Saudi Journal of Biological Sciences (2016) 23, S32–S44

King Saud University

Saudi Journal of Biological Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia

Khaled S. Balkhair [a,b,*], **Muhammad Aqeel Ashraf** [c,d]

[a] *Department of Hydrology and Water Resources Management, King Abdulaziz University, P.O. Box 80200, Jeddah 21589, Saudi Arabia*
[b] *Center of Excellence in Desalination Technology, King Abdulaziz University, P.O. Box 80200, Jeddah 21589, Saudi Arabia*
[c] *Faculty of Science & Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[d] *Centre for Research in Biotechnology for Agriculture (CEBAR), University of Malaya, 50603 Kuala Lumpur, Malaysia*

Received 12 June 2015; revised 10 September 2015; accepted 14 September 2015
Available online 9 October 2015

KEYWORDS

Health risk;
Heavy metals;
Sewage water;
Metal transfer index;
Soil

Abstract Wastewater irrigated fields can cause potential contamination with heavy metals to soil and groundwater, thus pose a threat to human beings . The current study was designed to investigate the potential human health risks associated with the consumption of okra vegetable crop contaminated with toxic heavy metals. The crop was grown on a soil irrigated with treated wastewater in the western region of Saudi Arabia during 2010 and 2011. The monitored heavy metals included Cd, Cr, Cu, Pb and Zn for their bioaccumulation factors to provide baseline data regarding environmental safety and the suitability of sewage irrigation in the future. The pollution load index (PLI), enrichment factor (EF) and contamination factor (CF) of these metals were calculated. The pollution load index of the studied soils indicated their level of metal contamination. The concentrations of Ni, Pb, Cd and Cr in the edible portions were above the safe limit in 90%, 28%, 83% and 63% of the samples, respectively. The heavy metals in the edible portions were as follows: Cr > Zn > Ni > Cd > Mn > Pb > Cu > Fe. The Health Risk Index (HRI) was >1 indicating a potential health risk. The EF values designated an enhanced bio-contamination compared to other reports from Saudi Arabia and other countries around the world. The results indicated a

---

[*] Corresponding author at: Department of Hydrology and Water Resources Management, King Abdulaziz University, P.O. Box 80200, Jeddah 21589, Saudi Arabia.

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sjbs.2015.09.023

potential pathway of human exposure to slow poisoning by heavy metals due to the indirect utilization of vegetables grown on heavy metal-contaminated soil that was irrigated by contaminated water sources. The okra tested was not safe for human use, especially for direct consumption by human beings. The irrigation source was identified as the source of the soil pollution in this study.

1. Introduction

The volume of sewage water generated by domestic, industrial and commercial sources has increased along with the increasing population, urbanization, improved living conditions, and economic development (Qadir et al., 2010). In the urban areas of many (developing) countries, urban and peri-urban agriculture depends, at least to a certain extent, on sewage water as a source of irrigation water. The quality of water and the conditions under which this water is used vary significantly. In poor countries, this water may, in extreme cases, take the form of diluted raw sewage, even if this practice is considered illegal (Huibers et al., 2004). However, the quality of the wastewater used and the nature of its use vary enormously, both between and within countries. In many low-income countries in Africa, Asia and Latin America, the wastewater tends to be untreated, whereas in middle-income countries, such as Tunisia and Jordan, treated wastewater is used (Al-Nakshabandi et al., 1997; Qadir et al., 2010).

Sewage water irrigation is also known to contribute significantly to the heavy metal content of soils (Mapanda et al., 2005). Plant species have a variety of capacities to remove and accumulate heavy metals; therefore, there are reports indicating that certain species may accumulate specific heavy metals, causing a serious risk to human health when plant-based foodstuffs are consumed (Fytianos et al., 2001). The disposal of sewage water and industrial waste is a significant problem. The sewage water and industrial waste are often drained to agricultural lands where they are used for growing crops, including vegetables. These sewage effluents are considered a rich source of organic matter and other nutrients, but they elevate the levels of heavy metals, such as Fe, Mn, Cu, Zn, Pb, Cr, Ni, Cd and Co, in the receiving soils (Rattan et al., 2005).

There is an increasing risk of public exposure to heavy metals because of the consumption of food grown in sewage wastewater (Chary et al., 2008). There are numerous reports in the literature supporting this assertion (Sharma et al., 2007; Khan et al., 2008; Srinivasan and Reddy, 2009; Tijani, 2009; Hani et al., 2010). The problem of heavy metals entering the food chain requires systematic assessments to make timely decisions to avoid severe health effects because of the invisible mode of heavy metal toxicity (Chary et al., 2008). Risk assessments have been performed using various risk assessment techniques, such as the hazard quotient (HQ) (Chary et al., 2008), the Health Risk Index (HRI) (Khan et al., 2008), the morbidity status (MS) (Srinivasan and Reddy, 2009), the enrichment factor (EF), the degree of contamination (C_{deg}), the uptake/transfer factor (UF) (Tijani, 2009), statistics, geostatistics and geographic information systems GIS (Hani et al., 2010).

Wastewaters are contaminated with trace elements, such as lead (Pb), copper (Cu), zinc (Zn), boron (B), cobalt (Co), chromium (Cr), arsenic (As), molybdenum (Mo) and manganese (Mn), many of which are non-essential and, over time, are toxic to plants, animals and human beings (Kanwar and Sandha, 2000). The long-term application of treated and untreated wastewater has resulted in a significant buildup of heavy metals in the soil (Khan et al., 2008; Ullah et al., 2012); as well as leachate to groundwater through dumpsites (Oyeku and Eludoyin, 2010) and in vegetables and cereals and their subsequent transfer to the food chain, causing a potential health risk to consumers (McGrath et al., 1994; Kumar Sharma et al., 2007). Heavy metal concentrations in plants grown in wastewater-irrigated soils were significantly higher than in plants grown in the reference soil. (Khan et al., 2008; Singh et al., 2010) have concluded that the use of treated and untreated wastewater for irrigation increased the contamination with Cd, Pb and Ni in the edible portions of vegetables, causing a potential health risk in the long term. (Sachan et al., 2007; Khan et al., 2012) have found that the bioaccumulation of Pb and Cr in vegetables was above the critical concentrations for plant growth, while Pb and Cd were above the prescribed limit for animal diets.

Although zinc is an essential element for plants, its elevated concentration is phytotoxic, directly affecting crop yield and soil fertility. Soil concentrations ranging from 70–400 mg/kg are classified as critical, above which toxicity is considered likely (Alloway, 1990). In addition it is an essential element required by the human body in small amounts. The average daily zinc intake through the diet ranges from 5.2 to 16.2 milligrams. Food may contain levels of zinc ranging from approximately two parts of zinc per million (2 ppm) parts food (e.g., leafy vegetables) to 29 ppm (meats, fish and poultry). Cadmium and its compounds might travel through the soil, but its mobility depends on several factors, such as pH and the amount of organic matter, which will vary depending on the local environment. Generally, cadmium binds strongly to organic matter, becoming immobile in the soil and is taken up by plant life, eventually entering the food chain.

Heavy metals are one of the important types of contaminants that can be found on the surface and in the tissues of fresh vegetables. The prolonged human consumption of unsafe concentrations of heavy metals in foodstuffs may lead to the disruption of numerous biological and biochemical processes in the human body. Vegetables, especially leafy vegetables grown in heavy metal-contaminated soils, accumulate higher amounts of metals than do those grown in uncontaminated soils because they absorb these metals through their leaves (Al Jassir et al., 2005). Leafy vegetables, such as cauliflower, cabbage and spinach, grow quite well in the presence of sewage water (Cobb et al., 2000), whereas other vegetables, such as radish, are sensitive to sewage water (Kapourchal et al., 2009). Vegetables grown using sewage water contain many heavy metals, which cause serious health hazards to the community and animals (Avci, 2013). This concern is of special importance in locations where untreated sewage is applied for longer periods of time to grow vegetables in urban lands. Heavy metal bioaccumulation in the food chain can be especially dangerous to human health. These metals enter the human body primarily through two routes, namely, inhalation and ingestion, with ingestion being the main route of exposure to these elements in the human population.

Okra (*Abelmoschus esculentus* (L) *Moench*) is an annual vegetable crop and belongs to the family Malvaceae. Okra is a good source of carbohydrates, protein, dietary fiber, calcium, magnesium, potassium and vitamins A and C (Mabberley, 1997). Okra contains glycans, substances responsible for the viscosity of aqueous suspensions (Falade and Omojola, 2010) and the stringy, gum-like consistency that is desired in good-quality soups. Glycans are also an excellent source of iodine, which is useful for the treatment of goiters. The powdered root of okra is consumed along with sugar as a treatment for leucorrhoea and backache. Okra acts as a tonic for both men and women and enables them to increase their vitality and vigor. The tender pods of okra are mainly used as a vegetable. The okra pods are also used as snacks and are sliced and sun dried for offseason use. Okra gum obtained from the seedpods of Hibiscus esculentus is an anionic polysaccharide, which can be used as a flocculant for the removal of solid waste from tannery effluent (Agarwal et al., 2003).

