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Assessment of Trace Elements in Wastewater Effluent in Al-Hassa Eastern Province of the Kingdom of Saudi Arabia

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ABSTRACT

In the city of Al Hassa, Eastern Province, Kingdom of Saudi Arabia, wastewater emanating from industrial, municipal and agricultural activities is discharged to open lakes through two main drainage channels D1 and D2. To supplement the inadequate irrigation water, this wastewater is being used by some farmers to irrigate their crops. Untreated or inadequately treated wastewater effluent can degrade the quality of receiving water bodies and be a potential source of water-borne pathogens. Due to water scarcity, especially in arid or semi-arid countries, the reuse of wastewater for agriculture is widespread in the developing countries. This study is an attempt to characterize wastewater being discharged into the lakes through D1 and D2 channels with particular reference to trace elements. The wastewater contained elevated levels of several trace elements and heavy metals. These values were compared with the standards established for wastewater reuse by the Saudi Arabian Standards Organization (SASO) and the Food and Agricultural Organization (FAO) of the United Nations. It is, therefore, recommended that efforts should be made to explore alternate sources of irrigation water for farming instead of using the available wastewater. Because, its reuse may contaminate both the agricultural land and the limited underlying groundwater resources.

Key words: Trace elements, heavy metals, wastewater, drainage channels, degradation, contamination, irrigation, crops

INTRODUCTION

Wastewater is defined as water that has been adversely affected in quality by anthropogenic influences. Wastewater comprises waste effluents from domestic use, commercial properties, industries and agricultural activities. Therefore, it can encompass a wide range of potential chemical and biological contaminants.

Wastes are generated from human and animal activities and are subsequently disposed of with or without treatment as useless materials on land or in water bodies. Since the beginning of civilization, land disposal has been the primary means of human solid and liquid waste management. However, improperly operated or maintained waste disposal sites may become major sources of various hazardous materials contaminating the water, air and soil in the vicinity of the disposal sites. Various adverse health effects have been associated with such improperly managed land-disposed wastes. Biological, chemical and radiological agents are present in municipal, industrial and agricultural wastes that may pose significant public health threats, such as infections and chemical and radiation poisoning, although the latter threat is rare (Ikehata and Liu, 2011).

Municipal effluents present a major threat to the aquatic environment and are an important source of environmental pollution (Chambers *et al*., 1997). Because effluents from municipal wastewater treatment plants are derived both from domestic and industrial sources containing a wide variety of constituents. These are generally described in different categories, such as solids, substances that exert a biological/chemical oxygen demand (BOD/COD), nutrients, pathogens, organic chemicals, metals, oils and greases and plastics and floatables (Chambers *et al*., 1997). Only total suspended solids, BOD, COD, nutrients (P and N), pathogenic bacteria, plastic material and floatables are typically targeted by wastewater treatment processes resulting in the inefficient removal of metals and other chemicals. Surveys in Canada have shown that metals and organic chemicals are present in municipal effluents at levels above background concentrations (OMOE., 1988; Rutherford *et al*., 1994; Ministere de l'Environnement du Quebec and Environment Canada, 2001).

Toxic heavy metals are among the most serious pollutants and may be derived from mining operations, refining ores, sludge disposal, fly ash from incinerators, the processing of radioactive materials, metal plating or the manufacture of electrical equipment, paints, alloys, batteries, pesticides or preservatives. Industrial and municipal effluents contain high amounts of heavy metal ions such as chromium, nickel, copper, lead, cadmium and zinc. These heavy-metal-bearing wastewaters are a cause for considerable concern because they are non-biodegradable, highly toxic and sometimes carcinogenic (Musyoka *et al*., 2013).

Among the various contaminants released in municipal wastewaters, the total metal loads are generally higher than the loads of organic chemicals (OMOE., 1988; Rutherford *et al*., 1994). A number of relatively small metal industries release metals directly into municipal sewer systems (Ministere de l'Environnement du Quebec and Environment Canada, 2001). Although industry is a frequent source of metals but some of the metals in municipal effluents are also partly derived from domestic waste. Metals such as Cu, Zn, Fe, Co, Mn and Mo are derived from human food consumption, whereas other metals can be introduced by cookware and from a variety of household cleaning agents (US EPA, 1986; Chambers *et al*., 1997). The pollution of waters by municipal effluents is a serious environmental problem. Because the contaminants such as metals are more difficult to control when released into municipal sewer systems than the industrial effluents (Gagnon and Saulnier, 2003).

The impacts of urban wastewater discharges on receiving waters are numerous and inputs of contaminants can cause acute and chronic toxicity to organisms in the receiving waters (NRC., 1993; Gagne *et al*., 2002). The toxicity of municipal effluents is occasionally caused by high metal concentrations (Rutherford *et al*., 1994; Wong *et al*., 1995). The relative contribution of metals to the overall toxicity of municipal wastewater may be small but once released to receiving waters, their toxicity remains unknown (Ministere de l'Environnement du Quebec and Environment Canada, 2001). Although the toxicity of a municipal effluent is dependent on factors related to the treatment and disinfection processes, yet the physical, chemical and biological characteristics of the receiving waters modify the toxicity of contaminants once they are released into the environment (Lijklema *et al*., 1993). The physicochemical conditions of receiving waters influence metal speciation (Lijklema *et al*., 1993). The biological availability of metals, in turn, is determined by their speciation in both the dissolved and particulate phases (Campbell *et al*., 1988; Luoma, 1983; Luoma *et al*., 1992; Gagnon and Fisher, 1997). Factors such as temperature, pH, hardness, alkalinity, dissolved oxygen and the amount and the nature of suspended matter can modify the toxicity of the chemical constituents of effluents.

Trace metals in an agro-eco-system originate either from the parent soil materials or human activities (Adriano, 2001; Yaman, 2006; Fairbrother *et al*., 2007). The sources of contamination by terrestrial Trace Elements (TEs) include atmospheric deposition from industrial air emissions (e.g., metal smelters), vehicle exhaust and degradation, mining and smelter wastes and agricultural amendments such as fertilizers and pesticides. Municipal refuse and sewage sludge can also be significant sources of soil TEs on a local scale (Sensesi *et al*., 1999; Obbard, 2001; Smith, 2009). The ecological and human health impacts of elevated environmental metal concentrations have been known for several decades and focused research efforts on adverse effects and mitigation strategies have gained momentum over this same time period.

The widespread use of industrial and municipal wastewater for irrigation, often in peri-urban ecosystems, is due to its availability; the scarcity of clean water, fresh water and the challenges associated with the disposal of wastewater (Arslan-Alaton *et al*., 2007; Avci, 2013). Although this practice may be convenient and cost-effective but the TEs in wastewater can find their way into the human food supply and pose significant adverse health effects, especially to those who are more vulnerable because of higher dietary proportions of certain foods and/or their age and pre-existing health issues. Many studies have demonstrated that plants grown on wastewater-irrigated soils accumulate higher levels of Tes (Demirezen and Aksoy, 2006; Chary *et al*., 2008; Tiwari *et al*., 2011).

