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Impact of Sewage and Industrial Effluents on Soil-Plant Health

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1. Introduction

Effluent irrigation has been practiced for centuries throughout the world (Shuval *et al.*, 1986; Tripathi *et al*., 2011). It provides farmers with a nutrient enriched water supply and society with a reliable and inexpensive system for wastewater treatment and disposal (Feigin *et al.*, 1991). In India also being a cheap source of irrigation farmers are applying this water to their fields. Rapid industrialization, population explosion and more urbanization in India have created enormous problems of environmental pollution in terms of generating the variable quantity and quality of solid and liquid wastes. In developing countries, there has not been much emphasis on the installation of sewage treatment plants and all the industrial effluents are generally discharged in to the sewage system. The sewage waters are used as potential source irrigation for raising vegetables and fodder crops around the sewage disposal sites which are directly or indirectly consumed by human beings. Soil contamination by sewage and industrial effluents has affected adversely both soil health and crop productivity. Sewage and industrial effluents are the rich sources of both beneficial as well as harmful elements. Since some of these effluents are a rich source of plant nutrients, therefore soil provides the logical sink for their disposal. But many untreated and contaminated sewage and industrial effluents may have high concentration of several heavy metals such Cd, Ni, Pb and Cr (Arora *et al*., 1985; Narwal *et al.,* 1993). Their continuous disposal on agricultural soils has resulted in soil sickness (Narwal *et al.,* 1988**)** and accumulation of some of the toxic metals in soil (Adhikari *et al.,* 1993; Antil & Narwal, 2005, 2008; Antil *et al.,* 2004, 2007; Gupta *et al.,* 1986, 1994, 1998; Kharche *et al.,* 2011; Narwal *et. al.,* 1993) which may pose serious human and animal health. Ground water in Punjab has been contaminated by Hg and Pb to such an extent that it is causing DNA of the people, who drink it, to mutate (Bajwa, 2008). The present chapter, therefore, discusses the composition of sewage and industrial effluents in India and their possible effect on soil-plant health.

2. Sewage water

Raw sewage water available from cities is a mixture of domestic, commercial and industrial activities. Currently more than 450 cities in India generate more than 17 million cubic meters of raw sewage water per day (Bijay-Singh, 2002). Since the raw sewage water is rich in organic matter and essential nutrients, sewage farming is quite common in all urban areas.

In the country as a whole, about 200 sewage farms, covering as area of about 50,000 ha, are utilizing sewage waters to supplement the nutrients and water supply. Some city sewage waters where industrial effluent is discharged in to sewer system may contain toxic metals in high amounts. Thus the composition of domestic sewage may be changed with the type of industries discharging their effluents.

2.1 Composition of sewage water

The composition of sewage water is quite variable depending upon the contributing source, mode of collection and treatment provided. Although a large proportions of these sewage waters is organic in nature and contains essential plant nutrients but sometimes toxic metals are also present in appreciable amounts. The sewage water generated in India contains more than 90% water. The solid portion contains 40-50% organics, 30-40% inert materials, 10-15% bio-resistant organics and 5-8% miscellaneous substances on oven dry weight basis (Antil & Narwal, 2008).

The chemical composition of sewage waters varied from site to site which was in accordance with the type of industries discharging their effluents. Some city sewage waters where industrial effluent is discharged in to sewage system may contain toxic metals in high amounts. Many investigations have found variations in pH, electrical conductivity (EC), suspended solids, organic C, CO_3, HCO_3, Ca^{++}, Mg^{++} and other essential and toxic elements in the sewage water from Indian cities. The pH of the sewage water of different cities ranged from 7.2 to 8.3 (Table 1) and it was within normal range and irrigation with these waters in not going to cause any significant change in the soil pH due to high buffering capacity of the soils. The EC of sewage waters collected from different cities varied from 1.1 to 3.8 dS m^{-1} and their continuous use in the agricultural fields may cause increase in salinity of the soils and ultimately restricting the plant growth. Organic C content of sewage waters of different cities ranged from 59 to 480 mg L^{-1} being lowest in sewage water from Bhatinda and highest in sewage water of Gurgaon. Since organic C has a direct relationship with biochemical oxygen demand (BOD), their harmful effects may be due to high BOD values. The sodium absorption ratio (SAR) ranged from 0.8 to 10.4 m $mol^{-½}L^{-½}$ and some of these waters are not suitable for irrigation. Apart from these properties, the sewage waters contained appreciable amount of N, P and K. However, their content in sewage water varied from city to city. The amounts of N, P and K in sewage waters ranged from 8 to 106, 4.2 to 53 and 19 to 2500 mg L^{-1}, respectively.

Sewage waters of many cities also contained appreciable amounts of micro-nutrients and toxic metals. In general the content of heavy metals was higher in cities of Haryana and West Bengal than cities of Punjab (Adhikari *et al*., 1997; Gupta & Mitra 2002; Gupta *et al*., 1986; Narwal *et al,*. 1993; Singh & Kansal, 1985a). The Zn, Mn, Fe, Cu, Pb, Cd and Ni of different cities of Haryana varied from 2.8 to 11.0, 1.6 to 15.0, 5.6 to 205, 0.6 to 1.9, 1.5 to 40, 0.15 to 5.80 and 1.0 to 6.4 mg L^{-1}, respectively (Table 2). The wide variation in metal content of sewage water of different cities is a reflection of variability of sources of metals entering in the sewage system. Arora *et al.* (1985) and Tiwana *et al.* (1987) also reported wide variation in the concentration of heavy metals in sewage water collected from different outlets of Ludhiana city. The concentration of Cr in sewage water of Ludhiana city was found one thousand times higher than that of New York City.