Saudi Arabia is an arid country with no permanent rivers or lakes and very little rainfall. Water is scarce and extremely valuable, and with the country's rapid growth, the demand for water is increasing. Therefore, Saudi Arabia has turned to innovative ways to provide enough water to support its development. Aquifers, which are vast underground reservoirs of water, are a major source of water in Saudi Arabia (Alkolibi, 2002). Another major source of water is the sea, which is used through desalination, a process that produces potable water from brackish seawater (El-Ghonemy, 2012). Saudi Arabia is the world's largest producer of desalinated water, and an expanding water source is recycled water. The Kingdom aims to recycle as much as 40% of the water used for domestic purposes in urban areas. To this end, recycling plants have been built in Riyadh, Jeddah and other major urban industrial centers. Recycled water is used for the irrigation of farm fields and urban parks. The use of wastewater is emerging as a potential alternative to augment the water supply in Saudi Arabia, especially in the agricultural sector.

The use of treated wastewater for different purposes is one of the most important strategic alternatives for renewable water in many countries, especially those that suffer from a shortage of traditional water resources. The use of wastewater in agriculture provides water, N, P, and organic matter to the soils; however, there is concern about the accumulation of potentially toxic elements, such as Cd, Cu, Fe, Mn, Pb and Zn, from both domestic and industrial sources (Devkota and Schmidt, 2000). Heavy metals can also accumulate in the soil at toxic levels, as do the salts during long-term applications of untreated and treated wastewaters. Soils irrigated by wastewater accumulate heavy metals, such as Cr, Zn, Pb, Cd and Ni, in the surface soil. When the capacity of the soil to retain heavy metals is reduced due to the repeated application of wastewater, heavy metals leach into the ground water or the soil solution, which are available for plant uptake. For the metals derived from anthropogenic sources, this factor can strongly influence their speciation and, hence, their bioavailability (Singh and Agrawal, 2008).

The aim of this research is to evaluate the effect of heavy metal accumulation in sewage-irrigated soil and vegetable crops. The empirical data on the physiological, biochemical and growth responses due to heavy metal accumulation in the okra plants are rarely available for multi-metal-contaminated soil. Therefore, the present study was conducted with an aim to investigate the accumulation of heavy metals and the consequent responses of okra (*Abelmoschus esculentus* L.) plants grown in soil irrigated with sewage water.

2. Materials and methods

The Bani–Malik wastewater treatment plant is a typical plant in Jeddah city. The plant is located at the center of the city and receives its wastewater from neighboring households covering several districts. This treatment plant treats water up to the secondary stage. Three wastewater samples were collected from the influent and effluent of the plant every month for six months beginning in February 2011. The samples were obtained 10 cm below the water surface to avoid floating solids and were immediately placed inside a cold container with ice cubes to stop any microbiological activity before reaching the laboratory. Collection of the samples and bacteriological analysis were performed as quickly as possible, avoiding an overnight delay. The analyses were conducted in the microbiology lab of the Faculty of Science, which was previously prepared with the required reagents and equipment. The results of the physical, chemical and microbiological analyses of the effluent were compared to the standards of the Ministry Water and Electricity (MWE, 2005) and Food & Agriculture Organization (FAO, 1985).

2.1. Wastewater sampling and analysis

2.1.1. Physical and chemical analysis

Common wastewater parameters were analyzed according to the calibration methods used by the American Public Health Association for water and wastewater Analysis (APHA, 2005). These parameters include Electrical Conductivity (EC), Suspended Solids (SS), Total Soluble Salts (TSS), pH, Biochemical Oxygen Demand (BOD5), Total Nitrogen (T. N.), Total Carbon (T. C.), NH_3–N, NO_3–N and NO_2, Phosphorus (P), Chloride (Cl^-), major, minor elements (Na, Ca, Mg, K, Fe, Mn), and heavy metals (Cu, Pb, Cr, Cd, Ni, Zn). These elements were extracted by a perchloric–nitric digestion procedure described by (Shelton and J, 1941). Afterward, the concentrations were measured using Inductively Coupled Plasma-Optical Emission (ICP-OES Varian 720/730-ES series Spectrometers).

2.2. Soil sampling procedure and analyses

2.2.1. Initial physical and chemical soil analysis

Surface (0–30 cm) complex soil samples were collected from the experimental site before planting plots for the initial physical and chemical soil analysis. The complex sample was collected from six different locations. All the samples were completely mixed together to form a representative surface sample for analyses.

Table 1 Analytical methods used for the chemical analysis.

Parameter	Method of analysis
PH	Beckman pH meter, Jackson (1973)
EC	Electric conductivity meter, Jackson (1973)
Cd	Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES)Varian 720/730-ES series
Pb	
Ni	
Cr	
Fe	
Mn	
Zn	
Cu	
P	
N	Kjeldahl method (Jackson, 1973) using a Kjeltec auto 1030 analyzer
K	Flame photometry according to Jackson (1973)
Na	Flame photometry according to Jackson (1973)
Ca	Titration method
Mg	Titration method
Organic Matter (O.M)	Walkley–Black acid digestion method

Table 2 Initial soil analysis of the experimental site before cultivation.

Parameter	Unit	Concentrations
pH	–	7.9
EC (Electrical Conductivity)	dS/m	2.4
Organic Matter (OM)	%	0.55
Ca (calcium)	%	0.19
Mg (Magnesium)	%	0.11
Na (Sodium)	%	0.017
K (Potassium)	%	0.22
N (Ammonium)	%	0.07
P (Phosphorus)	mg/kg	0.05
Fe (Iron)	mg/kg	21
Zn (zinc)	mg/kg	3.2
Mn (Manganese)	mg/kg	2.5
Cu (Copper)	mg/kg	0.9
Pb (Lead)	mg/kg	0.9
Cd (Cadmium)	mg/kg	0.001
Cr (Chromium)	mg/kg	0.001
Ni (Nickel)	mg/kg	0.03

At the end of the growing season, surface soil samples (0–30 cm depth) were collected for chemical analyses. The samples were collected from two replications at each crop plot under each irrigation system for each water treatment. The samples were air dried and sieved, and then chemical analysis of the first season samples was performed.

2.2.2. Chemical analyses

Before analysis, samples were prepared using the proposed standard methods. Samples for different chemical parameters were prepared as follows:

EC 1: 1 water extraction.

PH 1: 1water suspension.

Total Nitrogen: digestion and distillation.

K, Na, Ca, Mg, Fe, Zn, Mn, Cu, Pb, Cr, Cd and Ni: The samples were extracted from the plant with ammonium acetate and digested in nitric perchloric acid following the procedure given by (Shelton and J, 1941). Due to the similarity of most of the chemical properties of the pre-season soil's surface and sub-surface layers (the initial condition), an average value of each chemical parameter was calculated and presented. Table 1 shows the methods used to analyze the chemical parameters. Table 2 shows the pre-season soil chemical properties.

2.2.3. Physical and chemical soil analysis after cultivation

After harvesting each crop, the soil samples of each treatment were collected. Each sample was placed in a plastic bag and thoroughly mixed to homogenize the sample for testing. Each sample was analyzed for macronutrients, micronutrients and toxic metals. The methods of analysis were identical to those used for the initial soil analysis.

2.3. Chemical analysis of plant samples

The experimental plants were analyzed for macronutrients (N, P, K, Ca, Mg, Na), micronutrients (Fe, Zn, Mn, Cu), and toxic elements (Ni, Cd, Cr, Pb). The methods of analysis were identical to those used in wastewater analysis.

2.4. Field experiments

2.4.1. Experimental design

The okra vegetable field crop experiments were conducted at the Agricultural Research Station of King Abdulaziz University (KAU). The station is located at Hada Al-Sham village, 110 km northeast of Jeddah city. Beside Okra, several vegetable crops were studied for different purposes. However, in this research only Okra was selected for detailed investigations due to its importance in the daily human diet and its nutritional value. A strip plot design (Split block) was used for each studied crop. The main plot treatments contain six wastewater qualities, whereas the irrigation systems were arranged in strips as subplot treatments. The crop was cultivated under each wastewater quality treatment for each irrigation system. The subplot area was 2 × 3 m with 4 replicates.

2.4.2. Irrigation water quality

The Bani–Malik wastewater treatment plant was the primary source of irrigation water. The water was conveyed to the field site by trucks and stored in two large reservoirs, one for each

Table 3 Irrigation water quality used in the experiments.

Percentages of treated wastewater						
LGW	20%	40%	60%	80%	100%	Irrigation quality code
X						LGW
					T	100T
X	T					20T
X		T				40T
X			T			60T
X				T		80T

LGW: local groundwater.
T: treated wastewater.

irrigation system. Each reservoir was connected to six different storage tanks constituting six different water qualities; the dilution process occurs within these storage tanks based on the desirable ratio of wastewater and local groundwater. The wastewater was diluted with the local groundwater source to four different percentages. A water quality of 100% wastewater in addition to the local groundwater and the four dilutions of wastewater provide six irrigation water qualities, as shown in Table 3. Irrigation water qualities were given codes according to the dilution percentages. The six water qualities are as follows: local groundwater source, 100% treated wastewater, and four different dilution percentages as shown in the table above. For example, the code 40T indicates 40% treated wastewater mixed with 60% local groundwater of known quality. Hence, the six storage tanks were used to supply the experimental plots, each with its assigned water quality.

