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Usage of Untreated Sewage Effluent for Irrigation and its Impact on Vegetables Quality

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Abstract: City effluent from Pakistan's third largest city (Faisalabad) is used as supplementary irrigation water to produce vegetables for human consumption. This paper reports a study to commence the assessment of risks and opportunities associated with this practice, with emphasis on cadmium (Cd), which is a toxic heavy metal that can enter the food chain as an impurity in vegetables. Cadmium and other properties were measured in typical effluents, four soils and a range of vegetables in the absence of fertilizer additions. It was found that the city effluent increased soil salinity, sodicity and cadmium concentrations. The Cd concentrations in the vegetables were also above those normally associated with suitability for human consumption. There were suggestions that soluble Cd concentrations in the effluent could be lessened by the addition of lime, concurrently lowering the sodium adsorption ratio of the effluent.

Key words: City effluents, irrigation quality, cadmium, soil, vegetables.

Introduction

Cadmium is a toxic and carcinogenic element (Gochfeld, 2000). Up to late 1950s, cadmium intoxication was considered to be strictly an occupational disease with severe pain in the chest, back and legs due to multiple fractures in the skeleton (Friberg, 2000). Nowadays several dangerous diseases have been associated with the excess of cadmium and it is considered to be one of the most toxic element (Nogawa et al., 1987; Kido et al., 1989; Benoff et al., 2000; Satarug et al., 2000). This can be one of the reasons that cadmium is not included in the essential micronutrients which play a vital role in the economical growth of the plants (Brady, 1996).

To overcome the shortage of water, it is a common practice in Pakistan to utilize city effluent for raising vegetables around the cities which is mostly contaminated with untreated industrial waste as very few industries are equipped with satisfactory operating treatment plants (Nazir, 1994; Ghafoor et al., 1994; Nabi et al., 2001). This city effluent is a good source of irrigation as it is rich in nutrients and organic matter; consequently the farmers do not need fertilizer for economical production (Ahmad et al., 1994). Unfortunately city effluent at the same time is also a big source of heavy metals like cadmium, chromium, nickel and zinc (Khan et al., 1994). Due to more multidimensional and versatile industries in the Faisalabad, the extent of cadmium contamination was evaluated in the city effluent, soils and vegetables. Further more a try has also been made to remove the cadmium from the city effluent and make it fit for irrigation by lowering the SAR and RSC values to permissible level.

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Materials and Methods

Analysis of City Effluent

City effluent sampling was carried out from the open channels flowing through the farmers' fields located in Gandakhue, Mulkhanwala, Awanwala and Khanuwala at Faisalabad. Eight samples on weekly basis were collected from each selected site after rinsing the plastic jars thrice with the effluent. These samples were analysed for pH, EC (Electrical Conductivity), RSC (Residual Sodium Carbonate) and SAR (Sodium Adsorption Ratio) by following the standard methods described by US Salinity Laboratory Staff, 1954. Cadmium (Cd) concentration was determined on Varian AA-1445 series Atomic Absorption Spectrophotometer (AOAC, 1984).

Sampling and Analysis of Soils

Soil sampling was performed at different depths (0-15, 15-30, 30-60 and 60-90 cm) at four selected sites of effluent irrigated field with the help of soil sampler (auger). The samples were air dried, ground with the wooden articles, mixed thoroughly and passed through 2 mm sieve and stored in labeled plastic bags. These were later analysed for pHs, ECe (Electrical conductivity of the soil extract) and SAR by following the standard methods given by the US Salinity Laboratory Staff (1954).

Cadmium concentration in soil samples was determined by digesting the sample in the acid mixture (HNO_3– H_2O–HCl). Cadmium concentration was determined by atomic absorption spectrophotometer Model Varian Spectra AA250 plus (Rowell, 1994).