Currently, search for non-conventional water resources, e.g., desalination and wastewater reuse, is an emerging phenomenon. However, due to the high cost of desalination of sea water, many countries see wastewater reuse as a more feasible alternative water source for agriculture. This wastewater reuse in turn poses a public health risk (Keremane, 2010; Scheierling *et al*., 2011).

The World Health Organization (WHO., 2006) has published guidelines for the safe use of wastewater, excreta and gray water in agriculture and aquaculture. The United States Environmental Protection Agency (US EPA., 2004) has published Guidelines for Water Reuse (EPA/625/R-04/108 September 2004). The Kingdom of Saudi Arabia (KSA) (in year 2000) has set standards for the reuse of wastewater (raw and treated) in agriculture and its disposal under the rules and regulations mentioned in Royal Decree No. M/6, 'Treated Sanitary Wastewater and its Reuse Regulations' (Um Alqura Newspaper, 2000).

This study evaluates the quality of wastewater flowing in the two main drainage channels (D1 and D2) in the city of Al-Hassa, with particular reference to trace metals.

MATERIALS AND METHODS

Study area: Al-Hassa lies between the coordinates 49°33'42"E-49°34'12"E and 25°27'25"N-25°28'N. It is a major agricultural area and is considered as one of the largest oases in the world. In 1951, 280 natural springs were active, supplying water to irrigation channels that flow naturally by gravity (Vidal, 1951). The quality of groundwater, the main source for irrigation, has degraded due to excessive groundwater extraction resulting in resalination of irrigated agricultural lands.

In Al-Hassa, there are two main drainage channels, D1 and D2, each having several sub-drainage channels (Fig. 1). These channels collect the sub-surface drainage water from the irrigated soil and prevent salt build-up in the soil. In the past, two-thirds of the agricultural area was irrigated by irrigation channels and one-third was irrigated by drainage channels carrying only agricultural drainage water. Presently, the drainage channels carry not only agricultural wastewaters but also municipal and industrial wastewaters, as well as the storm water. At present,

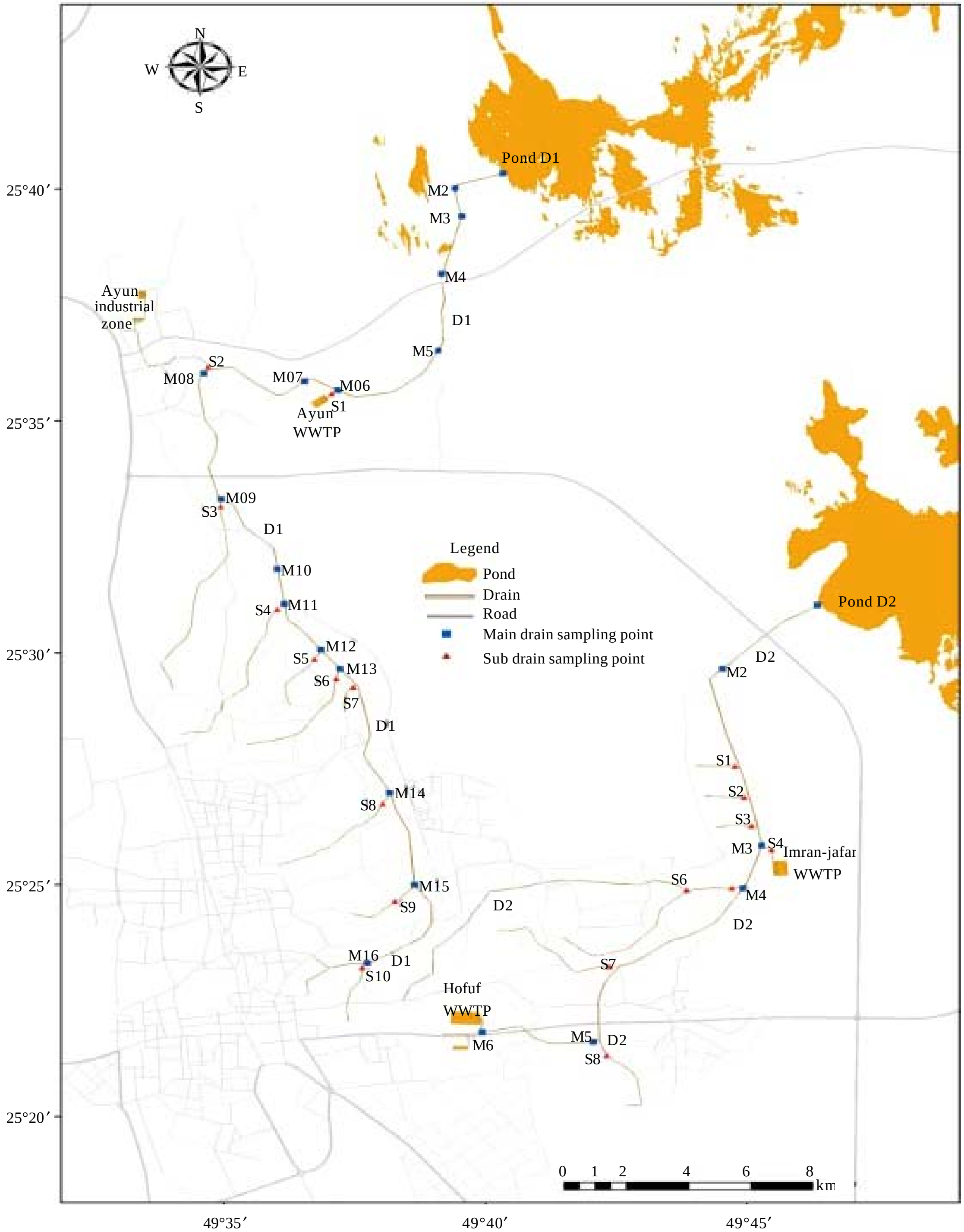

Fig. 1: Sampling stations along D1 and D2 drainage channels

there are 48 functioning factories and 17 under construction in the industrial zone in the Al-Hassa area. The industrial waste effluent is discharged into the agricultural drainage channels and mixed with municipal wastewater and agricultural wastewater. The wastewater discharged into the channels flows by gravity and terminates in two large ponds at the end of each channel.

The local authorities have warned the farmers against using wastewater for irrigation, especially in those areas where municipal and industrial wastewaters are mixed with agricultural drainage water. However, in spite of the warning, many farmers still use the drainage wastewater to supplement the existing irrigation supplies.

Discharge measurements: The discharge was measured in both channels (D1 and D2) at the selected sites chosen according to their accessibility and location downstream of the wastewater treatment plant in both channels. The methods described by French (1985) and Buchanan and Somers (1976) were followed for wastewater discharge measurements.

Collection of samples: Wastewater samples were collected from 16 stations on D1 main channel and 10 stations on D1 sub-channels. The 16 stations were located at the start and end of the main channel and after the sub-channel connection with the main channel. Wastewater samples were also collected from D2 channel with 6 stations on the main channel and 8 stations on sub-channels. In the four-year study period, each station was sampled 17 times. In the initial three years, wastewater samples were collected once every 3-4 months. However, in the final year, the samples were collected on a monthly basis. The total number of samples collected were 485 and 273 from D1 and D2 channels, respectively. The locations of wastewater sampling stations are shown in Fig. 1.

