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ORIGINAL PAPER

Effect of application of wastewater treatment on soil chemical and physical properties under millet cultivation

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Abstract
Treated wastewater is valuable water source to supply water and compensation of drought, especially in arid and semiarid regions. However, it should be noted that soil pollution and environmental protection should be considered during its application. The objects of this study were the evaluation of the effects of treated wastewater on the availability of soil nutrients, physical properties, and soil pollution. For this purpose, treated wastewater was used for irrigation in two ways. In the first method, only the treated wastewater was used during the growing season and in the second, the treated wastewater was used periodically with well water for irrigation throughout the growing season. After the end of the growing season, a chosen number of plats were randomly selected for sampling. The results showed that the application of treated wastewater improved the physic-chemical properties of soil in both application methods. The percentage of nutrients in both methods was increasing. Geoaccumulation index and contamination factor indicated that in the first method, cadmium and iron had high and medium pollutions, respectively. The results indicated that treated wastewater increased soil organic matter content to 0.52% as a soil modifier, which resulted in a decrease in bulk density (from 1.44 to 1.31) and stability of soil structure (from 10.81 to 7.59). Therefore, depending on the type and quality of treated wastewater used in irrigation water supply, it can be used as a soil modifier as well as a fertilizer source.

Keywords Sewage · Heavy metals · Soil quality · Soil physic

Introduction

In arid–semiarid areas, where water resources are scarce and constrained, and due to the population growth and increased demand for freshwater in urban, industrial and agricultural areas, problems have arisen in the supply of irrigation water (van der Hoek et al. 2002; Alemu Bekele 2021). On the other hand, population growth coupled with urban development has increased the volume of municipal wastewater (Darvishi et al. 2010; Jia et al. 2021). A large part of this wastewater enters nature either treated or untreated. By proper management, this rich resource could be used to compensate for water scarcity in arid and semiarid areas. Treated wastewater can be a viable option for water deficit reduction in agricultural and urban green areas (Dobrowolski et al., 2008; Guo et al. 2021) to address water scarcity issues. It is noteworthy that this water source is also a good substitute for chemical fertilization because of its rich nutrients (Hadas and Kislev 2010; Lahlou et al. 2021). According to Al-Hamaiedeh and Bino (2010), wastewater is a valuable resource in terms of nutrients and organic matter, although it contains toxic elements and pathogens, which are a threat to the environment and human health. In contrast, many studies have shown that the use of untreated or non-treated wastewater has a significant effect on changing soil properties (Rusan et al. 2007; Chen et al. 2010; Singh et al. 2012; Mojiri et al. 2013; Hussain et al. 2019; Pratap et al. 2021). Studies by Rusan et al. (2007) showed that long-term use of wastewater as an irrigation resource in agricultural lands

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increased the concentration of salts, organic matter, and plant nutrients. In contrast, Singh et al. (2012) stated that using wastewater for irrigation had no significant effect on clay properties, except for very slight changes in the salt solubility and alkalinity. According to the literature, the main negative effects of municipal treated wastewater on soil are 1. Osmotic effect on water potential in soil and plants (Carden et al. 2003): increasing osmotic effect reduces water uptake by root plant (Assouline et al. 2015). 2. Toxic effect of some elements including boron, sodium, and chlorine (Noshadi et al. 2013). And 3. Reduction of some physical and hydrological properties of soil including hydraulic conductivity and aggregate stability. Due to the increase in soil sodium concentration and consequently, the increase in sodium adsorption rate (SAR) and exchangeable sodium percentage (ESP) (Assouline and Narkis, 2013; Bardhan et al. 2016). Studies in recent decades also indicate that by treated wastewater irrigation, the amount of soluble organic matter is equivalent to the increase in the percentage of SAR (Suarez and Gonzalez-Rubio 2017). Increasing soil organic matter content during irrigation with wastewater improves structural porosity (Bardhan et al. 2016). The use of wastewater as a source of irrigation at the forest cover showed that it improved soil chemical properties such as providing macro- and microelements, soil organic matter, increasing water retention and soil acidity (pH) (Ferrer et al. 2011; Pratap et al. 2021). It also improves the structural porosity of the soil by increasing the percentage of organic matter, increasing the population of worms and micro-organisms leading to plant root growth and soil conditioning (Lyberatos et al. 2011). Abegunrin et al. (2016) showed that the use of treated wastewater is a valuable resource as compared to rainwater for improving soil fertility and increasing crop growth, although it needs to be managed and treated prior to its application as a soil irrigation source. According to Mosime et al. (2011), irrigation with wastewater causes increased physical, chemical and biological quality of the soil. Due to its nutrient richness, wastewater improves soil fertility, which plays an important role in plant growth and metabolic processes (Sacks and Bernstein, 2011; Tiwari et al., 2011; Pratap et al. 2021). Because one of the major challenges around the world is climate change and population growth, this has limited the cultivation lands and depleted water resources. One of the promising solutions is to increase production per unit area of land, which is accompanied by the use of low-quality unusual irrigation water, including saline, treated or untreated wastewater. Pollution degree and the quality of these water resources affect the quality of the soil and, in turn, human and environmental health, which should be considered in long-term use. Wastewater treatment and management play a very constructive role in the removal of environmental pollutants and pathogens from the ecosystem, although it can be considered as a suitable option for irrigation water supply in arid and semiarid areas. Also, it is an appropriate choice to fight against desertification and increase vegetation on the surface of pastures and deserts which has a practical role in controlling wind erosion. Considering the positive consequences of treated urban wastewater in addition to the environment and agriculture as an inexpensive water selection in semiarid areas, it is inevitable to study the use of wastewater from the point of view of the environment under different weather conditions. However, in the last decade, there have been studies on the use of raw and treated wastewater in greenhouse and farm cultivation. But the effects of this irrigation source on soil characteristics in Iran have not been well understood due to the existing climatic conditions and the type of management of wastewater resources. Because the type of source of supply, the physical structure of the soil, the geological formation of the area, the type of vegetation prevailing in the area, the amount of annual rainfall and the hours of sunshine are some of the things that should be considered in the interpretation of the results at the study level. Therefore, the results of studies conducted in other parts of the world cannot be fully generalized. So, further studies are needed on the effects of treated wastewater on soil physicochemical quality. In this study, in addition to investigating the effect of treated wastewater, its effectiveness was studied in the intermittent irrigation method with well water available in the region. With this aim, considering the prevailing conditions in the region in terms of the geological formation, the physical structure of the soil, vegetation and climate, what effects does the use of treated wastewater alone and in combination with well water have on the characteristics of the soil in one cropping season, also the effect of these two methods of irrigation was evaluated from the environmental point of view. So, two irrigation sources were designed in this search, treated wastewater and well water, in an intermittent irrigation plan (treated wastewater and well water) in a completely randomized block for the cultivation of foxtail millet. This study was to evaluate the trend of changes in soil physicochemical properties and soil nutrient during application of treated wastewater, to investigate the soil pollution rate during irrigation with treated wastewater by intermittent irrigation method using pollution indexes, and also soil quality indicators (MWD, Ks, and Bd) in the study to compare the effect of treated wastewater and intermittent irrigation on soil quality were evaluated, especially the average weight of soil aggregate in a clay loam.

