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Evaluation of the effects of industrial wastewater on soil properties and land desertification

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Abstract

During past decades, increased wastewater production by human activities intensified the problem of wastewater use without causing undesirable impacts on the environment and human life. However, practice of wastewater use in irrigation crops and green spaces needs careful control because of the potential presence of unwanted constituents such as heavy metals and organic contaminants. This research was designed to evaluate the effects of industrial wastewater on soil properties in Yazd, Iran. For this purpose, two plots were prepared and irrigated for five years, one with industrial wastewater and the other with local groundwater. Finally, soil samples collected from both plots were analyzed in laboratory and important factors and elements including EC, pH, SAR, K, N, P, Ca, Pb, Fe, Cd, $CaCO_3$ and OC (organic carbon) which are important in soil degradation and land desertification were determined. According to the results obtained from this research it should be reported that this type of wastewater may cause soil degradation due to increasing SAR, EC, pH and Pb and also decreasing N, K and OC. It is clear that soil degradation is the main factor which causes and accelerates the process of desertification.

Keywords: Industrial wastewater, Irrigation, Water reuse, Land desertification, Soil degradation

1. Introduction

Growing urban agriculture and also green space expansion (due to population increase) in many cities in developing countries has resulted in increased demand for resources such as land and water. In the context of access to water for irrigation, urban farmers and even urban green space administrators have inclined in wastewater, which is a readily available resource in all the times. In the other hand, rapid urbanization in developing countries has resulted in generation of huge volumes of municipal and industrial wastewater requiring treatment and safe disposal. Using treated wastewater for irrigation, provides a means through which wastewater can safely be reused and managed. The potential for wastewater use for irrigation can best be realized in an enabling environment that ensures adequate wastewater treatment and management, however, in most of the cities in developing World, wastewater used for farming is largely not treated. These potential health risks and environmental damages are a major constraint of current wastewater use practices, and can possibly limit its long-term sustainability.

The use of wastewater for irrigation is an important livelihood strategy especially for arid regions where water scarcity is a main problem. However, its use can result in an increased health risk for farmers and consumers and also for soil

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sustainability if not well managed. To ensure sustainable and safe wastewater use for food production and green space expansion in urban and peri-urban areas, there is need to explore safe wastewater use and management options. The best approach will need to balance both farmers needs, and soil destruction concerns. Several research projects have been completed to evaluate the effects of different agricultural activities and especially irrigation water quality on soil degradation and land desertification around the world. Abrol. *et al.,* (1988) announced on behalf of the FAO that more than half of the irrigation projects in the World causes soil salinity or sodicity and eventually facilitates desertification. He also added that about 50% of the irrigated lands in arid and semi-arid regions of the World suffer from soil salinity. Follett *et al.*, (1985) concluded that land use change, inappropriate irrigation water, soil salinity and soil erosion (by water and by wind) are the main causes of desertification in Asian countries. Glazovski (1987) emphasized that saline groundwater used for irrigation is the main factor caused soil salinity in Kazakhstan, Dagestan, Azerbaijan, Turkmenistan, Uzbekistan, Gergizestan and Tajikistan. He specifies that about 2.7 million tones of salt is added to the soil in the area of Dagestan every year due to saline irrigation groundwater. Mashali (1995) estimated (using FAO and UNESCO World soil map) that 83.4 millions hectares of the near east agricultural lands are salt affected. Then he concluded that this has been happened mainly due to inappropriate agricultural activities such as using inappropriate water for irrigation. Dregne, *et al.*, (1991) analyzed the process of desertification in the World, and concluded that the main cause of this problem is undesirable agricultural activities. Kirsta (1993) emphasized that salinization caused by inappropriate irrigation water is the main factor of desertification in Turkmenistan. Gerhart, et al., (2006) investigated the possibility of using high-TDS (total dissolved solids) industrial wastewater to irrigate common landscape plants in a desert urban environment. In his research nine species were planted in a replicate block and three types of water (normal well water and two types of industrial wastewater with different EC and TDS) were used for irrigation. The results showed that although all plants grew well over the study period (27 months), but at the end, soil salinities were higher in plots irrigated with high-TDS industrial wastewater. Bahmanyar (2008) evaluated the effects of long-term irrigation using industrial wastewater on soil properties and elemental contents of rice, spinach, clover and grass. Results indicated that the concentration of zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) increased in river water when wastewater was discharged into it, and use of the river water influenced by the industrial wastewater for irrigation of rice and other plants increased the amounts of Zn, Cu, Mn and Fe in soil. El-arby and Elbordini (2006) evaluated the effects of treated wastewater on accumulation of heavy metals in soils and their content in growing plants in El-Sadat city, Egypt. The results showed that the total content of such heavy metals to soils were higher in surface layers than those of lower ones. Concentrations of such heavy metals in the surface layer (0-5 cm) of soil irrigated with treated water 8, 3.4, 3.4, 10.3, 9.6, 7.4, and 3.3 times more for Fe, Zn, Cu, Co, Ni and Pb compared to the soil irrigated from well water respectively.

