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RESEARCH ARTICLE

Health risks of heavy metal exposure and microbial contamination through consumption of vegetables irrigated with treated wastewater at Dubai, UAE

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Abstract
The shortage of fresh water is a major problem throughout the world, but the situation is worst in the arid and semiarid regions. Therefore, reuse of nonconventional water resources such as treated wastewater (TWW) is a common practice to irrigate field crops, vegetables, and forestry sectors. The present study was conducted to evaluate the significant impact of different heavy metals such as copper (Cu), iron (Fe), chromium (Cr), and zinc (Zn) on the soil and leafy, root, and fruit vegetables following irrigation with TWW through subsurface drip irrigation. Our results indicate that iron (Fe) was highest in lettuce followed by spinach, and Zn and Cr were second and third most abundant element in the different vegetables. Eggplant and radish showed the lowest concentrations of various heavy metals. A significant difference was observed in transfer factor (TF) among vegetables, and highest $TF_{soil\text{-}veg}$ was observed for Fe in lettuce and the lowest for Cr in eggplant. Estimated daily intake (EDI) was the lowest in adults and highest in children. Target hazard quotient (THQ) of Cu, Zn, and Fe being < 1.0 appears relatively safe in all the tested vegetables. Risk index (RI) values showed that heavy metals were lower than 1.0 and hence lower risk for human. The combined HI values for Cu, Zn, Cd, Cr, and Pb were substaintionaly higher 12.8 and 9.21 after consumption of lettuce and carrot. So, consumption of these vegetables should be avoided after irrigation with TWW. Spinach exhibited maximum total coliform loading, while ecological risk was negligible due to sandy nature of soil type. Health risks to human could be reduced through proper selection of suitable vegetables, time of maturity, and consumed organs (leaf, fruit, or root part). Appropriate should be followed to decontaminate the microbial load in order to avoid any risks to human health (both adults and children).

Keywords Wastewater reuse · Heavy metals · Target hazard quotient · Health risk index · Vegetable contamination · Subsurface irrigation · Microbial contamination · United Arab Emirates

Introduction

Fresh water scarcity is one of the most important commodities that have emerged in many countries including Middle East, North Africa, and South Asia (Qadir et al. 2010; Pontoni et al. 2016; Hussain et al. 2019). Most of the fresh water demand comes from several sectors such as agriculture followed by industry. Therefore, sustainability of fresh water has significantly threatened and hence created immense pressure on freshwater resources (Aydin et al. 2015; Al-Dakheel et al. 2015). Several factors (climatic change, fresh water scarcity, population increase) has significantly increased pressure to look alternate sources to meet requirements for agriculture and forestry. Furthermore, water is vital for food production systems, domestic uses, industry, and tourism and for sustaining the earth ecosystem functioning. Major portion of water (about 80%) is used for irrigation in agriculture, but fresh water resources are significantly decreased (Hussain and Al-Dakheel 2015; Hussain et al. 2019). The drought episodes and water shortage is menacing the agriculture, landscaping, and forestry sector in West Asia, Arabian Peninsula, and several Mediterranean countries and causing severe consequences to

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regional food security (Alcamo et al. 2007). The continued water demand by user such as urban, pre-urban, and industry, other than agriculture, is threatening the ecosystem services and the environmental health and food security (Hussain et al. 2019). Moreover, the food production, on the existing croplands, needs to be increased to meet the increasing food demands of growing population, but it alone cannot be sufficient (Ray et al. 2013) to meet the present food request. Expansion of agriculture towards marginal and degraded lands can not only help to increase the food supply but also may help to avoid the environmental concerns of land degradation (Gibbs et al. 2008). For instance, Lantican et al. (2003) reported 25% increase in global wheat production from marginal lands.

Most of the Arabian Peninsula are classified as hyper-arid with aridity index < 0.03 (UNCCD 2004). In Arabian Peninsula, the driest country is Oman with 62 mm/year rainfall on average (FAO 2013). The renewable water resources per capita decreased from 1250 m^3 in 1950 to 100 m^3 in 2007 (WRI 2007) and 76.2m^3 in 2014 (The World Bank 2017) while considered the lowest in the world. Water demand in all these countries is steadily increasing due to expansion in all sectors particularly agricultural activities and public needs by increasing population. Total water demand in all countries rose from 6.6 to 22.5 billion m^3during the period of 1980–1990 and is expected to reach 36.7 billion m^3 by 2025 (Jaradat 2005). Since agriculture depends on irrigation and uses 80 to 90% of the water resources, the agricultural water demand is estimated to be 24.3 billion m^3 (Uitto and Schneider 1997). Water requirements for 2010 calculated at 28.2 billion m^3as against the projected groundwater availability of 18,030 million m^3 in the Peninsula.

Despite the scarcity of water resources in the UAE, water consumption by the agricultural sector in increased from 950 million m^3/year in 1990 to 3320 million m^3/year in 2011 (Shahin and Salem 2014). This was mainly achieved with using groundwater aquifers, which covered at least 82% (above 579 million m^3) of the water requirements of the forestry sector. The UAE is using part of the treated domestic wastewater to cover the gap between water availability and consumption. In Abu Dhabi Emirate, for example, 130 million m^3 (18.3%) of the irrigated lands use treated wastewater (TWW) (Environmental Agency of Abu Dhabi 2009). However, according to the federal statistics of 2016, the total amount of treated wastewater in the UAE during 2016 has jumped to be 733,054 million m^3. Around 64% of this water used in irrigation of UAE's street trees, landscape, and public gardens. In addition, 31.7% (232,237 million m^3) of the treated wastewater is disposed in Gulf water (Federal Competitiveness and Statistics Authority 2016). It is important to use the treated wastewater that is currently disposed to the Gulf water in agricultural purposes. As it is rich with organic matters and some macronutrients, the use of TWW may contribute to reducing the need for fertilizers (Kfir et al. 2012).