Location	pH	EC(dSm^{-1})	Organic C (mgL^{-1})	SAR (m mol$^{-½}$L$^{-½}$)	N (mg L^{-1})	P (mg L^{-1})	K (mg L^{-1})
Haryana							
Faridabad	7.5	3.8	180	10.0	35	20	110
Gurgaon	7.4	3.8	480	10.1	50	35	275
Bahadurgarh	7.2	3.6	90	4.6	8	53	388
Hisar	7.4	2.1	105	10.4	106	25	294
Panipat	8.2	1.6	15	0.8	61	18	2500
Sonepat	7.7	2.6	30	0.9	71	17	2125
Punjab							
Abohar	8.3	1.4	200	ND	29	4.2	46
Bhatinda	7.8	3.0	59	ND	17	5.6	60
Jalandhar	7.9	1.1	117	ND	38	7.6	35
Amritsar	7.2	1.7	108	ND	34	8.4	42
West Bengal							
Calcutta	8.0	2.0	ND	2.9	ND	7.0	20
Dhapa	7.8	1.2	ND	2.9	ND	ND	19

ND – Not determined
Source (Adhikari *et al.,* 1997; Narwal *et al.,* 1993, 2002; Singh & Kansal, 1985a)

Table 1. Chemical composition of sewage water of some cities of India.

Location	Zn	Mn	Fe	Cu	Pb	Cd	Ni
Haryana							
Faridabad	4.2	1.6	5.6	1.0	3.0	0.48	2.0
Gurgaon	2.8	3.2	25	0.6	2.5	0.15	1.0
Bahadurgarh	5.0	5.6	34	0.8	1.5	0.15	1.0
Hisar	10.0	15.0	145	1.9	38.0	5.80	2.8
Panipat	11.0	14.0	205	1.7	38.0	5.60	3.4
Sonepat	10.0	14.0	66	1.7	40.0	5.60	6.4
Punjab							
Abohar	0.14	0.10	1.6	0.09	0.03	0.01	ND
Bhatinda	0.20	0.14	2.9	0.35	0.04	0.01	ND
Jalandhar	0.38	0.23	5.3	0.37	0.09	0.02	ND
Amritsar	0.31	0.30	4.1	0.18	0.06	0.01	ND
West Bengal							
Calcutta	0.30	0.66	656	0.07	2.9	1.3	58
Dhapalock	ND	2.3	ND	3.35	18.0	3.8	ND

ND – Not determined
Source (Adhikari *et al.,* 1997; Gupta & Mitra, 2002; Gupta *et al,.* 1986; Narwal *et al.,* 1993; Singh & Kansal, 1985a).

Table 2. Heavy metal content (mg L^{-1}) in sewage water of some cities of India.

The composition of sewage waters is not constant and changes within the year due to several factors. The extent of the contaminants will be least during the rainy seasons. During the same year, the pH of the sewage water of one location of Hisar varied from 7.3 to 8.7 and EC from 0.52 to 1.55 dSm^{-1} (Antil & Narwal, 2008). The variation in the composition of sewage water within season has also been reported by Singh & Kansal (1985b) for different cities of Punjab. The concentration of metals in sewage water is season specific (Adhikari *et al.*, 1994). For example, Pb content varied from 8.1 to 30 mg L^{-1} during monsoon and 11.0 to 41.3 mg L^{-1} during summer. Similarly, Cd ranged from 4.0 to 22.0 mg L^{-1} in summer season while it was not detected during monsoon and Cr content in raw sewage during summer was 7.2 mg L^{-1} while in monsoon it was 1.6 mg L^{-1}.

Kharche *et al*. (2011) found that the pH of sewage waters of Ahmednagar city of Maharashtra was neutral to slightly alkaline (7.4 to 8.4) which was within safe limits of 6.0 to 8.5 as suggested by United States Salinity Laboratory staff (USSL) (1954). The EC (0.97 to 1.77 dS m^{-1}), BOD (100-210 mg L^{-1}), chemical oxygen demand (COD) (700-940 mg L^{-1}), total dissolved solids (400-1200 mg L^{-1}) values of effluents were higher than the recommended limits prescribed by FAO (1985). The concentration of Fe (4.81-7.26 mg L^{-1}), Mn (0.45-1.17 mg L^{-1}), Zn (0.63-2.00 mg L^{-1}), Cu (0.024-1.18 mg L^{-1}) and B (2.11-5.75 mg L^{-1}) was higher in sewage effluents indicating that they are good source of plant micronutrients which may help in mitigating emerging problems of their deficiency that are otherwise overcome by application of costly chemical fertilizers (Kharache *et al*., 2011). However, their concentrations in sewage effluents was higher than the recommended maximum concentration suggested by Indian Standards (1982) and FAO (1985) (Table 3) indicating that they can lead to contamination of soil and may be potentially toxic for plants, human and animal health.

Heavy metal	*Recommended maximum concentration
Fe	5.0
Mn	0.2
Zn	2.0
Cu	0.2
B	2.0
Cd	0.01
Cr	0.1
Ni	1.2

Source (*FAO, 1985; Indian Standards, 1982)

Table 3. Recommended maximum concentration (mg L^{-1}) of heavy metals for use of effluents in agriculture.