Building on previous studies, this research looks at the on-going challenges of industrial wastewater use for irrigation in the research area (Yazd, Iran), particularly highlighting the effects on soil properties. The paper presents a case study of industrial wastewater use in a green space surrounding a tyre factory in Yazd, Iran.

2. Materials and methods

In this study, the effects of industrial wastewater produced by a tyre factory on the irrigated soil have been evaluated. The research project was completed after a time period of 5 years. In 2002, an area of about four hectares was selected for green space development around the Yazd Tyre Factory in Yazd, Iran. At the same time this research project was also planned to evaluate the acceptability of the factory effluent for irrigating the established green space. Therefore, after required coordination with the related authorities, the area was divided into two parts exactly similar in size, slope and soil type. Each part of two hectares was prepared and planted with olive young trees (*Olea europaea*). Figure 1 shows a schematic plan view of the experimental and control plots prepared around the factory. Traditional surface irrigation system was employed for both plots using the same volume of water (equal to local irrigation requirement) as well as a same irrigation interval but one using factory effluent (for experimental plot) and the other one using normal local groundwater (for control plot). Soil samples were collected from both experimental and control plots before irrigation took place. Laboratorial analyses of these samples confirmed about homogeneity of the soil in both plots at the beginning of the research project. Plots were irrigated in a designed way for about five years. In October 2007, soil and water samples (wastewater and local normal groundwater) were collected and transfered to the laboratory for the required analyses.

