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Mitigating Environmental Risks of Wastewater Reuse for Agriculture

Ahmed Al-Busaidi and Mushtaque Ahmed

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/65871>

Abstract

The study was aimed to maximize and optimize treated wastewater reuse in conjunction with surface and ground waters resources. Moreover, environmental, agronomic and economic components were also considered. The project was funded by USAID and implemented in three countries (Oman, Tunisia and Jordan). In Oman, the study was done at Sultan Qaboos University experimental station field. Four types of waters (A: 50% of treated wastewater with 50% of groundwater, B: 100% of groundwater, C: 25% of groundwater with 75% of treated wastewater, and D: 100% of treated wastewater) were used to grow three different crops (okra, maize and sweet corn). Results showed no significant differences in soil physical and chemical properties with treatments irrigated with treated wastewater as compared to groundwater. On other hand, some chemical properties significantly increased ($p < 0.05$) when treated wastewater was applied such as soil total carbon and some major elements (N, K, Mg). Crop physical analysis showed significant increases in plant productivity when plants were irrigated with treated wastewater and values of chemical properties were within the international standards. Crop biological analysis showed no effect on crop quality and all tested crops were free from any microbial contamination.

Keywords: treated wastewater, soil, fruits, yield, heavy metals

1. Introduction

Drought and overexploitation of conventional water resources present a critical problem in many regions of the world, especially the Middle East [1]. Therefore, water resources including nonconventional water should be well managed. Usage of treated wastewater (TWW) on agriculture can save fresh water resources and minimize the applications of chemical fertilizers. In many parts of the world, treated wastewater has been successfully used for irrigation, and

many researchers have recognized its benefits [2, 3]. The continuous use of treated wastewater in irrigation increases the total soluble salts in the soil. The cation exchange capacity values are increased by increasing the period of using treated wastewater for irrigation, especially in the surface layer (0–30 cm). Moreover, Fe, Zn, Cu, Mn, Pb, and Co were increased by irrigation using treated wastewater as compared to virgin soil [4]. The use of treated wastewater for irrigation increased the mitotic index of divided cells, chromosome abnormality, and contents of individual amino acids. However, no differences in the profile of protein bands were observed between control and treated wastewater irrigation plants [5]. Whereas the accumulations of heavy metals in the edible part of some plants were detected which adversely affect human and animal health through the food chain [6].

Many countries have included wastewater reuse as an important component of water resources planning. Some countries like Oman have a national policy to reuse all treated wastewater effluents and have already made considerable progress toward this end [7]. Sultanate of Oman is one of the Middle East countries that is considered as the driest or semidriest region in the world with rapidly developing economy and a high population growth [8]. Soil and groundwater (GW) resources of good quality irrigation water have become limited. Rainfall is scanty to support crop production with annual mean rainfall of 100 mm. Therefore, its agriculture is almost fully dependent on groundwater [9]. Water resources augmentation together with conservation has been adopted by the government to combat the water shortage problem. The rapid development of Oman's urbanization, increase in population, and increase in agricultural production has led to high demand for water and urgent need to use treated wastewater as an alternative source of freshwater in agriculture. However, treated wastewater may contain high concentrations of salts, heavy metals, pathogens, and emerging pollutants with unknown effects on the ecological system [10]. High concentrations of heavy metals in plant fruits could affect human health and cause many environmental problems. However, the conjunctive use of treated wastewater and groundwater resources could be employed, helping to safeguard farmer's income and sustain food production. Despite this promising option, more research and education efforts are needed to ensure proper use of treated wastewater for agricultural production. Therefore, the study aimed to optimize treated wastewater reuse in conjunction with groundwater by taking into consideration their quantity and quality, in addition to the agronomic, environmental, and economic components.

2. Materials and methods

The field work was done in plots at the Agricultural Experiment Station, Sultan Qaboos University. Twelve plots (2.5 × 3.5 m each) were designed and sweet corn, okra, and maize crops were grown during the study. The plots were irrigated with four types of waters (A: 50% groundwater and 50% treated wastewater; B: 100% groundwater; C: 75% treated wastewater and 25% groundwater; and D: 100% treated wastewater) as shown in **Figure 1**. Plants were daily irrigated based on evapotranspiration (ET_c). Soil samples were taken before and at the end of the study at a depth of 0–30 cm. Whereas plant samples were taken when the crop was mature and ready for analysis.