Wastewater samples were collected in 1 L plastic bottles. The sampling bottles were washed with distilled water in the laboratory. At the time of sampling, the bottles were rinsed at least two times with the wastewater to be collected. Nitric acid was added to preserve the samples for trace metals analysis. Samples were stored in an ice chest and transferred to the National Center for Water Technology at King Abdulaziz City for Science and Technology (KACST) in Riyadh for analysis.

Analysis of wastewater samples for the determination of trace elements: Standard methods for the analysis of water and wastewater (APHA., 2005) were followed for analysis of trace elements in the wastewater samples.

Trace elements were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) (Optima 2000 DV Perkin Elmer) using a device equipped with an ultrasonic nebulizer (model Cetec U 5000 AT). The use of an ultrasonic nebulizer provides a 5-50 fold improvement in the detection limits of the instrument. The instrument was calibrated with relevant PerkinElmer (PE) Pure spectroscopy-grade standards.

Quality assurance and quality control program: In order to assess the precision and accuracy of the results, replicate analyses of blanks, standards and samples were performed. The relative standard deviations were determined to find the precision of the analysis. Recoveries were calculated to determine accuracy. Experiments were repeated until an accuracy of 95-100% and precision of +/- 5% were obtained. Certified standards were used for the calibration of the instrument. One standard sample was analyzed routinely for each analysis batch.

RESULTS AND DISCUSSION

The maximum measured discharge in D1 during the study period was 6.7 million m^3 per month in 2008 at station D1M6 (Table 1). In D2, the maximum measured discharge was 9.1 million m^3 per month at station D2M2 in 2008 (Table 2). However, the flow in D1 includes 46% from WWTPs,

Table 1: Measured wastewater discharges in D1 drainage channel

Discharge measurement location	Latitude (deg.dec)	Longitude (deg.dec)	Current meter (No.)	Date (dd/mm/yyyy)	Starting time (hh:mm)	Discharge ($m^3 sec^{-1}$)	Discharge (million m^3/month)
D1M6	25.595352	49.616024	2030 R	02/03/2008	9:25	2.501	6.699
D1M4	25.637369	49.648912	2030 R	02/03/2008	8:30	2.500	6.697
			2030 R	08/06/2008	10:50	1.865	4.995
			2030 R	19/01/2009	9:40	2.227	5.965
D1M6	25.595352	49.616024	1693	02/03/2008	10:40	2.010	5.384
			1693	05/08/2008	7:50	1.218	3.261
D1M6	25.595352	49.616024	2030 R	03/03/2008	10:05	2.463	6.596
D1S3	25.553077	49.579265	1693	03/03/2008	9:35	0.050	0.133
D1S4	25.51647	49.597812	2030 R	03/03/2008	9:10	0.633	1.696
D1S5	25.498712	49.609908	2030 R	03/03/2008	10:20	0.412	1.104
D1S8	25.446854	49.632234	2030 R	03/03/2008	11:15	0.383	1.026
D1M6	25.595352	49.616024	2030 R	25/01/2010	10:40	2.092	5.602
D1M4	25.637369	49.648912	2030 R	02/03/2010	13:45	1.399	3.385
			2030 R	30/03/2010	9:30	1.731	4.635
D1M6	25.595352	49.616024	2030 R	27/04/2010	9:30	1.844	4.780
D1M4	25.637369	49.648912	2030 R	25/05/2010	8:30	1.679	4.498
			2030 R	29/06/2010	9:30	1.020	2.645
D1M3	25.658109	49.655106	2030 R	27/07/2010	8:35	0.599	1.605
			2030 R	23/08/2010	6:35	0.713	1.909
D1M3*	25.658109	49.655106	2030 R	27/09/2010	8:55	0.443	1.148
			2030 R	27/10/2010	8:45	0.364	0.974
D1M11**	25.518247	49.600067	2030 R	27/10/2010	10:50	1.465	3.925
D1M4*	25.637369	49.648912	2030 R	26/11/2010	8:47	1.299	3.368
D1M3	25.658109	49.655106	2030 R	28/12/2010	9:50	2.270	6.079

*Seepage and WWTP flow in the drain, ** Full drain flow before HIDA blocking the drain, for recycle water into irrigation canals

Table 2: Measured wastewater discharges in D2 drainage channel

Discharge measurement location	Latitude (deg.dec)	Longitude (deg.dec)	Date (dd/mm/yyyy)	Starting time (hh:mm)	Discharge ($m^3 sec^{-1}$)	Discharge (million m^3/month)
D2M1	25.519444	49.770524	04/08/2008	16:30	1.664	4.456
D2M2	25.496319	49.740208	01/03/2008	16:00	3.390	9.081
			08/06/2008	10:50	1.749	4.685
			18/01/2009	16:20	2.882	7.719
D2S5	25.418217	49.746935	01/03/2008	17:20	2.325	6.227
D2M5	25.361831	49.700444	02/03/2008	16:30	2.189	5.863
D2M6	25.364923	49.664901	02/03/2008	17:40	0.938	2.512
D2S6	25.416645	49.729686	02/03/2008	15:30	0.359	0.960
D2M1	25.519444	49.770524	25/01/2010	14:00	2.086	5.588
			28/02/2010	16:25	1.835	4.440
			29/03/2010	13:30	1.041	2.788
			26/04/2010	13:30	2.264	5.869
			24/05/2010	11:00	2.534	6.787
D2M2	25.496319	49.740208	28/06/2010	15:20	2.861	7.416
			26/07/2010	15:10	2.258	6.048
			23/08/2010	15:40	1.889	5.059
			27/09/2010	13:55	2.534	6.569
			26/10/2010	15:15	1.528	4.093
			25/11/2010	14:55	2.302	5.967
			27/12/2010	14:25	3.070	8.222

49% from agricultural wastewater and 5% from industrial wastewater. In D2, 75.5% of the flow derives from WWTPs and 24.5% from agricultural wastewater. Presently, there are three wastewater treatment plants in Al-Hassa city with one discharging its effluent in D1 channel, whereas the other two discharge the effluent in D2 channel.

The industrial area of Al Hassa is located in the northwest of D1 channel. The industrial wastewater is collected in an oxidation pond in the industrial area before discharging into the sub-channel connected to D1. Figure 1 shows the treatments plants on channels D1 and D2, as well as the industrial area and the sub-channel connecting the industrial zone oxidation pond to D1 channel.

Different trace elements and heavy metals such as aluminum (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), fluoride (F), iron (Fe), mercury (Hg), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), strontium (Sr), titanium (Ti), vanadium (V) and zinc (Zn) were determined in the wastewater samples.

Data in Fig. 2(a-j), 2(k-v), 3(a-j) and 3(k-v) show the minimum, maximum and average concentrations of all the trace elements and heavy metals found in wastewater in the two channels during the study period.

