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A critical analysis of wastewater use in agriculture and associated health risks in Pakistan

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Abstract Freshwater shortage and its contamination with various types of pollutants are becoming the most alarming issues worldwide due to impacts on socioeconomic values. Considering an increasing freshwater scarcity, it is imperative for the growers, particularly in semiarid and arid areas, to use wastewater for crop production. Wastewaters generally contain numerous essential inorganic and organic nutrients which are considered necessary for plant metabolism. Besides, this practice provokes various hygienic, ecological and health concerns due to the occurrence of toxic substances such as heavy metals. Pakistan nowadays faces a severe freshwater scarcity. Consequently, untreated wastewater is used routinely in the agriculture sector. In this review, we have highlighted the negative and positive affectivity of wastewater on the chemical characteristics of the soil. This review critically delineates toxic metal accumulation in soil and their possible soil–plant–human transfer. We have also estimated and deliberated possible health hazards linked with the utilization of untreated city waste effluents for the cultivation of food/vegetable crops. Moreover, we carried out a multivariate analysis of data (144 studies of wastewater crop irrigation in Pakistan) to trace out common trends in published data. We have also compared the limit values of toxic metals in irrigation water, soil and plants. Furthermore, some viable solutions and future viewpoints are anticipated taking into account the on-ground situation in Pakistan—such as planning and sanitary matters, remedial/management technologies, awareness among local habitants (especially farmers) and the role of the government, NGOs and pertinent stakeholders. The data are supported by 13 tables and 7 figures.

Keywords Wastewaters · Pakistan · Heavy metal · Soil pollution · Vegetable contamination · Health risks

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Introduction

Freshwater scarcity at a global scale: a reason for wastewater use for crop irrigation

Water is considered one of the most indispensable components of life. However, it has quantitative limitations and qualitative vulnerability. At a global scale, freshwater is insufficient to sustain the rapidly increasing population. Moreover, the demand for good-quality water has enhanced due to high fiscal growth, demographic extension and improved living values. The global water use is projected to increase up to 55% by 2050 (Connor 2015), primarily due to growing burdens from domestic use, thermal electricity generation and manufacturing.

The available groundwater supplies are under serious threat with about 1/4th of the global aquifers currently over-used (Connor et al. 2017). Presently, about 4000 km^3 of freshwater is pumped per year at a global scale (Connor et al. 2017). Meanwhile, per capita withdrawal of freshwater extents to 552.1 m^3/year, out of which almost 70% is used in the agriculture sector (WTO 2011). At the current growth rate of population/urbanization, the agriculture sector will have to produce 60% more foods globally and 100% more in low-income nations (Islam and Karim 2019). About 93% of global urbanization takes place in developing countries, 40% of which is the expansion of original slums. Rapid economic growth, formidable population expansion, rising biofuel production and the severe contamination by organic and inorganic contaminants together have exerted significant pressure on limited freshwater resources.

Mismanagement of water use is also a major reason of freshwater scarcity in many countries around the globe (White and Howe 2004; Carvalho 2018). The concept of "water footprints" is also highly topical to encourage a shift toward the efficient and sustainable use of freshwaters globally (Wichelns 2017). Water footprints act as indicators to assess efficiency, sustainability and equity of water allocations worldwide (Wichelns 2017). For example, the municipal sector is reported to consume about 11% of the total global water withdrawal (FAO 2017) and agriculture sector is the major consumer of global freshwater.

It is observed that about 88% of the water used in municipal sector is discharged as wastewater, which makes up to 330 km^3 annually (Sarwar et al. 2019). This water can be used to irrigate about 40 million ha of land area (Mateo-Sagasta et al. 2015), which represents about 15% of the total cultivated area. Similarly, a large amount of water used to grow food may be wasted. For example, about 5 m^3 of water is used to produce food products per day per person in Europe. Annually, about 1.3 billion tons of food is wasted, which consumes about 250 km^3 of water for its production (Connor et al. 2017). The food losses are even higher in less developed countries such as Pakistan (Khalid et al. 2018a), which ultimately results in the loss of a great amount of freshwater.

Global use of wastewater for soil irrigation

Globally, the urbanization and industrialization, in addition to several other factors, have resulted in an increased production of wastewater. Approximately 400 billion m^3 of wastewater is discharged annually from different sectors; this water is reported to contaminate about 5500 billion m^3 of surface water annually (Zhang and Shen 2017). In the Asia and Pacific region, about 80–90% of the total wastewater produced is discharged into the environment/surface water bodies (UNESCO 2017). The quantity of industrial wastewater generated and discharged into the environment will be doubled by 2025 (Connor et al. 2017), which will further put pressure on freshwater reservoirs.

Wastewater use in the agricultural sector is considered as potential and most appropriate management. Particularly, under freshwater scarce scenario, the application of municipal wastewater in agriculture has now become a common exercise worldwide. About 11% of the total cultivated area worldwide is irrigated using untreated wastewater (Thebo et al. 2017). Similarly, around 10% of the people globally consume crops and vegetables produced using untreated wastewater (Khalid et al. 2018b). This ratio is expected to rise in the future owing to unchecked urbanization, expansion in cities and industries, climate change and increase in living standards.

According to different reports published at national and international levels, there has been a tremendous increase in wastewater use for crop production (Khalid et al. 2018b; Sasmaz et al. 2020). For example, wastewater used for crop production has increased around 10–29% annually in China, USA and European Union. In Australia, this increase is even up to 41%

(Aziz and Farissi 2014). India, Pakistan, China, Iran and Mexico are considered the five major countries at a global scale where untreated wastewater is used in the agricultural sector, especially under semiarid to arid climatic conditions.

In China, about 108.16 billion m^3 of wastewater was produced in 2010 by municipal and industrial sectors (Gyampo 2012). By the end of the twentieth century, $\approx$ 36.2 thousand km^2 of the agricultural area in China was irrigated with sewage effluents (Wang and Lin 2003). Although China has recently developed and adopted urban wastewater treatment and reuse system, millions of hectares are irrigated using wastewater. In India, more than 2600 Mm^3 of untreated wastewater is used in agriculture sector. During 1947–1997, there was a sixfold rise in wastewater production in major cities of India (Amerasinghe et al. 2013). Currently, about 38,000 M L/day of wastewater is produced by major cities of India, out of which only 35% is treated (Amerasinghe et al. 2013). Similarly, a diluted wastewater with rivers or streams is used to irrigate an area of 11,500 ha in Ghana (Keraita and Drechsel 2004). According to AQUASTAT-FAO, worldwide, a great amount of wastewater after treatment is used for crop irrigation: 280 Mm^3 in Australia, 8 Mm^3 Brazil, 1260 Mm^3 China, 5183 Mm^3 in Germany, 87 Mm^3 in Italy and 103 Mm^3 in Jordan.

Moreover, the treatment of wastewater before its possible application in the agricultural sector or release to water bodies greatly differs between low- and high-income nations (Zheng and Kamal 2020; Khalid et al. 2018b). For example, in high-income nations, around 70% of wastewater is released into the environment after treatments (Connor et al. 2017). In low-income nations, respective percentage greatly drops to only 8% of the total wastewater produced. On an average, about 80% of the total wastewater flows untreated to the ecosystem (Connor et al. 2017).

Freshwater reservoirs in Pakistan

Pakistan is the sixth most heavily populated nation worldwide with around 208 million people according to a latest 2017 census. By an increase in the current ratio, the country's inhabitant index may cross 240 million by 2030. This increase in population may have numerous drastic effects on freshwater availability, supply and demand to different allied sectors. As the population increases, water demand is projected to far outstrip supply, which will further enhance wastewater production and release to ecosystem.