Materials and methods

This study was conducted in a randomized complete block design at a water and wastewater treatment plant in Birjand city, South Khorasan Province of Iran, 5 km west of Birjand on Birjand-Tabas road, adjacent to Amirabad village with the latitude of 32°53’N and the longitude of 55°13’E, with an altitude of 1,480m from the seawater (Fig. 1). According to climatic conditions of the region, the most precipitation falls in December to May and in winter it is sometimes snowy. The maximum and minimum temperatures in the region are 24 and 8° C, respectively. The average annual rainfall and the relative humidity are 171 mm and 36%, respectively, Golmohammadi (2014).

The water treatment plant has been established in 2005 and treats the water by the evaporable ponds. The soil of the study area is poor in terms of organic matter and other nutrients due to the lack of vegetation, high temperature and precipitation less than 2 mm/year. The soils of the region are mainly classified as Entisoil and Aridisols and under the Calcids category. Therefore, the soil of the area is salty and calcareous. For the initial evaluation of soil in the study area, soil samples were randomly taken from the depth of 0–30 cm. They were air-dried, passed through a 2 mm sieve for measuring the physic-chemical properties and sent to the laboratory (Table 1).

Water samples were also collected from wells in the area for water analysis and a complete report on the characteristics of municipal treated wastewater was provided by the Birjand Water and Wastewater Organization (Table 2).

In this project, 36 plots with a size of 2 × 2 m were designed. The distance between plots was considered to be 1 m. In order to reduce soil salinity and breaking the crust of the surface soils, the plots were irrigated by basin irrigation for three days at 5-day intervals. Then, furrows were created in the soil and the seeds of millet were planted manually on 26 July 2018. It is noteworthy that no fertilizers (chemical or organic) were added to the soil prior to planting, during the plot preparation stage, or during the growing season. The irrigation method used in this study was basin irrigation. After the harvest season, samples were randomly taken from each plot at a depth of 0 to 30 cm and transferred to

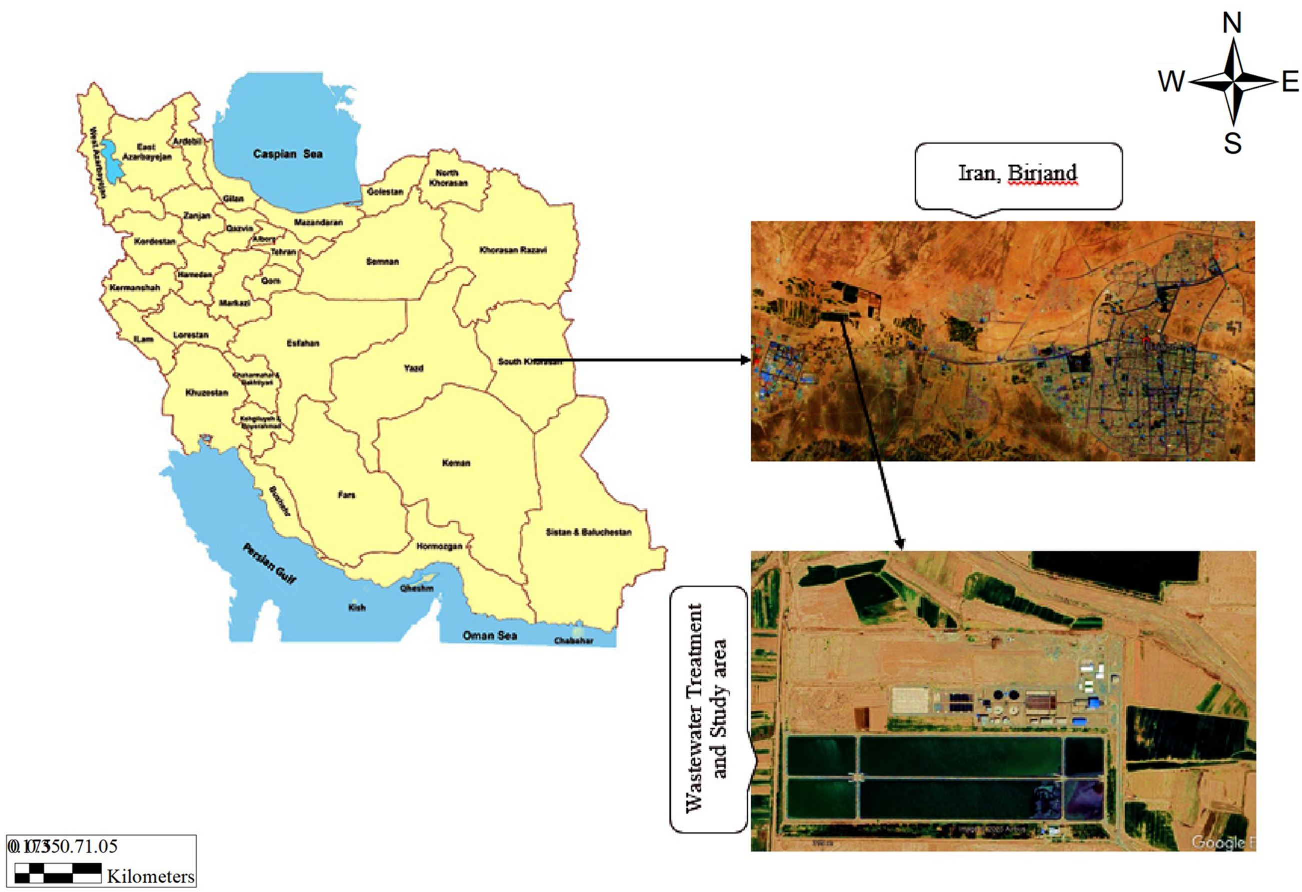

Fig. 1 Location Map of The Study Area in Iran

Table 1 Some physical–chemical soil properties of the 0–30 cm layer of the soil used for the experiment

a) Chemical properties

pH	Ec (ds/m)	Na (ppm)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	O.M (%)	N (mg/l)	P (mg/g)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Cd (ppm)	Pb (ppm)
7.45	5.51	3100	8.4	24.4	340	0.4	7.04	0.05	0.003	0.001	0.002	0.0002	0.0004

b) Physical Properties

Soil texture	Sand (%)	Silt (%)	Clay (%)	pb(gr/cm3)	Ks (cm/min)	MWD(mm)
Clay Loam	27	40	33	1.5	0.007	5

Table 2 Well water and treated wastewater properties and comprised their on base FAO