The analysis of wastewater samples collected from both channels was compared with SASO standards (Saudi Arabian Standards) given in Table 3 for the raw wastewater discharge. Because

Table 3: Number and percentage of samples in D1 and D2 that exceed Saudi wastewater effluent standards

		Samples exceeding Saudi standards			
		D1		D2	
Elements	Saudi wastewater effluent standards (mg L^{-1})	No. of samples	Percentage	No. of samples	Percentage
Al		-		-	
As	0.10	-		-	
B	2.00	69	13.5	22	8.0
Ba	1.00	-		-	
Be		-		-	
Cd	0.02	11	2.2	-	
Co		-		-	
Cr	1.20	-		-	
Cu	1.20	-		-	
F		-		-	
Fe		-		-	
Hg	0.05	-		-	
Li		-		-	
Mn	5.00	-		-	
Mo	0.50	1	0.2	-	
Ni	2.00	-		-	
Pb	1.00	-		1	0.4
Se	0.50	-		-	
Si		-		-	
Sr		-		-	
Ti		-		-	
V	1.00	-		-	
Zn	2.60	11	2.2	-	

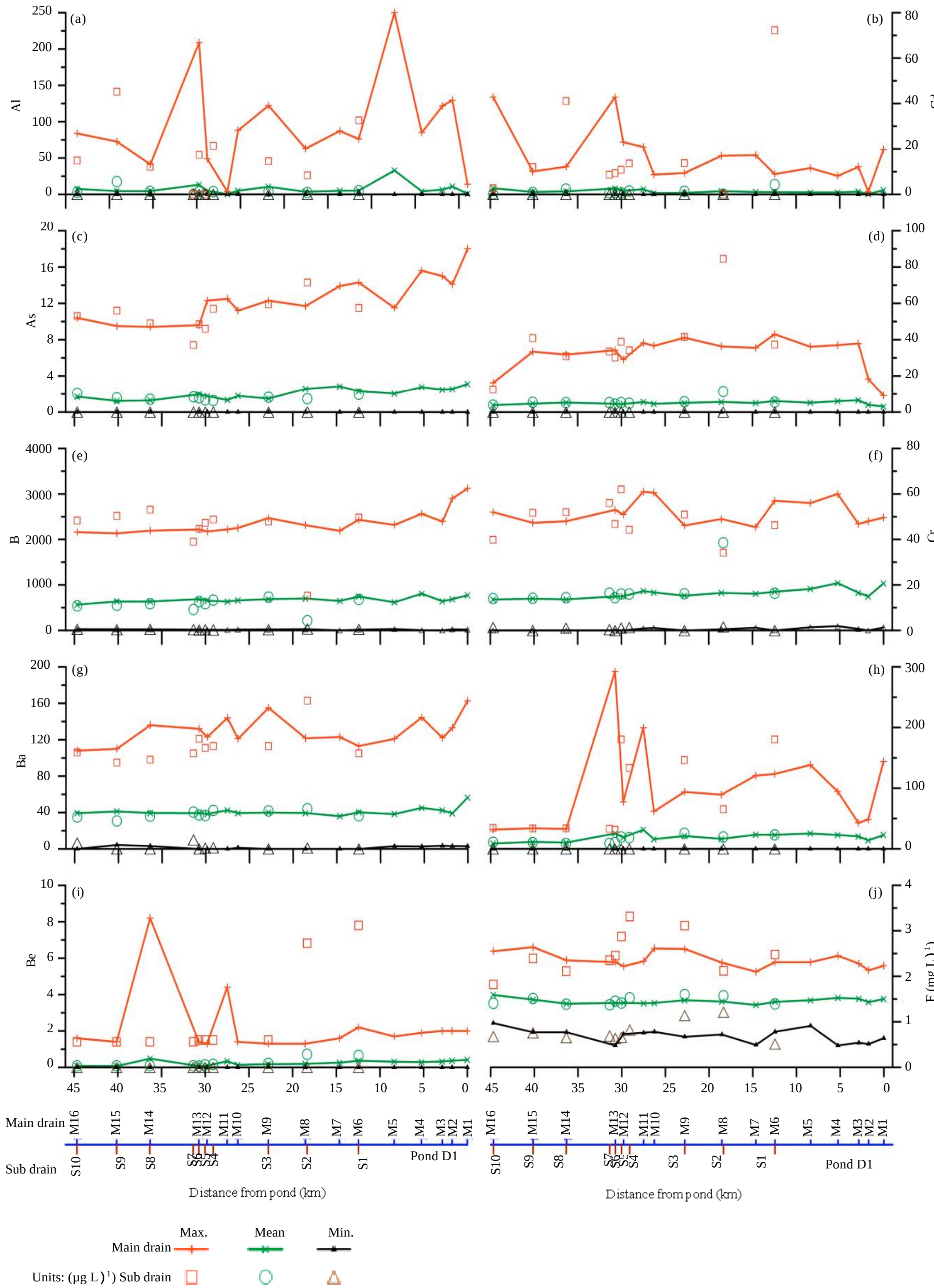

Fig. 2(a-j): Minimum, maximum and average concentrations of trace metals in D1 main and sub-channels, (a) Al, (b) Cd, (c) As, (d) Co, (e) B, (f) Cr, (g) Ba, (h) Cu, (i) Be, (j) F