Although Pakistan contains ample groundwater and surface water reservoirs, the high rise in population, unsustainable urbanization and wastewater production have exerted great impacts on the water reservoirs (Murtaza et al. 2020). Like other low-income countries, currently Pakistan lacks sufficient freshwater reservoirs to sustain rapidly growing population. According to the report of Pakistan Water Partnership (PWP), total groundwater reserves of Pakistan are about 24 million acre feet, while total accessible surface water resources are about 150 MAF. Annually, Pakistan receives about 145 MAF of water, albeit it has the capacity (dams) to save only 13.7 MAF (Mubeen et al. 2015). Pakistan needs 40 MAF of water annually, but 29 MAF is wasted because of a shortage of dams (Mubeen et al. 2015).

Pakistan has basically drained its available freshwater resources at a high rate. Pakistan, previously a water-blessed state, now faces a stern challenge of sustainable freshwater supply. The country has already exceeded its freshwater pumping limit. Globally, the country is placed among top five most water-stressed countries. The recent United Nations agency reports revealed that Pakistan is going to come across an issue of "acute water shortage." The increasing inequity between water demand and supply has caused a severe water shortage in all the sectors of its use, thus presenting a severe risk to the country's future sustainability.

Recent media reports indicated a decrease in water availability below the threshold level of 1000 m^3 per capita (Pakistantoday 2018; Shams 2017; Hussain 2018). Low rainfall in Pakistan in recent past has resulted in water level to reach "dead level" in the Mangla and Tarbela dams, country's two major water reservoirs (Pakistantoday 2018; Shams 2017; Hussain 2018). The water level in Rawal lake, the major reservoir of drinking water for twin cities of Rawalpindi and Islamabad, has also reduced to a critically low level in 2018. According to some media reports under drought periods, freshwater reservoirs in Pakistan in the form of rivers and canals may fall to less than 10 days. Therefore, instant synchronized planning and execution are necessary to deter this issue.

The situation of freshwater scarcity might get worse in Indus Basin, where normal water supply per capita per year is already below the standard value of 1000 m^3 (WWF-Pakistan 2007). In certain regions of Sindh Province, people already have a diverse scarcity of freshwater, even for drinking purpose (Solomon 2019). Underground aquifers in Baluchistan are falling around 3.5 m annually (Mirza and Ahmad 2005). This highlights severe freshwater scarcity scenario of the country, which will further get severe in the future.

Water contamination in Pakistan

In Pakistan, the composition of freshwaters is not fully suitable for agricultural or drinking purposes in some parts of the country (Shahid et al. 2018a). This is a usual scenario in various semiarid and dry sub-humid areas worldwide. Moreover, delivery efficacy of canal water to field is declining in Pakistan, which has enhanced dependence on groundwater and wastewater. Generally, groundwater contains high sodium, calcium, total dissolved salts, free ions and in some cases high concentrations of toxic substances such as heavy metals (Murtaza and Zia 2012; Shah et al. 2020).

Several reports delineated high quantities of arsenic and other toxic metals in groundwater of country (Shah et al. 2020; Shahid et al. 2020b; Khalid et al. 2020b). According to PCRWR-Pakistan, 69% of water suppliers in the country do not meet the National Standards for Water Quality, posing a stern health danger to millions of the people. Pakistan is ranked 80th out of 122 nations considering drinking water quality.

Sources of wastewater in Pakistan: collection, treatment and disposal

In Pakistan, the domestic wastes are released directly to a natural drain which then flows into waterbodies. However, there are municipal water collection systems in some cities of the country, which normally flow to the nearby water bodies. These systems generally collect $< 50\%$ of total waste produced in different urban areas (WWF-Pakistan 2007). It is estimated that almost 10% of the total sewage is subjected to threat in the country using different technologies (WWF-Pakistan 2007).

The models of wastewater collection and treatment at secondary or tertiary levels do not exist in Pakistan (WB-SCEA 2006; Kanwal et al. 2020). Treatment plants exist in some cities, while many of these do not have allied sewerage networks. As a result, the treatment systems in these cities are often either over-loaded or abandoned and hardly 1% of total wastewater is treated efficiently (WB-SCEA 2006). A survey carried out at national level in Pakistan showed that only 2% of the cities had wastewater treatment systems, while 80% of the cities (having a population $> 10{,}000$ inhabitants) use their untreated wastewater directly for irrigation of soils (Ensink et al. 2004). Recently, the concept of using constructed wetlands to remove toxic metals from wastewater has been introduced in Pakistan (Batool and Saleh 2020).

According to an estimation (WB-SCEA 2006), > 7500 million liters of wastewater is disposed off to water drains daily in Pakistan. According to AQUASTAT-FAO, roughly 1.8×10^7 m^3 h^{-1} of wastewater was generated during 2000 in 14 major cities of Pakistan. It is estimated that > 960 thousand million gallons of wastewater is generated in the country (Pakistan Water Sector Strategy). Out of this, almost 675 and 290 thousand million gallons are generated by municipal and industrial sectors, respectively.

In Pakistan, about 1228 out of the 6634 registered industrial units generate highly toxic wastewaters (Sial et al. 2006). Major industrial units causing water contamination in Pakistan include tanneries, petrochemicals, food processing, textile, refineries, paper and sugar industries, etc. These industries are producing several thousand gallons of the wastewater having huge quantities of contaminants such as nitrites, nitrates, anions (Cl^-, CO_3^{2-}, HCO_3^-) and cations (K, Na, Ca, Mg) and potentially toxic metals (Hg, Pb, Cd, Cr, Ni, Fe, Cu, Co) (Sial et al. 2006).

Majority of the industrial units in Pakistan are situated in or nearby main cities which add their waste directly into the nearby water bodies or cultivated soils (Ullah et al. 2009) (Supplementary Fig. 1). River Ravi is the most contaminated river in Pakistan. It is reported that almost 18 m^3 s^{-1} of wastewater is discharged from Lahore into the river Ravi (Murtaza and Zia 2012). More recently, this quantity increased to > 28 m^3 s^{-1} (Iqbal et al. 2018).

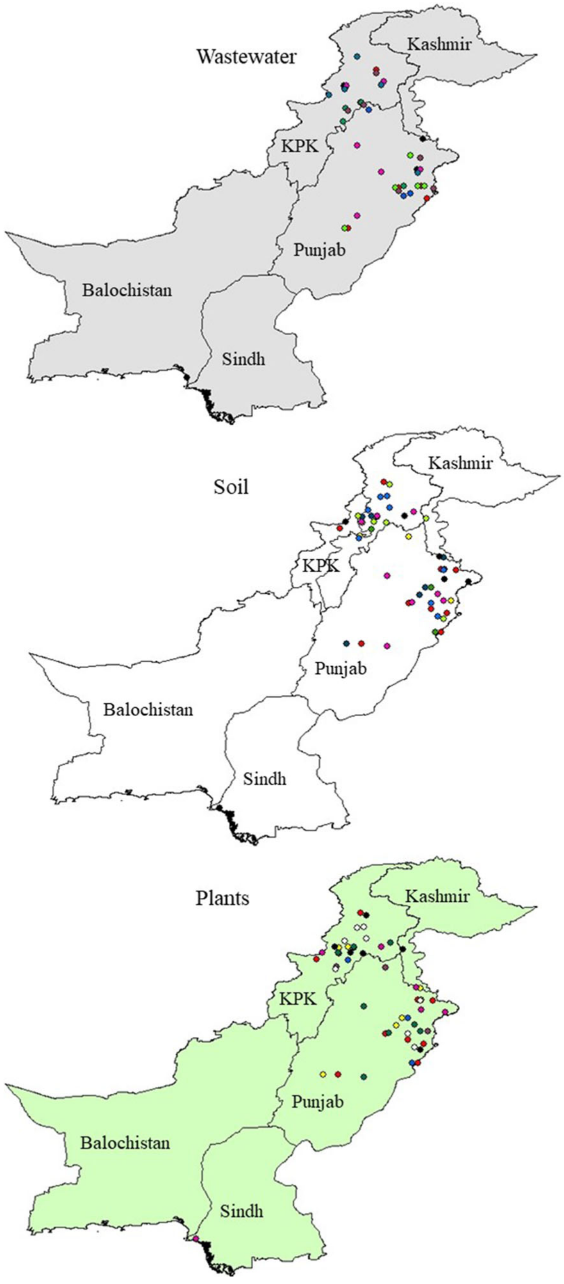

Fig. 1 Map showing heavy metal contamination of wastewater, soil and plants in different areas of Pakistan