2.2 Composition of sewage sludge

The agricultural use of sewage sludge has been a common practice in waste disposal in the recent decades. Since it contains plant nutrients and organic matter, sewage sludge may be beneficial to soils and their productivity. However, depending on its source, sewage sludge often contains considerable amount of toxic metals and organic toxicants. The presence of toxic metals in sewage sludges collected from different treatment plants of some cities of India has also been reported by Adhikari *et al.* (1993) and Jurwarkar *et al*. (1991). The contents of Cd, Cr, Ni and Pb varied from 1.5 to 8.3, 17.3 to 176.2, 11.7 to 191.5 and 14.3 to 200 mg L^{-1}, respectively (Table 4).

The Central Pollution Control Board (CPCB) formulated a Ganga project in 1984 to clean the water of Ganga river. This project aimed at the installation of sewage treatment plants at various sites along Ganga river in the important cities and towns. Cities selected for the installation of sewage treatment plants include 26 cities in Uttar Pradesh, 15 in Bihar and 59 in West Bengal have been identified as the worst polluting cities because they contribute 84% of the total pollutants of the Ganga. Similarly under Yamuna Action Plan, sewage treatment plants have been installed at Yamunanagar, Karnal, Panipat, Gurgaon and Faridabad in Haryana. The chemical composition of sewage sludge indicates that that it contains appreciable amount of useful plant nutrients but at the same time also contain toxic metals (Table 5). So that the continuous use of sewage sludge may result in accumulation of toxic metals in the soils. Thus, it should be used carefully and soil must be monitored continuously to prevent the entry of toxic metals in food chain.

Name of city	Cd	Cr	Ni	Pb
Allahabad	3.5	60.4	32.3	76.8
Delhi	1.5	82.0	191.5	41.7
Nagpur	1.5	49.2	14.8	24.3
Madras	8.3	38.5	60.5	16.5
Kanpur	0.6	17.3	11.7	14.3
Jaipur	7.3	176.2	37.5	66.0
Pagladanga	4.0	101.0	ND	200.0
Topsia	2.0	101.3	ND	185.0

Source (Adhikari *et al.,* 1993; Jurwarkar *et al.*, 1991).

Table 4. Heavy metal (mg kg^{-1}) content of sewage sludge of some cities in India.

Element	Range	Mean	Element	Range	Mean
N (%)	0.75-1.32	1.06	Mn (mg kg^{-1})	154-721	259
P (%)	0.31-2.31	0.68	Fe (mg kg^{-1})	3263-12606	8139
K (%)	0.22-1.67	0.50	Cu (mg kg^{-1})	24-2050	460
S (%)	0.29-1.94	1.00	Pb (mg kg^{-1})	14.7-139.7	73.2
Ca (%)	1.00-4.33	2.48	Ni (mg kg^{-1})	4.1-624.2	123.7
Mg (%)	0.39-0.78	0.59	Cr (mg kg^{-1})	10-3796	715
Zn (mg kg^{-1})	100-4835	1376	Cd (mg kg^{-1})	1.02-6.88	3.56
Cr (mg kg^{-1})	10-3796	715	Cr (mg kg^{-1})	10-3796	715
Cd (mg kg^{-1})	1.02-6.88	3.56	Cd (mg kg^{-1})	1.02-6.88	3.56

Source (Antil & Narwal, 2005)

Table 5. Composition of sewage sludge from various locations in Haryana (n=8).

2.3 Effect on soil properties

In India, land around the cities receiving sewage waters containing both the domestic and the industrial wastes. These wastes are suitable for crop production provided the content of major plant nutrients is high and that of toxic elements is low. Its long-term application would affect the physical, chemical and biological properties of soils (Antil *et al.*, 2007).

2.3.1 Physical properties

The bulk density of soils irrigated with sewage water was low (1.2 to 1.39 Mg m^{-3}) as compared to those for the well-irrigated soils (Table 6). The hydraulic conductivity was also higher (1.10 to 1.33 cm h^{-1}) for sewage irrigated soils.

Soil depth (cm)	Soil physical property			
	Bulk density (Mg m^{-3})	Hydraulic conductivity (cm hr^{-1})	Water retention (%)	
			33 kPa	1500 kPa
	Sewage-irrigated soils			
0-30	1.28 (1.20-1.36)	1.22 (1.12-1.33)	43.2 (40.0-46.4)	15.4 (13.2-17.2)
30-60	1.30 (1.22-1.39)	1.19 (1.10-1.28)	45.5 (42.0-49.4)	18.5 (17.3-19.8)
	Well-irrigated soils			
0-30	1.40 (1.39-1.41)	1.12 (1.10-1.15)	38.0 (38.0-38.0)	13.4 (12.8-14.0)
30-60	1.38 (1.34-1.41)	0.94 (0.90-0.98	42.6 (40.8-44.4)	15.7 (14.6-16.8)

Source (Kharche *et al.*, 2011)

Table 6. Mean values of physical properties of sewage- and well- irrigated soils.

Mathan (1994) recorded significantly lower bulk density and increased hydraulic conductivity in sewage farm soils with sewage irrigation for 15 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), however, reported that the application of sewage reduced the hydraulic conductivity of soils due to pore clogging by suspended solids. 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 waters.