Vegetable Sampling and Analysis

One sample of each fruit and leaf except spinach was collected from each field randomly. The vegetables considered for the purpose were Spinach (*Spinacia oleracea* L.), Egg plant (*Solanum melongena* L.), Okra (*Abelmoschus esculentus* (L.) Moench), Bitter gourd (*Momordica charantia* L.) and Pumpkin (*Cucurbita moschata* (Duch) Duch ex pior). Samples were washed with 1% HCl, followed by three to four washing with distilled water to remove the foreign material and then spread on a clean paper for drying. These samples were then oven dried at 60-70 °C. The dried samples were digested in di-acid mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$). Cadmium concentration in the prepared samples was determined by using atomic absorption spectrophotometer Model Varian Spectra AA250 plus (AOAC, 1984).

Results and Discussions

City Effluents

pH of the city effluent: pH values reflect the acidity or alkalinity of the effluent. Mean pH values of the samples taken from Gandakhue, Mulkhanwala, Awanwala and Khanuwala were 7.12, 7.42, 7.29 and 7.30 respectively (Table 1), which is near to neutral pH.

Electrical Conductivity (EC): Electrical conductivity reflects the total soluble salts concentration in the effluent. Higher the conductivity higher will be the soluble salts. The effluent samples were found unfit for irrigation due to higher values of EC (Table 1) than the permissible level of 1.50 dS m^{-1} suggested by US Salinity Staff (1954). Higher concentration of soluble salts may cause salinity problem (Brady, 1996).

Residual Sodium Carbonate (RSC): Mean RSC values of the city effluent (Table 1) at Gandakhue were 2.89 mmol L^{-1}, Mulkhanwala 3.52 mmol L^{-1}, Awanwala 3.49 mmol L^{-1} and Khanuwala 4.23 mmol L^{-1}. Residual sodium carbonate values are quite higher than the critical level of 2.25 mmol L^{-1} suggested by US Salinity Staff (1954). Irrigation with effluent having higher RSC values deteriorates soil and causes permeability problem, hence is not recommended for the purpose of irrigation (Rashid and Memon, 1996).

Sodium Adsorption Ratio (SAR): Mean SAR values of the city effluent (Table 1) at Gandakhue was 13.21 $(mmol\ L^{-1})^{-1/2}$, Mulkhanwala 14.45 $(mmol\ L^{-1})^{-1/2}$, Awanwala 13.91 $(mmol\ L^{-1})^{-1/2}$ and Khanuwala 13.78 $(mmol\ L^{-1})^{-1/2}$. Sodium adsorption ratio values are found higher than the critical level of 10.00 $(mmol\ L^{-1})^{-1/2}$

Table 1: Average Chemical Analysis of the City Effluent

Sr. No.	*Parameters*	*Units*	*Site of the sampling*			
			Gandakhue	*Mulkhanwala*	*Awanwala*	*Khanuwala*
1	pH	-	7.12	7.42	7.29	7.30
2	EC	dS m^{-1}	3.12	3.49	3.31	3.58
3	RSC	mmol L^{-1}	2.89	3.52	3.49	4.23
4	SAR	$(mmol\ L^{-1})^{-1/2}$	13.21	14.45	13.91	13.78
5	Cd	ppm	0.03	0.03	0.04	0.04

suggested by US Salinity Staff (1954). Higher SAR values in the irrigation water cause salinity and sodicity problem thus decreasing the production (Rashid and Memon, 1996).

Cadmium (Cd): Ayres and Westcot (1985) suggested that the Cd concentration in the irrigation water should not be more than 0.01 ppm. Mean concentration of Cd in the effluent samples was 0.03, 0.03, 0.04 and 0.04 ppm from all four sites Gandakhue, Mulkhanwala, Awanwala and Khanuwala respectively (Table 1). Cadmium concentration from all four sites was quite higher than the permissible level. Cadmium can be added to the city effluents from car exhaust, metal processing industries, battery and paint manufacturing, waste hauling and other disposal activities of the solid wastes of different industries (Brady, 1996).