Before harvesting, 10 random guarded plants/plots were labeled, and the following traits were measured for each labeled plant/plot:

Plant height (at the 5th harvesting stage, cm).

- Number of fruits/plant: accumulated numbers of fruits over the 5th harvesting.
- Fresh fruit weight/plant: accumulated weights of the harvested fruits over the 5th harvesting.
- Fresh fruit yield/ha (t): accumulated fresh fruit weights over the 5th harvesting in the 2 × 2 m/plot was determined and converted into yield/ha.

2.5. Translocation factor calculation

Heavy metals have the capability to translocate from the soil to the edible parts of the food crop and can be determined by the accumulation factor (AF) (Li et al., 2012). The AF values for the selected heavy metals were calculated according to the following equation:

$$AF = \frac{\text{Heavy metal concentration in the food crops edible parts}}{\text{Heavy metal concentration in the soil}}$$

2.5.1. Daily intake of metals (DIM)

The daily intake of metals was calculated using the following equation:

$$DIM = \frac{C_{\text{metal}} * C_{\text{factor}} * D_{\text{intak}}}{B_{\text{weight}}}$$

where C_{metal}, C_{factor}, D_{intake} and B_{weight} represent the heavy metal concentrations in the food crops, the conversion factor, the daily intake of the food crops and the average body weight, respectively. The conversion factor (CF) of 0.085 was used for the conversion of fresh vegetables to dry weights. The average daily intake of the food crops was 0.527 kg person^{-1} d^{-1}, and the average body weight for the adult population was 55.5 kg; these values were used for the calculation of HRI as well.

2.5.2. Health risk index (HRI)

The HRI refers to the ratio of the daily intake of metals in the food crops to the oral reference dose (RfD) (EPA, 2002) and was calculated using the following equation:

$$HRI = \frac{DIM}{RfD}$$

An HRI > 1 for any metal in food crops indicates that the consumer population faces a health risk.

2.5.3. Target hazard quotient (THQ)

The health risks to the local inhabitants from the consumption of vegetables were evaluated based on the THQ, which is the ratio of a determined dose of a pollutant to a reference dose level. An increasingly large value of the THQ above unity indicates an increasing level of concern. The method of estimating the risk using the THQ is based on the following equation (Abdu et al., 2011):

$$THQ = \frac{EFr * ED * FI * MC}{RfD * BW * AT} * 0.001$$

where EFr is the exposure frequency (365 days year^{-1}), ED is the exposure duration (60 years for adults), FI is the food ingestion, MC is the metal concentration in the food (mg kg^{-1} fresh weight), RfD is the oral reference dose (mg kg^{-1} day^{-1}), BW is the average body weight for an adult (60 kg) and AT is the average exposure time for non-carcinogenic effects (365 days year^{-1} × number of exposure years, assuming 60 years in this study). The RfD is an estimation of the human daily exposure that is unlikely to pose an appreciable risk of adverse health effects during a lifetime.

3. Results

The Bani–Malik wastewater treatment plant (WWTP), a main source of irrigation water in all of the experiments, is one of several treatment plants in Jeddah city that exceeds its design capacity. Therefore, the secondary treatment level of the plant is inefficient. However, sustainable reuses in agricultural projects depend upon the quality of the effluent and the environmental risk associated with the land application for a variety of crops and activities.

3.1. Physicochemical characterization of the soils

The soil properties (Table 4) were evaluated according to the AFNOR protocols (Association française de, 1994). The evaluated properties included particle size (clay, silt, and sand), pH

Table 4 Physiochemical characteristics of cultivated soil.

Characteristics	Type	Value*
Particle size g kg^{-1}	Clay	210 ± 60
	Silt	230 ± 18
	Sand	571 ± 49
pH	pH water	6.0 ± 0.5
Organic matter mg g^{-1}	OM	44.9 ± 1.6
	TKN	3.0 ± 0.4
Available phosphorus mg kg^{-1}	P_{ash}	14.5 ± 0.3
Exchangeable cations mg kg^{-1}	Ca_{exch}	68 ± 14
	Mg_{exch}	20 ± 13
	K_{exch}	4.5 ± 1.5
	Na_{exch}	2.8 ± 0.8
Cation exchange capacity (meq per 100 g)	CEC_{exch}	18 ± 3

Mean* ± Standard Deviation (N = 6).

of the water, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), available phosphorus (P), cation exchange capacity (CEC) and exchangeable bases (Ca_{exch}, Mg_{exch}, K_{exch}, Na_{exch}). Considering the average content of carbon in soil organic matter (58% w/w), a conversion factor of 1.724 was used to calculate the percentage of organic matter (OM) from the content of organic carbon (Abollino et al., 2002).

3.2. Total salt concentration

The effect of salts on crop growth is believed to be largely osmotic in nature. Osmotic pressure is a collaborative property; therefore, it is related to the total salt concentration rather than to the concentration of individual ionic species (Shainberg, 1978). Table 5 shows the mean values of the chemical and biological characteristics of the LGW, influent and effluent of the Bani–Malik WWTP along with the standards of the Ministry of Waters and Electricity (MWE, 2005) and the Food and Agriculture Organization (FAO, 1985). The average total dissolved solids (TDS) of the influent and effluent from the Bani–Malik WWTP are 782.1 mg/l and 764.6 mg/l, respectively, and the corresponding electrical conductivities (EC) are 1.23 and 1.18 dS/m, respectively. However, the average TDS of the local ground water (LGW) at Hada Al-Sham that is used in the dilution process to produce different water qualities is 1612 mg/l, corresponding to an EC of 2.53 dS/m, as shown in Table 1 along with other chemical and biological properties. The salinity value lies within the range of both the local standards of the Ministry of Water and Electricity (MWE) and the (FAO). This result suggests its use for the irrigation of coarse-textured soils of good permeability. Mixing Bani–Malik wastewater effluent at different percentages with LGW to produce six different wastewater qualities (LGW, 20T, 40T, 60T, 80T and 100T) reduced the salinity of the irrigation water.

Wastewater irrigation significantly affected the soil chemical properties, especially at a 0–30 cm soil depth, and the plant nutrients. The application of wastewater increased the soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant-available P and microelements and decreased the soil pH. (Kiziloglu et al., 2007; Najafi and Nasr, 2009) have reported that the application of wastewater in drip irrigation caused an increase in the EC, OM, SO_4, Ca, Na and Cl. Soil irrigated with wastewater caused an increase in the EC, P, OM, TN, K, Na, Cl, Fe, Cd and Zn, but it caused a decrease in the soil pH (Mojiri and Jalalian, 2011).

The most reliable index of the sodium hazard, which is the tendency of irrigation water to form exchangeable sodium in the soil, is the sodium adsorption ratio (SAR). The average SAR values of the influent and effluent of the Bani–Malik WWTP were 6.81 and 7.27, respectively (Table 5). However, the average SAR value of the local groundwater was 13, which exhibits a moderate sodium problem. This type of irrigation water can be classified as a C_3S_1 influent and effluent, respectively, on the U.S. Salinity Laboratory Scale, whereas the local groundwater is classified as C_4S_2, as shown in (Fig. 1). A number of documented reports have indicated the successful use of saline water in irrigation. (Jury, 1978) grew wheat in lysimeters with water up to 7.1 m mho/cm (4544 mg/l). Several workers (Dhir, 1977; Bressler, 1979) using waters of relatively high salt concentration levels lying between 4 m mhos/cm and 15 m mhos/cm have concluded that such water could be used for certain crops without a drastic yield reduction.

Table 5 The mean values of the chemical and biological characteristics of the LGW, influent and effluent of the Bani–Malik WWTP along with the standards of the Ministry of Waters and Electricity (MWE, 2005) and the Food and Agriculture Organization (FAO, 1985).

Parameter	Bani–Malik WWTP		LGW***	MWE**	FAO*
	Influent	Effluent			
pH	7.29	7.45	7.89	6.0–8.4	6–9
EC (dS/m)	1.23	1.18	2.53	5.1	3.1
Ca (mg/l)	83.75	61.15	54.28	200	400
Mg (mg/l)	13.4	11.51	27.66	150	60
Na (mg/l)	47.03	43.53	83.76	–	900
K (mg/l)	6.88	6.5	3.89	–	–
NH_4- N (mg/l)	37.41	33.31	0	5	30
NO_3- N (mg/l)	24.32	23.48	0	10	–
P (mg/l)	9.85	6.56	0	–	–
SAR	6.81	7.27	13		15
Fe (mg/l)	1.63	1.58	0.018	5	5
Zn (mg/l)	0.106	0.096	0.001	4	2
Mn (mg/l)	0.106	0.096	0.002	0.2	0.2
Cu (mg/l)	0.051	0.050	0.079	0.4	0.2
Pb (mg/l)	0.022	0.019	0.004	0.1	5
Cd (mg/l)	0.0096	0.0091	0.0001	0.01	0.2
Cr (mg/l)	0.015	0.014	0.029	0.1	0.1
Ni (mg/l)	0.036	0.032	0.006	0.2	0.2
TDS (mg/l)	782.1	764.55	1612	2500	2000
SS (mg/l)	704.16	130.55	0	10	–
COD (mg/l)	532.51	170.4	0	150	–
BOD (mg/l)	324.85	48.62	0	10	–

* FAO: Food and Agriculture Organization, ** MWE: Ministry of Water and Electricity, *** LGW: Low Groundwater Pumping Scenario.

