City						
Abohar	1.8	0.09	0.08	0.07	0.04	0.010
Industrial Cities						
Jalandhar	3.5	0.28	0.33	0.20	0.05	0.011
Amritsar	4.5	0.52	0.66	0.94	0.08	0.010

Composition at different locations in the same city

The composition of sewage water varied within a city depending upon the command area from where the sewage is being collected. The domestic zone sewage contained very low amounts of toxic elements where are the effluents from the electroplating area contained the toxic elements such as Cr, Ni and Cy in amounts higher than maximum tolerable limits for their disposal on agricultural lands (Table 2). It is therefore important that the disposal for both types of sewage water should be separated. Industrial effluents should not be allowed to mix in domestic sewage, which can safely be used for irrigation purposes. However the irrigation with effluents of industrial units may cause environment pollution if allowed to be mixed in domestic sewage water without their pretreatment (Tiwana *et al.,* 1987).

Table 2 Quality of waste water in domestic and industrial area of Ludhiana city in Punjab (India).

Location	Elements (μg ml^{-1})		
	Chromium	Nickel	Cyanide
Domestic Area	0.1-0.2	0.2-0.2	0.03-0.07
Electroplating area	0.2.-2.5	1.0-3.0	0.42-0.97
Max limit for disposal on acquic land	<0.1	<0.005	<0.20

Composition at different sites in the same sewage drain

Different industries throw their untreated effluents in open sewage drain. Leather complex (LC) at Jalandhar city is a complex where factories dealing with the preparation of leather and manufacture of leather products are located. To study the effect of disposal of effluents of leather complex on the composition of wastewater of open sewage drain, the samples were collected from different site both upstream and down stream of the leather complex. Out of the entire elements the Cr and Al were the two elements whose content was drastically changed in the sewage water after the disposal of effluents from the leather complex. Results in Table 3 showed that the concentration of both Cr and Al were almost constant over the period of three months at the site about 2 km upstream of the leather complex. The concentration of Cr decreased in the sample collected from about 500 m upstream of leather complex. This was due to dilution effect caused by the mixing of domestic sewage between these two sites. At the site 200 m down stream of the leather complex the content of Cr increased many fold indicating that effluents of leather complex contains a lot of Cr and its disposal into the sewage drain caused this increase. The content was again decreased in sampling taken 2 km downstream of the leather complex due to settling of some of the elements at the base of the drain. The increase in content of Al down stream of the leather complex also indicated the presence of some units in the leather complex dealing with aluminum products. Over the periods of time the content of Cr and Al varied to much extent. February sampling contained the highest content, indicating the release of effluents some time before the sampling. This further show that large amount of effluents is stored in big tanks and is released to the sewage drain without treatment. The most dangerous period for irrigation with these waters is after the disposal of LC effluents in to the sewage drain. The farmers should be watchful about the release of these effluents and should not irrigate their fields after the release of effluents in the sewage drain at least for few days.

The date in Table 3 further revealed that treatment plant installed at the complex is very effective in lowering down the content of pollutant elements. The content of Cr was decreased from 21.0 μg $ml^{-1}$to 0.80 μg ml^{-1}after the operation of the treatment plant. However the high content of Cr in sewage drain indicates that treatment plant is not being operated regularly and affluent are thrown into the drain untreated.

Table 3 Concentrations of Cr and Al in the effluents of sewage drain during different months.

Sampling month	Sampling site	Cr (μg mL^{-1})	Al (μg mL^{-1})
December	2 km upstream of LC	2.74	2.82
	500 m upstream of LC	2.58	3.24
	200 m downstream of LC	8.42	6.00
	2 km downstream of LC	7.3	2.20
January	2 km upstream of LC	2.82	3.84
	500 m upstream of LC	2.34	4.24
	200 m downstream of LC	10.0	2.52
	2 km downstream of LC	6.43	1.97
February	2 km upstream of LC	3.13	2.94
	500 m upstream of LC	2.71	2.35
	200 m downstream of LC	31.6	12.8
	2 km downstream of LC	20.4	3.4
Before operation of treatment plant		21.0	3.18
After operation of treatment plant		0.80	1.22
Maximum tolerance limit		0.11	NA

Incidentally Municipal Corporation of Jalandhar had taken the project of cleaning the drain. So the settled material along with soil was removed from the drain few months back and placed at the bank of the drain. Samples of this material were collected and were also analyzed for Cr and Al content. The results (Table 4) gave the similar trend as were reported for sewage water. This confirmed the release of toxic elements from the Sewage complex and the water does not carry all these element away and some of these were settled down at the surface of the drain. The high content of Cr and Al in primary sludge also indicated that most of the pollutant elements are removed from the water and are concentrated in the sludge.

Table 4 Concentrations of Cr and Al in the material settled at the bottom of the drain and mixed with soil during cleaning operation of the drain and primary sludge of the Leather complex.