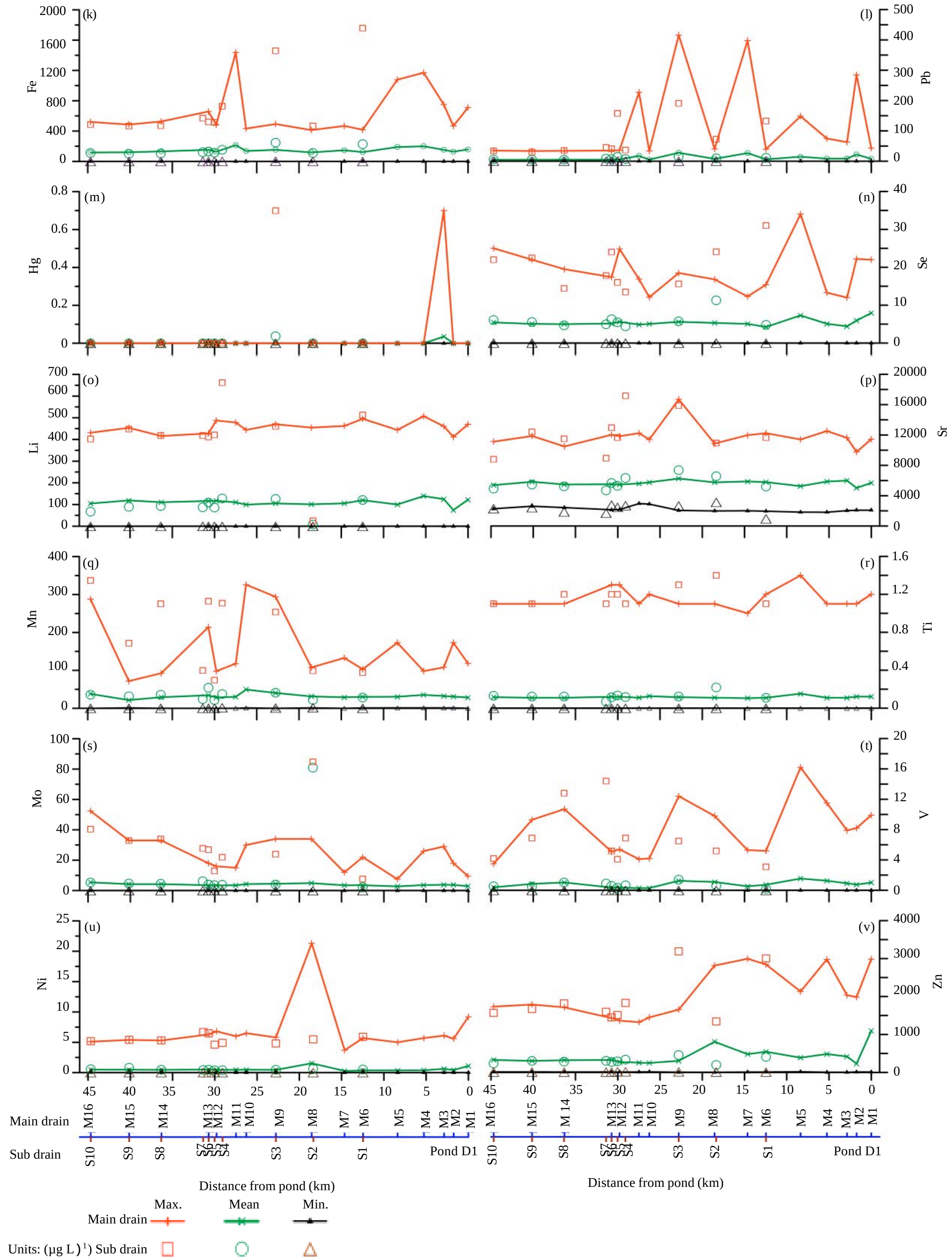

Fig. 2(k-v): Minimum, maximum and average concentrations of trace metals in D1 main and sub-channels, (k) Fe, (l) Pb, (m) Hg, (n) Se, (o) Li, (p) Sr, (q) Mn, (r) Ti, (s) Mo, (t) V, (u) Ni and (v) Zn

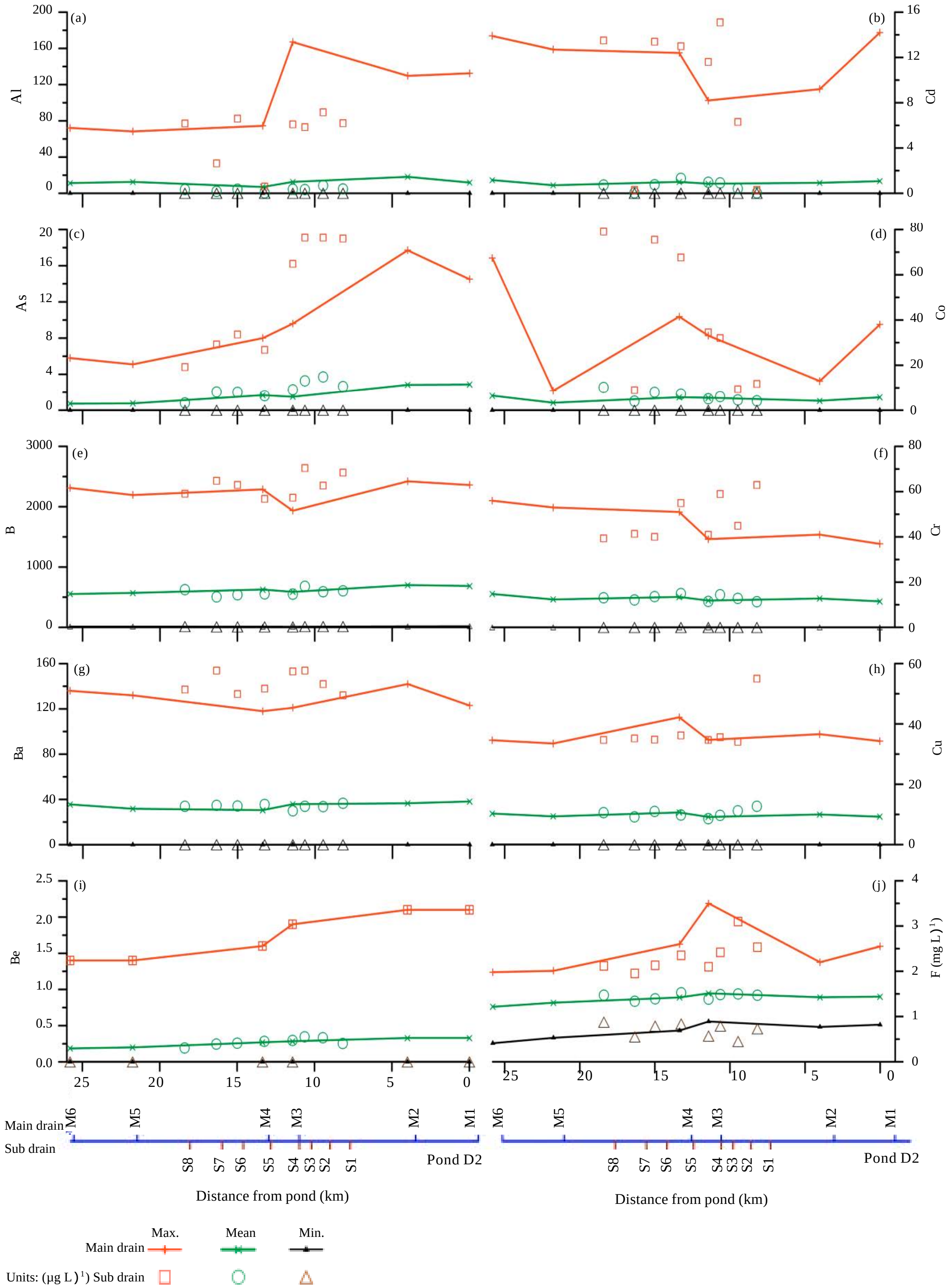

Fig. 3(a-j): Minimum, maximum and average concentrations of trace metals in D2 main and sub-channels, (a) Al, (b) Cd, (c) As, (d) Co, (e) B, (f) Cr, (g) Ba, (h) Cu, (i) Be, (j) F