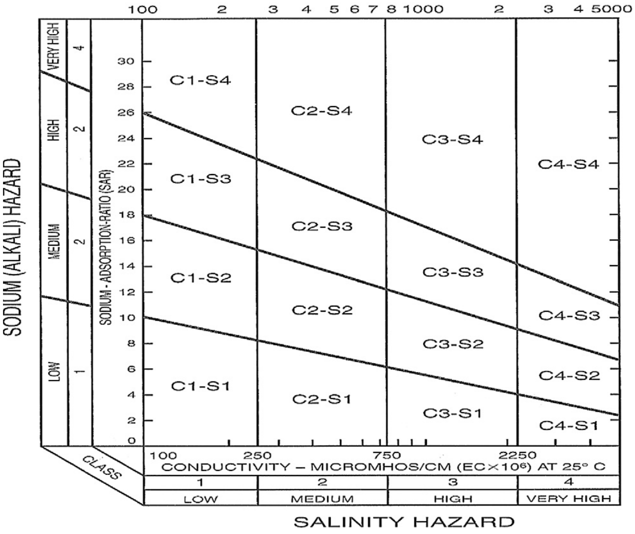

Figure 1 Diagram for the classification of irrigation water according to the United States Salinity Laboratory.

Nitrogen (N), Phosphors (P), Potassium (K), Magnesium (Mg) and Calcium (Ca) are the primary constituents of wastewater effluent and are essential for plant growth. Exceeding the safe limit or having a shortage of these elements may

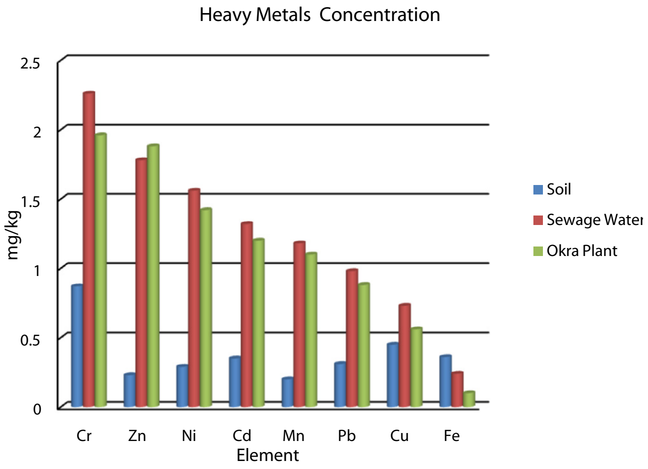

Figure 2 The mean concentrations of heavy metals in the soil, sewage water and the okra plants.

cause diverse problems for irrigated crops. These constituents were monitored in the effluent of the Bani–Malik WWTP. Excluding nitrogen (N), all of the elements were found to be within the acceptable safe limit.

The average ammonium (mg/l) and nitrate (as N) (mg/l) levels of the effluent from the Bani–Malik WWTP were 33.31 and 23.48 mg/l, respectively. These values exceeded the safe limit according to the standards shown in Table 5, whereas NH_4–N and NO_3–N were undetected in the local groundwater samples. Nitrogen fertilization exceeding the allowable limit may produce considerable vegetative growth, although many side effects could occur. The side effects might include: (1) insufficient fruits of adequate size, (2) crop lodging, (3) delay of maturity or harvest ability of crops, (4) low sugar or starch content, and (5) adverse effect on the texture, flavor and/or color of the fruit and vegetable crops. A high nitrate concentration in vegetable crops would be problematic when consumed by infants, possibly causing blue baby syndrome (methemoglobinemia) (Bouwer and Crowe, 1988). The same problem could occur with alfalfa for cattle. In a study conducted by (Kiziloglu et al., 2007), the results indicated that the application of wastewater to soil increased the yield and the N, P, K, Fe, Mn, Zn, Cu, B and Mo contents of cabbage plants without causing undesirable side effects to the plant's heavy metal contents. (Mohammad Rusan et al., 2007) have detected a high concentration of essential nutrients (Total-N, NO_3, P and K) in plants grown in soils irrigated with wastewater. The toxic and micronutrient elements may have an inhibitory effect on plant growth when their concentrations exceed the safe limit.

The contents of total Fe, Zn, Mn, Cu, Pb, Cd, Cr and Ni in the effluent of the Bani–Malik WWTP and the local groundwater were within the safe limit according to both (FAO, 1985; MWE, 2005) standards, as shown in Table 5. Using wastewater in irrigation for a long period may lead to an accumulation of heavy metals in agricultural soils and plants. Wastewater is considered to be a rich source of organic matter and other nutrients, but it elevates the levels of heavy metals, such as Fe, Mn, Cu, Zn, Pb, Cr, Ni, Cd and Co, in the receiving soils. Therefore, the use of wastewater in irrigation leads to contamination of the food chain (Muchuweti et al., 2006). Several studies have been conducted to quantify the accumulation of heavy metals in plants. (DemİRezen and Aksoy, 2006) have investigated the concentrations of heavy metals, such as Cd, Pb, Zn, Cu and Ni, in different vegetables grown in various parts of Turkey. The levels of heavy metals (lead, cadmium, copper and zinc) were examined in selected fruits and vegetables sold in the local markets of Egypt (Radwan and Salama, 2006).

The average BOD and COD values of the effluent were 48.62 mg/l and 170.4, respectively. Nevertheless, no BOD or COD levels were detected in the local groundwater (Table 5). These values are considered high in the effluent of the Bani–Malik WWTP according to the MWE, 2005 standard (Table 5). High BOD and COD values adversely affect the growth of the plant. The suspended solids affect the plant growth because they reduce the permeability of the soil, which, in turn, reduces the availability of oxygen for the plant roots. The effluent concentration of SS that was used in irrigation was 130.55 mg/l, which was 13-fold higher than the allowable limit according to the MWE, 2005 standards. Note that the MWE, 2005 standards are quite restrictive as compared with standards in arid countries. For example, the SS in Jordan reaches up to 50 mg/l for cooked vegetables. However, no SS were detected in the local groundwater.

3.3. Metal concentrations in the soil, sewage water and okra plants

The mean concentrations of Cr, Zn, Ni, Cd, Mn, Pb, Cu and Fe in the soil, sewage water and the okra plants were 30.78, 15.58, 12.37 and 3.74 mg kg^{-1}, respectively (Fig. 2). The sequence of heavy metals in the soil, sewage water and plant crop at the Bani–Malik site was found in the order of Cr > Zn > Ni > Cd > Mn > Pb > Cu > Fe > Ni. A comparison of the data with the criterion established by Kabata-Pendias and Pendias (2001) for the approximate concentrations of heavy metals in plants revealed that Cr was in excessive or toxic concentrations in 1.96 (90%), Zn in 1.88 (26%), Ni in 1.42 (78%), Cd in 1.20 (40%), Mn in 1.10 (13%), Pb in 0.88 (24%), Cu in 0.56 (8%) and Fe in 6 (15%) of the leaf samples.

3.4. Metal Concentrations in the soils and translocation factors

The concentrations of Cr in the soils of the study area ranged from 0.87–1.00 mg kg^{-1}, whereas those of Fe ranged between 0.36–0.75 mg kg^{-1}. These ranges exceed the permissible limits for mineral soils in arid regions (Brady and Weil, 1996). The rate of absorption of elements by plants depends upon the cultivated plant and the soil properties, such as the pH, CEC and distribution of metals in different soil fractions (Kos et al., 2003). At an acidic pH, high Mn concentrations in cultivated soils could pose a risk of toxicity to the okra plant. Under an acidic pH, free Mn may be the predominant form in the soil solution, making it readily available for the okra plants. (Renella et al., 2004) have reported that in Mn- and Zn-polluted soils, the solubility of Mn and Zn was significantly higher in the presence of organic acids, which are typically released by plant roots, thus suggesting that plants can mobilize trace elements via their root exudates.

The metal AF in plants is used to describe the extent of accumulation of a compound in an identified biological system. Table 6 presents the AF values of the metals in the

Table 6 Daily intakes of metals (DIM) (mg kg^{-1} $person^{-1}$ d^{-1}) and the Health Risk Index (HRI) for individual heavy metals in food crops irrigated with sewage water.