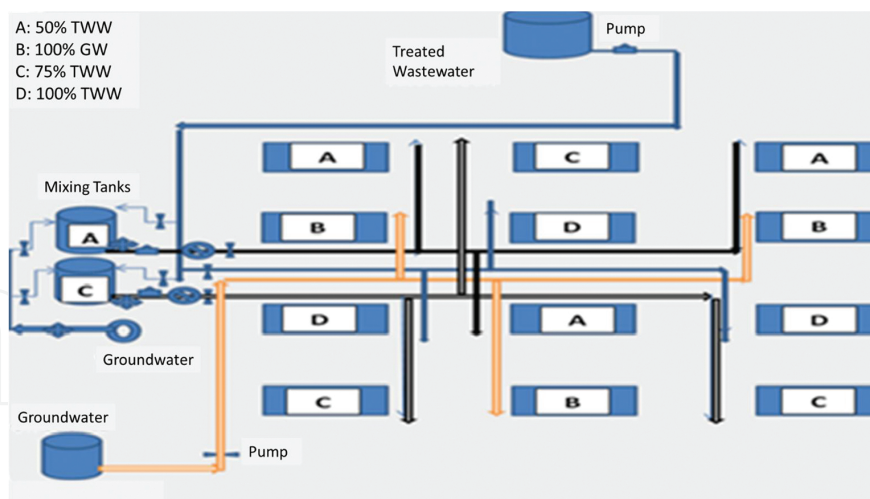


Figure 1. Field experimental design with different treatments.

Plants growth and yield of each crop irrigated by different waters were monitored. Fruits quality and quantity were assessed. Samples from soil and plants were taken for different physical, chemical, and biological analyses. All physicochemical analysis for soil and plants were done in soil and water labs (SQU) following standard methods [11] and using inductively coupled plasma (ICP) instrument for metals analysis. Soil and plant nitrogen (N) were analyzed in Rumais Research Laboratory (Ministry of Agriculture and Fisheries). Whereas biological analyses for crop samples were done in Muscat Municipality Laboratory.

The data were analyzed statistically using the analysis of variance (ANOVA) and the means were compared at the probability level of 5% using the least significant difference [12].

3. Result and discussion

3.1. Heavy metals in irrigation water

Growing conditions and the irrigation water are the most important parameters controlling plant life. **Table 1** demonstrates heavy metal concentrations in the irrigation waters that were used in the study. Comparing the used waters with national and international standards, it can be seen that elements concentrations mentioned in **Table 1** had lower values than applied standards. However, long-term application of some waters may accumulate some harmful elements in soil and plant tissues if mismanagement occurs. In some studies, it was found that wastewaters could carry appreciable amounts of trace toxic metals [13, 14] and concentrations of trace metals in sewage effluents vary from one city to another [15]. Although the concentration of heavy metals in sewage effluents are low, long-term use of these wastewaters on agricultural lands often results in the build-up of elevated levels of these metals in soils [15]. The results of Rattan et al. [15] reported high amount of Cr, Cu, Pb, Co, Ni, Mn, Cd, Fe, Zn, and As in sewage effluents compared to groundwater. Whereas soil organic matter was also increased in soil samples irrigated with sewage effluents compared to groundwater.

Water	Mn	Fe	Zn	Cu	Cr	Cd	Pb	Ni	B
Groundwater	0.002	0.013	0.013	0.008	<0.002	<0.001	<0.001	<0.001	0.295
Treated wastewater	0.002	0.016	0.064	0.024	<0.002	<0.001	0.066	<0.001	0.508
EPA Standard	0.200	5.000	5.000	0.500	0.100	0.010	0.100	0.100	0.750
FAO Standard	0.200	5.000	2.000	0.200	0.100	0.010	0.500	0.200	0.750
Omani Standard	0.500	5.000	5.000	1.000	0.050	0.010	0.200	0.100	0.750

*Summary of U.S. EPA guidelines for water reuse for irrigation [16].

Table 1. Comparing heavy metals concentration (mg/l) in the irrigation waters with national and international standards*.

3.2. Soil physicochemical properties

Quality of irrigation water could affect soil physicochemical properties. It could improve the soil quality by adding more nutrients or degrading the soil by adding toxic salts. Soil organic matter and total carbon are usually interconnected parameters and they are good indicators for soil fertility. In our study, some of them were found to be high in treated wastewater (TWW) compared to groundwater (GW) treatments. It is an expected result since treated wastewater is usually rich in nitrogen and other nutrients, which enrich soil and enhance plant growth (Figure 2a and b).