Several studies demonstrated different water resources such as quality saline water, treated wastewater, and gray water for agricultural activities (agriculture, landscaping, crop production, forestry, forage crops, and aquaculture) (Hussain et al. 2016; Al-Dakheel and Hussain 2016; Hussain et al. 2019). The sustainable management and use of nonconventional water resources for rehabilitation of marginal and degraded lands could fulfill the ever-increasing demand of food, feed, and fiber for the increasing population in MENA but has poorly addressed in the past. At present, approximately 20 million hectares of arable land worldwide is being irrigated with wastewater (Mateo-Sagasta et al. 2013; Ayoub et al. 2016). However, it is imperative to emphasize and share knowledge on the effects of different wastewaters on soil properties, ecosystem functioning, and soil fertility with the aim of identifying the perspectives of using wastewater for soil recovering and soil as mean for wastewater treatment. Several researchers reported that treated wastewater might exhibit significant amount of contaminants (heavy metals and organic toxic compounds), and the degree of toxicity of these elements depends upon the level of treatment. Therefore, using this water for agriculture, landscaping and forest plantation might open doors for heavy metals entry into plant-soil-ecosystem because most of these pollutants might be persistent, highly toxic, and are also considered as bioaccumulative properties (Liu et al. 2013; Aydin et al. 2015). The impact of heavy metals on soil properties and on different crops, vegetables, and grasses, when cultivated under irrigation of treated wastewater (Lu et al. 2016; Turner et al. 2016) and untreated wastewater (Khan and Bano 2016; Meng et al. 2016), are previously addressed. The presence of heavy metals, organic pollutants, and toxic elements in soil and plant system might led to the development of ecological degradation, and risks for human health through dietary exposure can be expected (Cao et al. 2016).

Due to increased demand for water and growing scarcity, the use of nonconventional water for agriculture and forestry has got momentum in the GCC countries. In the Arab states alone, nearly 11 Bm^3 of wastewater is produced annually; out of that, about 5.6 Bm^3 is treated to various levels of treatments. About 4.3 Bm^3 of the TWW is used for agricultural production. Several countries from Asia, Africa, and North America are using nonconventional water (Qadir et al. 2010) due to ecological, for irrigation in agriculture, landscaping, roadside plantation, and forestry for a sustainable environment. The judicial use of nonconventional water such as treated wastewater has reached to 600 million cubic meters (Mm^3) in UAE. With the increase in the population at the present rate, the quantity of treated wastewater in UAE is expected to reach to 1400 Mm^3 by 2030. Therefore, this treated wastewater can become an attractive option for conserving freshwater resources. For improvements in wastewater quality and human exposure control, management of wastewater at the farm level by selecting appropriate crops and irrigation management strategies can help a great deal in minimizing the risk of wastewater use for agriculture. Currently, wastewater use for agriculture is largely restricted to grow vegetables and cereals (Raschid-Sally and Jayakody 2007). Leafy vegetables (such as spinach, cauliflower lettuce) accumulate greater amounts of heavy metals than do non-leafy species (Qadir et al. 2010).

This study was aimed to understand the concentration of heavy metals in the soils, irrigated with treated wastewater and in different leafy, root, and fruit vegetables, and translocation factor of different heavy metals (Cu, Fe, Zn, Cr) in five vegetables (lettuce, carrot, eggplant, spinach). As a consequence of vegetable consumption by humans, a risk is associated with heavy metals transfer to humans through consumption of these vegetables through estimated dietary intake. In order to ameliorate, the complete environmental risks of heavy metal (loid)s based on their potential mobility and bioavailability in soils and impact on human health was calculated through total health quotient (THQ) and health risk index (HRI) and health index.

Materials and methods

Characterization of the study area

The experiment was carried out at field research station of ICBA (25° 5' N and 55°23′E), Dubai, UAE (Fig. 1). The soil is carbonatic, hyperthermic typic torripsamment having a negligible level of inherent soil salinity (0.2 dS m^{-1}). The climate of the UAE is subtropical arid with hot summers and warm winters and a detailed climatic characteristics are depicted in Fig. 2.

Field preparation and experimental design

The experimental field block was plowed by tractor prior to the installation of irrigation system. The organic fertilizer was applied as compost (@ 3.0 kgm^{-2}) to enhance soil biochemistry, fertility, and water-retaining capacity. The nutrient application practice was followed by planking. A composite sample was collected from field plots for soil biochemical analysis.

The field experiment was conducted on 1800 m^2 (60 m × 30 m) field block, which was divided into two separate sub-blocks of 900 m^2 (30 m × 30 m) each. Each sub-block was further divided into 18 plots of 50 m^2 each (5 m X 10 m). These both sub-blocks were separated by 2 m land strip to avoid the influence of treatment of one sub-block to the other. Six vegetables (eggplant, lettuce, carrots, tomatoes, radish, and spinach) were grown using surface drip methods. For each crop, three replications were used. In surface drip irrigation system, linear low-density (LLD) polyethylene drippers of 4.0 lph capacity were used.

The plant samples (leaves, fruit, roots) were collected from each plot-middle row to get a representative sample and to avoid boarder effect. The concentration of TWW samples were collected from the storage pond and analyzed for different trace elements such as Fe, Zn, Cd, and Cu. The trace elements were analyzed using atomic absorption spectrophotometer (Pye Unicam. Model Sp – 9, 1984).

Plant, soil, and water sampling and biochemical analysis

From each subplot, field soil samples were collected in polyethylene bags from a depth of 30 cm. Several physio-chemical soil properties such as pH, EC, ammonia nitrogen, nitrate nitrogen, phosphate phosphorus, potassium, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids, turbidity, residual chlorine, and soil hardness as $CaCO_3$ were determined according to standard protocol (Table 1). Heavy metals were measured through atomic absorption spectrophotometer (ICP-OES, Perkin- Elmer OPTIMA-2000, USA). Analysis was carried out in the Dubai Central Analytical Laboratory, Dubai (U.A.E.). Standard soil analysis methods (Burt 2004) were used, and the physio-chemical soil properties of the experimental area on oven-dried soil weight basis are given in Table 1.

We collected the samples from different organs (leaves, roots, and fruit part) from the central rows of each subplot, in order to avoid the boarder effects. At physiological maturity, different vegetables such as lettuce (*Lactuca sativa* L.), radish (*Raphanus sativus* L.), spinach (*Spinacia oleracea* L.), and tomatoes (*Lycopersicon esculentum* Mill.) were harvested and then divided into leaves, roots, and fruits. The samples were properly washed with distilled water to remove all dust particles and sand. Heavy metals accumulation in the selected vegetables was determined according to standard protocol using atomic absorption spectrophotometer (Pye. Unicam. Model Sp – 9, 1984). The biological characteristics of the TWW () was elaborated in Table 1.