Metals	Translocation factor AF[a]	Risk assessment index			RDA[b] (mg day^{-1})	RfD[c] (mg kg^{-1} day^{-1})
		DIM	HRI	THQ		
Cu	0.0122–0.0246	3.30E-03	2.20E-03	0.873	6.0–9.0	0.2
Ni	0.1265–0.1489	3.20E-03	1.62E-01	0.902	2.0–8.0	0.4
Mn	1.0777–1.0964	4.06E-02	2.90E-01	1.164	1.8–2.3	0.14
Pb	1.0124–1.0429	2.85E-02	8.14E-00	1.803	2.0–6.5	0.6
Cd	0.0991–0.1820	1.70E-03	1.67E-00	2.904	1.8–6-8	0.5
Zn	1.1422–1.1622	4.00E-04	3.00E-04	0.065	8.0–11.0	0.3
Fe	0.6162–0.8354	1.90E-03	9.68E-02	0.442	8.0–18.0	0.8
Cr	1.6730–1.8240	2.28E-02	1.63E-01	2.279	5.0–9-0	0.3

consumed parts of the studied plants. The accumulation factors of the metals in the consumed parts of the plants were less than the values obtained for Fe and Cr. Chromium, with AF values in the range of 1.6730–1.8240, was the most accumulated. Thus, the bio-concentration factor (BCF) values of metals in the food crops showed a trend in the order of Cr > Zn > Ni > Cd > Mn > Pb > Cu ≈ Fe. The best accumulators for Cr are okra plants that preferentially concentrate metals in their leaves, the consumable part of the plant.

3.5. Daily intake of metals and human health risk assessment

To observe the health risk of each pollutant, it is important to estimate the level of exposure by detecting the routes of exposure to target organisms. There are several possible pathways of exposure to humans, but among them the food chain is the most important pathway. In our study, the only intake pathway considered for Cr, Zn, Ni, Cd, Mn, Pb, Cu and Fe was assumed to be vegetable consumption. The DIM values were estimated according to the average vegetable consumption for adults (Table 6) and compared with the recommended daily intakes (WHO, 1996; Trumbo et al., 2001). The results for the evaluation of the DIM and HRI from the heavy metal-contaminated okra crop are presented in Table 6 for sewage water irrigation. The results showed that the DIM and HRI values were high in the okra crop. The DIM of the sewage water-irrigated crop ranged from 1.2E-02 to 4.9E-02, 2.7E-03 to 5.2E-03, 1.2E-03 to 1.6E-02, 1.8E-02 to 3.3E-02 and 1.0E-03 to 3.1E-03 mg kg^{-1} $person^{-1}$ d^{-1} for Cr, Ni, Mn, Pb and Cd, respectively (Table 6). Similarly, in sewage water-irrigated food crops, the HRI values for Cr, Ni, Mn, Pb and Cd ranged from 8.0E-02 to 3.3E-01, 1.4E-01 to 2.6E-01, 8.6E-01 to 1.2E-00, 5.2E-00 to 9.4E-00 and 9.5E-01 to 3.1E -00, respectively (Table 6).

4. Discussion

4.1. Fertility parameters of the soils

The results for uncultivated soils (not presented) showed that all of the studied soil fertility parameters (pH, OM, NTK, CEC, exchangeable bases and available P) decreased significantly (Kos et al., 2003) by 60% in the cropped soils, presenting a sandy clay loam texture (Table 4). However, based on Landon's classification28 of different parameters of agricultural arid soils, the levels of these fertility parameters remained significant for good agricultural performance. This observation was also made by Guichard (via personal communication), who analyzed soil samples from gardens in this study area. Edou observed that the organic fertility of cultivated land was renewed through an annual or periodic amendment of the cultivated area. This practice only occurred after the observation of infertility signs, including a decline in yield, typically due to soil acidification. The decrease in the pH value in the surface layer may also be associated with changes in particle size and a relative loss of soil OM. The available P, influenced by mineralogy and the soil texture, is mostly concentrated in the organic fraction of tropical soils (Kamprath, 1980; McAlister et al., 1998).

The pH is one of the factors influencing the bioavailability and the transport of heavy metals in the soil, and according to (Smith and Giller, 1992), heavy metal mobility decreases with increasing soil pH due to the precipitation of hydroxides, carbonates or the formation of insoluble organic complexes. In the present study, it was observed that the heavy metal contents increase significantly with a decrease in the pH ($p < 0.05$). The soil Electrical Conductivity (EC) also varied significantly with depth ($p < 0.05$). By comparison, (Boulding, 1994) classified the EC of the soils as: non saline < 2; moderately saline 2–8; very saline 8–16 and extremely saline > 16. From the results of the study, the EC is classified as moderately saline. The amount of heavy metals mobilized in the soil environment is a function of the pH, properties of the metals, redox conditions, soil chemistry, organic matter content, clay content, cation exchange capacity and other soil properties (Mukherjee, 1998). Heavy metals are generally more mobile at pH < 7 than they are at pH > 7. The pH of the soils from the Bani–Malik site ranged from 5.98 to 7.26. Therefore, these pH conditions are hazardous for agricultural purposes because crops are known to take up and accumulate heavy metals from contaminated soils in their edible portions (Wei et al., 2005).

4.2. Water pH, EC and heavy metals

All of the water samples tend toward being alkaline, with pHs ranging from 7.29 to 7.45. (Shainberg, 1978) have reported that the pH of irrigation water is not an acceptable criterion of water quality because it tends to be buffered by the soil, and most crops can tolerate a wide pH range. The EC of sewage water varied from 973.25 to 941.15 dS m^{-1}. (Ayers and Westcot, 1984) have suggested that water having EC values higher than 300 dS m^{-1} are not safe for irrigation purposes. The EC of the soil samples revealed that all of the fields had no salinity problem (EC < 4.0 dS m^{-1}). The concentrations of heavy metals showed spatial and temporal variations, which may be ascribed to the variation in the heavy metal sources and the quantity of heavy metals in sewage water. This trend suggests that the continuous application of sewage sludge and municipal wastewater influenced the soil physicochemical properties (Willett et al., 1984).

The levels of organic carbon in the soil sample increased significantly with depth, whereas the levels of organic matter decreased. The OC also increased with an increasing water rate (Davis et al., 1988). This result may be of significant environmental consequence because it was shown that higher rates of applied water (irrigation) during the study periods increased the amounts of the OC, which influences the solubility and availability of heavy metals. Among the studied metals, the Cd concentration ranged from 7.13 to 11.13 mg kg^{-1}, which exceeded the permissible limits set by (European, 2002). Cd has a greater exchangeable capacity, thus easily becoming available and soluble in soils and becoming bio-available and accumulating in the edible parts of the plants (Luo et al., 2011). Compared with the current study, a higher level of Cd (22.2–51.0 mg kg^{-1}) was found in wastewater-irrigated soil samples collected from Titagarh, India, whereas lower concentrations of Cd were found (0.41–1.71 mg kg^{-1}) in the wastewater-irrigated soils from Beijing, China (Gupta et al., 2008). In contrast, (Mapanda et al., 2005) have reported a lower level of Cd (3.4 mg kg^{-1}) in the wastewater-irrigated soil in Zimbabwe.

4.3. Heavy metals in the okra plants

The mean concentrations of Cr, Zn, Ni, Cd, Mn, Pb, Cu and Fe in the okra plants were 1.96, 1.88, 1.42, 1.20, 1.10, 0.88, 0.56 and 0.10 mg kg^{-1}, respectively (Fig. 2). The present study indicated that all of the heavy metal concentrations in the wastewater-irrigated food crops were higher than the permissible limits. Our results showed that the Cd, Zn, Ni, Cd and Pb exceeded the permissible limits in all the wastewater samples. The Cu and Fe contents were also above the permissible limits in sewage water-irrigated food crops, with the exception of *L. esculentum*. Various scientists have reported elevated levels of heavy metals in sewage and industrial effluent-irrigated vegetables. (Mohammad Rusan et al., 2007) have stated that the levels of plant Pb and Cd increased with wastewater irrigation, and a longer period of wastewater irrigation led to a higher concentration of heavy metals. (Singh and Kumar, 2006) have collected samples of vegetables (spinach and okra), soil and irrigation water from 5 peri-urban sites of New Delhi to monitor their heavy metal loads. These authors have concluded that although the heavy metal load of the irrigation water was above the maximum allowable limit, it was lower in the soils and higher in the vegetable samples. The spinach and okra samples showed Zn, Pb and Cd levels that were higher than the WHO limits.

Although the wastewater contains low levels of the heavy metals, the plant samples showed higher values due to accumulation (Gupta et al., 2010). High levels of heavy metals in vegetables irrigated with sewage water were observed because the sewage water was enriched with heavy metals, thus polluting the soil and, consequently, the vegetables. These findings are a clear reflection of wastewater irrigation and the subsequent accumulation of heavy metals in the okra plant. In addition to the aforementioned sources of heavy metals in the selected food crop contamination, the use of phosphate fertilizers is a prominent practice and is the most important cause of Cd accumulation in the agricultural field. Cd is known to be present as an impurity in phosphate rocks (Qixing et al., 1994) and is transferred to plants (edible parts) due to its high mobility. Leafy vegetables (*S. oleracea, M. spicata, C. sativum*) had maximum metal concentrations (except for Ni and Pb) among the food crops studied because of the large surface area of their leaves, their higher transpiration and faster growth rate, which enhances the metal translocation in leafy vegetables (Muchuweti et al., 2006). The expanded leaf of leafy vegetables sensitizes them to be a recipient of dust and rainwater splashes (Luo et al., 2011).