Even, there is no proper treatment system for industrial effluents in industrial estates of the capital city of Islamabad, and waste is directly discharged into the River Swan (Sial et al. 2006). Consequently, toxic pollutants of industrial effluents flow into water streams without any treatment. According to an estimate, different industries release about 40 × 10^9 L of waste effluents per day into water streams in Pakistan (Prasad and Karchiyappan 2018). The seepage/percolation of these effluents may also cause contamination of groundwater aquifers.

Excessive use of agrochemicals is another key source of water contamination in Pakistan. Surface and groundwater contamination due to excessive use of agrochemicals has been delineated at global scale (Pérez-Lucas et al. 2018). However, the situation is not very different in Pakistan as well (Ali et al. 2018). Application of agrochemicals (fertilizers/pesticides) along with irrigation water may penetrate via soil profile and eventually contaminates groundwater sources (Khalid et al. 2020a).

Application of wastewater for crop cultivation

The climate of Pakistan fluctuates greatly in its various areas. In Sindh and Southern Punjab provinces of country, freshwater is scarce due to semiarid to arid climate (Shah et al. 2019). Therefore, in addition to canal water, groundwater is mainly used for soil and crop irrigation. Pumping of groundwater for soil irrigation is costly and unreliable due to severe energy crises (Murtaza et al. 2019). Moreover, groundwater is mostly of poor quality in these areas of Pakistan due to enhanced concentrations of soluble salts and toxic metal contents (Murtaza et al. 2010).

Under such conditions, wastewater is commonly used in these areas. A large area in Pakistan is cultivated under wastewater irrigation. About ¼ of wastewater generated in the country is used to irrigate soils (Ensink et al. 2004). Considering the prevailing scenario of country, the application of untreated wastewater may increase greatly in the coming years.

We carried out the inverse distance weighted interpolation of almost all the studies carried out in Pakistan regarding wastewater soil application using ArcGIS (version 10.4.1) (Fig. 1). The data show that the majority of the studies in Pakistan regarding wastewater application and associated environmental and health risks have been carried out in Punjab and Khyber Pakhtunkhwa (KP) provinces (Fig. 1). Moreover, it was noted that Cd, Pb, Cu, Cr, Ni, Co and Zn were the main metals reported in these studies.

Wastewater irrigation in Pakistan: positive and negative effects

Farmers prefer wastewater soil irrigation due to the existence of nutrients and reliability of supply around the clock (Khalid et al. 2018b). Nevertheless, the threshold levels of nutrients in wastewater are not yet explored. Usually, the farmers do not take into consideration the health and environmental risks and use wastewater for direct economic benefits, when there is an opportunity.

The municipalities controlling city wastewater in Pakistan are well aware of the worth of wastewater and sell it to farmers, generating the income to keep wastewater collection and proper functioning of the pumping facilities. This serves as a win–win condition for both the parties: farmers getting a cheap source of irrigation, while municipal councils have invested very few to reuse/manage city wastewater. Therefore, some authors in Pakistan do not recommend the large-scale development of the wastewater treatment industry or enforcement of strict legislation about water sanitation (Murtaza and Zia 2012). Rather, they propose that it is more viable in Pakistan to look at other sustainable and environmental-friendly options to get the maximum benefit of wastewater use in agriculture sector along with minimum harmful effects of wastewater application.

Use of wastewater in the agriculture sector has several beneficial aspects (Supplementary Fig. 2). The meta-analysis of literature data shows that there is an average increase of 75% with a range of 0.05–575% in nutrient contents (N, P, K) in vegetables/crops irrigated with wastewater compared to freshwater (Supplementary Table 1). Therefore, it has been extensively used as a fertilizer to decrease crop production price, while at the same time to get the highest benefit from this resource.

The value of wastewater application for its nutritional worth varies with the composition of wastewater, soil type and fertility, and crop species (Supplementary Table 1). Wastewater contains nutrients in dissolved form, which are more mobile in soil and bioavailable to plants. Therefore, the nutrient use efficiency (NUE) for wastewater is almost 100%. Moreover, nutrients are supplied to soils and plants in different splits along with wastewater application, which in most cases matches with the nutrient demand of crops. Usually, farmers are benefitted for fertilizer saving (Fine and Hadas 2012).

Additionally, numerous disadvantages are allied with the application of untreated wastewaters for crop cultivation such as the occurrence of toxic pollutants, the buildup of pathogenic microorganisms and groundwater contamination (Murtaza et al. 2010; Qadir et al. 2010). The major problem related to wastewater application for soil irrigations is the existence of toxic metals (Raja et al. 2015). In fact, toxic metals are used greatly in different household articles and industrial activities in these days, which has ultimately enhanced their levels in wastewaters. Studies have delineated the probable hazards related to the toxic metals buildup in wastewater-irrigated topsoil (Riaz et al. 2020; Kanwal et al. 2020).

Metal contents of soil after wastewater application in Pakistan

Wastewater irrigation leads to the accumulation of toxic metal in the soil (Supplementary Fig. 3, Table 1, Supplementary Table 2). Wastewater is considered a key source of toxic metals in soils, plants, animals and foods (Supplementary Table 2). The continuous wastewater soil irrigation causes toxic metal buildup in soils, even with slightly contaminated wastewaters (Khalid et al. 2017a). Some studies even reported direct correlations of toxic metal accumulation in soil and wastewater application periods. Continuous application of untreated city/industrial wastewater may also introduce toxic metals in groundwater due to leaching through dumpsites.

The meta-analysis of toxic metals level in wastewaters, soils and plants is presented in Table 2. The average concentration of all the studied metals was 89.5 mg/kg in sol, which was almost 60 times higher than their level in wastewater (1.5 mg/L). These calculations are based on 144 studies/observations presented in Supplementary Table 2.

