Waste Water Use in Agriculture and Heavy Metal Pollution in Soil-Plant System

[1]MUHAMMAD SHARIF ZIA, [1]MUHAMMAD QASIM KHAN AND [2]MUHAMMAD JAMIL KHAN*

[1]*Faculty of Agriculture, Gomal University, Dera Ismail Khan (NWFP), Pakistan.*

[2]*Department of Soil Sciences, Faculty of Agriculture, Gomal University, Dera Ismail Khan (NWFP), Pakistan.*

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Summary: The use of wastewater (often untreated/ inadequately treated) for irrigation in agriculture has been practiced for many years in arid zones of industrialized as well as developing countries. Farmers mostly use wastewater for growing vegetables and fodder in urban areas because they do not have to use costly fertilizers. The use of wastewater is thus a highly economical option. But this water is loaded with salts, heavy metals and disease causing microorganisms. Continuous use of untreated city effluents for growing of vegetables may result in salinization of soil and accumulation of heavy metals in soil in phyto-toxic concentrations. The intake of contaminated vegetables may prove a health risk. This paper therefore, discusses heavy metal pollution in soil-plant system due to the use of waste water in agriculture.

Introduction

Pakistan is an agricultural country and agriculture is the main stay and lynchpin of its food security and economic stability. Water is life blood of agriculture. About 68 % of the land area of the country falls in arid and semi arid regions where evapotranspiration exceeds precipitation. Rainfall is low, uncertain and erratic. The storage capacity of Mangla and Tarbella dams has been reduced very much due to silting. Underground water is mostly unfit for irrigation. The country is thus experiencing a severe shortage of water for agriculture to meet the food demands of the present 150 million peoples of this country. The population of the country will rise to 350 million by 2050 [1]. In this scenario, the country may face a food crisis because of the non availability of enough water to grow food crops for this population. The situation is likely to be aggravated due to the growing demand of water for non agricultural purposes as result of rapid urbanization and industrialization under rapidly building demographic pressure.

Large amounts of city wastewater and industrial effluents are produced in the country as a result of rapid urbanization and industrialization. The disposal of such waters has become a serious problem. The application of industrial and city effluents to land has become popular during the recent years as an alternative means of treatment and disposal [2].

Effluent irrigation has been practiced for centuries throughout the world especially in many arid and semiarid regions. In Pakistan its reuse is extremely important in the wake of decreasing availability of water for irrigation, high cost of artificial fertilizer and the realization that the nutrients in the water can increase crop production [3]. It provides a reliable inexpensive system for wastewater treatment and disposal [4]. The use of wastewater and sludge may be important for sustainable agriculture as these add organic matter and nutrients to soil [5]. Urban effluents are normally used for raising vegetables in the vicinity of cities [6,7]. Leafy vegetables like cauliflower, cabbage, spinach *etc.* grow well in the presence of sewage water [8] whereas vegetables such as radish and potato are sensitive to sewage water [9,10].

Besides being a useful source of nutrients these effluents often contain high amounts of various organic and inorganic materials and are a potential source of micronutrients and heavy metals depending upon the industry from where these originate [11]. Continuous use of untreated city and industrial effluents for growing vegetables may result in

*To whom all correspondence should be addressed.

accumulation of metals in phyto-toxic concentrations [12,13]. The effluent borne potentially toxic elements are reported to enter the food chain through plant intake [14,15] and may cause health hazard.

In Pakistan information on the quality of various types of effluents, their heavy metal load and impact on soil and plants is scanty. This review paper, therefore, provides information on these aspects.

Compositions and Quality of City Wastewater and Industrial Effluents

Most of the city areas in Pakistan have a large number of open and covered drainage channels that spread within and around the urban land, and carry the city effluents. The compositions of such effluents vary with the source of the effluents.

Major Constituents of Typical Domestic Wastewater

The data in Table-1 shows the level of the major constituents of strong, medium and weak domestic wastewaters. In arid and semiarid countries, water use is often fairly low and sewage tends to be very strong where the concentration of salts, nutrients and solids is much higher than the seepages which are medium and weak [16].

Table-1: Major constituents of typical domestic wastewater

	Constituent/ Concentration mgL^{-1}		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids TDS	850	500	250
Suspended solids	350	200	100
Nitrogen as N	85	40	20
Phosphorus as P	20	10	6
Chloride	100	50	30
Alkalinity as ($CaCO_3$)	200	100	50
Grease	150	100	50
BOD	300	200	100

Table-2: Heavy metal concentration in different city effluent channels, D. I. Khan, Pakistan.