Sampling site	Cr (mg kg^{-1})	Al (mg kg^{-1})
2 km upstream of LC	7.9	3.2
500 m upstream of LC	5.5	7.8
200 m downstream of LC	37.8	10.1
2km downstream of LC	27.0	2.4
Primary Sludge	37.0	8.3

LC = Leather Complex

Effect of sewage effluents on the content of elements in soils

Nutrient potential of available sewage in India has been estimated to be 3.2 million tones of N, 1.4 million tones of P and 1.9 million tones of potash per annum with an economic value of about Rs.2,600 million rupees. It can also increase the irrigated command area by 1.1 million ha (Jurwarkar *et al.,* 1991). However, the excessive organic and inorganic loading beyond the capacity of soil to assimilate may cause problems in the state like Punjab, where farmers irrigate their field quickly with sewage water especially during summer months. Out of all the three cities the Ludhiana is the most industrialized city. Comparison of the data in Table 5 also shows that the soils irrigated by wastewater of Ludhiana are the most polluted soils. The range and average content of all the elements is higher in soils irrigated by sewage of Ludhiana City.

Analysis of the soil samples collected from fields growing berseem (Egyptian clover), spinach and coriander and irrigated by ground and sewage waters (Sharma and Kansal, 1986) also showed (Table 6) that soils irrigated by sewage water had accumulated much higher contents of all the elements as compared to ground water irrigated soils.

Soils irrigated by waters of non-industrialized and industrialized cities behaved differently with respect to build up of pollutant elements. The build up of micronutrients (Cu and Zn) was similar under both type of cities, however the content of pollutant elements (Pb and Cd) increased at alarming rate in soils irrigated by wastewater of industrialized cities only (Singh and Kansal, 1983). These results again indicated the need for treatment of sewage water of industrialized cities whereas sewage of non-industrialized cities can directly be used for irrigation.

Table 5 Content of micro and potentially toxic elements in soil irrigated by sewage and ground water around three big cities of Punjab.

Range & SD	Elements (mg kg $^{-1}$)									
	Fe		Mn		Zn		Ni		Pb	
	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW
	Ludhiana (Number of sites 34)									
Min	4.9	6.8	3.2	4.0	1.2	4.0	0.24	0.72	0.68	1.86
Max	32.0	148.6	14.0	64.0	12.0	37.4	1.65	7.20	1.58	7.32
Mean	12.8	49.2	8.4	25.4	5.6	11.9	0.78	3.58	1.09	3.21
SD$\pm$	7.8	36.7	3.6	19.3	3.2	5.9	0.53	2.17	0.33	1.10
	Jalandhar (Number of sites 34)									
Min	5.4	5.6	3.5	5.6	0.8	3.4	0.09	0.08	0.58	0.74
Max	21.5	61.2	10.9	30.4	10.2	23.0	1.46	3.72	1.32	3.80
Mean	12.9	25.9	6.1	14.9	4.6	10.4	0.72	1.31	0.95	2.24
SD$\pm$	5.0	13.8	2.2	7.1	2.4	6.2	0.44	1.06	0.26	1.06
	Amritsar (number of sites 35)									
Min	5.9	5.9	3.9	3.9	0.9	4.4	0.15	0.52	0.60	1.58
Max	24.8	24.8	12.4	12.4	9.8	25.9	0.62	2.85	1.60	6.20
Mean	13.6	13.6	7.0	7.0	3.8	10.0	0.26	0.99	0.98	2.99
SD$\pm$	6.2	6.2	2.8	2.8	2.8	5.3	0.14	0.54	0.34	1.19

GW= Irrigation with ground water & SW= Irrigation with sewage water

Table 6 Average content of DTPA extractable heavy metals in sewage and tubewell irrigated soils.

Crop	Average content in soils (mg kg $^{-1}$)					
		Cu	Fe	Mn	Zn	Cd
Berseem	GW	7.8	38.0	28.4	4.2	0.074
	SW	24.4	75.3	33.2	13.4	0.119
Spinach	GW	7.0	59.4	24.4	4.2	0.079
	SW	32.2	65.6	28.8	41.2	0.253
Coriander	GW	9.5	32.4	18.4	6.6	0.054
	SW	49.4	69.0	23.0	21.1	0.208

Table 7 Effect of Sewage and ground water irrigation on DTPA extractable metals in soil (mg kg $^{-1}$) in different cities of Punjab

Cities	Average content in soils (mg kg $^{-1}$)							
	Cu		Zn		Pb		Cd	
	GW	SW	GW	SW	GW	SW	GW	SW
Abohar	0.4	1.53	0.95	3.81	0.35	0.76	0.05	.06
Bathinda	0.4	1.67	0.98	2.75	0.20	0.69	.02	.014
Jalandhar	0.9	1.98	1.82	8.66	0.85	0.89	.05	0.17
Amritsar	0.95	5.59	0.95	7.30	0.50	1.69	.05	0.17
Ludhiana	0.62	3.44	2.13	4.13	0.41	2.07	.06	0.20

To under stand the leaching behavior of elements in soils irrigated by these waters a study was conducted on soils very low on organic carbon and very light in texture. Results compiled in table 8 showed that differences in elemental composition between soils irrigated by sewage water and ground water were significant upto the depth of 30 cm for Cr, Ni, and Cu and upto the depth of 60 cm for Fe, Mn, Zn and Al. This indicates that in low OC and light textured soils accumulation is not restricted only to surface but also the sub surface soils. Therefore both shallow as well as deep-rooted crops will be affected on soils polluted by these elements.