Installation of irrigation system and treatment application

The subsurface drip irrigation system was installed in the field plot area, and online drippers of 4 lph capacity were installed to irrigate vegetables with treated wastewater. In UAE, 650 Mm^3 of wastewater is generated every day, out of which 350 Mm^3 is used for agriculture purposes and the rest is discharged to the ocean. ICBA is receiving tertiary-level-treated municipal wastewater (TWW) from the Dubai

Municipality, UAE, to carry out experiments at the center for growing different crops. Biochemical analysis (heavy metals and microbial strains) of the treated wastewater has been demonstrated in Table 2. The crop water requirement was determined based on Penman-Monteith methodology and irrigated twice a day through subsurface drip irrigation. The Rain Bird timer and solenoid valve through 12AWG solenoid cable was used in installation of irrigation system.

Translocation factor (TF)

Translocation factor (TF) that is an important index to measure the translocation of heavy metals from soil to plant system (Cui et al. 2016) as follows:

$$TF = C_{vegetable}/C_{soil}$$

where $C_{vegetable}$ is the total concentration of an individual heavy metal in a particular vegetable and C_{soil} is the corresponding heavy metal concentration in the same soil environment of that particular vegetable.

Daily intake of metals

Daily intake (EDI) of trace elements (Cd, Cr, Cu, and Zn) was calculated according to the following equation:

$$EDI = C_{metal}\ X\ W_{food}/B_w$$

The calculation for EDI was done according to procedure described by several authors (Wang et al. 2014; Qureshi et al. 2016).

Health risk assessment

Health risk index (HRI) was determined according to the following equation:

$$HRI = \sum n\ (Cn \times Dn)/RfD \times Bw$$

where C_n represented the mean metal concentration in a specific vegetable on fresh weight basis (mg/kg), D_n denoted average daily intake rate of a specific vegetable in a whole year, *RfD* showed safe level of exposure by oral for lifetime, and B_w is the average body weight (70 kg for adult). In this study, the dietary reference intakes (DRI) of the elements were taken as *RfD* (FNB 2004), except Cd and Pb, for which maximum allowed levels (ML) were considered (EC 2006).

Target hazard quotient (THQ)

The health risks from consumption of vegetables were assessed based on the target hazard quotient (THQ). The THQ is a ratio of determined dose of a pollutant to a reference dose level.

Noncarcinogenic health risks for humans associated with the consumption of these vegetables were also assessed by calculating target hazard quotient (*THQ*) and hazard index (*HI*) (Storelli 2008; Yang et al. 2011). The method to estimate *THQ* was provided in USEPA region III risk-based concentration table (USEPA 2006):

$$THQ = C \times I \times 10^{-3} \times EF_r \times ED_{tot}/RfDo \times BW_a \times AT_n$$

where "*C*" is the mean metal level in vegetable (mg/kg, fresh weight); "*I*" is the ingestion rate (255 g/day/person); "EF_r" is the exposure frequency (350 days/year); "ED_{tot}" is the total exposure duration (70 years); "BW_a" is the average body weight, adult (55.9 kg); and "AT_n" is the averaging time, noncarcinogens ($ED_{tot} \times 365$ day/year).

Hazard index (HI)

The hazard index (*HI*) can be expressed as the sum of the hazard quotients for all trace metals (USEPA 2006):

$$HI = THQ_1 + THQ_2 + \cdots + THQ_n$$

where THQ_{1-n} is the target hazard quotients for $1-n$ trace metals.

Statistical analysis

Data was first checked for normality and analyzed through analysis of variance (ANOVA) and difference between treatment means which were computed at $P < 0.05$ according to post hoc Tukey HSD test. General linear model was used for data analysis using software (SPSS (version 19.00) for Windows (SPSS Inc., Chicago, IL, USA), and graphs were prepared using means and S.E. of the respective traits using Microsoft Excel package.

Results

Heavy metal accumulation in the soil

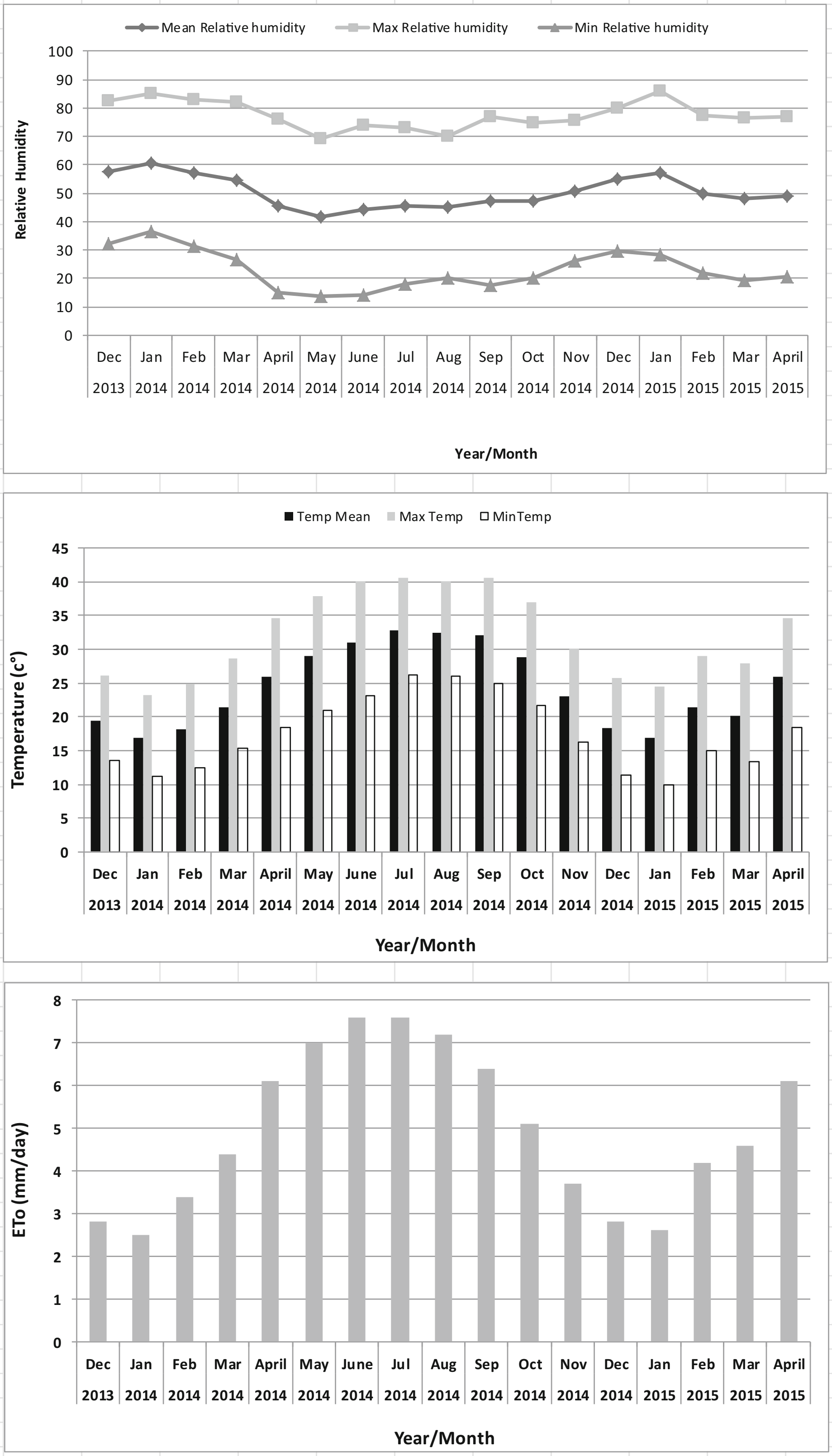
According to Table 2, the concentrations of heavy metals in experimental field plot soils showed significantly large variation, and samples were collected from the top 30 cm of the soil. The highest concentration ranges was reported for nickel (Ni) that was in the range of 40.9 mg kg^{-1}. It was followed by