Low metal concentrations in certain species, such as *T. aestivum*, *A. sativum* and *S. melongena*, and certain variant concentrations of heavy metals in food crops could be ascribed to the variability in the metal absorption of the plants and the physical and chemical nature of the soil (Zurera-Cosano et al., 1989). Leaves contained higher concentrations of heavy metals than did roots and stems. A similar study performed by (Santamaria et al., 1999) has shown that the heavy metal content differs in various parts of the plant. These authors reported that in vegetable parts, the concentrations of heavy metals are in the order of leaf > stem > root > tuber > - bulb > fruit > seed. (Amusan et al., 1999) have studied the plant uptake of heavy metals at a similar site at the University of Ife's dump site and reported that the Pb uptake by water leaf (*Talinum triangulare*) and okra (*Albennucus esculentus*) increased in the leaves and roots relative to those grown in the non-dump sites.

A similar study by (Ademoroti, 1996) has reported that vegetables accumulate a considerable amount of heavy metals, especially Pb, Cr, Cu and Zn, in the roots and leaves. The concentrations of heavy metals in all of the vegetable samples analyzed were higher than the FAO/WHO guideline values of 0.1–0.2 mg/kg Cr, 0.3 mg/kg Fe; 0.1 mg/kg Pb; 0.1 mg/kg Cu; 0.1 mg/kg Zn; 0.1 mg/kg Ni; 0.02 mg/kg Cd and 0.3 mg/kg Mn. The results from the present study and earlier reports (Liu et al., 2005; Muchuweti et al., 2006; Kumar Sharma et al., 2007) demonstrated that plants grown on wastewater-irrigated soils are contaminated with heavy metals and pose a health concern. The absorption and accumulation of heavy metals in plant tissues depend upon many factors. These factors include the temperature, moisture, organic matter, pH and nutrient availability, whereas the presence of organic matter has been reported to increase the uptake of zinc, chromium, lead, iron and copper in the wheat plant (Rupa et al., 2003).

In the present study, many soil factors, such as the pH, organic matter and organic carbon have interacted to influence the uptake. The acidic range of the soil is known to increase the mobilization of heavy metals, thus increasing their uptake. The field data support this argument in that the soil pH was acidic. The values of sulfate, phosphate, nitrate and nitrite in the vegetable samples show that the leaves are richer in this anion content than in the other parts studied. A similar study was performed by (Santamaria et al., 1999), which stated that nitrate and nitrite contents of various parts of a plant differ in the order of leaf > stem > root > tuber > bulb > fruit > seed.

(Qixing et al., 1994) have reported that vegetables that are consumed with their roots, stems and leaves have a high nitrate and nitrite accumulation, whereas melons and those vegetables with only fruits as consumable parts have a low nitrate accumulation.

This observation was also noted in a study by (Hunt and Turner, 1994) in which the leaf and stem accumulated the most nitrate, sulfate and nitrite, followed by the stem and roots. The concentrations of these anions were higher in the leafy vegetables (spinach and lettuce) than in the tomato. The results of the analysis of variance (ANOVA) showed that the differences between the vegetables and plant parts were statistically significant ($p < 0.05$). Morphological and physiological changes play a vital role in metal translocation, elimination, and accumulation (Itanna, 2002). The non-essential heavy metals become toxic via the consumption of food crops. These results indicate that the accumulation of certain metals beyond the permissible limits is a serious health risk factor for the human population. Our findings show that continuous sewage water irrigation accumulates heavy metals in food crops that were beyond the safe limits for most of the food crops. The local population is most likely unaware of the nutritional status of the vegetables that they consume daily. In addition, there is no alternative source of vegetable supplies. Therefore, the population in this area is at serious risk.

4.4. Heavy metal transfer (AF) in edible parts of the okra plant

The accumulation factor (AF) for Cr, Zn, Ni, Cd, Mn, Pb, Cu and Fe greater than 1 in most of the studied food crops indicates greater accumulation. Those metals that have a high transfer factor migrate to the edible part of the plant easier than do those with a low transfer factor (Luo et al., 2011); this is the reason that these metals reflect their high accumulation values in various food crops to such a high ratio. The AF values varied for heavy metals in various food crops and in wastewater and tube well water-irrigated sites (Cui et al., 2004). High AF values were observed in all of the studied metals with sewage water-irrigated food crops and could be one of the possible reasons for health risks in humans via their consumption. Low AF values for heavy metals were shown in the soil. This result indicated that the uptake of heavy metals by food crops did not increase linearly with increasing metal concentrations in the soil. Our study is in agreement with the previous findings of (Hooda et al., 1997; Rattan et al., 2005). This phenomenon is significant in terms of long-term wastewater irrigation so that the same proportions would not be part of the food chain.

4.5. Daily intake of metals and human health risk assessment

The human risk assessment quantification from the pathway of the food chain is of prime importance in countries such as Saudi Arabia, where the wastewater irrigation practice remains unregulated. There are several exposure pathways that primarily depend upon contaminated sources of air, water, soil, food and the consuming population (Caussy et al., 2003), but the route of exposure via the food chain is one of the key pathways of heavy metal exposure to humans (Muchuweti et al., 2006). The Saudi population is primarily vegetarian and relies on a cereal crop (*T. aestivum* L.) as a staple food. The food crops produced in the present study are consumed directly by the local inhabitants or are sold to the market for dispersed population consumption.

The oral reference dose (RfD) is the daily exposure of individuals to toxins or pollutants that can pose no appreciable hazard over their lifetime. The RfD values for the toxic metals Cd, Cr, Ni, Pb and Mn are 1E-03, 1.5E-0, 2E-2, 3.5E-3, 1.4E-1 mg kg^{-1} d^{-1}, respectively (EPA-IRIS 2006). In our study, the heavy metals, except for Cr and Ni, have HRI > 1, indicating a possible future human health risk via the intake of food crops. Cd showed a HRI > 1 in all of the wastewater-irrigated food crops except T. aestivum, whereas groundwater irrigated food crops have a HRI < 1. The highest HRI values (> 1) were observed for Pb, Cr and Mn in *S. oleracea* irrigated with wastewater. However, Cd and Pb are considered to be non-essential metals contributing to health hazards, even at extremely low concentrations. (Ikeda et al., 2000; Zhuang et al., 2009) have also reported a HRI value for Cd and Pb that is above the permissible limits in vegetables and cereals.

The THQ has been recognized as a useful parameter for evaluating the risk associated with the consumption of metal-contaminated food crops (Agbenin et al., 2009). An important number of the results obtained in this study were above this limit and suggested possible metal contamination through the okra plant. According to the THQ values, Cr present in consumed plants has the potential to pose a health risk to the local population. (Horiguchi et al., 2004) have suggested that the ingested dose of heavy metals is not equal to the absorbed pollutant dose in reality because a fraction of the ingested heavy metals may be excreted, with the remainder being accumulated in body tissues where they can affect human health. The present study is very important in terms of health perspectives, indicating the health risk to the human population from the consumption of heavy metals in food crops.

4.6. Conclusions and recommendations

The use of sewage water for irrigation has gained importance throughout the world due to limited water sources and wastewater treatment costs for discharge. The availability of land with suitable topography, soil characteristics and drainage enables the sewage effluent to be applied as a source of both irrigation water and plant nutrients. Sewage water contains a high amount of organic matter, nutrients and certain heavy metals that are toxic to plants when present above a certain limit. In our study, the cultivated okra plant that was irrigated with treated wastewater exhibit an increase in the concentrations of metals in both the soil and the vegetable. However, it was observed that different vegetables accumulate and translocate variable amounts of metals from the soil into their tissues. To avoid the absorption of these metals, most of the crops and vegetable species growing in metal-polluted soils cannot be consumed. Soils may accumulate metals in sufficient quantities to cause clinical problems to both animals and human beings consuming these metal-rich plants.

A significant accumulation of toxic heavy metals in soils and food crop samples is due to the sewage water irrigation in different cities of Saudi Arabia. To the best of our knowledge, no data are available from Saudi Arabia for a thorough hazards assessment from the intake of contaminated food and its outcome on human health. The current study indicates that sewage water irrigation is the primary source of metal accumulation in food crops, which upon human consumption may lead to adverse health outcomes on a large scale. The results reveal that heavy metals (Cr, Pb, Cd and Mn) showed high AF values. Furthermore, HRI values >1 were also observed for Cr, Pb, Cd and Mn consumption in food crops. This study provides a brief insight into the current scenario of food crop contamination and possible future health risk estimates. An urgent need exists to strictly monitor the wastewater and the groundwater of the study area and to develop different strategies to prevent the accumulation of heavy metals in food crops that may ultimately minimize the chronic health risk to the exposed population.