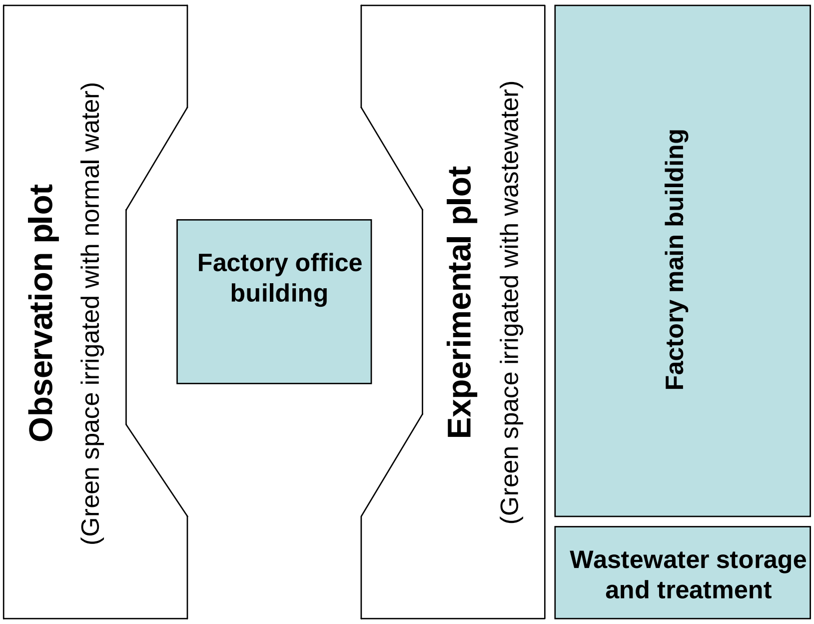


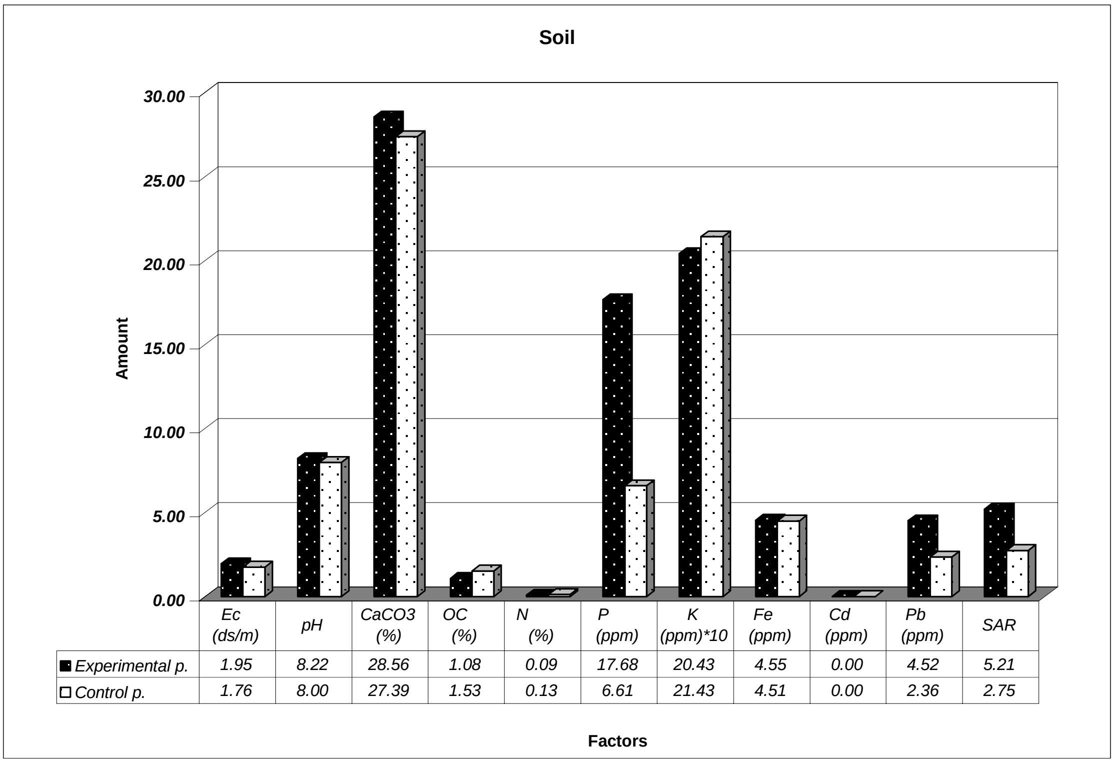
Fig. 1. Schematic plan view of the experimental and control (observation) plots

In laboratorial analysis of soil and water samples, the amount of the important factors including EC, pH, SAR (sodium adsorption ratio), K, N, P, Ca, Pb, Fe, Cd, $CaCO_3$ and OC (organic carbon) were determined using current existing procedures (American Public Health Association *et al.*, 1995, and also Chapman and Pratt, 1961).

To have a reliable comparison of collected data from the two plots, coefficient of skewness for the collected data was used to see whether these data follow normal distribution or not. For all the factors under consideration, data showed a symmetrical distribution around their averages, means that these data are normal (fit normal distribution). Therefore, parametric tests of mean comparison such as analysis of variance can be used in such case to evaluate statistical differences between the amounts of measured factors for the plots. Using the SAS software a one-way analysis of variance (ANOVA) was used to determine the effects of industrial wastewater on soil properties. Analysis of variance was carried out, and the level of differences for measured factors of the soil samples was determined.