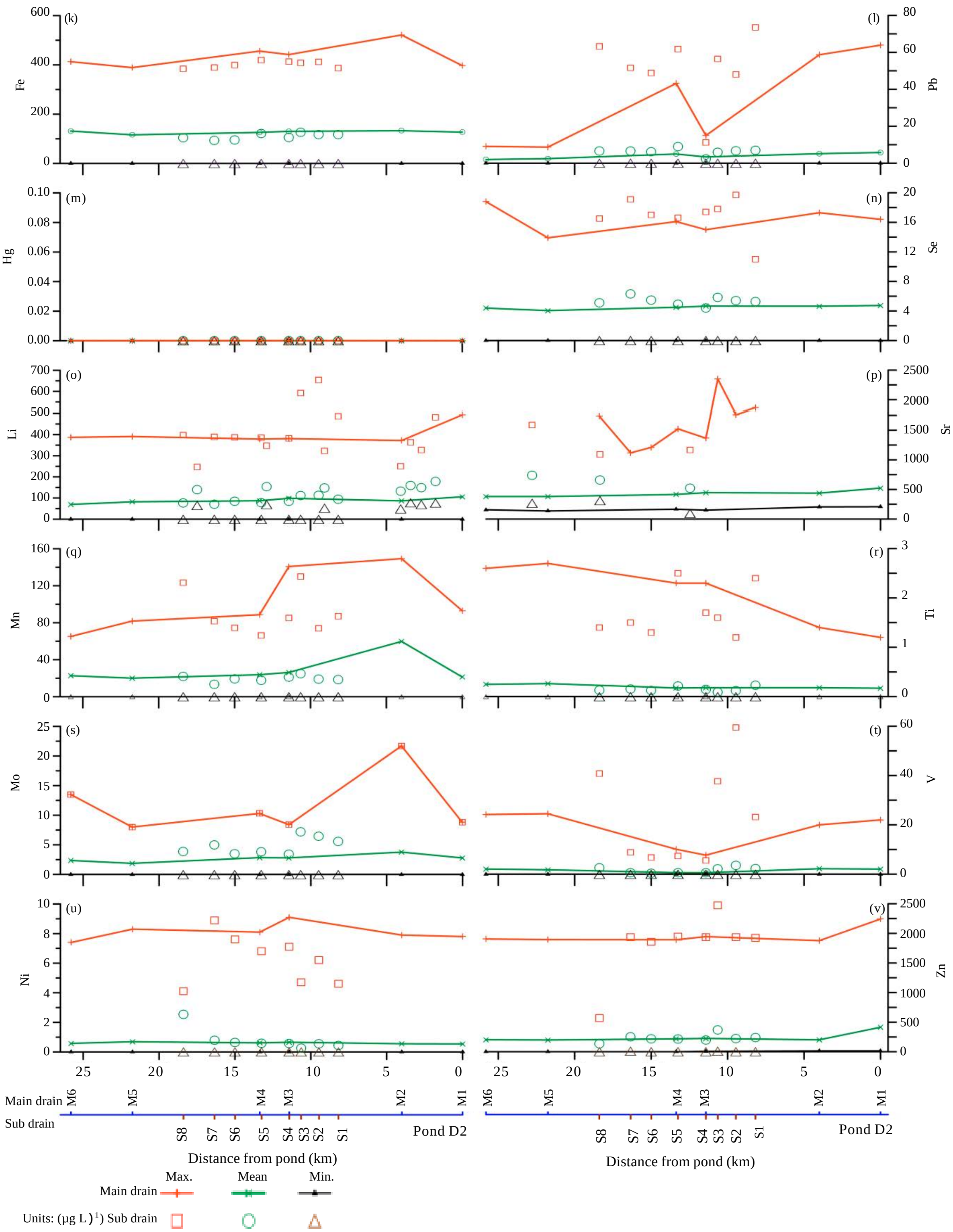

Fig. 3(k-v): Minimum, maximum and average concentrations of trace metals in D2 main and sub-channels, (k) Fe, (l) Pb, (m) Hg, (n) Se, (o) Li, (p) Sr, (q) Mn, (r) Ti, (s) Mo, (t) V, (u) Ni and (v) Zn the drainage water from both channels is used by many farmers to irrigate their crops. The trace element concentrations were also compared with the FAO recommended limits for trace elements in reclaimed water used for irrigation in the long and short term.

Comparison of trace elements concentration in wastewater with the standards promulgated by the Saudi Arabian Standards Organization (SASO): Table 3 shows the number and percentage of samples exceeding the Saudi standards for the disposal of raw wastewater. The descriptions of different elements are presented in the following paragraphs.

Boron (B): A total of 69 samples (13.5%) and 22 samples (8.0%) in channels D1 and D2, respectively exceeded the boron limit of 2.0 mg L^{-1} set by SASO. The maximum concentration of boron (3120 μg L^{-1}) was found at station D1M1 located at the end of the D1 drainage channel at the estuary of D1 pond. High concentrations of boron were found at almost all the stations on the D1 main drainage channel and in all the sub-channels except the sub-channel connecting the industrial zone to the main channel. In D2 channel, the maximum concentration of boron (2640 μg L^{-1}) was found in sub-channel D2S3 in the middle of D2 channel and after the second wastewater treatment plant. High concentrations of boron were found in all the samples from D2 stations in the main and sub-channels.

Boron is found naturally in soil due to weathering of rocks and soils and also due to industrial and agricultural activities, which include the use of boron fertilizers such as borax ($Na_2B_4O_7.10H_2O$) and boric acid (H_3BO_3). High concentrations of boron are toxic and can limit plant growth in soils in arid and semi-arid environments (Nable *et al*., 1997). The high concentration of B may be due to the low precipitation, a typical phenomenon in arid and semi-arid environments, which causes the accumulation of boron in the soils. In Al-Hassa region, the existence of drainage channels facilitates the leaching of boron from the irrigated fields and surroundings into the effluent water, which explains the high concentration of boron along the drainage channels.

Cadmium (Cd): The concentration of Cd in 11 samples (2.2%) in D1 was above the maximum contaminant limits set by SASO (0.02 mg L^{-1}). The maximum concentration of Cd (100.8 μg L^{-1}) was at station D1M15 in D1 and in sub-channel D1S06. The sub-channel D1S02, which received extensive wastewater from the industrial zone, showed concentrations above the Saudi standard limits. However, the samples from D2 channel did not show Cd concentrations above the SASO standards for wastewater.

Molybdenum (Mo): One sample (0.2%) in D1 showed a concentration of 884 μg L^{-1}, which was the only observed value higher than the maximum concentration limit of 0.5 mg L^{-1} as prescribed by SASO. This sample was found in the sub-channel connecting the industrial zone to main D1 channel. The Mo is the least abundant trace element in soils and is also the least abundant essential micronutrient found in most plant tissues (Kaiser *et al*., 2005). In industry, molybdenum is used as an alloy to enhance steel strength and corrosion resistance. Besides, there is also no evidence of phytotoxicity to crops from Mo in irrigation waters but toxicity to plants grown in aqueous solution has been observed at concentrations above 0.5 mg L^{-1} Mo (Tjandraatmadja *et al*., 2010; ANZECC and ARMCANZ., 2001). The accumulation of molybdenum in plants is toxic to grazing animals.

Zinc (Zn): A total of 11 samples (2.2%) in D1 showed Zn concentrations higher than the MCL of 2.6 mg L^{-1} prescribed by SASO. The highest concentration of Zn (8427 µg L^{-1}) was in the sample collected from station D1M01 at the end of D1 channel. High concentrations of Zn were also in sub-channel D1S01, which connects the wastewater plant to the main channel and sub-channel D1S02, connecting the industrial zone to the main channel. This clearly shows that the source of the Zn was mainly from domestic and industrial wastewater.