Soil Analysis

pH of the saturated paste (pHs): It has been observed that the pHs of most samples are lower than 8.00. Canal and tube well irrigated soils of Pakistan has pH more than 8.00 in majority of cases (Nazir, 1994). Results given in Table 2 reveals that pHs of the soil sampled at depth 0-15, 15-30, 30-60 and 60-90 cm was in the range of 7.49 to 7.70, 7.57 to 7.84, 7.69 to 8.00 and 7.71 to 8.12 respectively. Overall lower pHs was observed in the upper layer and it increased with increase in depth.

Table 2: Saturated Paste pH of Soil (pHs) at Different Fields Receiving City Effluent

Sr. No.	*Name of the field*	*Area*	*0-15*	*15-30*	*30-60*	*60-90*
1	Spinach	Gandakhue	7.50	7.62	7.72	7.89
2	Egg plant	”	7.65	7.79	7.93	8.12
3	Okra	”	7.49	7.57	7.69	7.71
4	Bitter gourd	”	7.59	7.67	7.80	7.91
5	Pumpkin	”	7.57	7.68	7.75	7.91
6	Spinach	Mulkhanwala	7.64	7.67	7.84	7.96
7	Egg plant	”	7.59	7.69	7.87	7.90
8	Okra	”	7.67	7.74	7.90	7.97
9	Bitter gourd	”	7.60	7.66	7.84	7.99
10	Pumpkin	”	7.64	7.74	7.88	7.89
11	Spinach	Awanwala	7.59	7.69	7.82	8.04
12	Egg plant	”	7.59	7.70	7.88	7.93
13	Okra	”	7.62	7.73	7.89	7.97
14	Bitter gourd	”	7.70	7.83	8.00	8.10
15	Pumpkin	”	7.67	7.84	7.91	8.00
16	Spinach	Khanuwala	7.63	7.77	7.86	7.90
17	Egg plant	”	7.60	7.76	7.83	7.89
18	Okra	”	7.70	7.79	7.85	8.00
19	Bitter gourd	”	7.64	7.77	7.82	7.89
20	Pumpkin	”	7.64	7.79	7.81	7.99

Electrical Conductivity of soil extract (ECe): Electrical conductivity of the soil extract was in the range of 3.36 to 6.51 dSm^{-1} (Table 3) in all the samples. In most of the cases it has been observed that salts are accumulated more in the 60-90 cm depth. Only 13.75% soil samples have lower ECe values than 4.00 dSm^{-1} recommended for normal soils (Rashid and Memon, 1996). This shows the built up of the salts in the soils receiving city effluent. Soil salinity increase Cd uptake by the crop (Smolders, 2000)

Table 3: Electrical Conductivity (dSm^{-1}) of Soil Extract at Different Fields Receiving City Effluent

Sr. No.	*Name of the field*	*Area*	*0-15*	*15-30*	*30-60*	*60-90*
1	Spinach	Gandakhue	3.36	3.49	3.67	3.97
2	Egg plant	”	3.39	3.74	3.98	4.12
3	Okra	”	3.97	4.10	4.58	4.91
4	Bitter gourd	”	3.52	3.89	4.20	4.35
5	Pumpkin	”	4.12	4.31	4.53	4.69
6	Spinach	Mulkhanwala	3.98	4.56	4.78	5.01
7	Egg plant	”	4.36	4.45	4.74	4.89
8	Okra	”	4.01	4.23	4.52	4.78
9	Bitter gourd	”	4.12	4.56	5.12	5.21
10	Pumpkin	”	4.20	4.25	4.34	4.40
11	Spinach	Awanwala	3.91	3.94	4.21	4.31
12	Egg plant	”	4.25	4.56	4.74	5.12
13	Okra	”	4.04	4.15	4.25	4.37
14	Bitter gourd	”	5.21	5.36	5.55	5.89
15	Pumpkin	”	4.36	4.37	4.89	5.10
16	Spinach	Khanuwala	5.17	5.20	5.78	6.36
17	Egg plant	”	5.62	5.74	5.89	6.51
18	Okra	”	4.56	4.72	5.36	6.12
19	Bitter gourd	”	4.29	4.37	4.79	5.31
20	Pumpkin	”	4.96	5.14	5.74	6.41