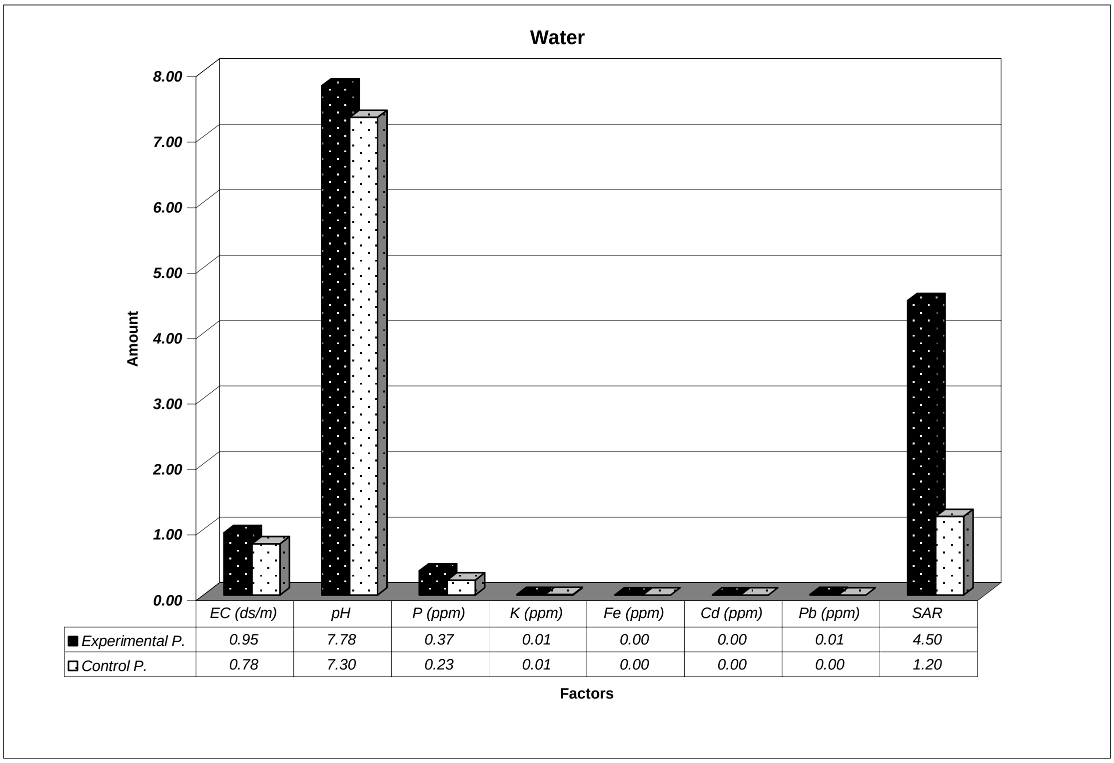
3. Results

After variance analysis for each site and determination of the differences between the measured factors in wastewater irrigated plot and the normal water irrigated plot, the obtained results are summarized below. The amount of measured factors in both experimental and control plots has been shown in figure 2. Figure 3 shows the presence and amount of considered factors in waters used for irrigation (industrial wastewater as experimental and local normal groundwater as control).



	Ec (ds/m)	pH	CaCO3 (%)	OC (%)	N (%)	P (ppm)	K (ppm)*10	Fe (ppm)	Cd (ppm)	Pb (ppm)	SAR
Experimental p.	1.95	8.22	28.56	1.08	0.09	17.68	20.43	4.55	0.00	4.52	5.21
Control p.	1.76	8.00	27.39	1.53	0.13	6.61	21.43	4.51	0.00	2.36	2.75

Fig. 2. The amounts of evaluated factors in soil samples taken from plots



	EC (ds/m)	pH	P (ppm)	K (ppm)	Fe (ppm)	Cd (ppm)	Pb (ppm)	SAR
Experimental P.	0.95	7.78	0.37	0.01	0.00	0.00	0.01	4.50
Control P.	0.78	7.30	0.23	0.01	0.00	0.00	0.00	1.20

Fig. 3. The amounts of evaluated factors in water samples used for plots

EC: As it is seen in figure 1, the amount of EC in wastewater irrigated plot is higher than the normal groundwater irrigated plot. It means that industrial wastewater has slightly increased the EC of the soil, however this increase is not statistically meaningful and considerable.

pH: About pH it can be said that the difference between wastewater irrigated plot and the related control plot is meaningful in the level of 99%. In other word, wastewater has increased the amount of soil pH.

$CaCO_3$: Industrial wastewater has had no considerable effect on soil $CaCO_3$.

OC (organic carbon): As figure 1 shows, wastewater has decreased the amount of soil OC, and the difference between experimental (wastewater irrigated) and control (normal groundwater irrigated) plots for this factor is statistically meaningful at the level of %95.

K: Wastewater has had no considerable effect on soil K.

P: The effect of wastewater on soil P has been statistically meaningful at the level of %99, and wastewater has considerably increased the amount of soil P.

N: Industrial wastewater has decreased the amount of N in the soil. The difference between experimental and the related control plots is statistically meaningful at the level of %99.

Fe: The difference between Fe of the soil samples collected from wastewater irrigated plot and the related control plot is not statistically meaningful, and as figure 1 shows the amount of this element in both plots is almost equal.

Cd: No Cd was found in soil samples taken from the plots.

Pb: Industrial wastewater has increased the amount of this factor in the soil. The difference between experimental and the related control plots is statistically meaningful at the level of 99%. As figure 1 shows, the amount of this element in wastewater irrigated plot is about as twice as in normal groundwater irrigated one.

SAR: About this factor it must be said that wastewater has statistically increased the amount of SAR at the level of 99%, meaning that industrial wastewater has had considerable effect on soil SAR.