Zinc is one of most common components of the earth's crust. Zinc occurs naturally in the air, soil and water and is found in food at certain concentrations. A high concentration of Zn in the environment may be related to human activities. In industry, Zn is used as a corrosion inhibitor; it is also used in the paint and rubber industries. A high concentration of Zn in domestic wastewater can be related to the use of household products (Tjandraatmadja *et al*., 2008). No other trace elements were found at concentrations above the standards set by the Saudi Arabian Standard Organization (SASO).

Comparison of trace elements determined with FAO standards (Pescod, 1992): FAO standards encompass two types of applications of treated wastewater for irrigation purposes: Long-term and short-term use. Table 4 shows the long-term and short-term standards promulgated

Table 4: Number and percentage of samples in D1 and D2 that exceed FAO recommended limits for trace elements in reclaimed water use for long-and short-term irrigation

	FAO recommended limits for trace elements in reclaimed water use for irrigation		No. and percentage of samples in D1exceeding standards				No. and percentage of samples in D2 exceeding standards			
			Long term		Short term		Long term		Short term	
Elements	Long term use (mg L^{-1})	Short term use (mg L^{-1})	No.	%	No.	%	No.	%	No.	%
Al	5.00	20.00	-	-	-	-	-	-	-	-
As	0.10	2.00	-	-	-		-		-	-
B	0.75	2.00	168	33	69	13.6	87	32	22	8.1
Ba	-	-	-	-	-	-	-	-	-	-
Be	0.10	0.50	-	-	-	-	-	-	-	-
Cd	0.01	0.05	24	4.7	3	0.6	12	4.4	-	-
Co	0.05	5.00	1	0.2	-	-	5	1.8	-	-
Cr	0.10	1.00	1	0.2	-	-	-	-	-	-
Cu	0.20	5.00	3	0.6	-	-	-	-	-	-
F	1.00	15.00	444	87.4	-	-	223	82.0	-	-
Fe	5.00	20.00	-	-	-	-	-	-	-	-
Hg	-	-	-	-	-	-	-	-	-	-
Li	2.50	2.50	-	-	-	-	-	-	-	-
Mn	0.20	10.00	-	-	-	-	1	0.37	-	-
Mo	0.01	0.05	24	4.7	2	0.4	16	5.9	1	0.37
Ni	0.20	2.00	-	-	-	-	-	-	-	-
Pb	5.00	10.00	-	-	-	-	-	-	-	-
Se	0.02	0.02	11	2.2	11	2.2	-	-	-	-
Sio	-	-	-	-	-	-	-	-	-	-
Sr	-	-	-	-	-	-	-	-	-	-
Ti	-	-	-	-	-	-	-	-	-	-
V	0.10	1.0	-	-	-	-	-	-	-	-
Zn	2.00	10.0	19	3.7	-	-	2	0.74	-	-

by FAO. The concentration of trace elements such as B, Cd, Co, Cr, Cu, F, MO, Se and Zn was above the FAO standards in the two categories. Long-term FAO standards are more stringent compared with the standards set for short-term irrigation by treated wastewaters.

Long-term use: Considering all the samples analyzed 33, 4.7, 0.2, 0.2, 0.6, 87.4, 4.7, 2.2 and 3.7% of the samples exceeded the FAO standards for long-term irrigation for B, Cd, Co, Cr, Cu, F, Mo, Se and Zn, respectively in D1 channel (Table 4). In D2 channel 32, 4.4, 1.8, 82.0, 0.37, 5.9 and 0.74% of the samples exceeded the FAO standards for long-term irrigation for B, Cd, Co, F, Mn, Mo and Zn, respectively (Table 4).

Short-term use: Again considering all the samples 13.6, 0.6, 0.4 and 2.2% of the samples exceeded the FAO standards for short-term irrigation for B, Cd, Mo and Se, respectively in D1 channel (Table 4), whereas 8.1 and 0.37% of the samples exceeded the FAO standards for short-term irrigation for B and Mo, respectively, in D2 channel.

It is further pointed out that elevated concentrations of trace elements can occur in agricultural land due to excessive use of pesticides that persist as long-lasting residues in the soil. The concentrations of trace elements in the soil are largely determined by sorption and desorption reactions in the soil exchange complex, as well as by co-precipitation with metal oxides. Sorption dominates at relatively low concentrations that are relevant to water quality criteria for irrigation use. Only a small fraction of the total elements present in soil is available to plants. In general, soils have a high capacity to reduce the toxicity of dissolved trace elements through adsorption on clay i.e., higher the clay contents, the more trace elements are adsorbed. Soil pH also affects the concentration of arsenic in the soils as its solubility decreases with increasing pH.

The implications for irrigation with water containing trace elements include the following:

- Trace elements can be expected to be retained in the soil surface layers because of strong sorption by the soil exchange complex; in cultivated land, trace elements accumulate in the plough layer
- Significant downward movement to below the plough layer and hence contamination of ground water with trace elements is possible
- In general, the larger the soil's cation exchange capacity, the more trace elements can be sorbed
- Because metals are retained by soils, they are likely to accumulate at phytotoxic levels. To prevent such accumulation, the total load applied to soil needs to be limited

CONCLUSION

In the present study, it is evident that trace elements including heavy metals are present in D1 and D2 channels carrying the industrial waste effluents and agricultural drainage waters. Some parameters exceeded the maximum contamination limits set by different regulatory agencies. It has been noted that many farmers use wastewater from the two main drainage channels for irrigating their crops. The reuse of wastewater for irrigation in Saudi Arabia is not surprising as this an arid country with a limited supply of groundwater. However, these farmers are not aware that when crops are irrigated with this water on long term basis, trace elements and heavy metals will accumulate in the soil thus might be taken up by the crop plants which may not be suitable for human consumption.

It is, therefore, recommended that the farmers should be encouraged to use alternate sources of irrigation and avoid the use of wastewater for irrigation on a long-term basis, because such use will not only contaminate the crop plants and soils but also the groundwater resources.

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REFERENCES

Adriano, D.C., 2001. Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals. 2nd Edn., Springer, New York, USA., ISBN-13: 9780387986784, Pages: 867.

ANZECC and ARMCANZ., 2001. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture Resource Management Council of Australia and New Zealand, Canberra, Australia.

APHA., 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edn., American Public Health Association, Washington, DC., USA., ISBN-13: 978-0875530475, Pages: 55.

Arslan-Alaton, I., A. Tanik, S. Ovez, G. Iskender, M. Gurel and D. Orhon, 2007. Reuse potential of urban wastewater treatment plant effluents in Turkey: A case study on selected plants. Desalination, 215: 159-165.

Avci, H., 2013. Heavy metals in vegetables irrigated with wastewaters in Gaziantep, Turkey: A review of causes and potential for human health risks. Fresenius Environ. Bull., 22: 146-151.

Buchanan, T.J. and W.P. Somers, 1976. Discharge Measurements at Gaging Stations. In: Techniques of Water-Resources Investigations Reports, USGS (Ed.) Chapter A8, U.S. Geological Survey, Washington, DC., USA.

Campbell, P.G.C., A.G. Lewis, P.M. Chapman, A.A. Crowder and W.K. Fletcher *et al*., 1988. Biologically Available Metals in Sediments. National Research Council of Canada, Ottawa, ON., Canada.