Table 8 Depth wise distribution of various elements in soils irrigated with ground water and sewage water.

Depth (cm)	Water Used	Concentration (mg kg^{-1})							
		Cu	Fe	Mn	Zn	Al	As	Cr	Ni
0-15	GW	o.99	13.8	14.4	2.9	3.6	1.87	0.81	0.56
	SW	4.20	39.7	18.9	14.7	6.5	2.09	1.72	1.27
	S E M & sig	0.88**	7.1**	3.2 NS	2.7**	1.2*	0.23 NS	0.15**	0.15 **
15-30	GW	1.06	10.5	8.2	1.8	2.9	1.72	0.48	0.49
	SW	1.72	25.6	12.1	5.7	5.9	2.01	1.07	0.91
	S E M & sig	0.31*	4.8**	1.5**	1.0**	0.9**	0.24 NS	0.13**	0.09 **
30-45	GW	1.21	6.9	5.4	1.2	1.9	2.10	0.59	0.42
	SW	1.23	14.8	9.7	3.3	3.8	1.67	0.64	0.78
	S E M & sig.	0.24 NS	3.1**	1.4**	0.7**	0,4**	0.32 NS	0.11 NS	0.08
45-60	GW	1.18	6.2	5.7	1.2	1.9	2.20	0.44	0.39
	SW	1.24	14.7	9.3	2.6	3.4	2.23	0.47	0.69
	S E M & sig	0.24 NS	3.2**	1.5*	0.6*	0.4**	0.27 NS	0.09 NS	0.07 **

Effect of sewage effluents on the concentration of elements in plants

Irrigation by sewage by waters containing sewage effluents increased the content of elements not only in soils but also in plants. However, the accumulation was not proportional in soils and plants. The soil therefore acts as a buffer and did not allow the absorption of elements in plants in proportion to their accumulation in soils. For pollutant element such as Ni the increase in accumulation due to irrigation was to the extent of 1512 per cent in soils as compared to 84 per cent in leaves and 87 percent in curds of cauliflower (Table 9). Another important fact was that edible part (Curd) has greater tendency to accumulate pollutant elements as compared non-edible parts such as leaves.

Higher concentration of almost all the elements have also been reported in cauliflower Brar and Arora (1997) and in potato Brar *et al.* (2000) in soils irrigated by sewage water containing untreated effluents discharged by different industries at Ludhiana and Jaladhar, respectively.

Table 9 Average content (mg kg $^{-1}$) of elements in soil, leave and curds of cauliflower irrigated by groundwater (GW) and sewage water (SW).

Nutrients	Soil			Leaves			Curd		
	IGW	ISW	% increase	IGW	ISW	% Increase	IGW	ISW	% Increase
Cu	5.1	18.1	255	3.6	4.1	14	4.4	4.9	11
Fe	8.6	29.8	246	101.0	149.0	47	114.0	149.0	31
Mn	9.9	11.8	19.2	29.9	33.7	13	19.8	22.6	14
Zn	3.6	21.4	494	31.6	39.5	25	39.3	49.0	25
Ni	0.08	1.29	1512	0.57	1.05	84	1.03	1.93	87
Pb	1.54	5.12	232	1.28	0.97	-	1.47	1.87	27

Problems in use of waste waters

Many agencies in different countries have fixed their own standards and no uniform standards are available. The other fact being ignored is that even in soils with high load of toxic elements but these may not be toxic to the plants due to their low availability. There may be a lot of variation in mineralization, volatilization and movement of these elements under tropical and temperate/humid climates. To work out the toxic limits, the inorganic form of elements has been applied. But in sewage effluents, most of the elements are in organic combinations. Invariably the amounts available from the organic combinations is only a fraction of the amount available from inorganic forms. The toxicity will further depend upon the total intake of elements by human/animals. Since source of vegetables is not same for every day, same vegetable is not consumed every day and processing of the vegetables such as washing, peeling and discard of some parts further reduces the chances of toxicity. The only concern is the industry from where very high quantities of toxic elements are discharged, which must be pre treated. Unless strong evidence of toxicity through heavy elements is available, it may not be proper to prevent the use of this valuable source of water and nutrients. Under site specific situations the wastewater must be pre treated before its discharge into the sewage system.

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