Fig. 1 Location and layout of experimental area at ICBA, Dubai, UAE

lead (Pb) whose average concentration was 29.2 mg kg^{-1}and followed by chromium (Cr) 16.7 mg kg^{-1}. The other elements (before and after 3 years of TWW irrigation) were Cd (3.3–3.4 mg kg^{-1}), Cu (5.3–4.4 mg kg^{-1}), Fe (10.2–13.06 mg kg^{-1}), and Zn (10.4–12.4 mg kg^{-1}), respectively. The mean highest concentration (40.9 mg kg^{-1}) of Ni was observed in the soil samples, while Cd was the lowest (3.4 mg kg^{-1}) element in the soil profile.

Evaluation of trace metals in different vegetables

The concentrations of the trace metals (mg/kg, dry weight) in leafy, root, and fruit vegetables are elaborated in Fig. 3. Generally, the highest concentration was detected for Fe in all vegetables, followed by the substantial levels of Zn. The Fe was considerably high as compared to other heavy metals such as Cr, Zn, and Cu that might be different physiological plant mechanisms prevailing in different vegetables. The lettuce exhibited maximum (87.6 mg/kg) Fe, followed by substantially higher levels of the metal in *spinach* (3.3 mg/kg), eggplant (3.04 mg/Kg), and carrot (2.91 mg/kg), while the lowest level of Fe (1.23 mg/kg) was noted in radish. The radish and eggplant showed relatively lower concentrations of Zn and Cr. Likewise, spinach, lettuce, and carrot exhibited comparatively higher levels of Cr. However, significantly higher level of Cu was observed in radish as compared to all other vegetables. Overall, lower concentrations of the Cu trace metal were observed in eggplant, tomato, and spinach.


Mean Relative humidity
Max Relative humidity
Min Relative humidity
Relative Humidity
Year/Month
Temp Mean
Max Temp
MinTemp
Temperature (c°)
Year/Month
ETo (mm/day)
Year/Month
Dec 2013
Jan 2014
Feb 2014
Mar 2014
April 2014
May 2014
June 2014
Jul 2014
Aug 2014
Sep 2014
Oct 2014
Nov 2014
Dec 2014
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Feb 2015
Mar 2015
April 2015

◀ **Fig. 2** Monthly average values of (a) mean (T mean), maximum (T maxi), and minimum (T min) air temperature and reference evapotranspiration (Eto) in the ICBA, Dubai, UAE from December 2013 to April 2015

Assessment of vegetable contamination and associated health risk evaluation

Heavy metal translocation in the soil-plant system

To better understand the heavy metal movement (uptake and translocation) process in the soil-vegetable system, translocation factors (TF) were calculated for each heavy metal (Fig. 4) in each vegetable. Among the vegetables, the $TF_{soil\text{-}veg}$ values for Fe were the highest (6.46), in lettuce. The TF in different vegetables were in the descending order of Fe > Zn > Cr > Cu. There was significant difference in $TF_{soil\text{-}veg}$ values among all the vegetables, and the highest $TF_{soil\text{-}veg}$ was observed for Fe in lettuce, and lowest $TF_{soil\text{-}veg}$ level was obtained for Cr in the eggplant (Fig. 4). Average $TF_{soil\text{-}veg}$ value of Cu was the highest (0.17) and (0.17) in radish spinach, respectively, and lowest $TF_{soil\text{-}veg}$ value of Cu was noted in eggplant (0.06). The $TF_{soil\text{-}veg}$ value of Zn was being the highest (0.48) in Spinach and being the lowest (0.07) in radish. Likewise, $TF_{soil\text{-}veg}$ value of some heavy metals was also relatively low, with $TF_{soil\text{-}veg}$ value of Cr being the highest (0.13) in lettuce and being the lowest (0.002) in eggplant. A significant difference was observed in TF values between different leaf, root, and fruit vegetables because different plants showed different behavior towards uptake, translocation, and distribution and plant eco-physiological attributes.

Table 1 Chemical and biological properties of the treated wastewater used in this study

Parameters	Units	Results
E. coli	CFU/100 ml	2
Fecal Streptococci	CFU/100 ml	3
Total coliform	CFU/100 ml	460
EC	dS/m	1.9
Ammonia nitrogen	mg/l	9.7
Nitrate nitrogen	mg/l	16.6
Phosphate phosphorus	mg/l	2.42
Potassium	mg/l	20.7
Biological oxygen demand (BOD)	mg/l	9
Chemical oxygen demand (COD)	mg/l	44
Total suspended solids	mg/l	11
Turbidity	NTU	1
Residual chlorine	mg/l	< 0.2
Hardness as $CaCO_3$	mg/l	194
Chromium	mg/l	0.2
Copper	mg/l	0.2
Zinc	mg/l	0.27

Table 2 Biochemical soil analysis of control and wastewater-treated field plots (mg/kg)