Property	Well water	Treated wastewater	Threshold value
EC (ds/m)	5.82	2.84	2.97
pH	7.93	8.07	6–8.5
Total Nitrogen(N) mg/l	–	60	43
Phosphor (P) mg/l	–	0.41	4.1
Potassium(K) mg/l	245	–	–
Sodium(Na) mg/l	380	325	270
Calcium (Ca) mg/l	0.305	44.8	–
Magnesium (Mg) mg/l	1.28	–	100
Iron (Fe) mg/l	0.011	0.119	3
Zinc (Zn) mg/l	0.009	0.045	2
Copper (Cu) mg/l	–	0.006	0.2
Cadmium (Cd) mg/l	–	0.0002	–
Lead (pb) mg/l	–	0.011	0.19
BOD1 mg/l	–	84	100
COD2 mg/l	–	174	200

the laboratory after being air-dried. Some of the chemical and physical properties of soils such as soil pH at 1:1 ratio (Jackson 1956), organic carbon, soil texture analysis were measured by pipette method (Klute 1986), soil calcium and magnesium content by titration method with EDTA, soil sodium and potassium content was measured using a flame photometer, macronutrients (nitrate, phosphorus, and potassium) by using spectrophotometry, the microelements (iron, zinc, and copper) and heavy metals (cadmium and lead) by using the falling head technique and the average weight of the soil aggregate by the wet sieve method. The general chemical–physical properties of soil were evaluated and calculated based on the standard water and wastewater measurement methods version 20.0. In order to investigate the ability to absorb and refine the soil during irrigation with treated wastewater, as well as the amount of organic load transfer in the soil root area, two indicators (BOD and COD) were evaluated. BOD stated the amount of required oxygen to oxide organic matter and convert them to minerals. COD is another indicator that shows the oxidation of organic matter and other oxidizable matters in wastewater. The threshold value of these two indicators for agricultural and irrigation use is presented in Table 2, which is based on the Environmental Protection Organization of Iran's standards.

Statistical analysis of data was performed in SAS 9.4 software and compared with Duncan's test at a 5% level.

Results and discussion

Table 2 presents the results of the evaluation of the chemical and physical properties of the water resources used in this study. According to the FAO standard, the treated water source used in this study is unlimited in terms of electrical conductivity, acidity, phosphorus, microelements as well as heavy metal soils and is unsuitable for use in agricultural applications. It is only limited in terms of sodium and nitrate of the soil, although the amount of soluble sodium in the well water is limited to the treated wastewater and is higher than the standard level. In addition, according to Table 2, the EC value of the well water is higher than standard and is of poor quality which enhances the soluble sodium yield. Also, considering that the wastewater was of sanitary-human type, based on the thresholds set for these two indices for agricultural and green space purposes, the BOD is 100 (mgl^{-1}) and COD is 200 (mgl^{-1}), respectively; values which are less than the threshold for the wastewater used in this study and are applicable for agricultural uses. The total suspended matter in the sewage is less than the set limit, so the treated wastewater can be used as the water source. Studying the soil pollution rate could survey the influence of these indicators on heavy metal concentration and accumulation. On the other hand, the value of these two indicators affects the variation of soil microbial population, which consequently impacts the amount of soil quality indicators (MWD, Ks, and Bd). The amount of nitrate in the treated wastewater is 60 (mgl^{-1}), which is high and pollutant. In contrast, according to Table 2, phosphorus, potassium and other microelements are not problematic in terms of pollution.

Effects of treated wastewater (TWW) on physicochemical properties of soil

After the end of the growing season and harvest of foxtail millet to evaluate the changes in chemical properties of plots irrigated by treated wastewater compared to the control plot, the plots were randomly sampled. Statistical results showed that the percentage of soil sodium in comparison with the control soil sample was not significantly different at a 1% level, although the percentage of Na in treated wastewater plots had a decreasing trend compared to the control plots. While the percentage of calcium and magnesium were significantly different from the control soil sample (Table 3) and have increased in comparison (Fig. 2), it can be noted that the sodium percentage in irrigated plots has a decreasing trend compared to the control plots. It is also noteworthy that although EC also had a significant difference at a 1% level, it has a decreasing trend compared to control plots (Fig. 2). Significant differences between treatments were shown with letters a, b, and c in Figs. 2, 3, and 4. The highest level of significance could be seen with the letter a and the lowest level of significance with the letter c.

This increasing trend of EC in control plots is correlated with the amount of EC of water applied as shown in Table 2, while the EC value of the wastewater is not restricted and is suitable for use in agricultural applications, as confirmed by and the results. Therefore, the treated wastewater source had no negative effect on soil structure in terms of EC as well as changes in sodium, calcium, and magnesium. In terms of macronutrients, plots irrigated with wastewater had a significant difference with the control plots at a 1% level (Table 3) and the trend of nutrients was also increasing (Fig. 2). FAO has determined the thresholds of 0.2 and 2 mg/l for copper and zinc, respectively. In this research,

Table 3 Analysis table of variance of soil chemical, physical and micro-elements at the level of the irrigation

Soil chemical properties										
Sources change	df	EC	pH	Na	Ca	Mg	O.M	N	P	K
Source water	2	17.46**	8.11**	3932$^{n.s}$	6.67**	23.04**	0.52**	60.04**	0.07**	379.88**
Error	12	0.14	0.012	132	0.002	0.003	0.00005	0.3556	0.000003	0.94
CV		0.51	0.39	14	0.77	0.34	1.52	0.59	2.9	0.25
		Soil physical and micro-elements								
Sources change	df	Fe	Cu	Zn	Cd	pb	MWD	K_s	Bd	
Sources change	2	3912.03**	25.64**	8.21**	3.07**	2.18**	10.81**	27.31**	1.44**	
Error	12	1453	0.039	0.069	0.0006	0.013	0.011	0.027	0.000001	
C.V		1.51	1.36	1.64	1.3	3.71	1.18	0.8	0.0001	

df degree of freedom, *CV* Coefficient of variation, *MWD* Mean weight diameter Osakwe, *Bd* Bulk density, *K* Saturated hydraulic conductivity