Sodium Adsorption Ratio (SAR): Results given in Table 4 shows that higher SAR values were observed in the soil samples taken from 60-90 cm depth. Only 16.25% soil samples have lower SAR values than the normal soils SAR value of 15 $(mmol\ L^{-1})^{-1/2}$ (Rashid and Memon, 1996). This shows the development of the sodicity in the soils irrigated with city effluent. Furthermore higher values in the lower depth (60-90 cm) indicate the development of hardpan in the soils. Continuous use of the city effluent will deteriorate the soils to such extent that these will go out of cultivation.

Cadmium (Cd): Results given in the Table 5 indicate that Cd concentration (ppm) in all the soil samples taken from different depth were in the range of 3.25 to 3.94 ppm. Cadmium concentration was equally distributed in

Table 4: Sodium Adsorption Ratio (SAR) of Soil $(mmol\ L^{-1})^{-1/2}$ Extract at Different Fields Receiving City Effluent

Sr. No.	*Name of the field*	*Area*	*0-15*	*15-30*	*30-60*	*60-90*
1	Spinach	Gandakhue	12.25	12.56	13.21	14.12
2	Egg plant	”	13.12	13.78	14.50	15.98
3	Okra	”	14.25	15.62	16.34	17.60
4	Bitter gourd	”	14.20	15.34	16.74	18.90
5	Pumpkin	”	15.63	15.99	17.10	18.20
6	Spinach	Mulkhanwala	15.12	16.36	18.29	19.40
7	Egg plant	”	16.20	16.51	16.85	17.78
8	Okra	”	14.96	16.39	16.97	17.89
9	Bitter gourd	”	15.74	16.10	17.42	18.24
10	Pumpkin	”	15.20	16.31	16.87	16.89
11	Spinach	Awanwala	13.69	14.57	15.64	15.78
12	Egg plant	”	15.89	15.96	16.79	17.91
13	Okra	”	15.68	15.79	16.15	17.25
14	Bitter gourd	”	15.63	15.89	17.28	18.12
15	Pumpkin	”	15.96	16.45	17.81	19.61
16	Spinach	Khanuwala	17.37	18.26	18.63	19.10
17	Egg plant	”	17.12	18.36	18.96	19.00
18	Okra	”	15.67	16.31	17.29	17.80
19	Bitter gourd	”	15.63	15.99	16.79	17.83
20	Pumpkin	”	15.91	16.49	17.60	17.90

Table 5: Cadmium (Cd) Concentration (ppm) in Soils at Different Fields Receiving City Effluent

Sr. No.	*Name of the field*	*Area*	*0-15*	*15-30*	*30-60*	*60-90*
1	Spinach	Gandakhue	3.65	3.45	3.45	3.75
2	Egg plant	”	3.55	3.45	3.65	3.60
3	Okra	”	3.50	3.35	3.60	3.50
4	Bitter gourd	”	3.75	3.55	3.55	3.75
5	Pumpkin	”	3.32	3.45	3.40	3.56
6	Spinach	Mulkhanwala	3.78	3.64	3.45	3.60
7	Egg plant	”	3.25	3.54	3.50	3.45
8	Okra	”	3.45	3.25	3.70	3.68
9	Bitter gourd	”	3.57	3.56	3.45	3.67
10	Pumpkin	”	3.58	3.61	3.58	3.50
11	Spinach	Awanwala	3.42	3.50	3.81	3.79
12	Egg plant	”	3.50	3.51	3.51	3.49
13	Okra	”	3.64	3.68	3.45	3.56
14	Bitter gourd	”	3.67	3.69	3.58	3.67
15	Pumpkin	”	3.43	3.50	3.56	3.60
16	Spinach	Khanuwala	3.59	3.57	3.94	3.81
17	Egg plant	”	3.70	3.72	3.67	3.91
18	Okra	”	3.49	3.57	3.78	3.67
19	Bitter gourd	”	3.67	3.51	3.49	3.60
20	Pumpkin	”	3.75	3.68	3.70	3.77