This study reveals that untreated sewage and industrial effluents are the primary source of pollution to the soil, and irrigation with contaminated sewage water containing variable amounts of heavy metals leads to an increase in the concentration of metals in soil and the vegetables that are grown using polluted water. The concentrations of the metals in the vegetables will provide baseline data, and intensive sampling is required for the quantification of the results throughout the country. Because cucumber accumulates metals and metalloids the least, it may be less risky to eat cucumber rather than eating okra from a health standpoint. To avoid the entrance of metals into the food chain, municipal or industrial waste should not be drained into rivers and farmlands without prior treatment. In addition to treating the discharge that enters into the farms, it is imperative to utilize alternative measures of cleaning up the already contaminated substrates. The continuous monitoring of the soil, plant and water quality along with preventing metals from entering the vegetables are prerequisites for the prevention of potential health hazards to human beings.

Acknowledgements

This work was supported by the Deanship of Scientific Research (DSR), King Abdulaziz University, Jeddah, under Grant No. (155-012-D1433). The authors, therefore, gratefully acknowledge the DSR technical and financial support.

References

Abdu, N., Agbenin, J.O., Buerkert, A., 2011. Phytoavailability, human risk assessment and transfer characteristics of cadmium and zinc contamination from urban gardens in Kano, Nigeria. J. Sci. Food Agric. 91, 2722–2730.

Abollino, O., Aceto, M., Malandrino, M., Mentasti, E., Sarzanini, C., Petrella, F., 2002. Heavy metals in agricultural soils from Piedmont, Italy. Distribution, speciation and chemometric data treatment. Chemosphere 49 (6), 545–557.

Ademoroti, C.M.A., 1996. Standard method for water and Effluents Analysis. Foludex pressLtd, Ibadan.

Agarwal, M., Rajani, S., Mishra, A., Rai, J.S.P., 2003. Utilization of okra gum for treatment of tannery effluent. Int. J. Polymer. Mater. Polymer. Biomater. 52 (11–12), 1049–1057.

Agbenin, J.O., Danko, M., Welp, G., 2009. Soil and vegetable compositional relationships of eight potentially toxic metals in urban garden fields from northern Nigeria. J. Sci. Food Agric. 89 (1), 49–54.

Al Jassir, M.S., Shaker, A., Khaliq, M.A., 2005. Deposition of heavy metals on green leafy vegetables sold on roadsides of Riyadh City, Saudi Arabia. Bull. Environ. Contam. Toxicol. 75 (5), 1020–1027.

Alkolibi, F., 2002. Possible effects of global warming on agriculture and water resources in Saudi Arabia: impacts and responses. Clim. Change 54 (1–2), 225–245.

Alloway, B.J., 1990. Heavy Metals in Soils. John Wiley and Sons, Inc., New York, ISBN 0470215984.

Al-Nakshabandi, G.A., Saqqar, M.M., Shatanawi, M.R., Fayyad, M., Al-Horani, H., 1997. Some environmental problems associated with the use of treated wastewater for irrigation in Jordan. Agric. Water Manag. 34 (1), 81–94.

Amusan, A.A., Ige, P.V., Olawale R., 1999. Preliminary investigation on the use of municipal waste dump for farming Paper presented at the 25th annual conference of soil science society of Nigeria held November Benin city, Nigeria, pp. 21–25.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater. APH Association, Washington, DS.

Association française de, n., 1994. Qualité des sols: recueil de normes françaises 1996. AFNOR, Paris-La Défense.

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 (1), 146–151.

Ayers, R., Westcot, D., 1984. Irrigation water quality criteria in "Irrigation with Reclaimed Municipal Wastewater "-A Guidance Manual Report No. 84–1 Calif. State Water Res. Ctr. Board, Sacramento, CA.

Boulding, R., 1994. Description and Sampling of Contaminated Soils: A Field Guide. CRC Press.

Bouwer, E.J., Crowe, P.B., 1988. Biological processes in drinking water treatment. J. Am. Water Works Assoc. 80 (9), 82–93.

Brady, N.C., Weil, R.R., 1996. The Nature and Properties of Soils. Prentice-Hall Inc..

Bressler, M., 1979. The use of saline water for irrigation in the USSR Joint Commission on Scientific and Technical Cooperation. Water Res.

Caussy, D., Gochfeld, M., Gurzau, E., Neagu, C., Ruedel, H., 2003. Lessons from case studies of metals: investigating exposure, bioavailability, and risk. Ecotoxicol. Environ. Saf. 56 (1), 45–51.

Chary, N.S., Kamala, C.T., Raj, D.S.S., 2008. Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. Ecotoxicol. Environ. Saf. 69 (3), 513–524.

Cobb, G.P., Sands, K., Waters, M., Wixson, B.G., Dorward-King, E., 2000. Accumulation of heavy metals by vegetables grown in mine wastes. Environ. Toxicol. Chem. 19 (3), 600–607.

Cui, Y.-J., Zhu, Y.-G., Zhai, R.-H., Chen, D.-Y., Huang, Y.-Z., Qiu, Y., Liang, J.-Z., 2004. Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environ. Int. 30 (6), 785–791.

Davis, R.D., Carlton-Smith, C.H., Stark, J.H., Campbell, J.A., 1988. Distribution of metals in grassland soils following surface applications of sewage sludge. Environ. Pollut. 49 (2), 99–115.

DemİRezen, D., Aksoy, A., 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 (3), 252–265.

Devkota, B., Schmidt, G.H., 2000. Accumulation of heavy metals in food plants and grasshoppers from the Taigetos Mountains, Greece. Agric. Ecosyst. Environ. 78 (1), 85–91.

Dhir, R., 1977. Investigations into use of highly saline waters in an arid environment. I. Salinity and alkali hazard conditions in soil under a cyclic management system. In: International Conference on Managing Saline Water for Irrigation, Planning for the Future, Lubbock, Tex., USA, 1976. ICASALS.

El-Ghonemy, A.M.K., 2012. Retracted: water desalination systems powered by renewable energy sources, Review. Renew. Sustain. Energy Rev. 16 (3), 1537–1556.

EPA, U., 2002. United State, Environmental Protection Agency, Region 9, Preliminary remediation goals. <http://www.epa.gov/region09/waste/sfind/prg> (accessed 07.08.12).

European, U., 2002. Heavy Metals in Wastes, European Commission on Environment <http://ec.europa.eu/environment/waste/studies/pdf/heavymetalsreport.Pdf>.

Falade, K.O., Omojola, B.S., 2010. Effect of processing methods on physical, chemical, rheological, and sensory properties of okra (*Abelmoschus esculentus*). Food Bioprocess Technol. 3 (3), 387–394.

FAO, 1985. Water quality for agriculture, FAO irrigation and drainage paper No. 29, Rome, FAO, Rome.

Fytianos, K., Katsianis, G., Triantafyllou, P., Zachariadis, G., 2001. Accumulation of heavy metals in vegetables grown in an industrial area in relation to soil. Bull. Environ. Contam. Toxicol. 67 (3), 0423–0430.

Gupta, N., Khan, D.K., Santra, S.C., 2008. An assessment of heavy metal contamination in vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. Bull. Environ. Contam. Toxicol. 80 (2), 115–118.

Gupta, S., Satpati, S., Nayek, S., Garai, D., 2010. Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. Environ. Monit. Assess. 165 (1–4), 169–177.

Hani, A., Pazira, E., Manshouri, M., Kafaky, S.B., Tali, M.G., 2010. Spatial distribution and mapping of risk elements pollution in agricultural soils of southern Tehran, Iran. Plant Soil Environ. 56 (6), 288–296.

Hooda, P.S., McNulty, D., Alloway, B.J., Aitken, M.N., 1997. Plant availability of heavy metals in soils previously amended with heavy applications of sewage sludge. J. Sci. Food Agric. 73 (4), 446–454.

Horiguchi, H., Oguma, E., Sasaki, S., Miyamoto, K., Ikeda, Y., Machida, M., Kayama, F., 2004. Dietary exposure to cadmium at close to the current provisional tolerable weekly intake does not affect renal function among female Japanese farmers. Environ. Res. 95 (1), 20–31.

Huibers, F.P., Moscoso, O., Durán, A., van Lier, J.B., 2004. 12. The use of wastewater in cochabamba, bolivia: a degrading environment. In: Wastewater Use in Irrigated Agriculture, 110.

Hunt, J., Turner, M.K., 1994. A survey of nitrite concentrations in retail fresh vegetables. Food Addit. Contam. 11 (3), 327–332.

Ikeda, M., Zhang, Z.-W., Shimbo, S., Watanabe, T., Nakatsuka, H., Moon, C.-S., Matsuda-Inoguchi, N., Higashikawa, K., 2000. Urban population exposure to lead and cadmium in east and south-east Asia. Sci. Total Environ. 249 (1–3), 373–384.

Itanna, F., 2002. Metals in leafy vegetables grown in Addis Ababa and toxicological implications. Ethiop. J. Health Dev. 16 (3), 295–302.

Jackson, M.L., 1973. Soil Chemical Analysis. Jackson Prentice Hall of India, New Delhi, India.

Jury, W.A., Frenkel, H., Fluhler, H., Devitt, D., Stolzy, L., 1978. Use of saline irrigation waters and minimal leaching for crop production [Wheat, sorghum]. Hilgardia 46.