Metals ($mg\ l^{-1}$)	Effluent Channels			
	Army Farm	Chah Mughalwala	Jhok Dhapwali	Critical level Irrigation [1]
Pb	1.20	2.25	1.12	5.00
Cu	2.23	3.11	2.12	0.20
Fe	3.22	3.80	4.23	5.00
Mn	1.10	1.12	1.30	0.20
Zn	2.25	1.56	2.25	2.00

[1] Recommended maximum concentration in irrigation water [18]

Heavy Metals in City Effluents

The data in Table-2 indicates that Fe and Cu were higher than their permissible levels for irrigation in all the three effluent channels of D. I. Khan. Zinc was higher than permissible limits in Army Farm and Jhok Dhap Wali channels, whereas Pb and Mn were much below the permissible limits.

Heavy Metal Ions in Soil – Water – Plant System:

Heavy Metal Ions in Wastewaters

Heavy metals ion composition of the wastewater and effluents tends to vary from city to city and largely depends on the industry of its origin.

The data in Table-3 indicate the heavy elements of city effluent coming from the three big cities of Punjab. The metal ion composition of such effluents varies from city to city. There is variation between sampling sites even in the same city as revealed by data collected during 1994 and 1998 in Faisalabad. The sampling sites of two surveys were different. On the average, the effluents of different cities had higher values of Cd, Cr, Cu and Mn than the maximum permissible concentration for irrigation water. Other metal ions also had concentrations approaching their maximum levels. Heavy ion concentration in effluents of different industries varies depending upon the type of industry (Table- 4).

Concentrations of Mn, Zn, Pb and Ni in effluents of all industries given in table 4 were mostly higher than the permissible critical limits. Especially the concentration of these metal ions was much higher in the effluents coming out from Lyallpur Chemicals. Mn concentration was higher in effluent from Lyallpur Chemicals and Kashmir Ghee Mill as compared to Kohi Noor Textile Mill and Pak Mehr Dying, Pb being the lowest in the effluent of Pak Mehr Dyeing. Metal ion concentrations in city effluents from different sites of Faisalabad city were also found to be different (Table-5).

As it is clear from the data in Table-5, Cd and Mn concentrations in city effluents from the two sites of Faisalabad were higher than their permissible limits. Whereas, the concentration of Co was much lower than the prescribed permissible limit. Continuous use of such effluents for irrigation, over long period may cause accumulation of Cd and Mn up to toxic levels for plant and animal health [24].

Table-3: Metal ion concentration (mg L^{-1}) in city/ industrial effluents of different cities of Pakistan.

Metal Ion	Effluent Sampling						
	Faisalabad[1]	Multan[2]	Lahore[3]	Faisalabad[4]	Mean	Critical disposal[5]	Critical level irrigation[6]
Cd	0.05	ND	0.01	0.01	0.02	0.10	0.01
Cr	ND	0.00	1.30	0.97	0.76	1.00	0.10
Cu	0.46	0.09	1.20	0.19	0.48	1.00	0.20
Fe	1.81	0.86	ND	2.00	1.56	2.00	5.00
Pb	0.51	0.10	1.10	0.12	0.46	0.50	5.00
Mn	1.67	0.04	2.00	0.28	1.00	1.50	0.20
Ni	ND	0.04	0.01	0.44	0.16	1.00	0.20
Zn	ND	0.11	ND	0.10	0.11	5.00	2.00

[1][19], [2][20], [3][21], [4][22], [5][23], [6][18]

Table-4: Heavy metal ion concentration (mg L^{-1}) in effluents of different industries at source [11]

Type of Industry	Metal Ions				
	Cu	Mn	Ni	Pb	Zn
Lyallpur chemicals	0.43	0.83	0.39	0.56	1.28
Kohi-Noor Textile Mill	0.23	0.32	T	0.55	0.17
Pak Mehr Dying	0.50	0.28	0.14	0.34	0.20
Kashmir Ghee Mill	0.23	0.83	0.29	0.54	-
Permissible limits	≤ 0.2	≤ 0.2	≤ 2.0	≤ 5.0	≤ 0.2

Table-5: Heavy Metal Concentration in City Effluents at 2 sites of Faisalabad [8]

Sites	Heavy Metal Ion conc. (mg L^{-1})	No of Samples	Range	Mean	SD
Kernailwala	Cd	5	0.03 - 0.10	0.06	0.030
	Co	5	0.001 - 0.009	0.006	0.003
	Mn	5	0.28 - 0.51	0.39	0.65
Judgewala	Cd	5	0.02 - 0.10	0.68	0.022
	Co	5	0.002 - 0.01	0.007	0.002
	Mn	5	0.30 - 0.48	0.382	0.071

Permissible limits Cd.01, Co 0.05, Mn 0.2 mgL^{-1} [18].

