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Impacts of Reclaimed Water Irrigation on Heavy Metal Distribution in Soil Properties and Crop

Ç. Kalkan Aktan & K. Yapsakli
Environmental Engineering Department, Faculty of Engineering, Marmara University, Turkey

B. Mertoglu
Bioengineering Department, Faculty of Engineering, Marmara University, Turkey

ABSTRACT: Reuse of treated wastewater for irrigation purposes have been recognized as the most effective ways for conserving the limited resources of freshwater. Treated wastewater reuse for irrigation purposes is accompanied by many advantages however; it may still pose various risks. The possible accumulation of trace elements and toxic organic contaminants over soil and plants should be investigated in detail. This study was conducted to analyze quality criteria of the wastewater treatment plant's effluents and possible accumulation of heavy metals in agricultural soils and plant in case of reuse for irrigation. In order to observe the possible accumulation of heavy metals in soil and lettuce plant (*Lactuca sativa*), a lab-scale lysimeter setup is constructed and irrigation was tested by using three different effluents of domestic wastewater treatment plants in Istanbul (Secondary clarifier effluents of Pasakoy and Tuzla Biological Wastewater Treatment Plants (WWTPs) and effluent water of UV disinfection unit of Pasakoy WWTP). Four separate lysimeter setup were constructed and one of them was irrigajuted with tap water (as blank) and the others were irrigated with different effluents of wastewater treatment plants. Inhibition in the growth of lettuce was observed after 30 days of irrigation with secondary clarifier effluent of Tuzla WWTP. However, any signs of retardation in growth were not observed for the lettuce which was irrigated with secondary clarifier and UV disinfection unit effluent of Pasakoy WWTP.

Keywords: Wastewater reuse, Lettuce, Heavy metal

1 INTRODUCTION

Water resources are rapidly dwindling as a result of rapid increase in world population and global warming. In proportion to the increase in population, the increase in food demand result in necessity for increased demands of agricultural area and production. Wastewater reclamation has been recognized as one of the most effective ways of conserving the limited resources of freshwater (Levine and Asano, 2004). However, the probable adverse effects of the usage of reclaimed water for irrigation purposes on environment and public health should be evaluated before any application.

In spite of the fact that irrigation with reclaimed water has advantages, the adverse effects that could be caused by chemical hazards - trace metals and toxic compunds – as a result of wastewater reuse requires good assessment. There is a concern about the accumulation of heavy metals which are potentially toxic elements such as Zn, Cd, Cu, Mn, Pb and Fe because of the usage of wastewater for irrigation purposes (Devkota et al., 2000; Sharma et al., 2006) Heavy metal contamination of agricultural soils can pose long-term environmental problems (Sauve et al., 1996; Ferguson, 1990). Toxic heavy metals get involved into the soil and aquatic system with the usage of wastewater especially for irrigation purposes (Khan et al.,2008). Long term irrigation through wastewater may result accumulation of heavy metals in soil and plants which may cause contamination of the food chain affecting food quality and safety (He et al. 2005; Muchuweti et al. 2006; Chen et al. 2009; Singh et al. 2010).

Lately a number of articles have been published on wastewater irrigated soils contaminated with heavy metals (Mapanda et al., 2005; Rattan et al., 2005; Liu et al., 2005). However, there are few studies which evaluate the soil contamination caused by usage of treated wastewater for irrigation purposes (Mosleh and Almagrabi,2013).

The aim of this study is to investigate quality criteria of the wastewater treatment plant's effluents and possible accumulation of heavy metals in agricultural soils and plant in case of reuse for irrigation. In order to observe the accumulation of heavy metals in soil and crop, lab scale lysimeters setup is constructed which are irrigated with effluents from two different treatment plants - Pasakoy and Tuzla Advanced Biological Wastewater Treatment Plants-in Istanbul obeying dicharge standards.

2 MATERIALS AND METHODS

2.1 *Wastewater Samples*

Wastewater samples were supplied from the secondary effluent of Pasakoy WWTP and Tuzla WWTP and effluent of disinfection (UV system) unit of Pasakoy WWTP, which are being operated as A^2O process. In these plants, organic carbon oxidation and nitrification occur in the same reactor and the reactors are operated at an average solids retention time of 20 days. In addition to the removal of carbon, nitrogen and phosphorus Pasakoy WWTP is also equipped with a rapid sand filter following a UV disinfection system.

2.2 *Lysimeter Setup*

Figure 1 shows the schematic view of the lab-scale lysimeter. Four identical lysimeter setup were constructed and they are both operated under the same conditions (temperature, flowrate etc) and one of them was irrigated with tap water (operated as blank) and the others were irrigated with effluents of wastewater treatment plants which are indicated above.