**Significance at $p < 0.01$

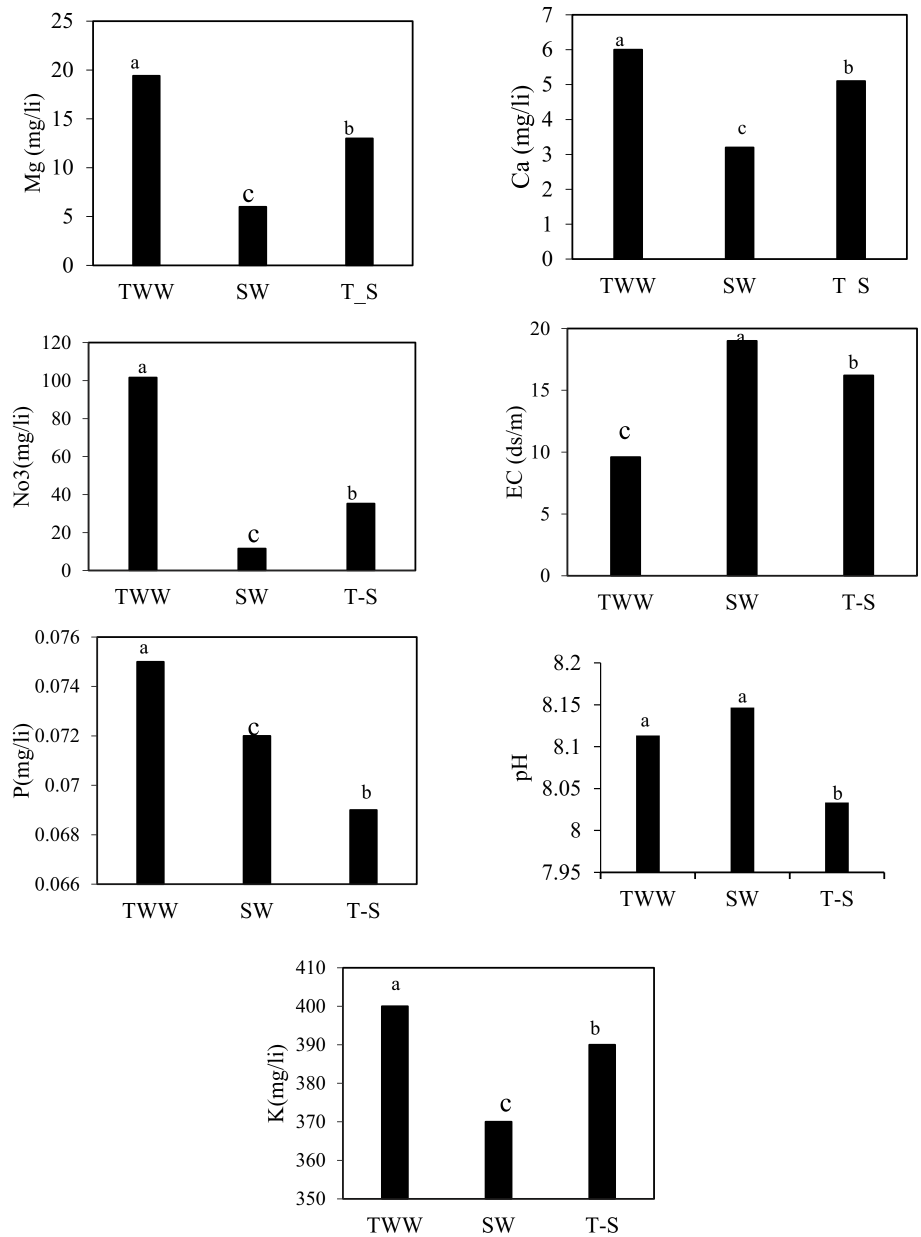

Fig. 2 Variability Soil Chemical Parameters under Various Management Irrigation. *TWW* Treated WasteWater, *SW* Spring Water, *T-S*: Alternative (WasteWater-Spring Water)

the changes in microelements such as Fe, Zn and Cu were evaluated. The results showed that the micronutrients were significantly different at the 1% level and had an increasing trend compared to the control plots (Fig. 3). Increasing nutrients (macro and micro) through the application of treated wastewater is very valuable for increasing soil fertility and creating better conditions for plant growth. An increase in soil nutrients can be attributed to soil acidity in order to provide a ground for the mineralization and increase soil organic matter content. Osakwe (2012) reported that the use of wastewater as irrigation source increased the percentage of soil nutrients. The heavy elements studied were cadmium (Cd) and lead (Pb) which showed an increasing trend with respect to Fig. 3. According to FAO, the threshold of lead and cadmium were 5 and 0.03 mgl^{-1}, respectively. Based on the results of Table 2, the treated wastewater is of high quality. On the other hand, according to FAO, the concentration of lead and cadmium in the soil is 50 mgl^{-1} and there were 10 and 3.5 mgl^{-1} of these two elements under this irrigation

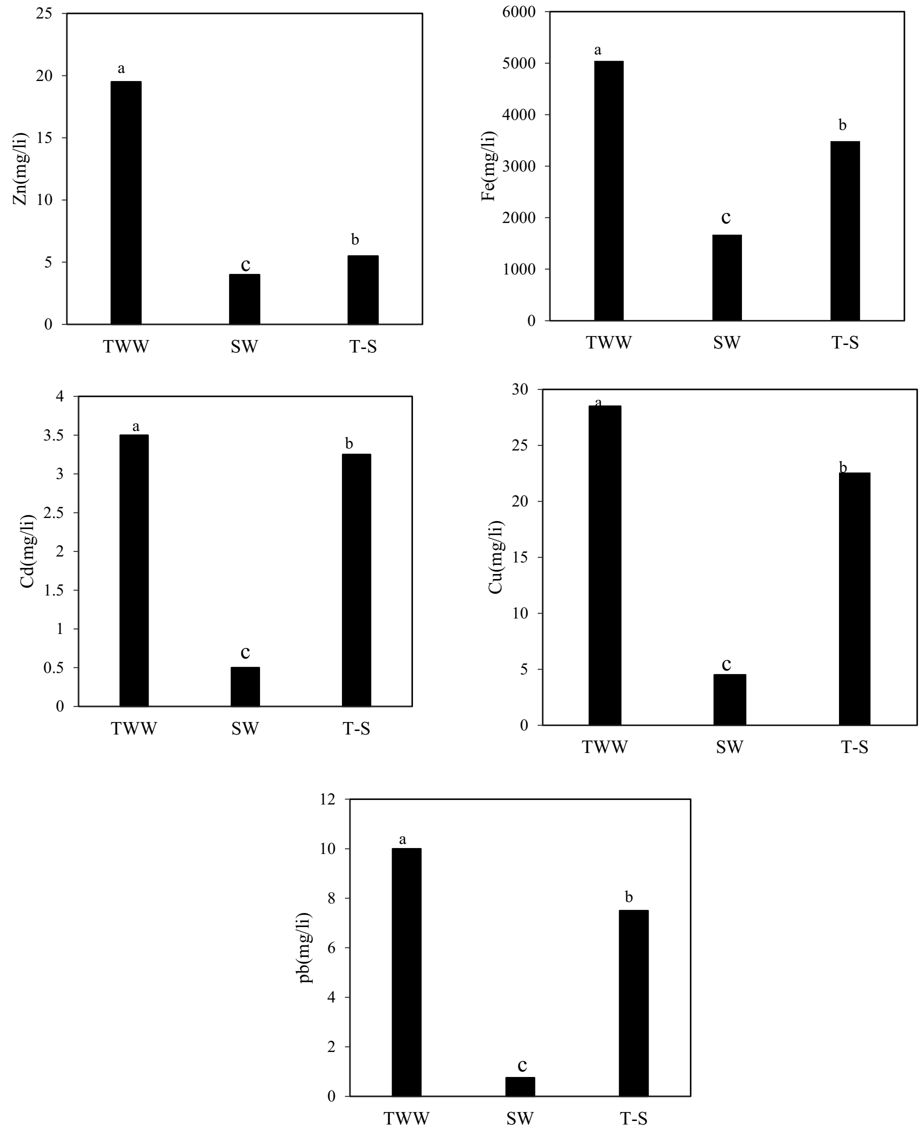

Fig. 3 Variability Soil Micro Elements under Various Management Irrigation. *TWW* Treated Wastewater, *SW* Spring Water, *T-S* Alternative (Wastewater-Spring Water)

source. Therefore, it can be stated that the treated wastewater is of suitable quality for agriculture.

Soil pH is an index to determine the changes in soil nutrients, its availability to the plant as well as the conditions for improving or destroying soil physicochemical properties. The initial soil acidity was neutral, and it did not change the soil acidity during irrigation with treated wastewater. However, some studies have shown that the use of treated wastewater increases soil acidity (Thapliyal et al. 2011) and some have shown that it decreases the soil acidity (Abegunrin et al. 2013).