However, concentration of heavy metals in wastewater in Haroonabad was within permissible limits [25]. Thus the metal concentration in the wastewater varies depending upon the source, population of the urban area and distance from the city.

Wastewater Effects on Heavy Metal Ions in Soil

Environmental studies have prompted interest in the determination of metals in surface soil, which can be considered the major recipient of pollutants [26]. Because of their capacity to enter the food chain through soil and plants, metals are considered environmental indicators [27]. Therefore, special attention should be given to heavy metal levels in soil, which are irrigated with wastewater.

Untreated wastewater, when used for growing crops for long periods may lead to the accumulation of heavy metals in soil to toxic levels [26-28]. With the increasing population, especially in cities and expansion of different types of industries, the use of wastewater is increasing and this trend is likely to continue, particularly in the vicinity of urban areas [29-32]. This situation is of growing concern since these metals, once added to the soil, may persist for a long time as they are fairly immobile in soil except under the influence of acid rain which is not the case in Pakistan. These metal ions generally accumulate in the surface soil layer [28] as a result of adsorption on the soil particles. Factors like soil pH, amount of organic matter, redox potential of soils and rate of addition of metals mainly affect their adsorption and retention in soil [33]. Analysis of soil samples from different sites in Faisalabad, where city effluent has been used on urban agricultural soils for growing vegetables for more than 30 years, indicates that these soils have attained concentrations of Cu, Fe, Mn which exceed their critical levels (Table-6).

Table-6: Metal ion concentration (mg kg^{-1}) in some urban soils under city effluent irrigation

Metal Ion	Mean for 4 Sampling Sites	Permissible Critical Level [18]
Cd	0.05	0.31
Cr	2.35	NES
Cu	6.24	0.5
Fe	13.11	5.0
Pb	5.94	13.0
Mn	4.63	1.0
Ni	1.88	8.10
Zn	5.84	1.50

NES: Not established

Higher concentrations of metals (Cu, Mn, Pb and Zn) were recorded in sewage receiving soils than

those irrigated with canal water (Table-7). In India total and DTPA extractable metals (Fe, Cu, Zn, Mn, Pb, Cd and Cr) were comparatively higher in soils being continuously irrigated with city sewage [34].

Table-7: Concentration of Zn, Cu, Mn, Pb (mg kg^{-1}) in soil under cultivation of summer vegetables irrigated with untreated city effluent and canal water, Faisalabad [11]

Irrigation with	Concentration of Metal Ions (mg kg^{-1})			
	Zn	Cu	Mn	Pb
Untreated city effluent	22.5	20.93	6.13	12.85
Canal water	0.69	4.00	4.15	7.57

Soil under cultivation of summer vegetable irrigated with city effluents accumulated very high concentration of Cu, which was several times higher than permissible critical level (Table-8). Accumulation in the surface layer (0-15 cm depth) was much higher than the lower layer (30 -60 cm depth).

Table-8: Copper concentrations (mg kg^{-1}) in soil under cultivation of summer vegetable irrigated with city effluents

Vegetable	Soil Depth cm		
	0 – 15	15 – 30	30 – 60
Egg plant	6.01	2.97	2.02
Okra	5.47	4.76	3.15
Marrow	9.48	1.98	1.20
Spinach	7.74	2.72	1.84

Critical level in soil ~ 0.5 mg kg^{-1} [35].

In D. I. Khan Fe, Mn and Zn in soils irrigated by three city effluent channels were higher than their permissive levels in soil (Table-9). However, Pb in the soils was much lower than the permissive critical level.

Table-9: Metal ion concentration (extractable) in soil under sewage channel irrigation, D. I. Khan, Pakistan.