Parameters	Pretreatment	Posttreatment
Cadmium (Cd)	3.3 ± 0.5	3.4 ± 0.87
Chromium (Cr)	14.9 ± 1.14	16.7 ± 1.18
Copper (Cu)	5.3 ± 0.98	5.4 ± 0.64
Lead (Pb)	28.5 ± 2.00	29.2 ± 2.54
Iron (Fe)	10.2 ± 1.03	13.06 ± 1.91
Nickel (Ni)	36.3 ± 3.06	40.9 ± 2.33
Zinc (Zn)	10.4 ± 1.14	12.4 ± 1.73

Estimated dietary intake (EDI) of metals

Greater estimated dietary metal intakes (EDI) were studied from spinach followed by tomatoes. The EDI of Cu through vegetable consumption varies among different vegetables and was lowest (1.75×10^{-4}) in adults (after consumption of eggplant) and was the highest (5.70×10^{-4}) in children (after consumption of radish) (Table 3). The EDI of Fe in this study was lower (1.10×10^{-3}) in adults (following eggplant consumption) and was the highest (8.35×10^{-3}) in children (after spinach consumption). The EDI of Zn through vegetable consumption varies among different vegetables and was lowest (1.06×10^{-4}) in children and was the highest (9.23×10^{-4}) in adult (after tomatoes consumption). We observed that children are at greater risk than adults as far as EDI was concerned through vegetable consumptions (Table 3).

Risk identification and human health risk assessment

To appraise the health risk associated with heavy metal contamination of vegetables grown at ICBA research station (Dubai, UAE) with treated wastewater (supplied to the plant roots through sub-surface drip irrigation), health risk assessment values (HRI), target hazard quotients (THQ), and hazard index (HI) were calculated and results are elaborated in Tables 4. THQ model is a more straightforward approach that helps to study human health impact due to HMs presence in leafy, root, and fruit vegetables. According to reports, THQ and HRI range should be < 1.0 (USEPA 2006). In the present study, Cu and Zn exhibited significantly lower values than 1.0 and hence in the safe limit. In lettuce, the THQ values were higher for Fe, while, contrary, it was lower in spinach, tomatoes, eggplant, carrot, and radish (Table 4). THQs of Cr were significantly higher than one, being 11.91, 7.75, and 4.22 for spinach, lettuce, and carrot, respectively. This indicated that Cr in spinach, lettuce, and carrot of the study area were of high health risk concern. Other heavy metals such as Cu, Zn, and

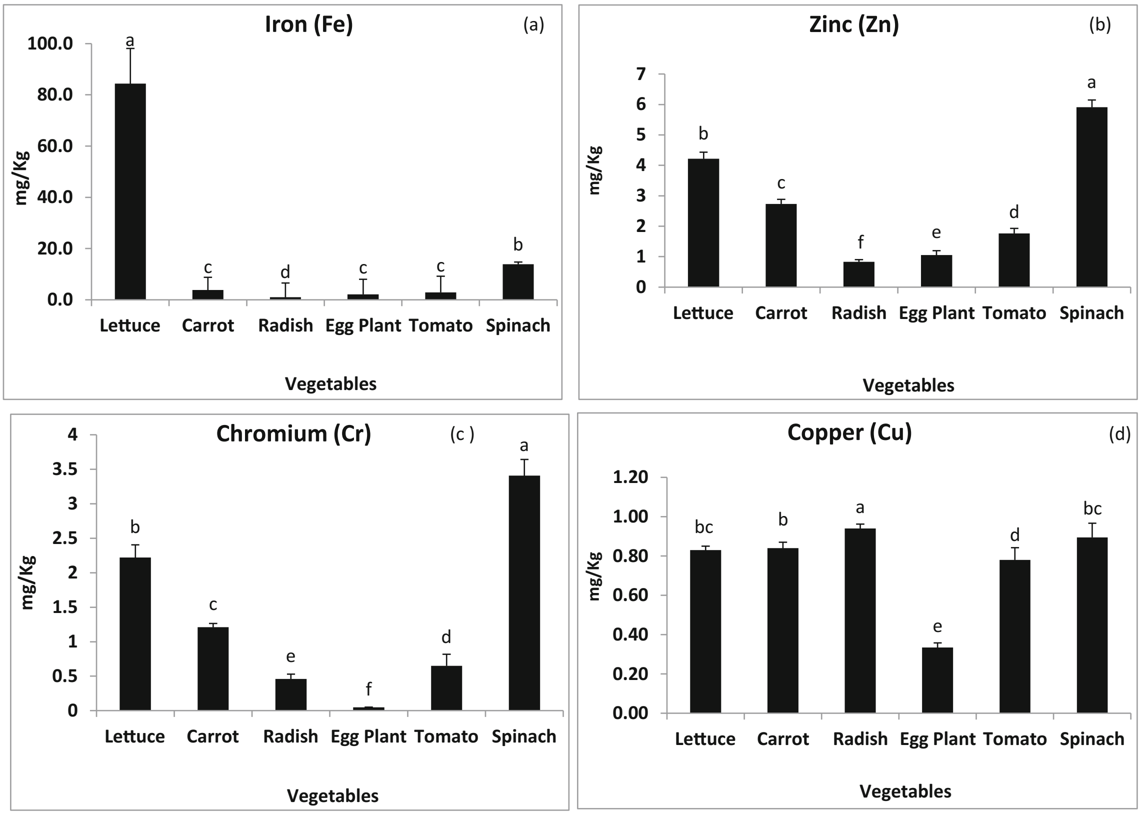

Fig. 3 Heavy metals (**a**) iron, (**b**) zinc, (**c**) chromium, and (**d**) copper concentrations ($n = 3$ for each species) in different leafy, fruit, and root vegetables (lettuce, carrot, radish, eggplant, tomato, spinach) irrigated with treated wastewater through subsurface irrigation. The error bars indicate the standard deviation, while the lowercase letters indicate significant differences in heavy metal concentrations between vegetables at $p < 0.05$