In addition to soil chemical properties, the soil physical parameters, mean weight diameter (MWD), bulk density (Bd), and saturated hydraulic conductivity (Ks), which is an index of soil quality, were also investigated in this study. As shown by the percentage of sodium, calcium, and magnesium in soil, in the plots irrigated with the wastewater compared to control plots, because of their chemical effects and also their molecular structure of the soil-genesis process, these three elements have a better performance than the control plot, which is confirmed by the results (Fig. 4). The high percentage of sodium increases the ratio of absorbable sodium in the soil, which results in the degradation of soil structure and a decrease in soil quality. With the continuous application of wastewater, the bulk density of the soil showed a decreasing trend that could be attributed to providing better conditions for soil structure formation and stability. Saturated

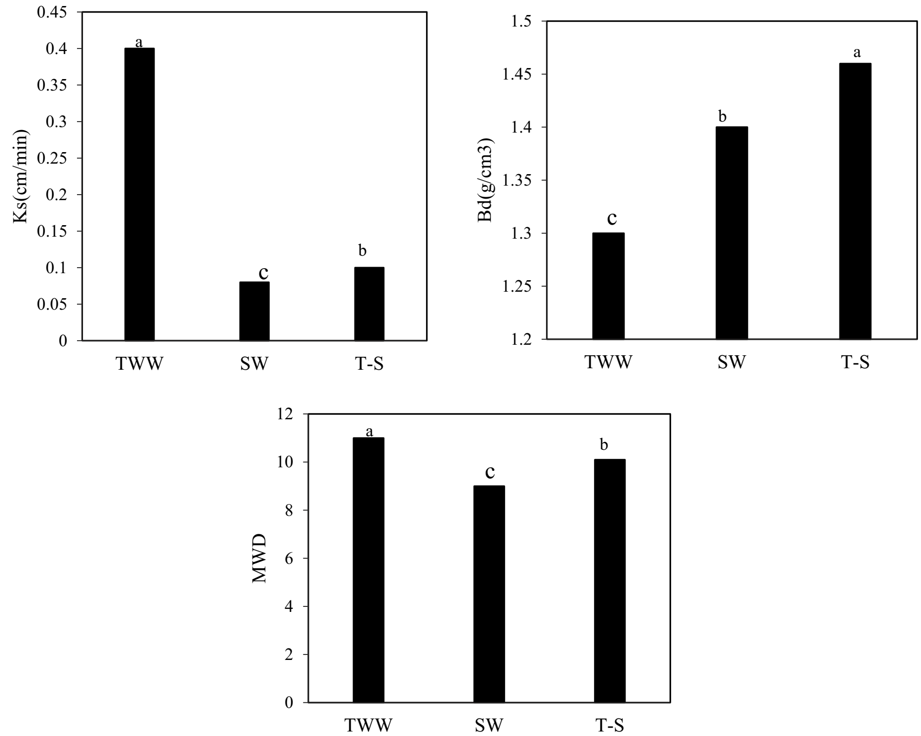

Fig. 4 Variability Soil Physical Properties under Various Management Irrigation. *TWW* Treated Wastewater, *SW* Spring Water, *T-S* Alternative (Wastewater-Spring Water)

hydraulic conductivity also did not change significantly when using wastewater in two consecutive crop seasons. Therefore, it can be said that a high percentage of calcium and magnesium in the treated wastewater prevented the activity of sodium in the soil and prevented the destruction of soil structure or reduction of soil porosity. The weighted average of soil aggregate diameter is another indicator of soil quality assessment. According to Fig. 4, it can be said that irrigation with treated wastewater during the growing season increased this index compared to the control plot. This incremental trend indicates improved environmental conditions for soil genesis. With this increase, the soil porosity is improved and it results in soil permeability. Bardhan et al. (2016) also suggested that the use of low-quality wastewater that results in an increase in the amount of sodium exchangeable percentage makes the soil susceptible to dispersal and decreases the soil hydraulic conductivity is decreased along with the decrease in organic matter content and degradation of soil structure.

Effects of intermittent irrigation management (treated wastewater—well water) on soil chemical and physical properties

In this study, in addition to treated wastewater, intermittent irrigation method (treated wastewater—well water) was also used to investigate the simultaneous use of these two water resources and the effects of this irrigation management method on physicochemical properties of soil compared to control conditions (use of well water alone). According to the analysis of variance (Table 3), the amount of EC, calcium, and magnesium at the 1% level was significantly different, although it is decreasing compared to the control plot (Fig. 2), as with the treated wastewater method, the soil sodium content was not significantly different. Therefore, the percentage of absorbable sodium also has a decreasing trend with respect to the use of well water (control). Macro- and micronutrients (nitrate and potassium) and heavy elements also have an increasing trend compared to the control plot. While soil phosphorus has a decreasing trend, considering the trend of changes in sodium and calcium content of the soil in this method compared to the control plot, soil physical properties also showed an increasing trend compared to the control plot. The results obtained of Table 2 indicate that although the water quality of the well (considering the high value of soil EC and soil Na and also the low value of soil Ca) is lower than the treated wastewater, the type and quality of wastewater used in this study caused reduced detrimental effects of simultaneous use of these two sources on the physicochemical properties of soil and it works to offset the effects of well water. Although Paudel et al. (2018) showed that by shifting the irrigation water from treated wastewater to normal water quality, the salinity percentage, absorbable sodium, chlorine, sodium, and exchangeable sodium percentage are reduced, leading to increased stability of soil structure. Bardhan et al. (2016) stated that due to the high concentration of alkaline elements, the consumption of treated wastewater increased the soil EC and made the soil prone to degradation.

Comparison of the performance of intermittent irrigation and treated wastewater

In the last two sections, the effects of treated wastewater on soil pollution and quality were studied, and then the effects of intermittent irrigation were investigated. The results showed that these two methods were more effective than irrigation with well water. This section compares the performance of these two methods to each other and their effects on soil quality. Investigation of soil physicochemical properties in irrigated plots showed that the percentage of soil calcium and magnesium in the intermittently irrigate plots had an increasing trend compared to the plots irrigated with treated wastewater, while the percentage of sodium as the same. The changes of macro elements (nitrate-phosphorus), microelements and heavy elements in the irrigation plots with treated wastewater have a decreasing trend. It is noteworthy, however, that the changes of soil potassium in these two methods are of the same trend. The results indicate that intermittent irrigation management to increase the percentage of soil calcium and magnesium which has a positive effect on both caution exchange capacity and soil genesis process has a better performance than wastewater use management. In contrast, the number of nutrients in the intermittent irrigation showed a decreasing trend compared to the

Table 4 Variability micro-elements trends at the studied soil and different standards

Concentration of elements at the Shale, degree of contamination on Igeo and CF

Micro-elements	Concentration of elements at the shale (mg. kg^{-1})	Statues of contamination on Igeo and CF			
Fe	4700	Degree of pollution	Igeo		CF
Zn	95	Completely uninfected	0	Low contamination	1 < CF
Cu	45	Non contaminated to moderate contamination	1	Moderate contamination	1 < p < 3
Cd	0.38	moderate contamination	2	Considerable contamination	3 < P < 6
pb	20	moderate contamination to high contamination	3	Very high contamination	6 > CF
		high contamination	4	–	–
		high contamination to very high	5	–	–