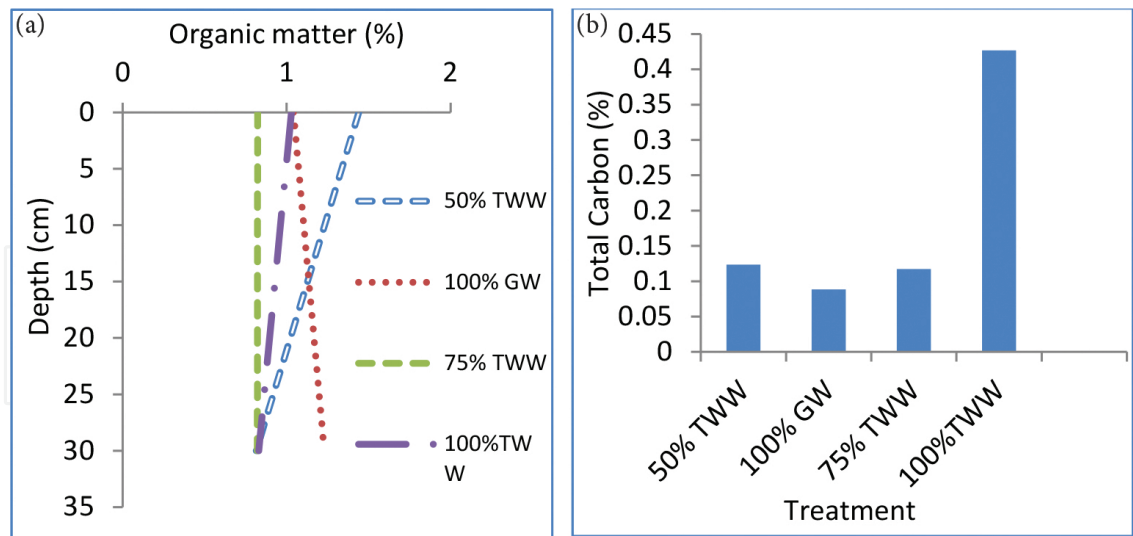


Figure 2. (a) Soil organic matter and (b) soil total carbon.

The presence of more nutrients (salts) in treated wastewater helps in keeping more water in plant root zone compared to groundwater (Figure 3). Nutrients as salts increased water viscosity and reduced evaporation process and as a result more water can be kept in the root zone [17].

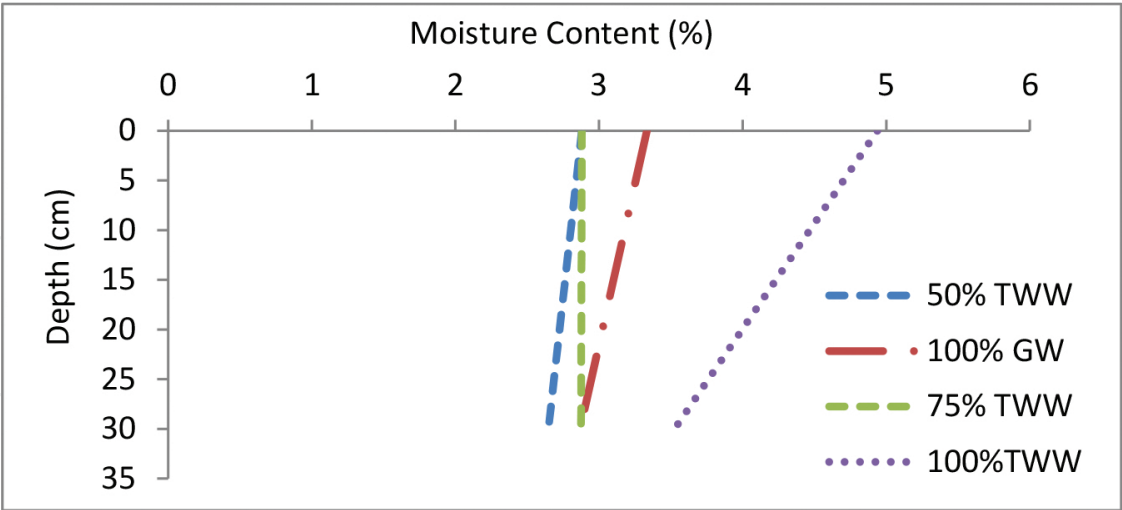


Figure 3. Soil moisture of all treatments.