In Pakistan, the peri-urban areas are mostly used for vegetables/crops cultivation. In most cases, these vegetables are often irrigated using untreated city wastewater, due to unavailability of freshwater. In various areas of Lahore City, continuous and long-term application of city wastewater for crop cultivation has build up high levels of toxic pollutants (especially toxic metals) in soil than those irrigated

Table 1 Concentrations of cadmium (Cd) in wastewaters, soils and plants after wastewater application

Vegetables/crops	Wastewater (mg/L)	Soil (mg/kg)	Plant (mg/kg)	TF	BF	References
Solanum tuberosum	–	13.2	0.12	–	0.0	Jan et al. (2010)
Coriandrum sativum	0.55	9.15	3.7	16.6	0.4	Khan et al. (2013)
Momordica charantia	0.059	0.08	0.058	1.4	0.7	Murtaza et al. (2008)
Spinacia oleracea	0.03	0.34	0.23	11.3	0.7	Qadir et al. (2000)
Raphanus sativus	0.24	0.78	1.7	3.3	2.2	Bakht et al. (2016)
Capsicum annuum	0.215	8.1	0.4	37.7	0.0	Hamid et al. (2016)
Solanum lycopersicum	0.02	23.1	10.47	1155	0.5	Hamid et al. (2017)
Spinacia oleracea	0.06	3.4	8.90	56.7	2.6	Hamid et al. (2017)
Mentha spicata	0.93	0.25	3.5	0.3	14.0	Anwar et al. (2016)
Nicotiana alata	2	–	140	–	–	Khan et al. (2019a)
Triticum aestivum	–	2.6	1.7	–	0.7	Khan et al. (2019b)
Chenopodium album	–	0.41	0.10	–	0.2	Mehmood et al. (2019)
Spinacia oleracea	0.02	1.6	1.8	80.0	1.1	Sarwar et al. (2019)
Brassica oleracea	0.15	0.01	0.37	0.1	37.0	Rehman et al. (2019)
Triticum aestivum	1.88	2.03	1.7	1.1	0.8	Ahmad et al. (2019)

The transfer and bioaccumulation factors indicate, respectively, wastewaters to soils and soils to plants transfer. Data for other toxic metals are presented in Supplementary Table 2

Data for other heavy metals are presented in Supplementary Table 2

Table 2 Descriptive statistics of data (144 studies related to wastewater use for crop irrigation) presented in Supplementary Table 2

Variable	Observations	Minimum	Maximum	Mean	SD
HM—wastewater	144	0.0	28	1.5	3.9
HM—soil	144	0.0	8598	89.5	716.7
HM—plants	144	0.0	973	39.8	109
TF	144	0.0	5476.4	86.9	480.1
BF	144	0.0	78.7	3.9	10.2

HM heavy metals, *TF* transfer factor, *BF* bioaccumulation factor

with groundwater (Amin et al. 2014). Studies carried out in neighbor countries of Pakistan (India and China) also described toxic metals buildup in soils due to the application of untreated industrial/domestic effluents or contaminated groundwater for soil irrigation (Alia et al. 2015; Ahamad et al. 2020).

We performed a scatter plot analysis for each toxic metal and together with all metals to trace out the possible transference of toxic metals from wastewater to the soil. Some metals such as Fe ($R^2 = 0.34$) showed a moderate correlation for wastewater to soil transfer of these metals (Supplementary Fig. 4). However, for other metals (Cd, Pb, Ni, Zn, Cr, Mn, Zn), the scatter plots showed very weak correlations. This shows that there can be some other sources of these toxic metals in soil besides wastewater application. When the data of all toxic metals were analyzed together, it shows buildups of toxic metals in soil but was weekly correlated ($R^2 = 0.05$) (Fig. 2A).

Generally, application of city wastewater to agricultural lands increases both the bioavailable and total toxic metal contents in soil. The major change takes place in a bioavailable pool of toxic metals in soil. Indeed, the toxic metals introduced in soil by anthropogenic activities (wastewater irrigation) build up predominantly in the surface soil layers and are mostly

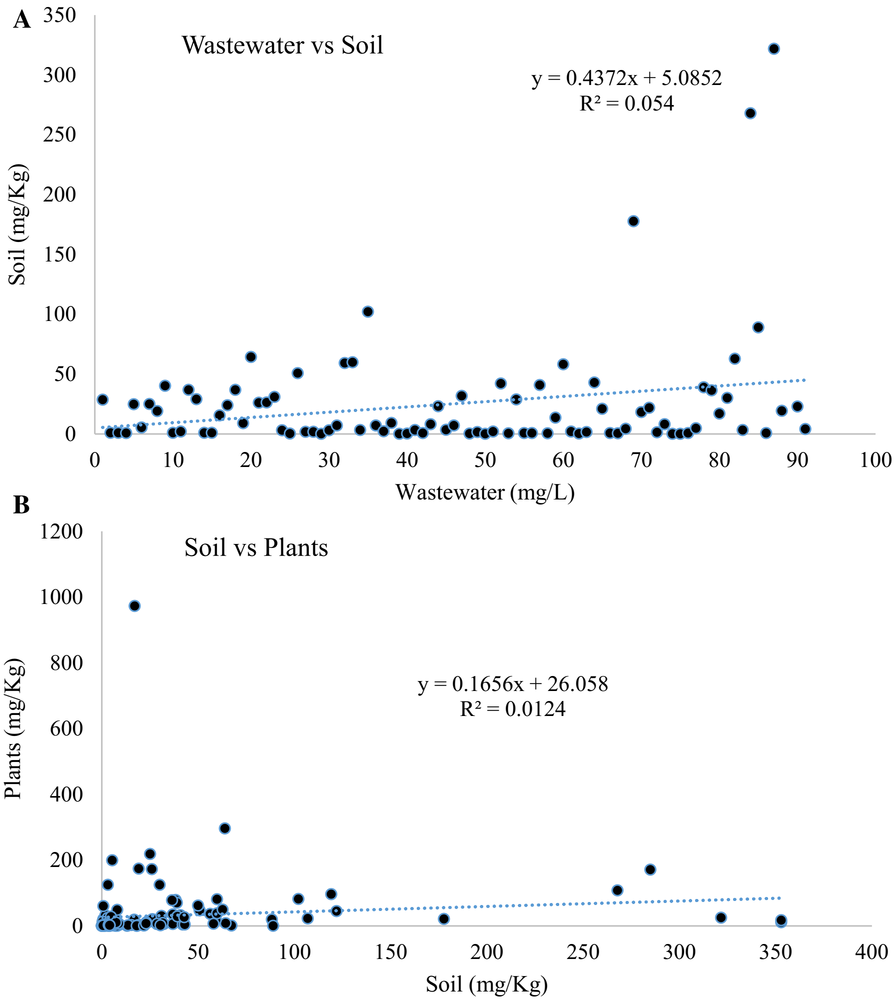

Fig. 2 Scatter plot description of all heavy metals together showing wastewater–soil (**a**) and soil–plant (**b**) transfer after crop irrigation with wastewater

more mobile/phytoavailable due to weak binding with soil constituents (Cecchi et al. 2008). Therefore, it is quite possible that wastewater-added toxic metals into the soils may endure more threat to soil ecosystem and food chain contamination compared to natural influxes of these metals.

In addition, soil characteristics significantly alter the biochemical behaviors of toxic metals in the soil–plant systems (Natasha et al. 2018b, 2019). Basically, these soil characteristics govern the basic soil processes that affect total metal concentration, metal speciation, as well as fate of toxic metals in the soils (Shahid et al. 2012). Therefore, the impact of wastewater application also depends on soil characteristics.

Influence of wastewater application on soil characteristics

The wastewater application can have negative impacts on soil health. Wastewater irrigation has exerted different physical, biological and chemical effects on the biosphere. Application of wastewater commonly alters the physico-biochemical properties such as pH, organic matter (OM), cation exchange capacity (CEC) and biological conditions of the soil. The modification in soil properties greatly governs the fate of toxic elements in the soil (Khalid et al. 2018b). However, these modifications can exert both negative and positive effects with respect to metal/nutrient soil–plant transfer, depending on wastewater composition and soil type.

Studies revealed that long-term application of wastewater can greatly modify the soil pH (Faryal et al. 2007) and consequently influences the mobile/phytoavailable fraction of metals and essential nutrients in the soil (Mushtaq and Khan 2010). Khalid et al. (2017a) reported a slight increase in soil pH after irrigation of different vegetables with wastewater. In contrast, Jan et al. (2010) revealed that long-term wastewater application can decrease the pH of soil. In addition, the soil buffering capacity and type can also affect the change in soil pH after wastewater application. However, any modification in soil pH due to wastewater application can significantly alter metal mobilization/adsorption and bioavailability in soil. Generally, toxic metals present in the soil become less mobile when the soil pH is > 7.0 due to the formation of complex metal–OM compounds and become less phytoavailable (Castro et al. 2013).