all the soil depth showing its mobility in all the soil depths. Cadmium concentration in the soil samples were found higher than the maximum allowable limits 3.00, 3.00 and 2.00 ppm used in different countries like Poland, Great Britain and Germany respectively while lower than the maximum allowable limits of 5.00 and 8.00 used in Austria and Canada respectively (Rattan et al., 2002).

Vegetables quality: Different plants accumulate cadmium in varying amounts and no side effects on the plant growth were observed during study. Results given in Table 6 reveal that the Cd concentration was found higher in the leaves as compared to the fruits of the plants except spinach which is a leafy vegetable. In case of fruits higher concentration of Cd was accumulated in the pumpkin and okra while lower in the fruit of bitter gourd. In case of leaves higher concentration was observed in pumpkin and lower concentration was detected in bitter gourd. This shows that the uptake of the cadmium by bitter gourd is quite less than pumpkin. In all the edible portion of the vegetables Cd concentration is found higher than the level normally found in the vegetables below 0.01 ppm (WHO, 1996).

Table 6: Cadmium Concentration (ppm) in Vegetables

Sr. No.	*Name of vegetable*	*Part of the vegetable*	*Site of sampling*			
			Gandakhue	*Mulkhanwala*	*Awanwala*	*Khanuwala*
1	Spinach	Leaves	0.89	0.82	0.93	0.97
2	Egg Plant	Leaves	0.57	0.61	0.64	0.71
3	”	Fruit	0.41	0.49	0.48	0.50
4	Okra	Leaves	0.62	0.73	0.71	0.80
5	”	Fruit	0.60	0.71	0.68	0.77
6	Bitter gourd	Leaves	0.30	0.27	0.39	0.37
7	”	Fruit	0.21	0.20	0.27	0.21
8	Pumpkin	Leaves	0.70	0.76	0.81	0.84
9	”	Fruit	0.61	0.66	0.73	0.70

Correlation between the Cadmium Concentration in City Effluent, Soil and Vegetables

Results obtained were plotted (Figure 1) and analysed statistically by developing correlation between different parameters listed in Table 7. In case of vegetables, only edible portion was used for statistical analysis while in case of soil only average results of the upper 30 cm soil from all the fields of each area was used because the roots of the vegetables mostly limited themselves upto that depth. Correlation was developed between following parameters:

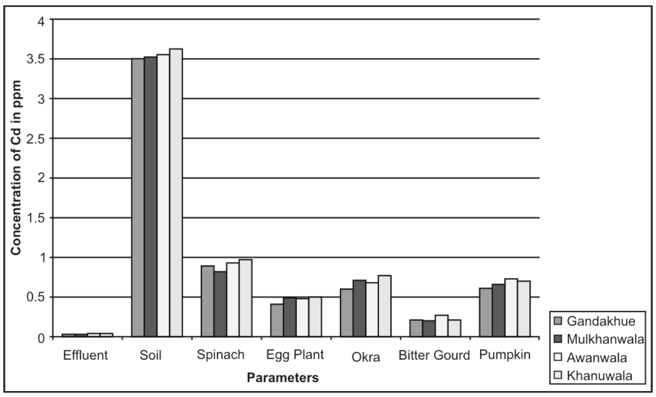

Figure 1: Concentration of cadmium in effluents, soils and vegetables sampled from different sites.