Treated wastewater has a good amount of nutrients (salts). Therefore, it will add more salts to the irrigated soil and increase soil salinity compared to soil irrigated with freshwater (Figure 4). Salts are usually managed and reduced by leaching process.

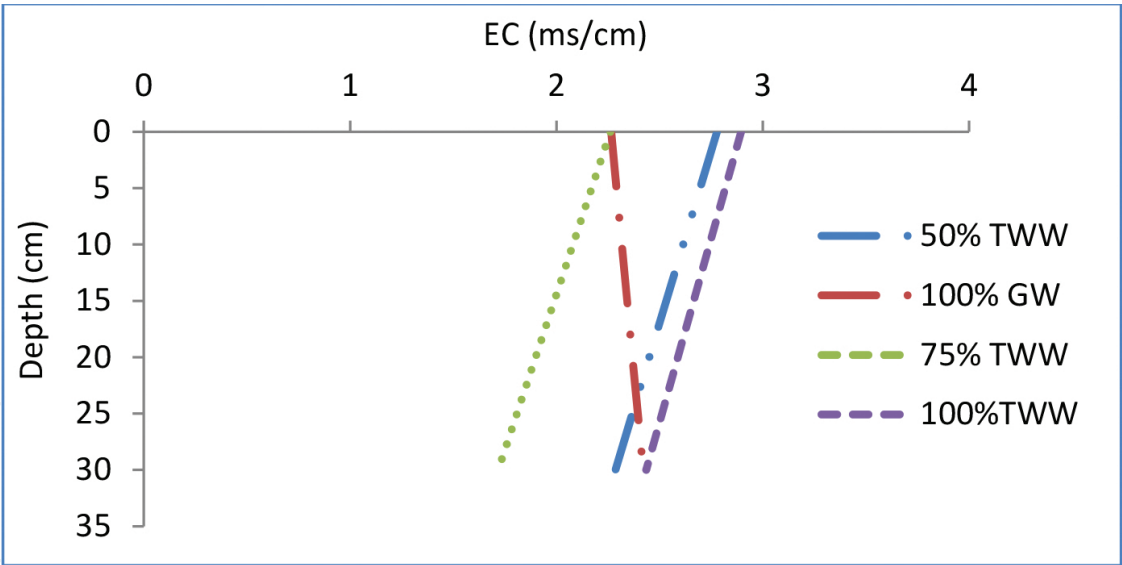


Figure 4. Soil electrical conductivity in all treatments.

In addition to organic matter, treated wastewaters have higher values for several nutrients compared to groundwater (Figure 5). These nutrients can improve soil fertility and later support plant growth. The variations in some elements' concentrations between treatments could be due to original nutrients concentrations in the soil and absorbance of those metals during plant growth. Mohammed and Mazahareh [10] found that treated wastewater irrigation increased soil salinity, soil phosphorous, potassium, iron, and manganese levels. They noticed that soil organic matter increased only in the topsoil.