2.3.2 Chemical properties

With the continuous long-term application of sewage water to field crops some of the heavy metals may get accumulated in the soil profile and may limit plant growth. Even domestic sewage water from household and dairy effluents application for longer times drastically reduced the hydraulic conductivity of the soil, increased the pH, EC, DTPA extractable and total Zn, Mn, Fe, Cu, Cd, Ni and Pb (Narwal *et al.*, 1988). Singh & Kansal (1985b) also postulated the problems like sickness, salinity and alkalinity in Punjab where farmers irrigate their fields too often with sewage water especially during summer season. Several studies conducted in India revealed that irrigation with sewage water had a profound effect on chemical properties of soils (Table 7). The pH of the soil decreased with sewage irrigation at all the locations. The decrease of about one unit in pH with sewage water irrigation was observed in soils of Haryana (Narwal *et al.*, 1993), but such large decrease in pH of the soils in Punjab was not seen. Higher reduction in pH of Haryana soils was due to the low pH of sewage water applied. The EC of the soils increased at all the locations because of high EC of sewage waters. The EC of Bahadurgarh (9.74 dSm^{-1}) and Faridabad (4.26 dSm^{-1}) were higher than the soils of other cities and it may be due to presence of high salt content of sewage water of these cities. This indicated that long-term use of sewage waters may develop the salinity problem and ultimately will render the soils unproductive due to high amounts of salt accumulation.

The organic C of the soil increased with sewage irrigation owing to the presence of C in sewage waters at all the location. However, highest increase in C content of soil was observed at Faridabad. Loehr *et al.*, (1979) and Narwal *et al.* (1988) reported that the long-term application of sewage water or dairy effluents of high organic matter resulted in soil sickness due to poor aeration and higher BOD. These results indicated that unwise use of sewage waters may deteriorate the soil physical environment due to accumulation of salts and poor soil aeration. The concentrations of heavy metals at all the locations increased with the sewage water irrigation. Gupta *et al.* (1986) and Narwal *et al.* (1993) found that the application of sewage water on agricultural land for long period increased the total content of Zn, Mn, Cu, Pb, Ni and Cd in soils of Haryana (Table 8). The extent of increase in metal content was higher in Sonipat soil which received sewage irrigation for 15 years. The results indicate that amounts of Cd increased four times and that of Ni three times in sewage irrigated soils. This increase was mainly due to mixing of Cycles industry effluent in the sewage system.

Location	pH		EC (dS m^{-1})		Organic C(%)	
	TW	SW	TW	SW	TW	SW
Haryana						
Faridabad	8.22	7.20	0.46	4.26	0.57	2.52
Gurgaon	8.10	6.95	0.33	3.04	0.42	0.53
Bahadurgarh	8.10	7.35	2.21	9.74	0.30	0.36
Hisar	8.26	8.37	0.19	0.23	1.02	1.50
Panipat	8.45	8.55	0.19	0.32	0.38	0.87
Sonepat	8.70	7.94	0.06	0.65	0.18	0.39
Punjab						
Abohar	8.47	8.19	0.66	0.78	0.37	0.72
Bhatinda	8.38	8.45	0.57	0.66	0.23	0.60
Jalandhar	8.35	7.59	0.19	0.31	0.31	1.09
Amritsar	8.24	7.94	0.23	0.97	0.45	1.16

TW – Tube well-irrigated soil, SW – Sewage-irrigated soil
Source (Brar *et al.*, 2000; Narwal *et al.*, 1993, 2002; Singh & Kansal, 1985b)

Table 7. Effect of sewage irrigation on chemical characteristics of soils.

Location	Duration of sewage irrigation (year)	Micronutrients			Toxic metals		
		Zn	Mn	Cu	Pb	Ni	Cd
Faridabad	0	85	350	25	37	33	1.9
	10	158	370	68	50	34	1.9
Gurgaon	0	83	340	25	25	42	1.9
	10	83	340	25	25	42	1.9
Bahadurgarh	0	65	310	16	25	33	1.9
	15	75	325	25	38	50	1.9
Hisar	0	8.26	8.37	0.19	0.23	1.02	1.50
	20	205	609	71	51	54	2.9
Panipat	0	140	656	37	40	48	3.4
	10	175	656	51	48	46	2.4
Sonepat	0	91	281	14	20	26	0.8
	15	183	406	52	32	72	3.2

Source (Gupta *et al.*, 1986, 1998; Narwal *et al.*, 1993)

Table 8. Effect of sewage effluent irrigation on total metal content (mg kg^{-1}) in soils of Haryana.

Build up of heavy metals in sewage water irrigated soils at other cities has also been reported. Mitra & Gupta (1997) has reported 143 times more accumulation of Cd in sewage effluent irrigated soils around Calcutta over non-sewage irrigated soils, followed by Zn (47 times), Pb (18.5 times), Cr (5.6 times), Co (3.9 times), Cu (3.6 times), Fe (2.4 times) and Ni (2.3 times). In soils of cultivated fields of Durgapur Industrial Belt (DIB) of West Bengal (comprising of steel plants, chemical factories, pharmaceuticals, fertilizer factory and hundreds of auxiliary factories) total Zn, Cu, Cd and Pb contents varied from 200 to 570, 24 to 69, 3 to 9 and 53 to 324 mg kg^{-1}, respectively (Antil & Narwal, 2008). In agricultural lands around Ludhiana city, increase in total Cd, Ni and Co contents of sewage effluent irrigated soils was 36, 86 and 46% over tube well irrigated soils (Azad *et al.,* 1986).

The effect of long-term irrigation with sewage effluents on available metal status of agricultural soils has also been reported at various places. Singh & Kansal (1983) reported that the use of sewage water for irrigation substantially increases the accumulation of DTPA extractable Zn, Cu, Pb and Cd in soils of different cities of Punjab. The accumulation was higher in soils receiving sewage water of industrial cities (Table 9).