Soil OM is an important soil parameter affecting metal/pollutant retention in soil and their soil–plant transfer (Khalid et al. 2020a). Usually, the OM of Pakistani soil is less than 1% (Khalid et al. 2018b). Studies have revealed that the OM of soil increases by wastewater irrigation compared to the background OM concentration of the soil. Khalid et al. (2017a) reported an increase in soil OM after vegetable cultivation under wastewater application, while a slight decrease in OM was observed for groundwater treated soil in Vehari, Pakistan. However, this modification in soil OM depends on soil type and wastewater composition. Generally, the wastewater application had no significant effect on soil OM contents of sandy soils compared to loamy soils. Faryal et al. (2007) reported that soils with high OM contents can bind metals more strongly and make them less bioavailable. Hence, an increase in OM by wastewater application can be a beneficial aspect for decreasing the phytoavailability of toxic metals present in the wastewater/soil.

Cation exchange capacity is an important property of the soil that greatly influences the soil pH and nutrient/metal availability. High pH and CEC of soil could be the main factors which can affect the metal availability. Soil CEC helps in holding positively charged ions and nutrients. Mushtaq and Khan (2010) reported the increase in soil CEC after long-term wastewater application in the Rawalpindi region, Pakistan. They described that soil CEC had a negative influence on the extractable fractions of soil metals. So, wastewater can potentially modify phyto-uptake of metal via altering soil characteristics.

Metal contents in food crops after wastewater application

Soil toxic metal levels correlate with their accumulation in food crops. Untreated wastewater application results in an enhanced phytoaccumulation of toxic metals in edible tissues (Supplementary Table 2). Wastewater-irrigated crops/vegetables may uptake toxic metals higher than the critical limits (Khalid et al. 2017a).

Numerous earlier reports in Pakistan showed toxic metal accumulation above the threshold levels in edible plant tissues after wastewater irrigation. For example, Natasha et al. (2020c) revealed that high concentrations of Cu, Cd, Ni and Pb were accumulated in radish when irrigated with wastewater. Khalid et al. (2017a) delineated high Pb levels in three vegetables viz. spinach, cauliflower and radish. Several other studies reporting high toxic metal levels in edible plant tissues are summarized in Supplementary Table 2.

Plants may vary in their potential to uptake and accumulate metals in different plant organs (Foucault et al. 2013). Some plant species can uptake and transfer significant concentrations of metals to their aerial parts after wastewater irrigation. Even some plant species can accumulate 100 times higher toxic metal contents compared to others (Khalid et al. 2017b). Leafy vegetables generally phytoaccumulate higher concentrations of metals than other vegetables after wastewater application (Khalid et al. 2017a).

Besides plant type, metal speciation inside soil after wastewater irrigation also affects its biogeochemical behavior (mobile and bioavailable fraction in soil, soil–plant transfers and compartmentations inside plants). Inside soil, toxic metals are present in several chemical forms (adsorbed on soil constituents, free metal ion or bound to different ligands) (Shahid et al. 2011). Phyto-uptake of metals varies with their soil chemical speciation in addition to other soil and plant factors (Rafiq et al. 2017). Therefore, wastewater application may affect metal phyto-uptake via altering their chemical speciation.

The storage of toxic metals in different organs (root, shoot, edible tissues) is mainly controlled by metal and plant type. In most cases, toxic metals are mainly sequestered in the root tissues of plants. Even some studies reported $> 90\%$ of toxic metals stored in root cells (Pourrut et al. 2011). Toxic metal accumulation in roots or transfer to aerial tissues is governed by different transporter proteins (Shabbir et al. 2020; Shahid et al. 2017). The genetic and cellular-level studies have discovered several transporter families involved in metal transfer to shoots. The induction of these metal transporter proteins, as well as their intensity inside the plant cell, is specific to metal and plant type (Shahid et al. 2014). Consequently, different metals may vary greatly in terms of root–shoot transfer in different plant species after wastewater irrigation.

The possible soil–plant transfer trend of toxic metals after wastewater application was assessed using scatter plots. Cadmium, Ni, Fe and Co showed moderate to strong correlations ($R^2 = 0.46$, 0.42, 0.94 and 0.97, respectively) between their contents in soil and plants (Supplementary Fig. 4). However, overall toxic metals showed week correlation ($R^2 = 0.01$) between their levels in soil and plants (Fig. 2B).

Range of toxic metals in plants and soils after wastewater application

We calculated the ranges (minimum and maximum values) of all the toxic metals in wastewaters, soils and plants (Table 3). In the case of Cu, the minimum and maximum values were 0.12 and 18.2 mg/L in wastewater, 0.45 and 107 mg/kg in soil, and 0.04 and 218.6 mg/kg in plants. The concentration ranges of other toxic metals, for wastewater (mg/L), soil (mg/kg) and plants (mg/kg) were as follows: Pb (0.14–7.8, 0.39–67, 0.05–172), Zn (0.01–10, 0.08–122, 0.09–296), Cd (0.02–2, 0.01–32, 0.06–140), Ni (0.04–5, 0.3–58, 0.3–280), Cr (0.05–4.7, 0.49–178, 0.04–60), Co (0.01–0.5, 0.06–8, 0.03–48) and Mn (0.15–28, 0.63–353, 0.4–973), respectively (Table 3). This shows that for Cu, Zn, Ni, Co and Mn, the order of concentration was plant $>$ soil $>$ wastewater, while for Pb, Cr and Cd, the order of concentration was soil $>$ plant $>$ wastewater. Based on trends in data, it may be perceived that Cu, Zn, Ni, Co and Mn are more readily taken up by plants than Pb, Cd and Cr in Pakistani soil conditions.

Moreover, the high transfer index of these toxic metals from soils to plants (37, 16, 38, 37, 10, 79, 13 and 57, respectively, for Cu, Pb, Zn, Cd, Ni, Cr, Co and Mn) can be due to high availability of these metals when applied via wastewater (Table 3). In contrast to natural sources, metals added into the soil via anthropogenic activities (e.g., wastewater) are more bioavailable. This is because anthropogenically added metals are present either in soil solution or on exchangeable sites, which have generally high soil–plant transfer index (Cecchi et al. 2008). This shows that more attention must be given to soil contamination with wastewater-mediated toxic elements.

Consequences of wastewater irrigations on physiological attributes of plants

Plant undergoes different morphological, biochemical and physiological changes upon exposure to the elevated concentrations of toxic metals (Shahid et al. 2020c). These changes in plants are mainly derived via different pathways and endpoints/biomarkers. Toxic

Table 3 Range of heavy metals in wastewater, soil and plants reported in different studies (144 studies presented in Supplementary Table 2)

Metals	Wastewater		Soil		Plants		Transfer factor		Bioaccumulation factor	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Cd	0.02	2.0	0.01	31.7	0.06	140.0	0.10	1155.0	0.00	37.0
Co	0.01	0.5	0.06	8.0	0.03	48.5	1.00	125.6	0.30	13.3
Cr	0.05	4.7	0.49	177.8	0.04	60.0	0.80	772.8	0.00	78.7
Cu	0.12	18.2	0.45	107.0	0.04	218.6	1.30	251.9	0.10	36.8
Fe	1.57	23.0	3.59	8598.0	1.67	682.0	0.40	5476.4	0.10	9.1
Pb	0.14	7.8	0.39	67.4	0.05	172.2	0.80	171.4	0.00	16.3
Ni	0.04	5.0	0.30	58.1	0.34	280.0	0.90	200.3	0.10	9.9
Mn	0.15	28.0	0.63	353.0	0.40	973.0	0.90	1072.0	0.00	57.0
Zn	0.01	10.0	0.08	122.0	0.09	296.3	0.20	707.0	0.00	38.5

Min, Minimum; Max, Maximum

metals generally elicit high-level generation of reactive oxygen species (ROS), which have the potential to aggravate various noxious alterations in plants (Shahid et al. 2020a; Shabbir et al. 2020). Excess ROS are generally accompanied by oxidation/peroxidation of plant macromolecules such as lipids, proteins, RNAs and DNAs. Thereby, toxic metal-provoked ROS may cause severe cellular harms and eventually may exaggerate cell death (Shahid et al. 2017; Natasha et al. 2019).