About industrial wastewater irrigated plot and the related control plot in this study, it can be summarized that about factors Ec, $CaCO_3$, K and Fe, there is no statistically meaningful difference between the soil samples taken from experimental and the control plots. The difference is statistically meaningful at the level of 99% between the soil samples of experimental and control plots for the factors including pH, N, Pb and SAR. For the remaining factor (P) the difference between the experimental and control plots is statistically meaningful at the level of 95%. Industrial wastewater has increased the amount of pH, Pb, P and SAR in the soil, while it has decreased the amount of N and OC of the soil. About remaining factors the effects of this type of wastewater can be ignored. Table 1 shows the amounts of the evaluated factors in soil and water samples collected from the industrial site plots.

4. Discussion

The factors evaluated in this research can be divided into two groups including destructive factors and amendatory factors. Increase in the amount of destructive factors such as SAR, EC, Pb and Cd facilitates soil destruction or toxicity and consequently process of desertification, while increasing the amount of amendatory factors such as N and OC increases soil fertility and prevents soil destruction and land desertification. As table 1 show, the amount of some destructive factors such as SAR and Pb has dramatically increased in the soil of plot irrigated with wastewater. The amount of these two factors in wastewater irrigated the plot is as twice as the control plot. In contrast, the amount of OC and N is lower in plot irrigated with wastewater in comparison to the control plot. The amount of some other factors including CaCO3, Cd, Fe and K is not considerably different in soil samples collected from the plots. The only amendatory factor that has dramatically increased in wastewater irrigated plot is phosphorus (P).

In this research obviously the most important effect of wastewater on irrigated soil would be dramatic increase of lead (Pb) and SAR. It must be mentioned that although, some metals are essential for plant growth, many are toxic especially at high concentration. Lead (pb) is a common toxic heavy metal, and its concentration on soil environment can cause serious problems for the plants. Examples of potentially toxic trace elements include mercury, lead, arsenic, copper, cadmium and manganese. Generally farmers grow leafy vegetables and those vegetables whose edible portions are root that flourish under or near the ground e.g., spinach, lettuce, radish, carrot, sugar beet, cabbage, cauliflower, etc.

Table 1. The amount of evaluated factors in soil and water samples collected from experimental plot and the related control one

Factors	Soil		Water	
	Exp. plot	Cont. plot	Exp. plot	Cont. plot
EC (ds/m)	1.95	1.76	0.95	0.78
pH	8.22	8.00	7.78	7.30
$CaCO_3$ (%)	28.56	27.38	-	-
OC (%)	1.08	1.53	-	-
N (%)	0.09	0.13	-	-
P (ppm)	17.68	6.61	0.37	0.23
K (ppm)	204.25	214.3	0.01	0.01
Fe (ppm)	4.55	4.50	0	0
Cd (ppm)	0	0	0	0
Pb (ppm)	4.52	2.36	0.01	0
SAR	5.21	2.75	4.50	1.20

This can accumulate higher amounts of heavy metals like cadmium, lead, zinc, copper, nickel and manganese on the vegetables. Australian Capital Territory Government on Environmental Protection Policy Act has specified the maximum concentration of some metals in irrigation water. In this act the maximum concentration of Pb is 0.2 mg/l. For the studied wastewater the amount of Pb is 0.01 ppm which equals about 0.1 mg/l. The difference between two plots soil samples in term of Pb indicates considerable effects of wastewater on soil Pb increase. During five years irrigation with wastewater the amount of Pb has been doubled in experimental plot. As table 1 shows it has been increased from 2.36 ppm (in control plot) to 4.515 ppm (in experimental plot). This clearly indicates the risk of soil contamination especially in long term irrigation using the industrial wastewater. Comparison of the findings of present research to El-Arby and Elbordiny (2006) shows that in El-Arby and Elbordiny (2006) wastewater has significantly increased the amount of Fe, Zn, Cu, Co, Ni and Pb. In present research wastewater has also significantly increased the amount of Pb.

Irrigation with raw sewage containing high level of trace elements and heavy metals is likely to be toxic to plants and also poses risk to human health. Heavy metal in sewage effluent in most developing countries is mainly related to the mixing of domestic and industrial wastewater in the same sewage system.