Under Keshopur effluent irrigation system of Delhi, the DTPA extractable Zn, Cu, Fe and Ni has increased by 253, 202, 237 and 153%, respectively in effluent irrigated soils as compared to that of tube well irrigated soils in two decades (Rattan *et al*., 2001). Kharche *et al.* (2011) found that the total content of Fe, Mn, Zn, Cu, Cd, Cr and Ni in the soils irrigated with sewage water for more than three decades was 1.05, 1.24, 3.98, 1.51, 2.10, 1.62, and 1.24 times higher as compared to their content in the well-irrigated soils. Although, the concentration of heavy metals in the sewage-irrigated soils is below the maximum permissible limits as given by Department of Environment (1989) and Kabata & Pendias (1992), but it can be observed that these soils expected to approach these critical concentration in few years from now and may become toxic on accumulation of these metals

Location	Zn		Cu		Pb		Cd	
	TW	SW	TW	SW	TW	SW	TW	SW
Abohar	0.95	3.69	0.40	1.53	0.35	0.76	0.05	0.06
Bhantinda	0.98	2.75	0.40	1.67	0.20	0.69	0.02	0.04
Jalandhar	1.82	5.66	0.90	1.98	0.85	0.89	0.05	0.17
Amritsar	0.95	7.30	0.95	5.49	0.50	1.69	0.05	0.17
Ludhiana	2.13	4.13	0.62	3.44	0.41	2.57	0.06	0.20

TW – Tube well-irrigated soil, SW – Sewage-irrigated soil
Source (Singh & Kansal, 1983)

Table 9. Effect of sewage irrigation on DTPA extractable metals (mg kg^{-1}) in soils of Punjab.

by continuous use of sewage (Table 10). In addition, if rather strict criteria of Ontario Canada (Seto & Deangelis, 1978) are considered for categorization soils in polluted category, most of the soils fall under contaminated category with respect to these heavy metals.

Element	Kabata and Pendias (1992)	Department of Environment (1989)	Ontario Canada by Seto and Deangelis (1978)
Cd	3-8	3	3
Ni	100	110	22
Cu	60-125	200	100
Mn	1500-3000	-	1500
Zn	70-400	450	216
Cr	-	400	-

Table 10. Suggested critical soil concentration values (mg kg^{-1}) for phyto-toxicity of heavy metals.

2.3.3 Biological properties

The microbial count in sewage-irrigated soils was higher for bacteria, fungi and actinomycetes which was about 1.34, 1.52 and 1.18 times (for 0-30 cm) higher as compared to that in normal soils, respectively (Table 11). This may be due to the suspended organic material added to soil through sewage which serves as a source of energy for microbial population (Joshi & Yadav, 2005; Seeker & Sopper, 1988).

Soil depth (cm)	Soil microbial count		
	Bacteria (10^6 x g^{-1})	Fungi (10^5 x g^{-1})	Actinimycetes (10^4 x g^{-1})
	Sewage-irrigated soils		
0-30	20.8 (15-26)	10.7 (8-12)	5.33 (4-6)
30-60	19.2 (13-24)	9.3 (7-11)	4.0 (3-6)
	Well-irrigated soils		
0-30	15.5 (15-16)	7.0 (6-8)	4.5 (4-5)
30-60	11.5 (11-12)	6.0 (5-7)	3.5 (3-4)

Source (Kharche *et al.,* 2011)

Table 11. Mean soil microbial counts of sewage- and well-irrigated soils.

2.4 Effect on plants

Several investigators have reported positive effect of sewage irrigation on crop yield. Mahida (1981) obtained higher yields of vegetable crops irrigated with untreated sewage water compared to irrigation with canal water (Table 12). Experiments conducted at National Environmental Engineering Research Institute, Nagpur revealed that the continuous use of untreated sewage for irrigation significantly reduced the yield of wheat, cotton and paddy. However, the use of primary treated sewage proved to be beneficial for both wheat and cotton (Juwarker *et al*., 1991). Application of sewage water resulted remarkable increase on the mean plant height (3.4%), number of tiller/plant (31.8%), length of ear (18.8%) in wheat crop. As a result, straw as well as grain yields also were increased significantly by 43.1 and 34.3%, respectively due to application of sewage water (ISSS Annual Report, 2006-07).

Crop	Source of irrigation	
	Canal water	Sewage water
Beet root	8.75	16.27
Carrot	9.71	11.75
Radish	7.26	8.33
Potato	6.12	9.33
Ginger	6.04	9.80
Knolkhol	9.70	16.57
Cabbage	9.27	12.13
Cauliflower	6.96	9.09
French beans	6.63	8.06
Tomato	10.01	13.38
Tobacco	1.12	1.25
Groundnut	2.88	2.90

Source (Mahida, 1981)

Table 12. Effect of sewage irrigation on yield (t ha^{-1}) of vegetable crops.