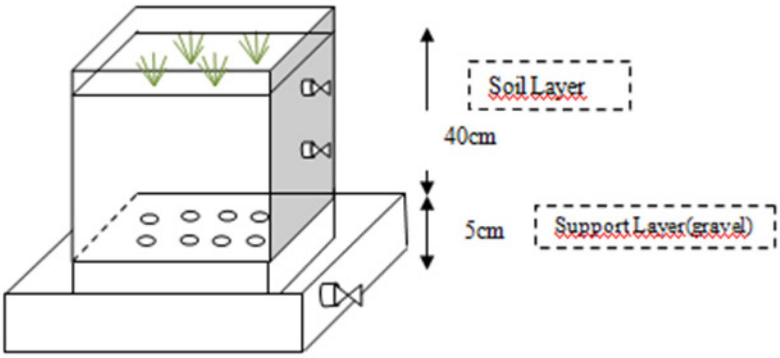

Figure 1. Configuration of lab-scale lysimeter

2.3 *Characteristics of Wastewater Samples*

Treated domestic wastewater samples were taken from two different biological wastewater treatment plants of Istanbul, Pasakoy WWTP and Tuzla WWTP. Effluent samples are stored at 4^{o}C immediately after sampling. Effluent water samples were taken from different units of treatment plant such as effluent of the UV disinfection unit and effluent of the secondary clarifier. Irrigation of lettuce was done with tap water (as a control), UV effluent of Pasakoy WWTP, secondary clarifier effluent of Pasakoy WWTP, and secondary clarifier effluent of Tuzla WWTP. Physical and chemical analysis such as chemical oxygen demand (COD), total organic carbon (TOC), ammonia, sulfate, pH, conductivity, phosphorus, specific adsorption rate (SAR), total and volatile suspended solids (TSS, VSS), total and dissolved solids (TS, TDS) are applied to treated wastewater samples.
The methods of the analyses are shown on Table 1. The analytical methods were based on the Standard Methods (APHA, AWWA and WEF, 1999).

Table 1. List of analysis and methods that is applied to the treated wastewater samples

Parameter	Method
pH	Electrometric Method
Conductivity	Electrometric Method
Chemical Oxygen Demand (COD)	Closed Reflux-Titrimetric
Total Organic Carbon (TOC)	TOC-TN analyzer
Ammonia Nitrogen (NH_4-N)	Nesslerization
Nitrite Nitrogen (NO_2-N)	Diazotization Method-Colorimetric
Nitrate Nitrogen (NO_3-N)	Cadmium Reduction Method-Colorimetric
Total Phosphorus (TP)	Amino Acid-Colorimetric
Chloride	Argentometric Method-Titrimetric
Total Suspended Solids (TSS)	Gravimetric
Volatile Suspended Solids (VSS)	Gravimetric
UV254 - A400 - A436	Absorbance Measurements
Heavy Metals*	Inductively Coupled Plasma

Heavy metals including Li, Be, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Mo, Cd, Pb, Fe,Na, Mg, Ca, and K were monitored by Inductively Coupled Plasma (ICP-MS) in treated wastewater and soil samples.

2.4 *Soil sampling and characterization*

Soil samples were collected at different heights of the lysimeter (0-10 cm, 10-20 cm).Soil samples were dried at 105^0C during 24 hours and grinded to a powder form manually. EPA-3051 method was followed during the digestion of soil samples. Digestion procedure was conducted in a microwave system using concentrated nitric acid. Metal determination in the wastewater effluents and final extracts of soil were determined using Agilent 7500 ICP-MS (EPA, Method 6020.A).

3 RESULTS AND DISCUSSIONS

Characterization of effluent wastewater samples (which are the influents of lab-scale setup) are done during eight month period and results are presented on Table 2.

Table 2. General characterization of treatment plants effluents (n=22)

PARAMETERS	Unit	PASAKOY WWTP UV EFFLUENT	PASAKOY WWTP SECONDARY CLARIFIER EFFLUENT	TUZLA WWTP SECONDARY CLARIFIER EFFLUENT
		Average	Average	Average
NH_4-N	ppm	1,33	1,43	2,29
NO_2-N	ppm	0,06	0,07	0,08
NO_3-N	ppm	1,21	1,27	3,27
PO_4	ppm	5,15	6,27	4,64
DOC	ppm	8,00	8,60	11,71
COD	ppm	60,29	55,38	73,45
BOD	ppm	18,91	20,01	20,64
MLSS	ppm	4,93	5,36	11,42
pH	ppm	7,16	7,14	7,19
Cl^-	ppm	93,5	116,8	1345,9
EC	µs	912,7	921,8	5890,1
TDS (mg/l)	ppm	584,2	589,9	4712,0

Inhibition in the growth of lettuce was observed after 30 days of irrigation with secondary clarifier effluent of Tuzla WWTP. However, any signs of retardation in growth were not observed for the lettuce which was irrigated with secondary clarifier and UV disinfection unit effluent of Pasakoy WWTP. Results show that highest TDS and chloride concentration was measured for the Tuzla WWTP effluent, therefore high salinity and specific ion toxicity (Cl^-) might influence adversely the growth of lettuce for this lysimeter setup.