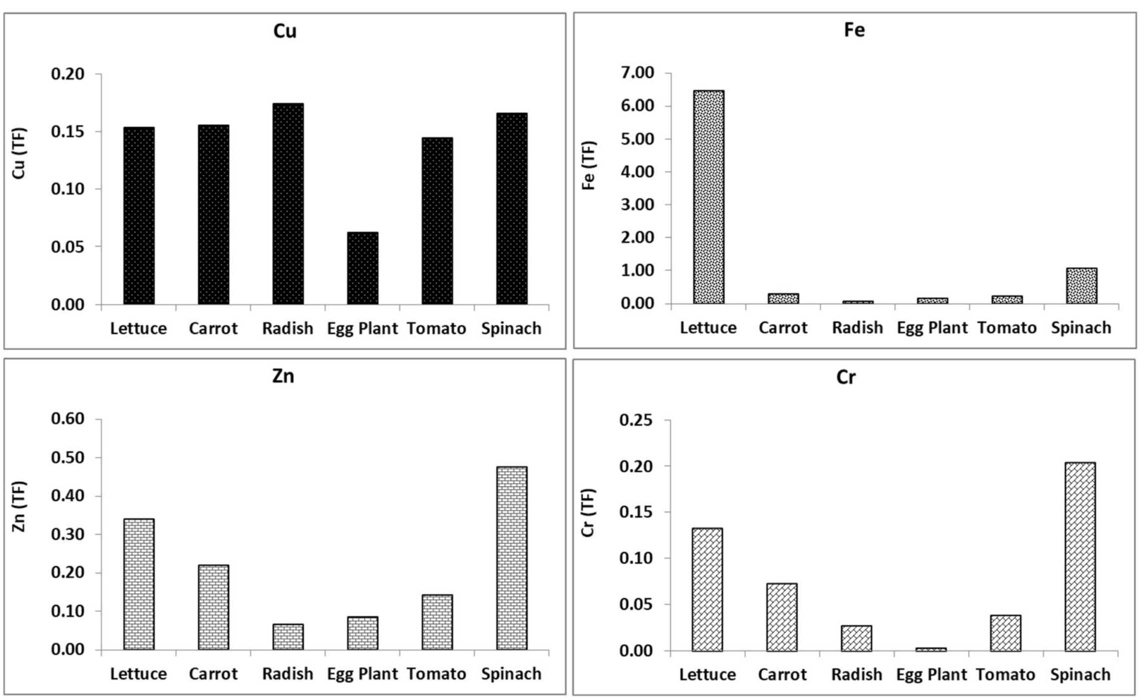

Fig. 4 Bioaccumulation factor (BAF), a ratio of heavy metals concentrations in the edible parts of leafy, fruit, and root vegetables to that in the corresponding soil

Table 3 Estimated daily intake (EDI) of individual heavy metals by adults and children

Vegetables		Cu	Fe	Zn	Cr
Lettuce	Adults	4.4×10^{-4}	4.42×10^{-2}	2.21×10^{-3}	1.16×10^{-3}
	Children	5.0×10^{-4}	5.09×10^{-2}	2.54×10^{-3}	1.33×10^{-3}
Carrot	Adults	4.40×10^{-4}	1.99×10^{-3}	1.43×10^{-3}	0.06×10^{-3}
	Children	5.06×10^{-4}	2.29×10^{-3}	1.65×10^{-3}	0.07×10^{-3}
Radish	Adults	4.93×10^{-4}	5.35×10^{-4}	4.35×10^{-4}	0.02×10^{-3}
	Children	5.70×10^{-4}	6.15×10^{-4}	5.00×10^{-4}	0.2×10^{-3}
Eggplant	Adults	1.75×10^{-4}	1.10×10^{-3}	5.5×10^{-4}	0.02×10^{-3}
	Children	3.80×10^{-4}	1.27×10^{-3}	6.3×10^{-4}	0.03×10^{-3}
Tomato	Adults	4.09×10^{-4}	1.52×10^{-3}	9.23×10^{-4}	0.34×10^{-3}
	Children	4.70×10^{-4}	1.74×10^{-3}	1.06×10^{-4}	0.39×10^{-3}
Spinach	Adults	4.69×10^{-4}	7.27×10^{-3}	3.10×10^{-4}	1.78×10^{-3}
	Children	5.39×10^{-4}	8.35×10^{-3}	3.56×10^{-4}	2.05×10^{-3}

Fe with average THQ values being less than one appear relative safe in all the tested fruit, leaf, and root vegetables. The risk identification (RI) based on the comparisons of measured concentration of heavy metals with risk screening values is significantly lower than international standards and limits reported from other countries (Table 5). Obviously, most of the RI values of the studied heavy metals were far below than one and hence lower than the risk screening value. It demonstrates that studies of metals (Cu, Fe, Zn, and Cr) in the soils could not cause any substantial ecological risk. The HI values for combined Cu, Zn, Cd, Cr, Pb, and As in this study area were 12.80 following consumption of lettuce, followed by carrot (9.21), respectively. It showed that consumption of lettuce and carrot should be avoided after irrigation with treated wastewater through subsurface drip irrigation because it can cause significant risks to the human health. The Cu, Zn, and Fe with average THQ values being less than one appear relative safe in all the tested fruit, leaf, and root vegetables.

RI values showed that heavy metals were lower than 1.0 and hence lower than the risk screening value. Meanwhile, Cu, Fe, Zn, and Cr are safe with no ecological risk. The combined HI values for Cu, Zn, Cd, Cr, and Pb were substaintionaly higher 12.8 and 9.21 after consumption of lettuce and carrot (Table 6). So, consumption of these vegetables should be avoided after irrigation with TWW.

Microbial load in the target vegetables

Contamination of vegetables with microbial load mainly arises from untreated waste water. In the present study microbial load (Gram-negative, facultative anaerobic, rod-shaped bacteria; *Escherichia coli* and rod-shaped Gram-negative non-spore-forming bacteria called Total coliform) results are reported in Fig. 5. Different vegetables exhibited different level of loading of coliform bacteria. The highest quantity of T. coliform bacteria was observed in spinach and followed by radish. All other vegetables sampled during the study period recorded same levels of coliform bacteria that were in the range of 9.56–9.77 cfu/g (Fig. 5). Meanwhile, the highest level of *Escherichia coli* bacterial contamination was found in carrot (34.87 cfu/g), followed by eggplant, lettuce, and tomatoes that was in the range of 9.44–9.73 cfu/g. The lowest level of *E. coli* was observed in spinach and radish in the range of 6.11–6.27 cfu/g (Fig. 5).