The accumulation of some of the usually prevalent heavy metals (Ni, Cd, Cr, Pb etc.) in sewage irrigated soils in different plant parts have been reported. Mitra & Gupta (1999) has reported that the contents of heavy metals in sewage irrigated radish, gourd, spinach and cauliflower around Calcutta were comparatively 2 to 40 times higher than the non-sewage irrigated vegetables. Brar *et al*. (2000) also reported higher accumulation of metals in leaves and tubers of potato grown on sewage irrigated soils as compared with ground water irrigated soils. Leafy vegetables and root crops are known to accumulate higher amounts of heavy metals than grain crops. Other factors like the composition, duration and rate of sewage irrigation, soil types, soil reaction and interaction among metals also affect their uptake. Kansal *et. al.* (1996) collected the plant samples of different crops from sewage irrigated soils and found that these plants contained higher amount of Zn, Mn, Fe, Cu, Cd and Pb than plants from tube well irrigated soils (Table 13). The leafy crops accumulated higher amounts of heavy metals than other crops. The maximum concentration of Mn Cu, Cd and Pb was found in spinach followed by berseem and least was absorbed by wheat. This indicate that selection of a crop which absorbed the lowest amount of heavy metals may prevent the entry of toxic metals from contaminated soils into food chain.

Crop	Source of irrigation	Zn	Mn	Fe	Cu	Cd	Pb
Maize	TW SW	38 53	26 37	128 170	8 12	0.85 1.74	1.98 3.82
Berseem	TW SW	25 46	25 38	293 356	9 15	0.69 1.67	1.93 4.48
Cauliflower heads	TW SW	22 43	11 15	80 117	3 7	0.48 1.80	1.27 1.60
Cauliflower leaves	TW SW	22 33	24 35	91 170	4 7	0.80 2.24	2.69 5.23
Spinach	TW SW	28 44	31 48	270 332	10 15	0.50 2.59	3.29 6.08
Fenugreek	TW SW	40 48	25 35	29 71	12 17	0.64 1.25	ND ND
Coriander	TW SW	37 62	27 29	47 64	8 14	0.85 1.64	ND ND
Wheat	TW SW	34 43	15 24	10 46	8 10	0.45 .82	ND ND

TW – Tube well water, SW – Sewage water, ND – Not determined
Source (Kansal *et al*., 1996)

Table 13. Heavy metal contents (mg kg^{-1}) of various crops grown on tube well and sewage water irrigated soils.

Kharche *et al.* (2011) reported higher concentration of heavy metals in the cabbage plant grown on the sewage-irrigated soils (Table 14). The mean concentration of Fe, Mn, Zn, Cu, Cd, Cr and Ni in cabbage grown on sewage-irrigated soils was about 1.11, 7.51, 1.72, 7.66, 4.36, 1.26 and 1.91 times than their content in well-irrigated soils, respectively. The concentration of heavy metals in cabbage is higher as compared to the suggested permissible tolerance levels (Table 17) as suggested by Council for Agricultural Science and Technology (1976); Melsted (1973) and Naidu *et al.* (1996).

Heavy metal	Concentration (mg kg^{-1})		Suggested tolrent level * (mg kg^{-1})
	Sewage-irrigated	Well-irrigated	
Fe	821.7 (524-1361)	736.5 (702-771)	750
Mn	220.3 (186-263)	29.3 (28.2-30.5)	300
Zn	124.9 (101-159)	72.4 (70.2-74.7)	300
Cu	127.3 (118-138)	16.6 (15.7-17.5)	150
Cd	2.75 (2.25-3.25)	0.63 (0.50-0.75)	3
Cr	2.09 (1.62-2.47)	1.65 (1.55-1.75)	2
Ni	134.7 (123-142)	70.5 (65-76)	50

Source (Kharche *et al*., 2011)

Table 14. Mean heavy metal contents in cabbage plant grown on sewage and well irrigated soils

3. Industrial effluents

With the industrialization of the country a large volume of liquid and solid wastes are generated daily. The quality of these wastes depends upon the nature of the industry and type of treatments given to these waters before their release from factory premises. The use of agricultural for the disposal of industrial effluents is becoming a widespread practice. Such materials may contain various toxic metals that could accumulate in excessive quantities in soils. Also, soil pollution by heavy metals is one of the major environmental problems associated with the application of effluents from industries involved in metal processing (Antil & Narwal, 2008).

3.1 Composition

In India, seventeen categories of heavily polluting industries have been identified by CPCB. They are cement, thermal power plant, distilleries, sugar, fertilizer, integrated iron and steel, oil refineries, pulp and paper, petrochemicals, pesticides, tanneries, basic drugs and pharmaceuticals, dye and dye intermediates, caustic soda, zinc smelter, copper smelter and aluminum smelter. Generally, these industries discharge their effluents into city sewage system, nearby water bodies or adjoining agricultural lands which cause environmental problem. The composition of some of the effluents from different type of industries is quite variable (Table 15). Effluents of Zn smelter and paper mills are acidic in nature having pH 3.5 and 4.8, respectively. The effluents of oil refinery, paper mill, distillery and sugar mill are rich in organic C ranging from 820 to 28350 mg L^{-1}. When such effluents of high BOD are disposed on soils they may develop anaerobic conditions and the soil becomes sick. Highest amount of toxic metals were observed in case of cycle industry effluents compared to the other industrial effluents. Thus, the composition of the industrial effluents varied according to the nature of process for manufacturing and the raw material used. Narwal *et al.,* (1992) found that effluents from cycle industry at Sonipat, Haryana, had high amounts of metals particularly Cu (64 mg L^{-1}) and Ni (30 mg L^{-1}).