Metal (mg kg^{-1})	Sewage Channels			
	Army Farm	Chah Mughalwala	Jhok Dhapwali	Critical level Irrigation (mg kg^{-1})
Fe	10.25	11.12	12.25	5.00
Mn	2.25	2.45	2.55	1.00
Pb	3.55	4.12	3.26	13.00
Zn	3.00	6.55	4.56	1.50

Wastewater Effects on Heavy Metals in Plants

We grow all plants on soil. Therefore, soil contaminated with heavy metal ions is likely to affect plant growth and crop quality. This aspect is very important and deserves our special attention, where food crops, especially vegetable are grown on heavy metal contaminated soils. Metal ion uptake is not only affected by plant species and physico chemical characteristics of soil but also by climatic conditions (mainly temperature and rain fall exert considerable effects). Plants grown in a warm environment (25 °C) accumulated substantially higher concentration than those raised in relatively cooler environment (15 °C). Concentration of Cd, Cr, Ni and Zn in spinach, fenugreeks and bitter gourd irrigated with city effluent was always higher than their permissible critical concentration (Table-10). Accumulation of Cd was comparatively much lower than the other metal ions.

Table-10: Heavy metal ion concentration in vegetables irrigated with city effluents in Faisalabad areas [36]

Name of Vegetable	Edible Portion	Cd	Cr	Ni	Zn
		ppm			
Spinach	Leaves	0.04	5.36	12.34	8.72
Fenugreek	Leaves	0.03	6.32	11.35	7.69
Bitter gourd	Fruit	0.04	3.25	10.63	5.89
Critical limit [29]		0.02	1.30	10.00	5.00

Concentrations of Pb and Cr in different parts of summer vegetables irrigated with untreated city effluent were several times higher than the vegetables grown under canal irrigation (Table- 11). The concentration of Cr in spinach roots was much higher than in the leaves, indicating its poor translocation to upper plant parts [37].

Table-11: Heavy metal concentration in summer vegetables under untreated city effluent and canal irrigation, Faisalabad [11]

Vegetable	Pb Concentration (mg kg^{-1}) Dry Weight							
	Under Untreated City Effluent				Under Canal Irrigation			
	Root	Shoot	Leaf	Fruit	Root	Shoot	Leaf	Fruit
Brinjal	28	23	39	30	5	8	8	6
Chilies	27	36	30	105	35	30	26	22
Spinach	33	-	31	-	31	-	19	-
	Cr concentration mg kg^{-1} dry weight							
Brinjal	22	79	16	16	16	9	10	9
Ladyfinger	9	36	18	20	7	7	9	7
Spinach	55	-	16	-	7	-	4	-

In another study, Cu concentration in vegetables irrigated with city effluent was found above permissible critical level (Table-12). Eggplant accumulated highest concentration of Cu, followed by spinach and Okra.

In D. I. Khan, cauliflower and spinach when grown under different effluent concentrations were found to have the following results: - Heavy metals in vegetables were much higher when irrigated with 100% of effluent compared to 50 % effluent concentration and the control (Table-13).

Table-12: Copper concentration in vegetables (mg kg^{-1}) irrigated with city effluent [11]

Vegetable	Plant Parts		
	Leaf	Fruit	Mean
Spinach	28.43	-	28.43
Vegetable marrow	15.25	22.62	18.94
Egg plant	30.10	30.22	30.16
Okra	26.40	26.95	26.68

Permissible concentration in eatable portions ≃ 10 mg L^{-1} [29]

Table-13: Metal ions in vegetable leaves under effluent irrigation, D. I. Khan, Pakistan.

Effluent Concentration	Cauliflower				Spinach			
	Fe	Mn	Pb	Zn	Fe	Mn	Pb	Zn
	mg kg^{-1}							
Control-0 % effluent	8.2	0.13	1.33	1.23	8.20	0.12	2.31	1.21
50 % effluent	12.5	1.78	2.64	2.81	11.50	1.21	2.21	2.54
100 % effluent	13.7	2.10	4.50	3.55	13.70	2.10	4.56	3.55

Source: [17]

As it is clear from data in Table-14, the Fe concentration was the highest in wheat followed by cauliflower. However, mustard and cabbage contained comparatively lower concentrations of Fe. Except for cauliflower, the concentration of Mn is high in cabbage, mustard and wheat. The Copper concentration was the lowest in cauliflower, followed by cabbage and mustard. However, wheat contained the highest amount of Cu. The Zinc concentration was found to be highest in cabbage, followed by cauliflower and mustard. Ni concentration was found to be highest in wheat, closely followed by cabbage and cauliflower. Its highest concentration was found in mustard. The Highest concentration of Cr was found in cauliflower, closely followed by mustard. The Cadmium concentration in the entire crop was almost same with slightly more concentration in wheat. The accumulations of certain heavy metals in wheat and cauliflower specially could get beyond human consumption level if use of sewage sludge effluent is continued. The average / normal concentration of Cd is 0.05 $\mu g\ g^{-1}$ and that of Ni is 260 $\mu g\ g^{-1}$ dry matter respectively [13]. Wheat out of the four plant species can to some extent tolerate the excess limits of heavy metals from contaminated soil and, therefore, can be treated as accumulator plant [38].