Table 4 Target health quotient (THQ) and health risk index (HRI) of consuming contaminated vegetables

Vegetables	Cu		Fe		Zn		Cr	
	THQ	HRI	THQ	HRI	THQ	HRI	THQ	HRI
Lettuce	0.09664	0.00039	1.10558	0.00442	0.04020	0.00016	7.75479	0.03100
Carrot	0.09781	0.00039	0.04991	0.00020	0.02601	0.00010	4.22671	0.01690
Radish	0.10945	0.00044	0.01336	0.00005	0.00791	0.00003	1.60685	0.00642
Eggplant	0.03901	0.00016	0.02764	0.00011	0.01000	0.00004	0.17466	0.00070
Tomato	0.09082	0.00036	0.03786	0.00015	0.01677	0.00007	2.27055	0.00908
Spinach	0.10421	0.00042	0.18156	0.00073	0.05630	0.00023	11.91164	0.04762

Table 5 Concentration ranges and safe limits of heavy metals in vegetables from different countries (mg/kg dry weight)

	Zn	Cu	Cr	References
China	–	8.65–317	0.08–15.4	Liu et al. 2006
India	19.54–42.06	8.63–27.94	3.70–9.03	Ahmad and Goni 2010
India	3.00–171.03	15.66–34.49	34.83–96.30	Gupta et al. 2008
India	59.61–79.46	10.95–28.58	5.37–27.83	Sharma et al. 2007
Greece	13.27–630	4.25–258	0.28–43.00	Stalikas et al. 1997
Greece	~ 18–~ 142	~ 0.00–~ 49	–	Fytianos et al. 2001
Uganda	10.5–743	1.26–33.0	0.19–70.5	Nabulo et al. 2010
Safe limits:				
FAO/WHO	60	40	5	CAC 1984
China	100	20	0.5	China EPA 2005
China	20 m	10 m	0.5 m	Cao et al. 2010, 2018

Discussion

Wastewater recycling and judicious use of treated wastewater (TWW) has fascinated significant attention due to scarcity of freshwater resources and to control pumping of ground waters (Hussain et al. 2016). Small and progressive farmers have been using reclaimed water to irrigate field crops, fiber and fuel crops, forage grasses, oil seed crops, vegetables, and in forestry campaign in different parts of the world with different treatment levels (USEPA 2006; Maiolo and Pantusa 2017; Hussain et al. 2019). Realizing the importance of treated wastewater as an important alternative water resource for irrigation in water scarce UAE marginal environment, a comprehensive study was conducted to evaluate the benefits of using treated wastewater for kitchen vegetables growth and to assess the possibility of reducing health risks by developing vegetable cultivar and soil-specific planting guidelines on sandy desert soils irrigated with treated wastewater. Our results indicates that iron (Fe) was the highest in lettuce followed by spinach, and Zn and Cr were second and third most abundant element absorbed by different vegetables. However, the eggplant and radish showed the lowest concentrations of various heavy metals. Other researchers reported that different vegetables exhibit different mechanism for absorption, uptake, and accumulation in different organs. Various biogeochemical factors such as soil physical condition, trace elements movements in the soil, soil structure, texture, plant species, and genotypes within same plant species play significant role in uptake and absorption of HMs in plants (Ahmad and Goni 2010; Hu et al. 2014).

Table 6 Hazard index (HI) of all the vegetables grown with treated wastewater

Vegetable	HI
Lettuce	9.00
Carrot	4.40
Radish	1.74
Eggplant	0.25
Tomato	2.42
Spinach	12.25

However, heavy loading of different trace elements in soil could enhance the buildup of heavy metals in vegetables and thus facilitate their entry into food chain ((Nabulo et al. 2010). The Zn is an essential element for plants; however, its excessive accumulation could be toxic (An et al. 2004). Adequately treated recycled water can be safely used for agriculture, landscaping, and forestry after proper treatment. However, it is well recognized that irrigation of crops and vegetables with untreated wastewater could be a potential risk factor for public health (Huang et al. 2014; Hussain et al. 2019).

Shortage of fresh water is being a major problem worldwide and the use of nonconventional water resources (agricultural drainage and treated municipal wastewater) (Mateo-Sagasta et al. 2013) for agriculture purpose is a preferred strategy for combating this scenario. To safe freshwater resources; nonconventional water resources and TWW are an important source for irrigating the crops and vegetables in United Arab Emirates (Abedi-Koupai and Bakhtiarifar 2003). Nutrient balance within soil is important for growth, biodiversity, and activity of soil microorganisms, which are directly responsible for soil ecosystem functioning and soil quality. The soil physical and biological characteristics in UAE sandy soil play role in the absorption and translocation of trace metals in plant-soil environment. Due to their sandy nature of UAE soils, high infiltration and evaporation rates and deep percolation losses will result in very less accumulation of trace metals in these soils. Subsurface drip irrigation can effectively protect farmers and consumers by minimizing crop and human exposure (Qadir et al. 2010). In addition pathogens loading and heavy metals accumulation in soils and crops was also discussed. The TF was in order of Fe > Zn > Cr > Cu. There was significant difference in $TF_{soil\text{-}veg}$ values among all the vegetables, and the highest $TF_{soil\text{-}veg}$ was observed for Fe in lettuce, and

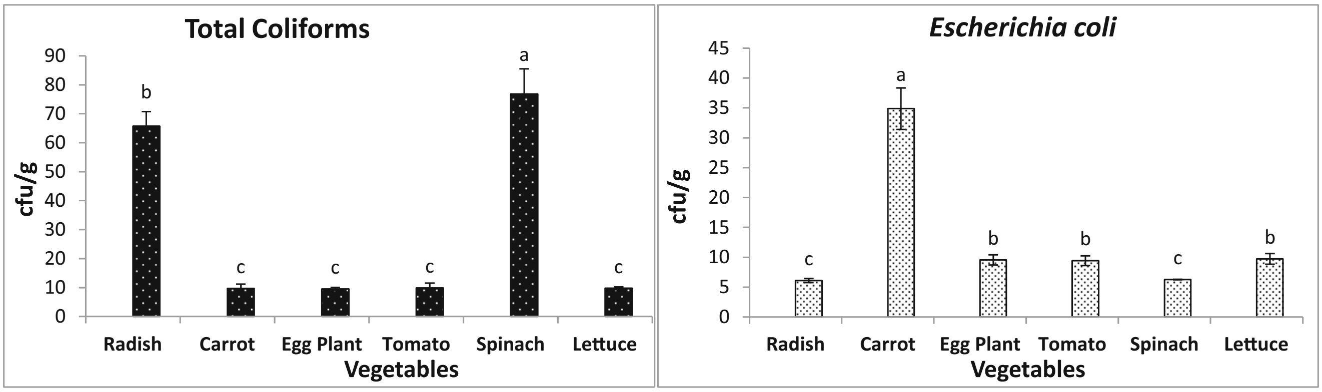

Fig. 5 Effect of treated wastewater on pathogen loading (Total coliforms, *Escherichia coli*) in different vegetables (radish, carrot, eggplant, tomato, spinach, lettuce).The error bars indicate the standard deviation, while the lowercase letters indicate significant differences at $p < 0.05$

lowest $TF_{soil\text{-}veg}$ level was obtained for Cr in the eggplant (Fig. 4). A significant difference was observed in TF values between different leaf, root, and fruit vegetables because different plants showed different behavior towards uptake, translocation, and distribution depends on the plant type and their ecophysiological attributes. Other researchers (Sinha et al. 2006; Sharma et al. 2006, 2007) also reported heavy metals accumulation and uptake in various vegetables grown in soils irrigated with long-term use of treated or untreated wastewater. In this regard, other anthropogenic factors (manures, sewage sludge, fertilizers, and agrochemicals) and soil physiochemical properties (pH, Ec, organic matter, soil nutrients) could play a key role in the absorption of heavy metals in the vegetables.