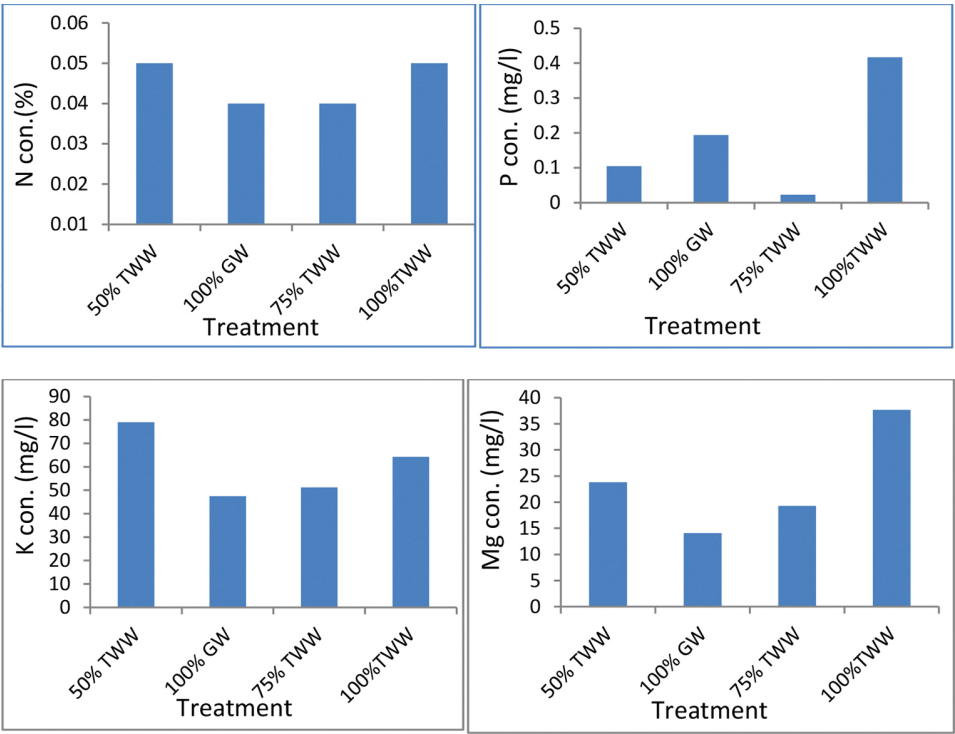


Figure 5. Mean concentration of some elements in soil samples.

Treatment	Mn	Cd	Fe	Zn	B	Ba	Cr	Co	Pb	Ni
50%TWW	0.018a	0.001a	0.330a	0.026a	0.166c	0.118a	0.043a	0.058a	0.196b	0.005a
100%GW	0.018a	0.001a	0.331a	0.001b	0.171b	0.123a	0.039a	0.060a	0.219a	0.011a
75%TWW	0.016a	0.001a	0.334a	0.001b	0.088d	0.087b	0.041a	0.061a	0.220a	0.005a
100%TWW	0.018a	0.001a	0.345a	0.003b	0.309a	0.110a	0.039a	0.062a	0.234a	0.001a

*Means in the column with same letter indicate no difference at Duncan's Multiple Range Test at $p < 0.05$.

Table 2. Mean concentration of heavy metals (mg/l) in soil samples*.

Checking soil for microelements (heavy metals) concentrations, it can be seen in **Table 2** that all values of heavy metals for both treatments (treated wastewater and groundwater) were very close to each other. However, some significant differences were found between some treatments which could be an indicator for long-term changes in soil chemical properties which is also found in Bansal et al. [18] and Palaniswami and Sree Ramulu [19] studies when they applied wastewater for long period. Rattan et al. [20] observed a build-up of Zn, Pb, Ni, Mn, Fe, Cu, Cr, Co, and As in the sewage-irrigated soils, over the well water-irrigated ones. Significant effect of irrigation through sewage water was observed in case of studied metals. There has been an enormous build-up in the available Fe content in the sewage-irrigated soils. Soils irrigated with groundwater and sewage water showed higher level of Cu and Zn. However, some sewage-irrigated soils accumulated more than 70 mg kg^{-1} total Zn, which could

cause a phytotoxicity problem [20]. Whereas Berry et al. [21] found that soil zinc and copper were not significantly affected by wastewater irrigation.

3.3. Crop physicochemical analysis

From **Table 3**, it can be seen that treated wastewater gave the best yield for all three crops compared to groundwater. The good supply of different nutrients from treated wastewater enhanced plant growth and improved plant productivity. Abohassan et al. [22] and Stewart et al. [23] have identified the beneficial effects of treated sewage water on some trees grown in Saudi Arabia and Australia. Shafiq et al. [24] found an increase of 24, 45, and 68% in maize total fresh biomass, dry yield, and grain yield irrigated by treated wastewater compared to groundwater. Same finding was also reported by Harati [25] in maize plants.

Treatment	Sweet corn	Okra	Maize
50% TWW	0.091	12.500	1.273
100% GW	0.141	11.091	1.193
75% TWW	0.085	10.556	1.160
100%TWW	0.090	13.958	1.593

Table 3. Average weight (kg) of some crops grown in the study.