Chambers, P.A., M. Allard, S.L. Walker, J. Marsalek and J. Lawrence *et al*., 1997. Impacts of municipal wastewater effluents on Canadian waters: A review. Water Qual. Res. J. Can., 32: 659-713.

Chary, N.S., C.T. Kamala and D.S. Raj, 2008. Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. Ecotoxicol. Environ. Saf., 69: 513-524.

Demirezen, D. and A. Aksoy, 2006. Heavy metal levels in vegetables in Turkey are within safe limits for Cu, Zn, Ni and exceeded for Cd and Pb J. Food Qual., 29: 252-265.

Fairbrother, A., R. Wenstel, K. Sappington and W. Wood, 2007. Framework for metals risk assessment. Ecotoxicol. Environm. Saf., 68: 145-227.

French, R.H., 1985. Open-Channel Hydraulics. McGraw-Hill, Book Co., Inc., New York, ISBN-13: 9780070221345, Pages: 705.

Gagne, F., C. Blaise, I. Aoyama, R. Luo, C. Gagnon, Y. Couillard and M. Salazar, 2002. Biomarker study of a municipal effluent dispersion plume in two species of freshwater mussels. Environ. Toxicol., 17: 149-159.

Gagnon, C. and I. Saulnier, 2003. Distribution and fate of metals in the dispersion plume of a major municipal effluent. Environ. Pollut., 124: 47-55.

Gagnon, C. and N.S. Fisher, 1997. The bioavailability of sediment-bound Cd, Co and Ag to the mussel *Mytilus edulis*. Can. J. Fish. Aquat. Sci., 54: 147-156.

Ikehata, K. and Y. Liu, 2011. Land Disposal of Wastes. In: Encyclopedia of Environmental Health, Nriagu, J.O. (Ed.). Elsevier Science, New York, USA., ISBN-13: 9780444522627, pp: 353-361.

Kaiser, B.N., K.L. Gridley, J.N. Brady, T. Phillips and S.D. Tyerman, 2005. The role of molybdenum in agricultural plant production. Ann. Bot., 96: 745-754.

Keremane, G.B., 2010. Recycling Urban Wastewater: An Alternative Source for Agricultural Irrigation. In: Adelaide: Water of a City, Daniels, C.B. (Ed.). Wakefield Press, Adelaide, Australia, pp: 340-343.

Lijklema, L., J.M. Tyson and A. Lesouef, 1993. Interactions between sewers, treatment plants and receiving waters in urban areas: A summary of the interurba 92 workshop conclusions. Water Sci. Technol., 27: 1-29.

Luoma, S.N., 1983. Bioavailability of trace metals to aquatic organisms: A review. Sci. Total Environ., 28: 1-22.

Luoma, S.N., C. Johns, N.S. Fisher, N.A. Steinberg, R.S. Oremland and J.R. Reinfelder, 1992. Determination of selenium bioavailability to a benthic bivalve from particulate and solute pathways. Environ. Sci. Technol., 26: 485-491.

Ministere de l'Environnement du Quebec and Environment Canada, 2001. Toxic potential assessment of municipal wastewater treatment plant effluents in Quebec: Final report. St. Lawrence Vision 2000, Phase III-Industrial and Urban Component, pp: 1-136.

Musyoka, S.M., J.C. Ngila and B.B. Mamba, 2013. Remediation studies of trace metals in natural and treated water using surface modified biopolymer nanofibers. Phys. Chem. Earth Parts A/B/C, 66: 45-50.

NRC., 1993. Managing Wastewater in Coastal Urban Areas. National Academies Press, Washington, DC., ISBN: 9780309538039, Pages: 460.

Nable, R.O., G.S. Banuelos and J.G. Paull, 1997. Boron toxicity. Plant Soil, 193: 181-198.

OMOE., 1988. Thirty-seven municipal water pollution control plants: Pilot monitoring study, volume 1: Interim report and volume 2: Appendix A. Canviro Consultants Ltd., Ontario Water Resources Branch, Ontario Ministry of the Environment, Canada, December 1988.

Obbard, J.P., 2001. Toxicological assessment of heavy metals in sewage sludge amended soils. Applied Geochem., 16: 1405-1411.

Pescod, M.B., 1992. Wastewater Treatment and Use in Agriculture. FAO United Nations, Rome, Itlay, Pages: 125.

Rutherford, L.A., K.G. Doe, S.J. Wade and P.A. Hennigar, 1994. Aquatic toxicity and environmental impacts of chlorinated wastewater effluent discharges from four sewage treatment facilities in the atlantic region. Proceedings of the 20th Annual Aquatic Toxicity Workshop, October 17-20, 1993, Quebec City, Quebec, pp: 179-195.

Scheierling, S.M., C.R. Bartone, D.D. Mara and P. Drechsel, 2011. Towards an agenda for improving wastewater use in agriculture. Water Int., 36: 420-440.

Sensesi, G.S., G. Baldassarre, N. Senesi and B. Radina, 1999. Trace element inputs into soils by anthropogenic activities and implications for human health. Chemosphere, 39: 343-377.

Smith, S.R., 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environ. Int., 35: 142-156.

Tiwari, K.K., N.K. Singh, M.P. Patel, M.R. Tiwari and U.N. Rai, 2011. Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India. Ecotoxicol. Environ. Safety, 74: 1670-1677.

Tjandraatmadja, G., C. Diaper, Y. Gozukara, L. Burch, C. Sheedy and G. Price, 2008. Sources of priority contaminants in domestic wastewater: Contaminant contribution from household products. CSIRO: Water for a Healthy Country National Research Flagship, Canberra, Australia.

Tjandraatmadja, G., C. Pollard, C. Sheedy and Y. Gozukara, 2010. Sources of contaminants in domestic wastewater: Nutrients and additional elements from household products. CSIRO: Water for a Healthy Country National Research Flagship, Canberra, Australia.

US EPA., 1986. Report to congress on the discharge of hazardous wastes to publicly owned treatment works (the Domestic sewage survey). EPA/530-SW-86-004, Office of Water Regulation and Standards, Washington, DC., USA.

US EPA., 2004. Guidelines for water reuse. EPA/625/R-04/108, U.S. Agency for International Development, Washington, DC., USA.

Um Alqura Newspaper, 2000. Treated sanitary wastewater and its reuse regulations. Royal Decree No. M/6, 2000, Published in Um Alqura Newspaper, Issue No. 3797.

Vidal, F.S., 1951. The Oasis of Al Hassa. ARAMCO., Dharan, Saudi Arabia.

WHO., 2006. Guidelines for the Safe use of Wastewater, Excreta and Greywater, Volume 3: Wastewater and Excreta Use in Aquaculture. World Health Organization, Washington, DC., ISBN: 9241546840, Pages: 140.

Wong, S.L., J.F. Wainwright and L. Nakamoto, 1995. Monitoring toxicity in four wastewaters in the Bay of Quinte, Lake Ontario. J. Great Lakes Res., 21: 340-352.

Yaman, M., 2006. Comprehensive comparison of trace metal concentrations in cancerous and non-cancerous human tissues. Curr. Med. Chem., 13: 2513-2525.