Mean and limited contamination of elements on WHO 1996(mg.kg^{-1})

Elements	Treated wastewater	Spring water	alternative	Low con	Moderate con	High con	Very high con
Fe	5045	1676	3486	2000	3000	–	
Zn	19.5	5.5	4.9	120	290	460	150–300
Cu	28.5	4.25	22.6	35	–	–	50–140
Cd	3.5	0.5	3.25	–	–	–	1–3
pb	10	0.75	7.5	36	83	130	50–300

Evaluation of level contamination of elements at the studied soil

Elements	Wastewater Igeo	Wastewater CF	Alternative Igeo	Alternative CF
Fe	0	1.07	0	0.74
Zn	0	0.2	0	0.05
Cu	0	0.63	0	0.5
Cd	2.6	9.2	2.5	8.5
pb	0	0.5	0	0.37

wastewater method. This decrease in performance can be attributed to the addition of well water, with lower amounts of nutrients, to the intermittent irrigation. Since no fertilizer was used in this study and only treated wastewater was used, it can be stated that although the treated wastewater decreased in the intermittent irrigation method, the nutrient requirement of the soil were met despite halving the amount of irrigation water, thus preventing nutrient deficiencies in the soil and reducing the need for fertilizers. Therefore, it can be noted that this management method too, the use of fertilizer can be avoided. In terms of soil physical properties, soil bulk density showed an increasing trend in intermittent management methods compared to treated wastewater (Fig. 4). But the mean weight of soil aggregate diameter and saturated hydraulic conductivity of soil decreased. The decrease in soil physical properties can be attributed to the decrease in soil organic matter content, soil nutrients, and salinity/sodium content of the wells used in the intermittent irrigation method. Although the volume of treated wastewater is halved in this method, soil organic matter is still increased and micronutrients and macronutrients are also supplied. However, the application of treated wastewater did not significantly affect the physical properties of the soil, although it performed better than the control.

Investigation of soil pollution rate

In this study, treated wastewater was used as an irrigation water resource. According to Table 2, it has microelements as well as heavy elements. Although these elements are in standard limits in the treated wastewater, during its application in a crop season, they would definitely increase and it makes the ground for their accumulation and makes the soil prone to pollution. So, it is necessary to check the soil pollution after every crop season. For this purpose, in this study, Geoaccumulation Index (Igeo) and Contamination Factor (CF) were used to evaluate the pollution of soil by heavy metals after a growing season. Igeo was introduced by Muller in 1969 and is a common method for estimating the severity of heavy metal pollution (Eq. 1). CF represents the contamination factor that describes pollution by the heavy element in question (Eq. 2) (Ferrer et al. 2011). The element content in the study area is placed in the numerator of the fraction and both baseline value indices of each element in the denominator (shale is presented in Table 4 in this study). Tables 2, 3, 4 also shows the range of contamination of micro- and heavy elements in the soil according to the WHO standard and the average amount of micro- and heavy elements in the soil under study.

$$I_{\text{geo}} = \log_2 \frac{c_n}{1.5 * B_n} \tag{1}$$

$$\text{CF} = \frac{M_x}{M_b} \tag{2}$$

In these two equations, c_n and M_x are the concentrations of the elements in the sample, B_n and M_b are the concentrations of the same element in the reference material (shale) presented in Table 4.

Table 4 shows the degree of contamination and the Igeo of each element according to the two studied indices. Accordingly, Table 4 was presented, which shows the accumulation rate and degree of contamination of the elements in this study. According to Table 4, only cadmium is restricted in terms of Igeo. In terms of contamination degree under irrigation management with iron wastewater, there is moderate contamination, cadmium has high contamination and other elements have a low contamination rate. Accordingly, after irrigation with treated wastewater throughout the growing season, first, the degree of contamination of cadmium and then the iron should be investigated. However, in the intermittent irrigation method, only cadmium contamination is considered.

In addition to these two indices, the PLI (Pollution Load Index) was used to assess soil contamination levels (Tomlinson et al. 1980).

$$\text{PLI} = \sqrt[5]{\text{CF}_{cd} * \text{CF}_{Fe} * \text{CF}_{Cu} * \text{CF}_{Zn} * \text{CF}_{pb}} \tag{3}$$

In Eq. 3, CF is again the degree of contamination. PLI also falls into four categories: first category: no contamination (PLI value less than 1), second category: moderate contamination (PLI value between 1 and 2), third category: high contamination (PLI value between 2 and 3) and last category: very high contamination (PLI values between 3 and 4). According to the classification, it can be stated that the level of soil contamination undertreated wastewater management is 0.91 and under intermittent management, it is 0.57. Thus, despite the risk of Cd contamination in both management methods, it can be said that soil contamination level is methods (treated wastewater and intermittent irrigation) that did not have an additive effect on soil basic properties and intensification of sodium in the soil. Meanwhile, it increased the soil exchangeable bases by increasing the percentage of soil calcium, magnesium, and potassium. The results showed that the use of treated wastewater in both irrigation management methods increased soil organic matter and (macro/micro) nutrients which enriched the soil and provided suitable conditions for plant growth. In terms of pollution and its detrimental effects on the environment, it can be stated that the concentration of heavy metals is below the threshold. Evaluation indices of accumulation rate and degree of contamination showed that in irrigation with treated wastewater during one crop year, it was observed the problem of moderate iron contamination and high cadmium contamination of the soil. In terms of physical properties of the soil, it can be stated that due to the chemical properties of the wastewater, its application did not have any detrimental effects on soil physical properties, but by maintaining the soil sodium content and increasing the divalent cautions of the soil, it makes the ground for soil genesis, which reduces bulk density and increases the average weight of soil aggregate diameter. Also in the intermittent irrigation method, soil quality indices showed a better performance than the control plot, indicating a positive effect of wastewater used in this study in two different amounts. Therefore, considering the type and quality of treated wastewater, it can be referred to as a source of irrigation standard in both methods and the soil is free of contamination after a crop season.

Discussion

Studying water sources quality based on Table 2 can be concluded that well water had reduction effect on soil quality to the performance obtained from treated wastewater. This condition was observed in plots under intermittent irrigation too. Therefore, the high value of soil calcium and magnesium during treated wastewater irrigation caused the proper condition to provide soil competitive cation. Influence of soil competitive cation was observed in the results of soil quality indexes and consequently decreasing the soil exchangeable sodium percentage. Surveying changes in caption's soil express the effective role of irrigation sources in the soil structuring process.