Characteristic	Industrial effluent					
	Oil refinery	Paper mill	Distillery	Cycle industry	Spent wash	Zn smelter
pH	6.9	4.8	7.1	7.1	7.2	3.5
EC (dS m^{-1})	0.5	1.2	13.0	4.8	29.0	7.7
C (mg L^{-1})	820	1350	28350	23	2225	ND
N (mg L^{-1})	140	168	42	84	1200	ND
K (mg L^{-1})	0.1	0.5	1576	163	6681	ND
Fe (mg L^{-1})	80	240	459	92	61	0.7
Mn (mg L^{-1})	7.8	16.4	37.9	15	4	ND
Cu (mg L^{-1})	4.0	10.9	19.3	64.0	0.8	13.0
Zn (mg L^{-1})	30.0	6.4	37.9	2.4	1.2	ND
Pb (mg L^{-1})	1.0	3.8	8.7	ND	0.7	ND
Ni (mg L^{-1})	3.0	4.2	6.6	30.0	0.7	ND
Cd (mg L^{-1})	0.1	0.2	0.3	5.4	0.06	0.02

ND – not determined
Source (Antil *et al.,* 2004; Gupta *et. al.,* 1994; Narwal et al. , 1992; Totawat, 1993; Zalawadia *et al.* 1997)

Table 15. Composition of some industrial effluents

Effluents of Zn smelter near Udaipur, Rajasthan, contained the high amount of Zn (13 mg L^{-1}) than the permissible limit (Totawat, 1993). Leather tanning contaminates the soil with Cr, As and B. In Punjab, tannery effluents contained as high as 9.2-13.8 mg L^{-1} of hexavalent Cr. The tannery water in Tamil Nadu had deteriorated the quality of surface and ground water making it unfit for drinking and agriculture. Effluents of electroplating units in Punjab are highly acidic (pH 2.1) and contain high amounts of pollutants like Ni (2.4 to 52 mg L^{-1}), cyanides (0.4 to 4.4 mg L^{-1}). Zalawadia *et al.* (1997) surveyed several industries effluents of Gujarat and also found higher amounts of heavy metals. The release of such effluents on agricultural lands will adversely affect the quality of crops grown on these soils, making unfit for consumption for animals and human beings.

3.2 Effect on soil properties

Industrial effluents when released in the open or on agricultural land contaminate the soil with heavy metals and organic pollutants. The total Pb, Ni, Cd and Cr were higher in soils irrigated with lead battery and distillery industries effluent compared to soils irrigated either with canal or tube well water (Table 16). In case of distillery effluent irrigated soil, about 14 times increase in organic C was observed. It may be because of presence of higher C amounts in distillery effluent samples (Antil *et. al.,* 1999). Lead content was almost 11.5 times more in lead battery effluent irrigated soils as compared to canal or tube well irrigated soils (Mahata & Antil, 2004). The EC, organic C and toxic metal content (Pb, Ni and Cd) of soil increased due to irrigation with cycle industrial effluent (Antil *et al.,* 2004) as compared to tube well irrigated soils (Table 17). Excessive use of cycle industry effluent had converted the productive land to unproductive land and soil became rust colored and fluffy. In this soil, very high amounts of toxic metals were accumulated.

Characteristic	Source of irrigation	
	Lead battery cell effluent	Distillery effluent
pH (1:2 soil:water)	8.5 (8.3)	8.0 (7.2)
EC (1:2) dS m^{-1}	0.31 (0.34)	0.9 (1.1)
Organic C (%)	0.45 (0.40)	0.2 (2.8)
Total Pb, mg kg^{-1}	52.1 (589.9)	0.5* (3.2)
Total Cd, mg kg^{-1}	1.0 (5.0)	0.4* (1.2)
Total Ni, mg kg^{-1}	41.9 (48.3)	0.6* (0.9)
Total Cr, mg kg^{-1}	1.1 (4.4)	ND

Values in parentheses denote the effluents irrigated soils; * - DTPA extractable toxic metals
Source (Antil & Narwal, 2008; Mahata & Antil, 2004).

Table 16. Soil characteristics and toxic metal content (mg kg^{-1}) in soils irrigated with lead battery cell and distillery effluents

3.3 Effect on plants

During the survey of sewage and industrial effluents composition, we found a site at Sonipat which had turned barren due to excessive irrigation with cycle industry effluent. Crops grown on this soil indicated the high accumulation of toxic metal. The health hazard problems due to Ni absorption by crops grown on metal polluted soil was more in carrot

Characteristic	Source of irrigation	
	Tube-well / canal water	Cycle industry effluent
pH	8.7	7.5
EC (dS m^{-1})	0.06	0.16
Organic C (%)	0.18	0.48
Zn	91	12188
Mn	281	281
Fe	15675	72600
Cu	14	1199
Pb	20	280
Cd	0.8	5.4
Ni	26	6000

Source (Antil *et al.* , 2004; Narwal *et al.,* 1992)

Table 17. Soil characteristics and toxic metal content (mg kg^{-1}) in soils irrigated with cycle industry effluent.

followed by spinach, fenugreek and wheat (Table 18). The accumulation of high amounts of heavy metal in plants may influence the consumer's health. The high intake of metals by human affects the body system and may deteriorate the health.

Toxic metal	Shoot			Grain Wheat
	Carrot	Fenugreek	Spinach	
Ni	434	167	300	65
Cd	13.4	5.5	4.5	4.7

Source (Narwal *et al.,* 1992)

Table 18. Toxic metal content (mg kg^{-1}) of different crops grown on polluted soil.