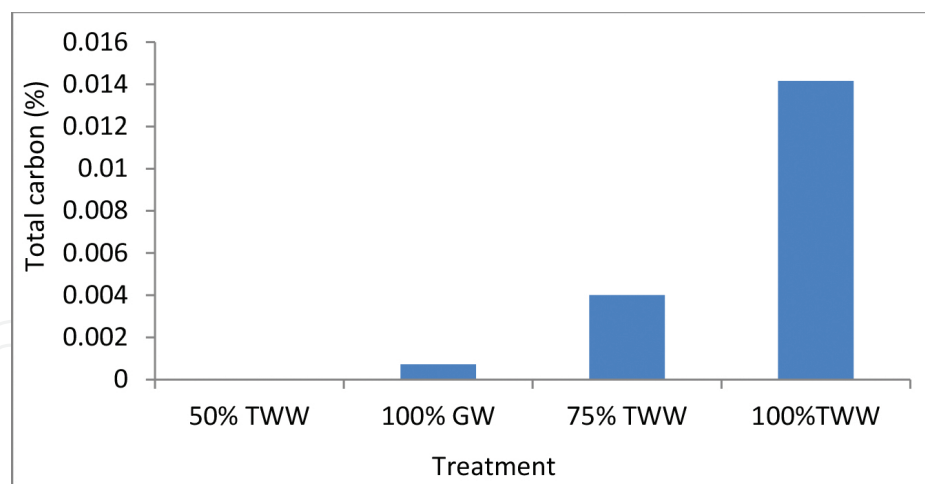


Figure 6. Percentage of total carbon in maize plant leaves.

Maize leaves were the best indicator for carbon content. Therefore, it can be seen from **Figure 6** that treated wastewater got the highest values compared to other treatments. It could be a reflection for what was found in water and soil samples. In a similar study done by Abd-Elfattah et al. [6], they found significant differences in metal content of plant leaves grown in soils irrigated with treated wastewater and plant leaves grown in soils irrigated with Nile water of both seasons.

Treatment	Element conc. (mg/l)								
Okra	Mn	Cd	Fe	Zn	B	Cr	Co	Pb	Ni
50%TWW	0.173d	0.001a	1.224c	0.357b	0.521c	0.060a	0.069a	0.252b	0.006b
100%GW	0.190c	0.001a	1.365b	0.364b	0.336d	0.071a	0.075a	0.229c	0.013b
75%TWW	0.242b	0.001a	2.372a	0.482a	0.745b	0.083a	0.087a	0.255b	0.127a
100%TWW	0.263a	0.001a	1.177d	0.495a	0.862a	0.057a	0.073a	0.300a	0.014b
Sweet corn	Mn	Cd	Fe	Zn	B	Cr	Co	Pb	Ni
50%TWW	0.177b	0.001a	1.295b	0.329c	0.073c	0.122b	0.091b	0.222c	0.068b
100%GW	0.204a	0.001a	1.582a	0.613a	0.492a	0.215a	0.100 a	0.191d	0.104a
75%TWW	0.152c	0.001a	1.584a	0.301c	0.122b	0.061c	0.070c	0.240b	0.011c
100%TWW	0.127d	0.001a	0.889c	0.400b	0.062c	0.064c	0.072c	0.444a	0.003d
Maize	Mn	Cd	Fe	Zn	B	Cr	Co	Pb	Ni
50%TWW	0.457b	0.001a	2.365b	0.256a	0.903a	0.136d	0.064a	0.210c	0.037a
100%GW	0.463a	0.001a	2.362b	0.219c	0.717c	0.146c	0.074a	0.213c	0.047a
75%TWW	0.366d	0.001a	2.279d	0.189d	0.454d	0.151b	0.075a	0.280a	0.040a
100%TWW	0.393c	0.001a	2.483a	0.226b	0.832b	0.181a	0.073a	0.241b	0.052a

*Means in the column with same letter indicate no difference at Duncan's Multiple Range Test at $p < 0.05$.

Table 4. Heavy metals concentration (mg/l) in tested crops*.

Standards/elements	Cd	Cu	Pb	Zn	As	Ni	Cr
WHO/FAO (2007)	0.2	40	5	60	–	–	–
European Union (EU 2006)	0.2	–	0.3	–	0.4	–	2.3
Indian Standard (Awashthi, 2000)	1.5	30	2.5	50	–	1.5	20

Source: CPCB [30].

Table 5. Guideline for safe limits of heavy metals in plants (mg/kg).