Constant soil acidity results in the preservation of soil genesis conditions and prevents soil sodium from dispersing soil structure and consequently reducing soil permeability. The activity of heavy metals in soil is affected by the process of soil acidity changes. The decrease in soil acidity provides the conditions for activity and increasing concentration of heavy metals. On the other hand, the acidity in the range of neutral or alkaline reduces the number of heavy metals available, which is very effective for the environment, for absorption by the plant and for human health (Bhattacharya et al. 2002). It is also noteworthy that although soil acidity has shown a consistent trend, the soil organic matter content has increased, indicating the positive role of the treated wastewater in increasing the nutrients in the soil and making it accessible to the plant. Moreover, increasing soil organic matter in this irrigation management methods caused the soil particles to follicular by adding organic compounds, growing soil microorganisms, and reducing soil SAR. So, this source could be considered to improve the soil's physicochemical properties as a fertilizer source, especially in arid and semiarid areas. Because the use of chemical fertilizers frequently during the crop season caused soil salinity and degradation of soil aggregate then the soil was susceptible to erosion. Mojid et al. (2019) stated that there is a linear relationship between soil organic matter content and bulk density, and an increase in the soil organic matter content, using the municipal wastewater decreases the bulk density of soil. Abegunrin et al. (2016) also stated that depletion of absorbable sodium and an increase of soil organic matter during wastewater use as an irrigation source had no effect on soil clay particle dispersion and had no destructive role in soil permeability. The results of Abegunrin et al. (2016) showed that application of treated wastewater increased the concentration of magnesium, calcium, potassium, organic matter and total nitrogen in the soil. The treated wastewater was referred to as a nutrient source for soil fertility, as well as a water source for agricultural purposes. Considering the trend of changes in soil properties in treated wastewater irrigation during one crop year, it can be said that it has a great contribution to the enrichment of soil organic matter and also increases soil nutrients such as nitrate, phosphorus, and potassium. Although soil acidity has been constant, since wastewater is rich in micronutrients such as iron, copper, and zinc, it has been highly effective in increasing these nutrients in the soil at various stages of plant growth to meet the needs of the plant. Although wastewater is a water resource, it should be analyzed in terms of heavy metals due to their detrimental environmental effects. Determining the threshold of lead and cadmium showed that the amount of these heavy metals in the wastewater was lower than their threshold in the soil during irrigation in a crop season, indicating the applicability of treated wastewater to irrigation without harmful effects. Therefore, a high percent of soil calcium and magnesium and also a suitable concentration of soil heavy metals point of view fertility and soil nutrition could be concluded that the type of treated wastewater used in this was a proper source to irrigate. Studies by Mojid et al. (2019) on the effects of wastewater on soil properties under in vitro conditions showed that, as a source of irrigation, wastewater causes significant changes in the number of nutrients needed in the soil environment. Studies by Uurban et al. (2017) on the effect of wastewater on soil chemical and physical properties showed that with the use of wastewater, the percentage of nutrients in the soil increased, and had no negative effect on soil physical properties. Therefore, considering the use of treated wastewater as an irrigation source during a crop year and its effects on the availability of nutrients in the soil without using fertilizers, it is another option to use treated wastewater. Based on the results of Table 2 could be concluded the used wastewater in this study was of high quality in terms of EC and concentration of heavy metal and also it had a positive role in the process of soil construction resulting from its constructive effects in soil physical properties in the two management methods studied. Bauder et al. (2014) showed that when using wastewater, soil permeability is affected by the percentage of exchangeable sodium and soil organic matter, which increases soil structural stability and porosity due to reduction in exchangeable sodium percentage and increase in soil organic matter, leading finally to increased soil permeability. Therefore, it can be mentioned that the simultaneous application of treated wastewater with well water not only does not decrease the quality of the well water but also reduces the effect of saline water during irrigation due to reduced salinity of the water well. It also increases the quality of the well water due to richness in minerals, so that it decreases the sodium and salinity effects of the well water and in turn increases the number of other elements, including calcium, in the irrigation water, which is very effective chemically and physically, and greatly improves soil quality.

According to Table 2, application of treated wastewater during a growing season increases nutrients, nitrate and phosphorus content as well as percentage of soil organic matter; on the other hand, it provides the micro-elements required for plant growth, although due to the percentage of microelements in the treated wastewater, especially for iron, its use should be managed so as not to cause toxicity to the soil and plants. In addition, the use of treated wastewater increases the percentage of heavy metals in soil, which has been observed in previous studies. Barakat et al. (2019) studied soil heavy metal accumulation during irrigation with treated wastewater. In this study, Igeo, CF, EF, PLI were used to evaluate the accumulation of contamination, and RI, HQ, HI indices were used to evaluate ecosystem and carcinogenic risk. Geoaccumulation and contamination factor indicated moderate contamination and increased accumulation of heavy metals in soil, which poses an environmental risk. Studies by Sahay et al. (2019) showed that in the first crop season, not only the use of treated wastewater as irrigation water was a good water resource, but also it supplied nutrients to plants and soil and prevented the use of fertilizers. Also, it was not problematic in terms of accumulation and contamination of heavy metals in soil. In the second growing season, however, repeated use of treated wastewater resulted in the accumulation of nutrients and heavy metals in the soil, requiring the use of treated wastewater along with groundwater. Lopez et al. (2019) studied the factors affecting contamination of soil and rhizosphere environment to heavy metals. Their results indicate that the presence of various pollutants in the environment causes heavy metals to accumulate in the soil, which is harmful to the environment and human health. To control this contamination, the use of organic compounds has been suggested to reduce the accumulation and activity of heavy soil elements over time. Xue et al. (2019) investigated the use of treated wastewater as an irrigation source for North China wheat fields. The results of this study showed that the application of this irrigation source in addition to providing macro and microelements over time causes heavy metals accumulation in the soil that accumulates these metals in crops and endangers the health of the community. Therefore, food safety and security must be constantly monitored in areas where this water resource is used as irrigation water.

Conclusion

In this study, the effects of treated wastewater on soil physic-chemical properties and soil contamination rate during the use of this source were investigated, aiming at providing the water needed for agriculture and compensating deficiency of freshwater resources. The results of this study indicate that the application of treated wastewater under two applied irrigation management water as well as a source of nutrients in arid/semi-arid regions. Also, treated wastewater can be applied by management methods to compensate for the freshwater deficiency. However, in addition to providing an irrigation source, environmental and community health needs to be taken into account. So, when using this water and fertilizer resource should also be considered food safety and security.

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Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abegunrin TP, Awe GO, Idowu DO, Adejumobi MA (2016) Impact of wastewater irrigation on soil physico-chemical properties, growth and water use pattern of two indigenous vegetables in southwest Nigeria. CATENA 139:167–178

Abegunrin TP, Awe GO, Idowu DO, Onigbogi OO, Onofua OE (2013) Effect of kitchen wastewater irrigation on soil properties and growth of cucumber (Cucumis sativus). JSSEM 4(7):139–145

Al-Hamaiedeh H, Bino M (2010) Effect of treated grey water reuse in irrigation on soil and plants. Desalination 256(1–3):115–119

Alemu Bekele D (2021) Water budgeting in the Jhelum River basin: application of hydro-economic WEAP model (Doctoral dissertation, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir)

American Public Health Association (1915) American Water Works Association, Water Pollution Control Federation, and Water Environment Federation. Standard methods for the examination of water and wastewater, vol 2. American Public Health Association

Assouline S, Russo D, Silber A, Or D (2015) Balancing water scarcity and quality for sustainable irrigated agriculture. Water Resour Res 51(5):3419–3436

Assouline S, Narkis K (2013) Effect of long-term irrigation with treated wastewater on the root zone environment. Vadose Zone Journal 12(2):1–10