Human Health Hazards Related to the Use of Wastewater

Effect of Heavy Metal Ion

The use of industrial wastewater in agriculture and livestock pose a potential risk to health, due to the toxic nature of chemical compounds present in wastewater.

Table-14: Average concentration of heavy metals in different plant species irrigated with wastewater.

Name of crop	Average concentration of metals (mg kg^{-1})							
	Fe	Mn	Cu	Zn	Ni	Co	Cr	Cd
Wheat	529	105	22.0	48.3	8.12	7.34	3.55	1.83
Mustard	374	125	19.7	71.5	5.17	8.80	6.14	1.50
Cabbage	370	130	17.3	75.9	7.65	3.45	5.81	1.65
Cauliflower	384	65	12.3	75.3	7.18	4.87	7.47	1.61

Source: [38]

Much of the urban population in big cities of Pakistan regularly consume the effluent-irrigated vegetables with high concentration of heavy metal ions, continuous use of which will result in toxic levels of accumulation of heavy metals in the human body. Information in Table- 15 indicates how heavy metal accumulation increases in human body over period of time.

Table-15: Metal ion intake in human body on the basis of 1.0 kg wk^{-1} vegetable consumption

Metal Ion	Human Intake of Metal Ion (mg)		
	Week	Month	Year
Cd	0.08	0.3	4
Cr	5.20	22.4	270
Cu	13.77	59.2	716
Fe	195.50	840.6	10166
Pb	3.11	13.4	162
Mn	9.27	39.9	482
Ni	10.59	45.6	551
Zn	8.55	36.8	445

Also several studies have demonstrated adsorption of heavy metals by plants, such as wheat and rice that can affect consumers [39]. An epidemiological evidence was the case of Toyama, Japan, where the population was affected by the ingestion of Cd contained in rice, the origin of this element was a nearby mine that contaminated the irrigation water.

Metal ions once taken up by human body are released and excreted very slowly. Because of their slow and silent action on human health, their effects on human health are rated as a silent epidemic. The effects of different metal ions on human health are

variable. In general, they increase birth defects and certain forms of cancer, and decrease the average weight of children at birth. Some of the ions such as Cd, Cr and Pb, which have high mammalian toxicity are more toxic to human beings than to plants (have medium phytotoxicity). Lead itself is not poisonous to human beings [29]. Some people have lived for years with lead containing bullets in their bodies. Irrigation water with low level of lead (around 30 μg L^{-1}) has a minimum influence on the toxicity of vegetables whose edible part grows beneath. Specific disorders related to toxic levels of different metal ions on human beings are given in Table-16 [40,41].

Table-16: Specific effects of excessive intake of metal ions on human health

Metal Ion	Expected Human Health Hazards
Cd	Severe nausea, salivations vomiting, diarrhea, lipid deposition in the arteries of heart, abdominal pain.
Cr	Lung cancer, gastro intestinal upset, ulcer, edema, dermatitis
Cu	Nausea, epigastric burning, diarrhea, gastrointestinal bleeding
Fe	Gastrointestinal hemorrhage, metabolic acidosis
Pb	Anemia, headache, dizziness, loss of memory
Mn	Lethargy, increase in muscle tone tremor, mental disturbance
Ni	Abdominal discomfort, vomiting, nausea, diarrhea, headache, cough
Zn	Dehydration, electrolyte imbalance, abdominal pain, nausea, lethargy, dizziness, muscular incardination

Conclusions

City waste water and industrial effluents are no doubt cheap sources of soil nutrients and organic matter but contain high concentration of salts and also are heavily contaminated with heavy metals. These effluents when used for irrigating the vegetables not only increase the heavy metals in soil but also increase their concentration in the vegetables. Continuous use of such effluents is likely to increase metal ion concentration in vegetables to phytotoxic levels. It is, therefore, recommended that such effluents should only be used for growing of vegetables and other crops only after proper treatment or at least after dilution with canal irrigation water.

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