1. Effluent and soil
2. Effluent, soil and spinach
3. Effluent, soil and egg plant
4. Effluent, soil and okra
5. Effluent, soil and bitter gourd
6. Effluent, soil and pumpkin

Results given in Table 8 clearly indicate that the F calculated is quite lower than F tabulated (199.5) at 0.05 level of significance so there is a linear relationship between the parameters and results are highly significant. It means any increase in the concentration of the cadmium in the effluent shall build up its level in the soil and ultimately its concentration in the vegetables will be increased.

Table 8: Statistical Analysis of all the Parameters

Sr. No.	*Parameters*	*Correlation Coefficient (R)*	*F calculated*
1	Effluents and soil	0.287	0.0449*
2	Effluents, soil and spinach	0.4987	0.1655*
3	Effluents, soil and egg plant	0.7320	0.5772*
4	Effluents, soil and okra	0.7938	0.8518*
5	Effluents, soil and bitter gourd	0.9976	103.7918*
6	Effluents, soil and pumpkin	0.6793	0.4284*

* Significant (There is a linear relationship between the parameters)

Methodology Adopted to Remove the Cadmium and More Toxic Parameters of Irrigation Water like SAR and RSC

Effluent was sampled in bulk quantity from the Khanuwala and analysed completely by following the standard methods given by US Salinity Laboratory Staff, 1954 and AOAC, 1984. Then the effluent samples were treated with lime and finally pH was adjusted to 7.00 with acid. Different amounts of lime were added in the effluent but 5 grams per litre gave excellent results not only to remove cadmium but also bring down the SAR and RSC value to permissible level (Table 9). The results clearly indicate that after the treatment cadmium and RSC values dropped down to nil while SAR value came to the permissible level. Further more results were confirmed by preparing 1000 ppm cadmium solution and treated similarly as the treatment was given to the city effluent. Results clearly indicated that cadmium concentration goes down to nil. Possibly the compound which is precipitated is cadmium hydroxide which is insoluble in water (Richard, 1998).

Conclusions

1. City effluents are unfit for irrigation due to higher EC, RSC, SAR and cadmium level than the recommended ones.

Table 7: Concentration of Cadmium (ppm) in Effluents, Soils (Average of upper 30 cm) and Edible Portion of Vegetables Sampled from Different Sites

Sampling site	*Effluent*	*Soil*	*Spinach*	*Egg plant*	*Okra*	*Bitter gourd*	*Pumpkin*
Gandakhue	0.03	3.502	0.89	0.41	0.60	0.21	0.61
Mulkhanwala	0.03	3.523	0.82	0.49	0.71	0.20	0.66
Awanwala	0.04	3.554	0.93	0.48	0.68	0.27	0.73
Khanuwala	0.04	3.625	0.97	0.50	0.77	0.21	0.70

Table 9: Comparison of Effluent before and after Treatment

Sr. No.	*Parameters*	*Units*	*Before treatment*	*After treatment*
1	Smell	-	Bad	Not bad
2	Colour	-	Blackish	Colourless
3	Turbidity	NTU	30	1.70
4	TSS	Mg/L	1000	20
5	pH	-	7.25	7.00
6	SAR	$(mmol/L)^{1/2}$	14.21	10.00
7	RSC	-	4.25	Nil
8	Cd	mg/L	0.04	Nil

2. Soil is deteriorating with the city effluents irrigation and cadmium level in it is also higher than permissible level.
3. Vegetables have higher cadmium concentration, which may cause different clinical problems like severe nausea, salivation vomiting, diarrhoea, abdominal pain and neuralgia by the human consumption.
4. There is a linear correlation between the effluent soil and vegetables.
5. By the addition of lime @ 5 grams per litre the cadmium can be precipitated in the form of cadmium hydroxide.
6. By the addition of lime @ 5 grams per litre RSC and SAR values also decreased to permissible level thus decreasing the threat of sodicity.

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