However, these physiological alterations have been less studied under wastewater irrigation, especially in Pakistan. There are few studies conducted to quantify ROS production and to access the physiological changes in plants after wastewater irrigation (Sardar et al. 2020; Natasha et al. 2020c). Hence, additional studies are required to completely elaborate the influence of wastewater application on plant physiological attributes.

Multivariate analysis of data

We carried out principal component analysis (PCA) of all the data presented in Supplementary Tables 1 and 2. The PCA is a useful multivariate analysis technique which converts a large number of input variables to some common factors based on correlations and variations in the data (Shahid et al. 2018b). In the current study, PCA transformed the entire data into five major component factors. These factors have different contribution proportions toward cumulative variance, which were 46%, 25%, 20%, 8% and 1%, respectively, for F1-F5 (Supplementary Table 3). In F1, there was a major contribution of all the studied metals except Zn and Mn. The trend was similar for other factors (F2–F5), where different metals were contributing different proportions toward total variance (Supplementary Table 4).

The PCA grouped the wastewater–soil–plant transfer parameters in four groups: (1) toxic metals in wastewater, (2) metals in plant, (3) bioaccumulation factor, and (4) metals in soil and transfer factor (Fig. 3). The PCA delineates weak correlation between metal contents in wastewaters, soils and plants. Moreover, metal enrichment in the soils is dependent on wastewater to soil transfer factor, while metal accumulation in plants is governed by soil–plant bioaccumulation factor. This was also evident from the Pearson correlation ($R^2 = 0.95$ for metals in soil and transfer factor) (Supplementary Table 3B).

In the case of different types of metals, PCA separated these metals in four different groups: (1) Zn and Cu on top left-side group, (2) Mn, Ni, Pb, Fe, Co, Cr and Cu on top right-side group, (3) Pb, Ni, Mn, Fe, Cd and Cu on bottom left-side group and (4) Mn, Ni, Pb, Cu, Cd, Cr, Co, Fe and Zn on bottom right-side group (Fig. 3). This shows a great variation in the overall wastewater–soil–plant transfer of different metals. This grouping of toxic metals was further confirmed by the squared cosines of the observations (Supplementary Table 4).

Influence of wastewater application on food chain contamination

Nowadays, food safety has gained considerable attention when above-optimum levels of toxic metals are accumulated by edible plant tissues. Some toxic metals (As, Pb, Cd, etc.) are not involved in any known biological metabolism. Indirect exposure to wastewater-born pollutants and pathogens occurs through wastewater-fed crops or fish or using contaminated drinking water (Mok and Hamilton 2014). Several recent and past reports published at national and international level showed various sanitation- or wastewater-related diseases in areas where untreated wastewater is commonly allied in the agriculture sector (Sardar et al. 2020; Natasha et al. 2020c; Khalid et al. 2018b).

Several previous research reports and clinical studies have revealed that exposure to toxic metals can result in serious health issues (Natasha et al. 2020b; Shahid et al. 2020a). Toxic metal exposure has been linked with numerous human diseases, particularly cardiovascular, nervous system, blood and kidney disorders. Ingestion of vegetables and food crops containing excess levels of toxic metals can result in a decrease in vital nutrients in the human body, and initiating numerous health issues in humans such as infertility and reproductive failure, bone demineralization, gastrointestinal cancer, impaired immunological defenses and psycho-social faculties (Onakpa et al. 2018).

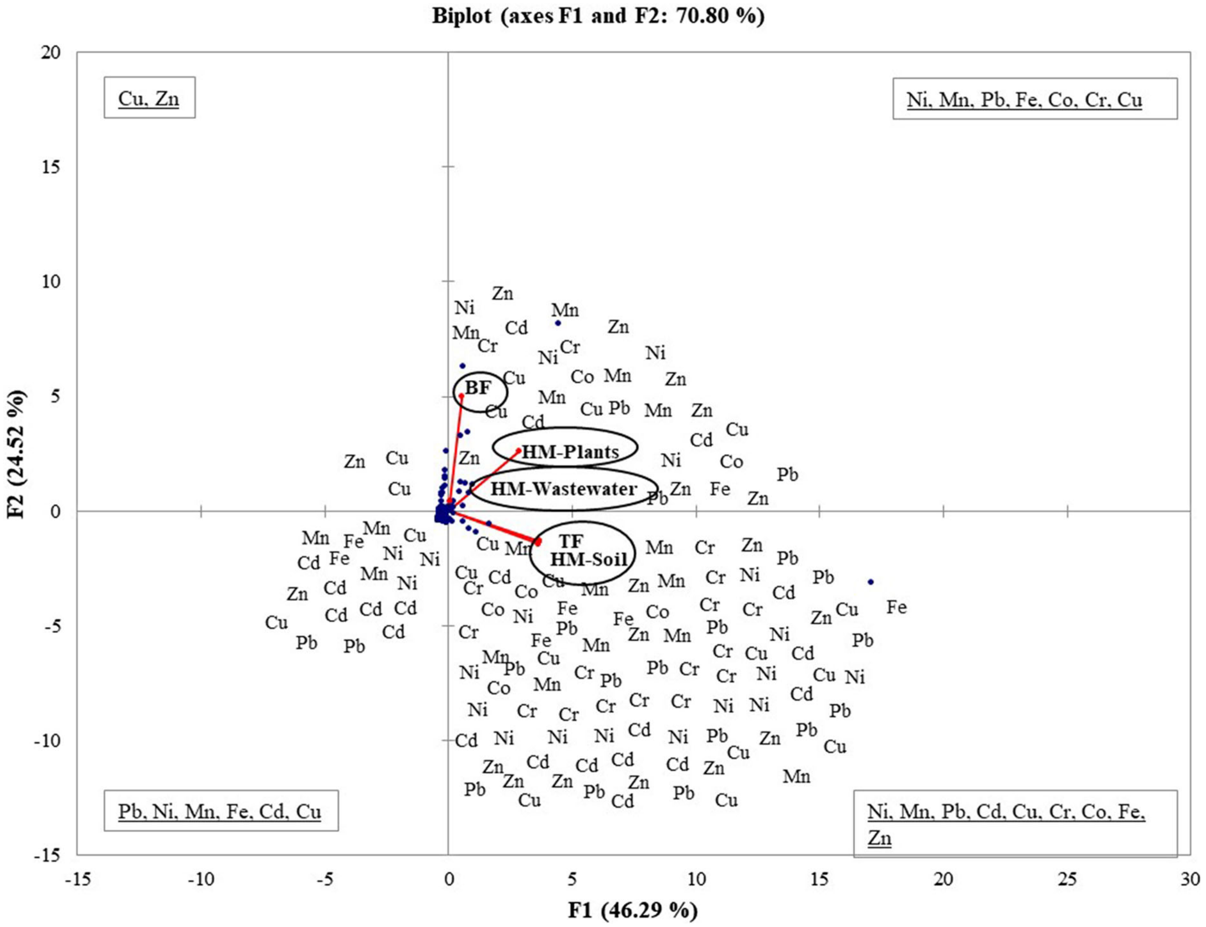

Fig. 3 Principal component analysis of data (144 studies presented in Supplementary Table 2)

Wastewater crop irrigation and health risks

Many drawbacks are allied with wastewater irrigation (Qadir et al. 2010; Khalid et al. 2017a). Wastewater contains toxic metals and pathogenic microorganisms, which can induce severe clinical and sanitary risks due to the spread of infectious diseases. Wastewater application to agricultural land can cause shallow groundwater pollution and soil hardening (Li et al. 2017). The buildup of toxic metals in soil and their uptake by crops due to wastewater application disturb food security and worth. Studies have revealed supra-optimal quantities of toxic metals in food grown with wastewater applications (Rezapour et al. 2019; Sardar et al. 2020).