Barakat A, Ennaji W, Krimissa S, Bouzaid M (2019) Heavy metal contamination and ecological-health risk evaluation in peri-urban wastewater-irrigated soils of Beni-Mellal city (Morocco). Int J Environ Heal R, pp 1–16

Bardhan G, Russo D, Goldstein D, Levy GJ (2016) Changes in the hydraulic properties of a clay soil under long-term irrigation with treated wastewater. Geoderma 264:1–9

Bauder TA, Waskom RM, Sutherland PL, Davis JG, Follett RH, Soltanpour PN (2011) Irrigation water quality criteria. Service in action

Bhattacharya P, Mukherjee AB, Jacks G, Nordqvist S (2002) Metal contamination at a wood preservation site: characterisation and experimental studies on remediation. Sci Total Environ 290(1–3):165–180

Carden DE, Walker DJ, Flowers TJ, Miller AJ (2003) Single-cell measurements of the contributions of cytosolic Na+ and K+ to salt tolerance. Plant Physiol 131(2):676–683

Chen S, Wu W, Hu K, Li W (2010) The effects of land use change and irrigation water resource on nitrate contamination in shallow groundwater at county scale. Ecol Complex 7(2):131–138

Darvishi HH, Manshouri M, Farahani HA (2010) The effect of irrigation by domestic waste water on soil properties. JSSEM 1(2):30–33

Dobrowolski J, O'Neill M, Duriancik L, Throwe J (2008) Opportunities and challenges in agricultural water reuse: final report. USDA Cooperative State Research, Education, and Extension Service, Washington, DC

Ferrer A, Mochón I, De Oña J, Osorio F (2011) Evolution of the soil and vegetation cover on road embankments after the application of sewage sludge. Water Air Soil Poll 214(1–4):231–240

Golmohammadi F (2014) Saffron and its farming, economic importance, export, medicinal characteristics and various uses in South Khorasan Province-East of Iran. IJFAS 3(5):566–596

Guo J, Niu H, Xiao D, Sun X, Fan L (2021) Urban Green-space Water-consumption characteristics and its driving factors in China. Ecol Ind 130:108076

Hadas E, Kislev Y (2010) Economic aspects of irrigation with treated wastewater. In: Treated wastewater in agriculture: use and impacts on the soil environment and crops. Wiley-Blackwell, Oxford, pp 113–127

Hakanson L (1980) An ecological risk index for aquatic pollution control. A Sedimentol Approach Water Res 14:975–1001

Hussain MI, Muscolo A, Farooq M, Ahmad W (2019) Sustainable use and management of non-conventional water resources for rehabilitation of marginal lands in arid and semiarid environments. Agric Water Manag 221:462–476

Jackson ML (1956) Soil chemical analysis—advanced course: Published by the author. Madison, Wisconsin

Jia Y, Zheng F, Maier HR, Ostfeld A, Creaco E, Savic D, Kapelan Z (2021) Water quality modelling in sewer networks: review and future research directions. Water Res, p 117419

Klute A (1986) Methods of soil analysis, part 1 physical and mineralogical methods. Arnold Klute ed. Agronomy. 9, (part 1)

Lahlou FZ, Mackey HR, Al-Ansari T (2021) Wastewater reuse for livestock feed irrigation as a sustainable practice: A socio-environmental-economic review. J Clean Prod, p 126331

López R, Hallat J, Castro A, Miras A, Burgos P (2019) Heavy metal pollution in soils and urban-grown organic vegetables in the province of Sevilla, Spain. Biol agric hortic, pp 1–19

Lyberatos G, Sklyvaniotis M, Angelakis AN (2011) Sewage biosolids management in EU countries: challenges and prospective

Mojid MA, Hossain ABMZ, Wyseure GCL (2019) Impacts of municipal wastewater on basic soil properties as evaluated by soil column leaching experiment in laboratory. J Soil Sci Plant Nutr, pp 1–11

Mojiri A, Aziz HA, Aziz SQ, Gholami A, Aboutorab M (2013) Impact of urban wastewater on soil properties and Lepidium sativum in an arid region. Intern J Sci Res Environ Sci 1(1):1–9

Mosime L, Areola O, Dikinya O (2011) Comparative effects of secondary treated waste water irrigation on soil quality parameters under different crop types

Muller G (1969) Index of geoaccumulation in sediments of the Rhine River. GeoJournal 2:108–118

Noshadi I, Salahi A, Hemmati M, Rekabdar F, Mohammadi T (2013) Experimental and ANFIS modeling for fouling analysis of oily wastewater treatment using ultrafiltration. Asia Pacific J Chem Eng 8(4):527–538

Osakwe SA (2012) Effect of cassava processing mill effluent on physical and chemical properties of soils in Abraka and Environs, Delta State. Nigeria JCMR 2(7):27–40
Paudel I, Bar-Tal A, Levy GJ, Rotbart N, Ephrath JE, Cohen S (2018) Treated wastewater irrigation: Soil variables and grapefruit tree performance. Agric Water Manag 204:126–137
Pratap B, Kumar S, Purchase D, Bharagava RN, Dutta V (2021) Practice of wastewater irrigation and its impacts on human health and environment: a state of the art. Int J Environ Sci Technol, pp 1–16
Rusan MJM, Hinnawi S, Rousan L (2007) Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. Desalination 215(1–3):143–152
Sacks M, Bernstein N (2011) Utilization of reclaimed wastewater for irrigation of field-grown melons by surface and subsurface drip irrigation. Isr J Plant Sci 59(2–4):159–169
Sahay S, Iqbal S, Inam A, Gupta M, Inam A (2019) Waste water irrigation in the regulation of soil properties, growth determinants, and heavy metal accumulation in different Brassica species. Environ Monit Assess 191(2):107–119
Singh PK, Deshbhratar PB, Ramteke DS (2012) Effects of sewage wastewater irrigation on soil properties, crop yield and environment. Agric Water Manag 103:100–104
Suarez DL, Gonzalez-Rubio A (2017) Effects of the dissolved organic carbon of treated municipal wastewater on soil infiltration as related to sodium adsorption ratio and pH. S.S.S.A. 81(3), 602–611
Thapliyal A, Vasudevan P, Dastidar MG, Tandon M, Mishra S (2011) Irrigation with domestic wastewater: responses on growth and yield of ladyfinger Abelmoschus esculentus and on soil nutrients. J Environ Boil 32(5):645–659
Tomlinson D, Wilson J, Harris C, Jeffrey D (1980) Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer meeresuntersuchungen
Urbano VR, Mendonça TG, Bastos RG, Souza CF (2017) Effects of treated wastewater irrigation on soil properties and lettuce yield. Agric Water Manag 181:108–115
Van der Hoek W, Hassan MU, Ensink JH, Feenstra S, Raschid-Sally L, Munir S, Matsuno Y (2002) Urban Wastewater: A valuable Resource for agriculture: A case study from Haroonabad. Pakistan IWMI 63:210–221
World Health Organization (WHO) (1996) Permissible limits of heavy metals in soil and plants. Geneva, Switzerland
Xue P, Zhao Q, Sun H, Geng L, Yang Z, Liu W (2019) Characteristics of heavy metals in soils and grains of wheat and maize from farmland irrigated with sewage. Environ Sci Pollut R 26(6):5554–5563