The translocation of trace elements in vegetables is influenced by a number of factors such as heavy metals concentrations in soil, weather conditions, soil type, and different kind of vegetables (leafy, fruit, root vegetables) grown (Bhargava et al. 2012; Ali et al. 2013), as well as harvest time and maturity stage.

The present experimental results clearly highlighted that translocation factors were significantly differed within different vegetables. Similarly, results were documented by Cui et al. (2004a, b). Moreover, Liu et al. (2005) and Khan et al. (2008) findings are consistent with our findings. The trace metals TF was in the order of Fe > Zn > Cr > Cu. Leafy vegetables were more susceptible to absorb and translocate HMs than fruit and root vegetables exhibit larger quantity of HMs, especially Fe and Zn. Other reports (Adamo et al. 2014) advocated that uptake of HMs is also closely related with soil physio-chemical properties. Moreover, it is recommended that monitoring and evaluation of safe reuse of treated wastewater in MENA region is irregular (Hussain et al. 2019). This also point out towards lack of equipment's trained personals and underdeveloped institutions with poor research infrastructure (Qadir et al. 2010). The less attention towards the management of present situation will led to negative impact on human health, biochemical water quality, environmental degradation, and ecological sustainability (Hussain et al. 2019). It is well recognized that heavy metals are significantly accumulated in leafy or root vegetables as compared to fruit organs and hence are less susceptible to trace elements accumulation (Zhong et al. 2018; Edelstein and Ben-Hur 2018; Hussain et al. 2019).

The present results demonstrate that EDI was lowest in adults (for Cu) following consumption of eggplant and the highest in children after radish. After eggplant consumption, the EDI of Fe was lower in adults and the highest in children following spinach consumption. Contrary results were obtained in adults and children for EDI for Zn and Cr. In general, EDI indicated that as compared to adults, children were at greater risk through certain vegetable consumptions. Khan et al. (2008) demonstrated that daily intakes (adults and children) of Cd, Cr, Cu, Ni, Pb, and Zn were happened following *Lactuca sativa* L, *Raphanus sativus* L, *Brassica napus*, and *Spinacia oleracea* L., respectively, consumption. They pointed out that these vegetables were grown in wastewater-irrigated soils. However, we report here that EDI was much less than the international standard recommendation, and hence there was no risk in consumption of these vegetables by local population, especially, eggplant, carrot, and tomatoes. However, spinach and lettuce should be consumed in less quantity because of potential risks associated with higher absorption and translocation into leafy vegetables. Occasional consumption of these vegetables is not injurious to human health. Our results demonstrated that EDI values of Cr were far below than that reported in literature (Bi et al. 2018; Fareena Samoo et al. 2018; Zakir et al. 2018).

The THQ is another useful index that widely used for health risk evaluation through vegetable consumption. Our results showed that Cu and Zn have values were lower than 1.0 while higher than 1.0 in case of Fe. The Cr exhibited THQ values more than 1.0, being the highest in spinach, lettuce, and carrot, respectively. The Cu, Zn, and Fe with average THQ values being less than one appear relative safe in all the tested fruit, leaf, and root vegetables. RI values showed that heavy metals were lower than 1.0 and hence lower than the risk screening value. Meanwhile, Cu, Fe, Zn, and Cr are safe with no ecological risk. The combined HI values for Cu, Zn, Cd, Cr, and Pb were substaintionaly higher 12.8 and 9.21 after consumption of lettuce and carrot. So, consumption of these vegetables should be avoided after irrigation with TWW. Similar THQ results were documented previously (Zakir et al. 2018; Gupta et al. 2018; Zhong et al. 2018).

There was significant variation in microbial load in different vegetables. Leafy vegetables (spinach) exhibited higher microbes as compared to fruit and root vegetables. We found that microbial load also varies significantly among vegetables types and tomatoes, and lettuce did not show heavy load of microbes. Trang et al. (2006) showed that different microbial strains including protozoa, worms, virus, and bacteria could cause serious health risks, and most vulnerable population are those persons who directly exposed to TWW or consumption of vegetables irrigated with wastewater. The microbial safety results reported by Azi et al. (2018) showed that pumpkin and *Amaranthus viridis* leaves were significantly higher than acceptable limit, and *Escherichia coli*, *Klebsiella pneumonia, and Aspergillus flavus* were prominent. Agriculture practices such as irrigating the plant species with contaminated, industrial waste water or untreated wastewater might impose different level of microbial contamination in soil-plant system (Mapanda et al. 2005). However, some researchers have documented that cooking might help in the reduction of microbial contamination or may be completely eliminate the harmful microbes (Botella et al. 2018). The outbreak of foodborne illness is mostly associated with consumption of raw or uncooked vegetables. However, it is well recognized that cooking at high temperature helps in reduction and elimination of microbial risks (Ssemanda et al. 2018). Therefore before endorsing irrigation with treated wastewater, a comprehensive evaluation of wastewater reuse on soil, plant, and human health needs to be evaluated.

Conclusion

The present study provides a better insight for vegetables contamination after irrigation with TWW through subsurface drip irrigation system. It also explains significant impact on plant-soil-environment system and its potential risks to public health. Several indicators such as EDI and THQ are useful for assessment of heavy metals uptake, translocation, and their possible risks through consumption of leafy, root, and food vegetables. Health risk index (HI) with less than one demonstrates that consumption of these vegetables is absent. The microbial content of the vegetables was, however, above safe limit than international standards that is health risky. Therefore, management and removal of microbes will properly help to identify the contaminations source and adequate solutions should be provided to prevent possible outbreak of food poisoning.

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