Continuous use of such foods can result in a continuous buildup of these metals in different human organs such as the liver and kidney causing detrimental effects. The risk assessment studies which take into account the intake of metal-contaminated foods are mainly carried out in developed (high income) nations; while limited data are available in less-developed (low income) nations (Natasha et al. 2020a).

In case of small cities where there is no major industry, the environmental and health hazards of soil pollution and allied health risks seem to be insignificant. Similarly, in areas where groundwater is free of major pollutants, mixed use of wastewater and regular irrigation water (groundwater) can minimize the environmental and health impacts and facilitates the farmer community to benefit from wastewater use. However, before using the mixture of wastewater and ground/canal water, it is necessary to determine the suitability of ground/canal water (level of different types of pollutants) for crop irrigation. This is because of the fact that the ground/canal water may also contain high levels of pollutants. Under such conditions, the risk of food chain contamination will withstand.

Range of risk assessment parameters for toxic metal contents in plants after wastewater application

Tracing the routes of toxic metal contamination and estimating their levels of exposure to living organisms are very useful for understanding the health hazards involved (Bech 2020; Shabbir et al. 2020). The use of untreated wastewaters for crop irrigation at high volume often contaminates surface waters, soil and public health (both adults and children) owing to consumption of vegetables/crop (Supplementary Tables 5, 6). Several studies support this assertion of food chain contamination due to wastewater crop irrigation (Khan et al. 2013).

These days, risk assessment is usually estimated using different soil metal contamination levels, soil–plant transfer indices and metal accumulation in edible food crops (Shahid et al. 2018a). These studies mainly use the bioaccumulation potential (BAP), the enrichment factor (EF), the translocation factor (TrF), the degree of contamination (Cdeg), the health risk index (HRI), the hazard quotient (HQ), the lifetime cancer risk (ILTCR) and the estimated daily intake (EDI) (Shahid et al. 2012; Shabbir et al. 2020). This study calculated in adults and children the THQ, EDI, ILTCR and HQ for different vegetables and metals cultivated using wastewater in Pakistan (Supplementary Tables 5, 6). The details of different parameters used for the estimation of these risk assessment factors have been explained in detail previously (Natasha et al. 2018a).

In this study, we calculated the ranges (minimum and maximum) for risk assessment parameters both for children and for adults (Table 4). For adults, the maximum HQ values were in order of Co (25) > Pb (6.8) > Cd (1.6) > Cu (0.9) > Ni (0.5) > Mn (0.3) > Fe (0.2) > Zn (0.2) > and Cr (0.001). In case of mean CR in adults, the order was Cd (2.61) > Co (2.2), > Ni (1.23), Cr > (0.9), > Pb (0.03). The trend was same for CR indices. The high HQ and CR assessment parameter values for Co, Pb, Cr, Ni and Cd can be due to their high carcinogenic potential and high levels reported in plant samples irrigated with wastewater in Pakistan. Generally, due to higher mobility, Cd may present a high risk to the human health and also that it is bioavailable to plants as divalent form (Cd^{2+}) that are not generally toxic to plants but can induce health risk to the human (Table 5).

The trends were the same for children, however, with higher potential risks. Hence, it is indispensable to monitor and control toxic metal contents in wastewater and their possible transfer/accumulation to soil, plant and human, and allied health disorders.

Comparison of metal levels in wastewaters, soils and plants with limit values

Finally, we compared and calculated the percentage of observations where the levels of toxic metals in wastewaters, soils and plants were higher than their respective limit values proposed by various organizations (Table 6). The percent observations of Pb, Cd, Cr and Mn exceeding their limits were comparatively higher compared to Cu and Zn for majority of organizations. In case of Pb, Cd, Cr and Mn, the percentage of observations exceeding their respective limit values in wastewaters, soils and plants was mostly > 50%. However, this percentage falls to below 50% for Cu and Zn.

When percentage of observations exceeding the limit values was compared among wastewaters, soils and plants, the maximum mean percentage for all the metals was observed for plants (42%), followed by wastewaters (37%) and soils (17%). This proposes that sometimes soil contamination level by toxic metals may not accurately represent the soil–plant transfer of these metals and allied health issues.

Future management and perspectives

In Pakistan, the environmental protection policies and laws, as well as their implementation in the true spirit, are not fully established. The environmentally sustainable approaches and environment-friendly practices are greatly missing with respect to wastewater treatment and its use in the agriculture sector of country which are necessary to avert health

Table 4 Health risk assessment for adults using cadmium (Cd) contents in edible parts of plants after using untreated wastewater for crop irrigation. Data for other toxic metals are presented in Supplementary Table 5

Vegetables/crops	EDI	HQ	CR	References
Solanum tuberosum	0.000016	0.0	0.10	Jan et al. (2010)
Coriandrum sativum	0.00049	0.5	2.99	Khan et al. (2013b)
Momordica charantia	0.00001	0.0	0.05	Murtaza et al. (2008)
Spinacia oleracea	0.00003	0.0	0.19	Qadir et al. (2000)
Raphanus sativus	0.00023	0.2	1.37	Bakht et al. (2016)
Capsicum annuum	0.00005	0.1	0.32	Hamid et al. (2016)
Solanum lycopersicum	0.00139	1.4	8.47	Hamid et al. (2017)
Spinacia oleracea	0.00118	1.2	7.20	Hamid et al. (2017)
Abelmoschus esculentus	0.00077	0.8	4.69	Ullah Khan et al. (2015)
Zea mays	0.00017	0.2	1.05	Khan et al. (2017b)
Mentha spicata	0.00046	0.5	2.83	Anwar et al. (2016)
Triticum aestivum	0.00023	0.2	1.37	Khan et al. (2019b)
Chenopodium album	0.00001	0.0	0.08	Mehmood et al. (2019)
Spinacia oleracea	0.00024	0.2	1.46	Sarwar et al. (2019)
Brassica oleracea	0.00005	0.0	0.30	Rehman et al. (2019)
Triticum aestivum	0.00023	0.2	1.37	Ahmad et al. (2019)

Data of risk assessment for other heavy metals are presented in Supplementary Tables 5 and 6

disorders allied with wastewater application particularly in peri-urban agriculture.

Farmers having small agricultural landholdings generally prefer wastewater for soil irrigation, even when freshwater is available for crop irrigation. The lack of awareness of health and environmental risks, especially among the farming community, is considered a key hindrance factor for proper implementation of environment-friendly approaches. The key role of funding agencies, research institutes/universities and government organizations is to create awareness in this regard.

In Pakistan, the comprehensive data concerning wastewater production, its treatments, discharge into different water bodies and possible use in the agriculture sector are scarce. The IDW interpolation also showed that there are very rare studies regarding wastewater use for soil irrigation and allied health disorders in South Punjab and Sindh provinces. The main reason for this is the lack of university–industry as well as university–public sector linkages. Consequently, problem-oriented research is greatly missing in the country.