Application of agro-based industrial effluent (Jam and pickle industry) to agricultural lands adversely influenced the germination and growth of different crops (Verma & Kumar, 2004). A significant variation in percent germination of wheat, maize and mustard with respect to different concentration of effluents was observed (Table 19). The germination percentage

Effluent concentration (%)	Germination (%)			Average height of seedling (cm)			Average length of root (cm)		
	Wheat	Maize	Mustard	Wheat	Maize	Mustard	Wheat	Maize	Mustard
0 (control)	100	92	100	27.8	55	20.7	12	25	9.5
25	89	80	90	27.6	49.5	17.4	12.8	20.5	8
50	84	68	69	26.0	47	16.8	10.5	20.1	7.7
75	52	28	38	20.6	45.0	15.0	8.3	19.4	6.8
100	24	23	27	21	40	14.2	4.3	18.9	6.3

Source (Verma & Kumar 2004)

Table 19. Effect of agro-based industrial effluent on germination and development of wheat, maize and mustard crops.

decreased in all the crop plants and inhibition of germination was significant. The high acidic nature of effluent might have decreased the germination. The morphometric analysis showed that the height of seedling and length of root was also reduced with the application of effluent. Thus, effluents must be diluted either with canal water or tube well water to avoid their adverse effect on plant growth.

4. Possible solutions of problems associated with the sewage and industrial effluents

To exploit the sewage waters as a potential source of irrigation and maintain environment, the sewage waters must be diluted either with canal or underground waters to avoid the excessive accumulation of soluble salts in the soils. It will help in maintaining the productivity of agricultural crops without any harmful effect on soil properties.

Entry of heavy metals into food chain can be reduced by adopting soil and crop management practices, which immobilize these metals in soils and reduce their uptake by plants.

Heavy phosphate application and also the application of kaolin/zeolite to soils can reduce the availability of heavy metals.

Application of organic manures can mitigate the adverse effect of the toxic metals on crops. Thus in the soils contaminated with high amount of toxic metals, application of organic manures is recommended to boost the yield potentials as well as decrease the metal availability to plants.

Raising hyper accumulator plants (mustard/trees) in toxic metals contaminated soils is recommended to avoid the entry of toxic metals in the food chain.

The sewage/industrial effluents, sludge and the soils must be monitored continuously to avoid the excessive accumulation of toxic metals in the soils and then transfer in the food chain.

There should be strict Government legislation that only those sewage and industrial effluents be used in the fields which are cleaned through sewage and effluent treatment plants.

Highest priorities should be given to proper disposal of solid and liquid effluents from industries for proper land management.

5. Conclusion

The major environmental concern is an urbanizing India relate to high levels of water pollution due to poor waste disposal, inadequate sewerage and drainage, and improper disposal of industrial effluents. The sewage and industrial effluents contain essential nutrients or possess properties which can easily be utilized for irrigating the field crops. But the sewage water of many cities where industrial effluent is mixed in the sewage system contained toxic metals. Continuous use of sewage and industrial effluents irrigation recorded improvement in water retention, hydraulic conductivity, organic C and build-up of available N, P, K and micronutrient status and soil microbial count. The EC although increased due to sewage irrigation, it was within the tolerance limit to cause any soil salinity hazard. The toxic metals like Cd, Cr and Ni were found to be accumulated in the soil and plant due to long-term use of sewage irrigation. Hence, Cd, Cr and Ni are more likely to be the elements that may become health hazards for consumers of the crops grown in sewage-irrigated soils. The concentration of these metals was greater in leafy vegetables than in grain crops. This warrants the potential hazard to soil and plant health suggesting necessity of their safe use after pretreatment to safe guard soil health and reduces the risk of animal and human health hazard. To avoid or delay such problems, continuous monitoring of quality of sewage and industrial effluents available in the country and their impact on soil-plant health is required in order to make use of sewage waters as a cheap potential alternative source of plant nutrients in agriculture. Based on these results the farmers around cities have been alerted about the adverse effects of unwise long-term application of sewage water to crops.

6. Future research needs

Research should be done to study the long-term effects of sewage and industrial effluents on salt and toxic metal accumulation in soils and their effect on soil biological health and crop productivity.

Effect of sewage/industrial effluents and heavy metal pollution in soils should be studied on fixed sites.

Bio-transpiration of the contaminates through farm forestry and the critical concentrations of toxic metals in soil and plants for better animal and human health needs to be initiated.

To develop eco-friendly technology for the use of sewage and industrial effluents to improve crop productivity and soil quality and to protect of quality of farm produce and environment from degradation.

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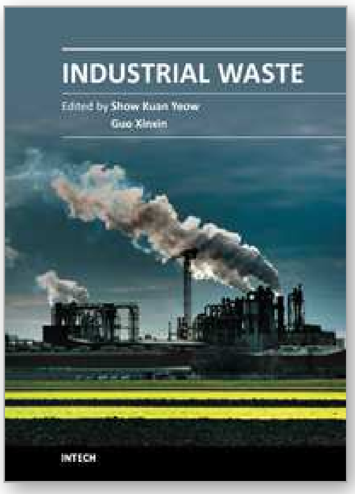

Industrial Waste
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This book is intended to fulfil the need for state-of-the-art development on the industrial wastes from different types of industries. Most of the chapters are based upon the ongoing research, how the different types of wastes are most efficiently treated and minimized, technologies of wastes control and abatement, and how they are released to the environment and their associated impact. A few chapters provide updated review summarizing the status and prospects of industrial waste problems from different perspectives. The book is comprehensive and not limited to a partial discussion of industrial waste, so the readers are acquainted with the latest information and development in the area, where different aspects are considered. The user can find both introductory material and more specific material based on interests and problems. For additional questions or comments, the users are encouraged to contact the authors.

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