Kabata-Pendias, A., Pendias, H., 2001. Trace Elements in Soils and Plants, third edition. CRC Press, pp. 397.

Kamprath, E., Watson, M., 1980. Conventional soil and tissue tests for assessing the phosphorus status of soils. In: The Role of Phosphorus in Agriculture (theroleofphosph), pp. 433–469.

Kanwar, J., Sandha, M., 2000. Waste water pollution injury to vegetable crops: a review. Agric. Rev. Agric. Res. Commun. Centre India 21 (2), 133–136.

Kapourchal, A., Pazira, E., Homaee, M., 2009. Assessing radish (*Raphanus sativus* L.) potential for phytoremediation of lead-polluted soils resulting from air pollution. Plant Soil Environ. 5, 202–206.

Khan, S., Cao, Q., Zheng, Y.M., Huang, Y.Z., Zhu, Y.G., 2008. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ. Pollut. 152 (3), 686–692.

Khan, H.A., Arif, I.A., Al Homaidan, A.A., 2012. Distribution pattern of eight heavy metals in the outer and inner tissues of ten commonly used vegetables. Int. J. Food Prop. 15 (6), 1212–1219.

Kiziloglu, M., Turan, F.M., Sahin, U., Angin, I., Anapali, O., Okuroglu, M., 2007. Effects of wastewater irrigation on soil and cabbage-plant (brassica olerecea var. capitate cv. yalova-1) chemical properties. J. Plant Nutr. Soil Sci. 170 (1), 166–172.

Kos, B., Greman, H., Lestan, D., 2003. Phytoextraction of lead, zinc and cadmium from soil by selected plants. Plant Soil Environ. 49 (12), 548–553.

Kumar Sharma, R., Agrawal, M., Marshall, F., 2007. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol. Environ. Saf. 66 (2), 258–266.

Li, Q., Chen, Y., Fu, H., Cui, Z., Shi, L., Wang, L., Liu, Z., 2012. Health risk of heavy metals in food crops grown on reclaimed tidal flat soil in the Pearl River Estuary, China. J. Hazard. Mater. 227–228, 148–154.

Liu, W.-H., Zhao, J.-Z., Ouyang, Z.-Y., Söderlund, L., Liu, G.-H., 2005. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environ. Int. 31 (6), 805–812.

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., Zhang, G., Li, X., 2011. Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. J. Hazard. Mater. 186 (1), 481–490.

Mabberley, D.J., 1997. The plant book: a portable dictionary of the vascular plants; utilizing Kubitzki's the families and genera of vascular plants (1990-), cronquist's an integrated system of classification of flowering plants (1981) and current botanical literature arranged largely on the principles of editions 1-6 (1896/97-1931) of Willis's A Dictionary of the Flowering Plants and Ferns, Cambridge University Press.

Mapanda, F., Mangwayana, E.N., Nyamangara, J., Giller, K.E., 2005. The effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. Agric. Ecosyst. Environ. 107 (2–3), 151–165.

McAlister, J.J., Smith, B.J., Sanchez, B., 1998. Forest clearance: impact of landuse change on fertility status of soils from the São Francisco area of Niterói, Brazil. Land Degrad. Dev. 9 (5), 425–440.

McGrath, S.P., Chang, A.C., Page, A.L., Witter, E., 1994. Land application of sewage sludge: scientific perspectives of heavy metal loading limits in Europe and the United States. Environ. Rev. 2 (1), 108–118.

Mohammad Rusan, M.J., Hinnawi, S., Rousan, L., 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination 215 (1–3), 143–152.

Mojiri, A., Jalalian, A., 2011. Relationship between growth of *Nitraria schoberi* and some soil properties. J. Anim. Plant Sci. 21 (2), 246–250.

Muchuweti, M., Birkett, J.W., Chinyanga, E., Zvauya, R., Scrimshaw, M.D., Lester, J.N., 2006. Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: implications for human health. Agric. Ecosyst. Environ. 112 (1), 41–48.

Mukherjee, A.B., 1998. Chromium in the environment of Finland. Sci. Total Environ. 217 (1–2), 9–19.

MWE, 2005. MWE (Ministry of water and Electricity) National wastewater Regulations, Section III – 2.2 and 3.2.3 Riyadh, Saudi Arabia.

Najafi, P., Nasr, S., 2009. Comparison effects of wastewater on soil chemical properties in three irrigation methods. Res. Crops 10 (2), 277–280.

Oyeku, O.T., Eludoyin, A.O., 2010. Heavy metal contamination of groundwater resource in a Nigerian urban settlement. Afr. J. Environ. Sci. Technol. 4 (4), 201–214.

Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. Agric. Water Manag. 97 (4), 561–568.

Qixing, Z., YanYu, W., XianZhe, X., 1994. Compound pollution of Cd and Zn and its ecological effect on rice plants. Chin. J. Appl. Ecol. 5, 438–441.

Radwan, M.A., Salama, A.K., 2006. Market basket survey for some heavy metals in Egyptian fruits and vegetables. Food Chem. Toxicol. 44 (8), 1273–1278.

Rattan, R.K., Datta, S.P., Chhonkar, P.K., Suribabu, K., Singh, A.K., 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agric. Ecosyst. Environ. 109 (3–4), 310–322.

Renella, G., Mench, M., van der Lelie, D., Pietramellara, G., Ascher, J., Ceccherini, M.T., Landi, L., Nannipieri, P., 2004. Hydrolase activity, microbial biomass and community structure in long-term Cd-contaminated soils. Soil Biol. Biochem. 36 (3), 443–451.

Rupa, T.R., Srinivasa Rao, C., Subba Rao, A., Singh, M., 2003. Effects of farmyard manure and phosphorus on zinc transformations and phyto-availability in two alfisols of India. Bioresour. Technol. 87 (3), 279–288.

Sachan, S., Singh, S.K., Srivastava, P.C., 2007. Buildup of heavy metals in soil-water-plant continuum as influenced by irrigation with contaminated effluent. J. Environ. Sci. Eng. 49 (4), 293–296.

Santamaria, P., Elia, A., Serio, F., Todaro, E., 1999. A survey of nitrate and oxalate content in fresh vegetables. J. Sci. Food Agric. 79 (13), 1882–1888.

Shainberg, I., Oster, J.D., 1978. Quality of irrigation water, International Irrigation Information Center.

Sharma, R.K., Agrawal, M., Marshall, F., 2007. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol. Environ. Saf. 66 (2), 258–266.

Shelton, W.R., J, H.H., 1941. A rapid method for the determination of total phosphorus in soil and plant material. Iowa State Coll. J. Sci 15, 403–413.

Singh, R.P., Agrawal, M., 2008. Potential benefits and risks of land application of sewage sludge. Waste Manage. 28 (2), 347–358.

Singh, S., Kumar, M., 2006. Heavy metal load of soil, water and vegetables in peri-Urban Delhi. Environ. Monit. Assess. 120 (1–3), 79–91.

Singh, A., Sharma, R.K., Agrawal, M., Marshall, F.M., 2010. Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food Chem. Toxicol. 48 (2), 611–619.

Smith, S.R., Giller, K.E., 1992. Effective *Rhizobium leguminosarum* biovar Trifolii present in five soils contaminated with heavy metals from long-term applications of sewage sludge or metal mine spoil. Soil Biol. Biochem. 24 (8), 781–788.

Srinivasan, J.T., Reddy, V.R., 2009. Impact of irrigation water quality on human health: a case study in India. Ecol. Econ. 68 (11), 2800–2807.

Tijani, M.N., 2009. Contamination of shallow groundwater system and soil-plant transfer of trace metals under amended irrigated fields. Agric. Water Manag. 96 (3), 437–444.

Trumbo, P., Yates, A.A., Schlicker, S., Poos, M., 2001. Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. J. Am. Diet. Assoc. 101 (3), 294–301.

Ullah, H., Khan, I., Ullah, I., 2012. Impact of sewage contaminated water on soil, vegetables, and underground water of peri-urban Peshawar, Pakistan. Environ. Monit. Assess. 184 (10), 6411–6421.

Wei, S., Zhou, Q., Wang, X., 2005. Identification of weed plants excluding the uptake of heavy metals. Environ. Int. 31 (6), 829–834.

WHO, 1996. Guidelines for Drinking-water Quality, Vol. 2, Health Criteria and Other Supporting Information. World Health Organization, Geneva.

Willett, I., Jakobsen, P., Malafant, K., Bond, W., 1984. Effect of land disposal of lime treated sewage sludge on soil properties and plant growth. Division of Water and Land Resource. CSIRO Canberra. Div. Rep 84 (3), 56.

Zhuang, P., McBride, M.B., Xia, H., Li, N., Li, Z., 2009. Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Sci. Total Environ. 407 (5), 1551–1561.

Zurera-Cosano, G., Moreno-Rojas, R., Salmeron-Egea, J., Lora, R.P., 1989. Heavy metal uptake from greenhouse border soils for edible vegetables. J. Sci. Food Agric. 49 (3), 307–314.