The urbanization and population are increasing at an alarming rate in Pakistan, thus forecasting even more generation of wastewater in the future. The treatment of wastewater in industrial sector is an important requirement to minimize its negative environmental/health effects. This situation will require new and sustainable approaches for wastewater management and food production in the country. Therefore, industries and metropolitans need to devise/establish wastewater treatment approaches in urban and peri-urban/rural areas.

In southern Pakistan, where the climate is arid or semiarid and the freshwater is declining, the city wastewater may be used after mixing with surface and/or groundwater. Consequently, the risk of contaminant accumulation in soils/crops and the allied health/environmental issues can be curtailed. Likewise, the cultivation of those food crops which accumulate low metal contents in their edible parts can be an effective wastewater management approach in these areas. However, the quality of groundwater used for mixing with wastewater will be a critical point in this management strategy.

Currently, the construction of new dams/reservoirs and developing new water reserves seems to be the only way that can save the country from water scarcity in the future. The current scenario is surely a critical time for Pakistan to come up with water policy and construct potential dams on a priority basis. It will also help to produce hydropower, providing water supply, irrigation development and flood control.

Pakistan is among the top five nations with the highest ratio of water utilized per person. The rate of water intensity and the volume of water utilized per

Table 5 Range of data about risk assessment presented in Supplementary Tables 5 and 6

Metal	Parameter	Adult			Children		
		EDI	HQ	CR	EDI	HQ	CR
All metals	Mean	0.0057	0.41	0.7	0.0048	0.34	0.6
	Min	0.0000	0.00	0.0	0.0000	0.00	0.0
	Max	0.1526	25.30	11.4	0.1290	21.40	9.6
Cd	Mean	0.0004	0.43	2.6	0.0004	0.36	2.2
	Min	0.0000	0.00	0.1	0.0000	0.00	0.1
	Max	0.0016	1.60	10.0	0.0014	1.40	8.5
Co	Mean	0.0015	4.93	2.2	0.0012	4.15	1.9
	Min	0.0000	0.00	0.0	0.0000	0.00	0.0
	Max	0.0076	25.30	11.4	0.0064	21.40	9.6
Cr	Mean	0.0018	0.00	0.9	0.0015	0.00	0.7
	Min	0.0000	0.00	0.0	0.0000	0.00	0.0
	Max	0.0094	0.00	4.7	0.0080	0.00	4.0
Cu	Mean	0.0056	0.14	NA	0.0047	0.12	NA
	Min	0.0000	0.00	NA	0.0000	0.00	NA
	Max	0.0343	0.90	NA	0.0290	0.70	NA
Fe	Mean	0.0200	0.03	NA	0.0169	0.01	NA
	Min	0.0003	0.00	NA	0.0002	0.00	NA
	Max	0.1070	0.20	NA	0.0904	0.10	NA
Pb	Mean	0.0031	0.77	0.03	0.0026	0.66	0.02
	Min	0.0000	0.00	0.0	0.0000	0.00	0.0
	Max	0.0270	6.80	0.2	0.0228	5.70	0.2
Ni	Mean	0.0015	0.06	1.2	0.0012	0.04	1.0
	Min	0.0001	0.00	0.0	0.0001	0.00	0.0
	Max	0.0097	0.50	8.1	0.0082	0.40	6.9
Mn	Mean	0.0171	0.03	NA	0.0145	0.02	NA
	Min	0.0001	0.00	NA	0.0001	0.00	NA
	Max	0.1526	0.30	NA	0.1290	0.30	NA
Zn	Mean	0.0074	0.02	NA	0.0063	0.01	NA
	Min	0.0000	0.00	NA	0.0000	0.00	NA
	Max	0.0465	0.20	NA	0.0393	0.10	NA

Min, minimum; Max, maximum

unit of domestic growth are the highest worldwide. This proposes that the economy of Pakistan is highly water-intensive. Therefore, the country needs a comprehensive planning at national level to tackle these challenges. Simultaneously, campaigns aiming to create awareness among the local community for behavioral change toward water use should be initiated. Research has shown women as important change-makers to start conservation efforts; therefore, women may be engaged in an attempt of behavioral change toward water use.

Roughly 95% of Pakistan's water is consumed by agricultural activities. Agriculture sector contributes to > 21% of the country's GDP, with 70% exports based on this sector. About 60% of its population is directly related to agriculture. Therefore, Pakistan needs to develop and maintain a clear water policy regarding its use in the agriculture sector.

Moreover, there is a lack of limit values of toxic metals for irrigation water, soil and plants in Pakistan. Different research reports use different limit values reported/recommended by various national and international organizations (Supplementary Table 7). However, these limit values may not be fully applicable to local conditions in

Table 6 Percentage of observations with levels of toxic metals in wastewaters, soils and plants higher than their respective limit values proposed by various organizations

Organization	Pb	Cu	Zn	Cd	Cr	Mn
Water (mean 37% for all metals)						
USEPA (2010)	80	25	0	89	56	63
WHO/FAO (2007)	10	50	0	89	71	63
NEQS-Pak	30	25	0	44	14	38
Soil (mean 17% for all metals)						
USEPA (2010)	0	13	–	67	–	38
European Union Standards (EU2002)	0	0	0	–	14	–
NEQS-Pak	0	–	–	–	–	–
USA	–	100	–	11	0	–
Plants (mean 42% for all metals)						
USEPA (2010)	–	–	0	–	–	–
WHO/FAO (2007)	70	25	17	78	43	12.5
European Union Standards (EU2002)	90	25	17	78	–	–
NEQS-Pak	50	–	–	–	–	–

Pakistan. Therefore, it is envisaged to establish and recommend the limit values for different metals keeping in view the local conditions in Pakistan.

Summary

Freshwater scarcity has become a global issue, which is confronting society and regulatory organizations worldwide. Wastewater is considered a useful source of soil/crop irrigation and a substitute to freshwater in areas with water scarcity, i.e., arid and semiarid climates. The collection, disposal and application of wastewater for crop irrigation have a long history. These days, wastewater use in the agriculture sector has become a common practice globally. This practice is getting more and more attention in Pakistan, especially in Southern Punjab and Sindh provinces. Wastewater use in the agriculture sector of Pakistan presents both challenges and opportunities keeping in view of its uses and health/environmental implications. Wastewater use in the agriculture is beneficial to conserve water and fertilizer as well as to manage municipal/industrial wastewater. However, the soil application of untreated wastewater provokes numerous health issues, due to the presence of various pollutants, especially toxic metals. In Pakistan, wastewater is generally discharged directly in water bodies or agricultural lands. This has resulted in the toxic metal buildup in soils, plants, food crops and eventually transfer to humans.

The problems of environmental and food chain contamination and allied health disorders have become more worsened in Pakistan due to low income and low literacy rate of farmworkers. The farmer community in Pakistan is not well aware of the intensity of environmental and health hazards of applying untreated wastewaters. Moreover, they do not have enough economical sources to use good-quality water and mostly rely on a cheap source of water such as wastewater. In addition, the role of public sectors and government organizations toward water sanitation is not encouraging. Even the standards and laws of wastewater collection, recycle and reuse are not properly implemented in the country, which has caused unrestrained use of wastewater for crop cultivation. In brief, the economic, social, legislative and corporate issues are obstructing the proper use of wastewater in Pakistan. Considering the possible health issues allied with wastewater application in the agriculture sector, it is dire need of the hour to develop and implement a cohesive wastewater sanitation and reuse policy in Pakistan, both for the domestic and for the industrial sectors. Moreover, the construction of new water storage resources has become almost inevitable in the country.

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