In a study conducted by Batarseh et al. (2011) shows that saline water might result in the reduction of crop growth, while high value of sodium adsorption ratio (SAR) leads to deterioration of the physical properties of the soil with consequent reduction in plant yield.

Moreover, in some research evidence of severe poisoning caused by some metallic compounds onto plants has been investigated. Nagajyoti et al.,(2008) studied application of industrial effluent on groundnuts seedlings and observed decreases germination percentage, root and shoot length, and fresh weight of seedlings. In another study (Oancea et al.,2005) on tomato plants, it was indicated that both growth and photosynthetic pigments are affected by the presence of heavy metals .Therefore, higher heavy metal concentrations in Tuzla WWTP effluents might also influence adversely the growth of lettuce.

Heavy metal concentrations in water and soil samples were shown in Table 3 and Table 4, respectively.

The mean concentrations of each heavy metal in the samples were compared with the permissible levels of international standards and low heavy metal concentrations were measured in the effluents of treatment plants and soil according to international standards, except manganese in the effluents of secondary clarifier of Pasakoy and Tuzla WWTP, molybdenum and iron in the effluents of secondary clarifier and UV of Pasakoy WWTP and the effluent of secondary clarifier of Tuzla WWTP.

Table 3. Heavy metal concentrations of effluent waters (n=16)

Sample ID		Li (ppb)	B (ppb)	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	As (ppb)	Se (ppb)	Mo (ppb)	Cd (ppb)	Pb (ppb)	SAR (meq/l)
Pasakoy WWTP UV Effluent	Average	2,17	81,02	106,11	0,60	24,74	182,17	0	67,85	4,83	81,80	1,40	0,21	9,72	0	2,03	4,74
	Max.	6,44	94,51	593,20	4,59	247,60	350,80	0	79,00	17,39	175,88	4,18	3,29	15,82	0	13,75	4,98
	Min	0	68,63	0	0	0	40,11	0	50,49	0,00	42,41	0,00	0,00	3,86	0	0,00	3,65
Pasakoy WWTP Secondary Clarifier Effluent	Average	2,92	79,10	64,39	0,39	20,68	231,22	0	71,96	6,19	88,37	1,21	0,07	9,12	0	1,18	56,67
	Max.	14,46	90,52	352,40	4,62	231,60	272,50	0	93,87	22,09	347,30	2,93	1,12	11,89	0	12,52	159,78
	Min	0,00	66,82	0,00	0,00	0,00	91,27	0	56,93	0,00	50,73	0,00	0,00	4,98	0	0	3,34
Tuzla WWTP Secondary Clarifier Effluent	Average	18,34	489,91	53,31	1,39	20,38	166,55	17,99	84,34	39,12	209,55	2,56	4,44	14,39	0,03	1,96	24,31
	Max.	27,92	625,50	303,10	4,50	39,16	384,30	284,70	360,60	51,51	423,80	5,48	8,55	21,87	0,43	13,85	29,24
	Min	10,65	322,50	0	0	6,39	11,29	0	29,48	19,11	36,79	0	0,58	9,93	0	0	17,36

Table 4. Heavy metal concentrations of soils (n=3)

Sample ID	Li (mg/kg)	Be (mg/kg)	B (mg/kg)	Al (mg/kg)	V (mg/kg)	Cr (mg/kg)	Mn (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Se (mg/kg)	Se (mg/kg)	Mo (mg/kg)	Cd (mg/kg)	Pb (mg/kg)
Lysimeter1	11,11	0,61	16,47	0	33,74	31,51	491,88	6,20	28,54	19,91	44,86	4,83	0,55	4,33	0,31	8,65
Lysimeter2	12,91	0,70	16,80	0	38,28	36,77	539,62	7,51	31,99	73,81	40,93	5,84	0,66	4,55	0,10	9,59
Lysimeter3	11,37	0,65	15,86	0	33,26	30,60	486,92	6,25	26,86	13,51	48,58	4,22	0,46	4,22	0,03	9,95
Lysimeter4	14,58	0,82	19,79	0	41,26	36,64	644,50	8,63	36,98	17,55	55,90	4,61	0,60	5,45	0,36	13,04

Lysimeter 1; irrigated with tap water, Lysimeter 2; irrigated with Pasakoy WWTP UV effluent, Lysimeter 3;irrigated with Pasakoy WWTP SC effluent ,Lysimeter 4;irrigated with Tuzla WWTP SC effluent

Irrigation sources were found to affect heavy metal distribution in soil. Significant increase of heavy metals in soil was not observed during our study. In future studies, for different harvest time accumulation of heavy metal in the soil and in the crop will be monitored and heavy metal transfer from soil to plant will be investigated.

4 CONCLUSIONS

The present results showed that high salinity levels might lead to decrease in productivity for lettuce growth. Lettuce irrigation using Tuzla WWTP effluent was not sufficient to meet the nutritive demands of the plants due to low uptake of essential nutrients produced by the accumulation of salinity in the soil. There was no significant increase of heavy metals for the first harvest time; however; further studies are required to investigate the long term effects of treated wastewater irrigation on different harvest times.

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