Studies in China, Japan and Taiwan indicate that the rice accumulated high concentrations of cadmium and other heavy metals when grown in soils contaminated with irrigation water containing substantial industrial discharges. These examples indicate that certain food crops have a higher possibility of transferring heavy metals to humans. Most heavy metals are carcinogenic and cause mental disorder, respiratory problems and hormonal imbalance. A more dangerous consequence of raw wastewater is transmission of heavy metals through animal milk into human as fodder grown by polluted water accumulates higher quantities of heavy metals in animals. Soil sampling in different studies has confirmed that chromium and other heavy metals accumulate in the soil, with very little passing below a depth of 0.3 m. It is thus not necessarily the most toxic components of an effluent which poses the main threat to groundwater, and this example highlights the importance of understanding pollutant transport in the subsurface. Moreover, increasing industrialization is changing the composition of wastewater, raising the level of heavy metals, acids and the like which impacts soil and crops. Groundwater contamination from nitrates and other pollutants including heavy metals is another potential danger, and many such problems are irreversible. Heavy metals, therefore, remains concern especially in instances where industrial effluent is an important factor. In addition, health risks of heavy metals can be looked at from an occupational hazard point of view where chemical pollutants in wastewater can cause harm to farmers as a result of direct contact with water during farming.

It must be mentioned that Gerhart et al, (2006) has concluded that industrial wastewater has increased soil salinities, and in long time will cause serious risks for plants. A comparison between the findings of this research and Gerhart et al (2006) shows that in both studies industrial wastewater has changed soil chemical but in Gerhart et al (2006) it has only increased the soil salinities in some plots, however, in the present research in addition to relatively small increase in soil salinities, the rate of SAR has been considerably increased. The effects of higher SAR and EC on soil destruction are quite clear. As mentioned earlier the soil SAR has been considerably increased in plot irrigated with industrial wastewater, which indicates increase of Na in soil solution. Increase of soil SAR has unwanted effects on soil structure by decreasing soil infiltration rate. Low infiltration rate causes more runoff in the field and reduces irrigation efficiency. Soil structure destruction also reduces soil aeration which results in oxygen deficit for plants root after irrigation, and if this condition continues for a longer time suffocation may occurs. Moreover, increase of Na in soil solution can directly cause toxicity for the plants (especially in its high concentration). Therefore, to be able to use such wastewater for irrigation amendatory materials containing Ca such as $CaSo_4.2H_2O$ must be added to balance the rate of Na to Ca in soil solution which reduces the effects of high SAR rate. However, long-term use of saline and sodium-rich water tends to destroy soil structure and reduces productivity. Consequently, in arid areas this condition will result in activation of desertification process. As it is seen from table 1 and figures 2 and 3, SAR has been increased from 2.75 in control plot soil to 5.21 in the soil of experimental plot. It needs to be mentioned that the environmental impacts of wastewater irrigation varies considerably from city to city depending on industrialization, type of industry, nature of water distribution and the degree of treatment and dilution if any. Environmental impacts of wastewater irrigation also raise doubts about its long-term sustainability and include visual untidiness, soil erosion, and destruction of vegetation, silting, depletion and pollution of land and water resources. However, the use of wastewater in agriculture helps water conservation. Sewage use scheme, if properly planned and managed can have positive environmental impacts. Some degree of treatment must normally be provided to raw wastewater before it can be used for irrigation. For local governments, using treated wastewater for irrigation can be beneficial, as an economically feasible and environmentally sound method of disposing sewage.

The management of wastewater through treatment has two major objectives. The first is to protect the environment by reducing the pollution of freshwater resources and productive lands and hence reducing health hazards. The second is to mobilize this available water resource for mitigating water scarcity and improving crop production. Properly treated sewage effluent can be used for groundwater recharge, aquaculture and irrigation of lawns and urban recreational parks and other non-potable uses. The best approach will need to balance both beneficial and concerns.

5. Conclusions

The results obtained from this research show that unfortunately industrial wastewater (evaluated in this research) can not be easily used for irrigation purposes because it increases soil salinity, and contamination (due to Pb increase), and it also decreases soil fertility.

The findings of the case study illustrate that although wastewater use is a critical aspect of urban farming and green space expansion especially in dryland environments suffering from water scarcity, but the potential of soil destruction risks will likely be serious. It is imperative to acknowledge this practice and explore options for safe wastewater use. It is argued that searching for appropriate and realistic options for wastewater use should look at how best to exploit the productive potential of this resource, while minimizing associated risks. These options will be a combination of technological development, social interventions and institutional support. In future, water shortage and wastewater handling would be a major challenge. The result of increased attention to this issue is expected to improve the health, economic and agricultural factors of developing community in relation to wastewater treatment and re-use in agriculture.

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