For soil, usually there is a direct relationship between salts found in the irrigation water and irrigated land. Whereas, for plants, root selectivity and present of salts in different forms could play a role in elements movement and translocation from soil to plant. From **Table 4**, it can be seen that concentrations of many elements were significantly ($p < 0.05$) different from one treatment to other. However, microelements in the edible parts of all crops grown in the field were not that high and they were within the international standards (**Table 5**). Same results were reported by Abdelrahman et al. [26] when they observed no significant difference between fresh and treated wastewater with regards to heavy metals accumulation in grown crops. Moreover, this finding was supported by Pescod [27] study, when he concluded that the concentrations of heavy metals in seeds were within normal level when treated wastewater effluent was used. Such results make it clear that heavy metal in soil are not readily bio-available for crop uptake and do not represent a threat to quality of crop consumption.

In general, treated wastewater contains variable amounts of nutrient elements and heavy metals. Availability and translocation of these elements to and within the plant tissues is highly dependent on the environmental conditions as well as their concentration and ratios in the plant organs [28]. Same results were also found by Mahdi et al. [29] when they reported that concentration of nutrient elements of different crops indicated that the crop nutrient uptake is affected by tree age and species. Longer exposure to treated wastewater did not indicate major effects on fruit minerals, including heavy metals. Sampling over longer period of time is needed to confirm the changes in nutrient composition over time. Therefore, in the present study it can be seen that treated wastewater treatment sometime got the highest values for heavy metals which could be an indication for heavy metal accumulation with long-term application if treated wastewater is used without proper management. This prediction could be similar to Abd-Elfattah et al. [6] findings when they found a significant difference in fruit contents of heavy metals and trace elements (Pb, Cd, Ni, Cu, Mn, Fe, Zn) between fruits produced by treated wastewater compared with Nile water in both seasons. The accumulation of heavy metals in the edible part of plant was detected which adversely affects human and animal health through the food chain [6].

Finally, the findings of this study are supported by many researches. As such, Omran et al. [31] found no significant problems with orange trees when they were irrigated with treated sewage water. Furthermore, in Hamad et al. [32] study, toxicity problems for some metals (Cd, Hg, Cr, Pb) in tested crops due to irrigation with treated wastewater was not observed. In the Sultanate of Oman it was found that treated sewage water did not cause any phyto-toxicity symptoms in date palm leaves and fruits [33]. Therefore, it can be concluded that proper management of wastewater irrigation and periodic monitoring of soil and plant quality parameters are required to ensure successful safe long-term wastewater irrigation [34].

3.4. Crop biological analysis

Usually microbial analyses are the direct indicators for microbial contaminations in different crops. In this study, the edible part of grown crops was checked by Muscat Municipality laboratory and different microbes were analyzed such as coliform bacteria, *Escherichia coli*, and *Salmonella* spp. All tested samples were free from any microbial contamination. This finding was supported by Mexican and Tunisian studies where sewage effluent at different levels of treatment has been employed to irrigate various crops. It has been used with no serious effect on man and plants [35].

4. Conclusion

The use of treated wastewater for irrigation is increasingly being considered as a technical solution to save fresh groundwater, minimize soil degradation, and improve soil fertility. In this study, usage of treated wastewater irrigation as compared to groundwater did not affect significantly some soil physical and chemical properties. Whereas some chemical properties such as major elements (N, K, Mg) and total carbon were significantly increased when treated

wastewater was applied. Concentrations of heavy metals were increased in soils irrigated with treated wastewater compared to groundwater. The differences in heavy metals concentrations of all treatments were small and data of all treatments was close to each other.

Treated wastewater is a rich source of nutrients and provides most nutrients that are necessary for crop growth. Therefore, treated wastewater improved significantly plant productivity compared to groundwater treatments. Whereas small increase was noticed with some chemical properties of plants irrigated with treated wastewater compared to groundwater. However, all measured values were within the international standards. Biologically, all tested crops were free from any microbial contaminations. In general, most crops gave higher yield with wastewater irrigation and reduced the need for chemical fertilizers, resulting in net cost savings to farmers. Therefore, it can be concluded that treated wastewater is an important source of water for agricultural production and to avoid any health or environmental problems, quality of treated wastewater should be monitored with time.

Acknowledgements

The authors like to thank the staff from Sultan Qaboos University and Ministry of Agriculture and Fisheries for their support in collecting and analyzing soil, water, and plant samples. Special thanks to USAID (FABRI) for their financial support.

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