WFL Publisher
Science and Technology
P L Box 48, FI-00981
Helsinki, Finland
e-mail: contact@wflpublisher.com

Journal of Food, Agriculture & Environment Vol.19 (2):131-136. 2022 *www.wflpublisher.com*

Effects of wastewater irrigation on soil physical and chemical properties

Sudesh Bhaskar Ghoderao[1] and Sarita Gajbhiye Meshram [2*]
Department of Chemistry, RNC Arts, JDB Commerce and NSC Science College, Nasik Road, Nasik, Maharastra, 422101, India.
Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam.
**email: gajbhiyesarita@gmail.com, sudeshghoderao@gmail.com*

Received 3 February 2022, accepted 28 March 2022.

Abstract
A growing number of scientists believe that using wastewater to irrigate crops is an effective way to reduce soil deterioration and restore soil nutrient content. Following long-term irrigation with wastewater, this study examined soil and ground water composition. Organic carbon (OC), manganese (Mn), iron (Fe), sodium (Na), copper (Cu), total alkalinity (TA) and zinc (Zn) were found in soil samples collected at the surface and 30 cm below the surface. Due to salt and poisonous metal concentrations from wastewater application to soil, it is vital to study the long-term impacts of wastewater concentration on soil salinity and toxic metal concentrations.

Key words*:* Irrigation, soil properties, wastewater, water quality.

Introduction

As the global population continues to rise, industrial and agricultural activities to increase food supplies, as well as a string of droughts in recent years have pushed water resources in arid and semi-arid countries to their limits. This is why it is important to explore any sources of water that can be used economically and effectively.

Worldwide, wastewater is used to irrigate agricultural land. Developing countries, whose water treatment expenses are prohibitive, are particularly susceptible to this [1]. Enhanced living standards in industrialized societies have resulted in a rise in waste items that may lead to contamination of the environment. Even though pollution prevention is costly, recycling trash is a particularly effective way to combat it [2]. A more cost-effective option to wastewater disposal is to use it on agricultural lands, where it improves nutrient cycling while also posing a risk to soil quality and production in the long run [1].

Since it contains so many different nutrients, wastewater irrigation is a great way to add a variety of essential macro- and micronutrients to the soil. These include nitrogen, phosphorus, potassium, zinc, iron, manganese, and copper (Cu) [3]. Wastewater may include a significant amount of organic matter, making it a valuable source of organic matter for soils and a stimulant for plant growth [4].

Soil type, wastewater properties, and the irrigated soil's vegetation all influence how wastewater application affects the environment. Water irrigation may alter soil qualities, including physical and chemical as well as biological properties. Applied wastewater contains nutrients that can be transformed by soil qualities [5]. Wastewater application to farmland and forestland is an attractive option for disposal since it can improve soil physical and nutritional qualities [6, 7]. There is a concern regarding the accumulation of potentially harmful metals such as Cd, Cu, Mn, Pb, and Zn from both home and industrial sources in the soils that are irrigated with wastewater. The amount of these elements in wastewater is the most important factor in determining how much of it can be used. As far as public concern goes, the uptake of trace elements by plants cultivated in wastewater-irrigated land is a major one [8]. The possible absorption by grazing animals of these components from soil under wastewater irrigation is also a cause for worry in terms of toxicity. As a result, it is imperative that the buildup of certain hazardous metals in plants and the consumption of contaminated water by farm animals be thoroughly investigated [9].

Reducing the demand for costly inorganic fertilizers and enhancing soil fertility and crop yield can be achieved by using wastewaters [10]. Reusing agricultural waste water to reduce pressure on freshwater supplies has been a common practice for centuries [11]. Wastewater use, regardless of its benefits, may have an impact on soil physical and chemical qualities and, ultimately, agricultural yields [12-15]. Soil salinization (an increase in sodium ions relative to other cations) and the accumulation of heavy metals in the soil and crops can result from the use of wastewater in agriculture. This can pose a long-term health risk to humans. On the basis of the source of the wastewater, treatment methods used, and the soil's natural properties, this may or may not happen[3, 16].

An investigation into how industrial wastewater irrigation affects soil and groundwater quality was the goal of this project (macro and micronutrients, heavy metal content).

Materials and Methods

Location: For this investigation, the city of Jabalpur was chosen. The experiment is based on industrial waste as a point source (Vehicle factory nala). Jabalpur has a sub-tropical, sub-humid

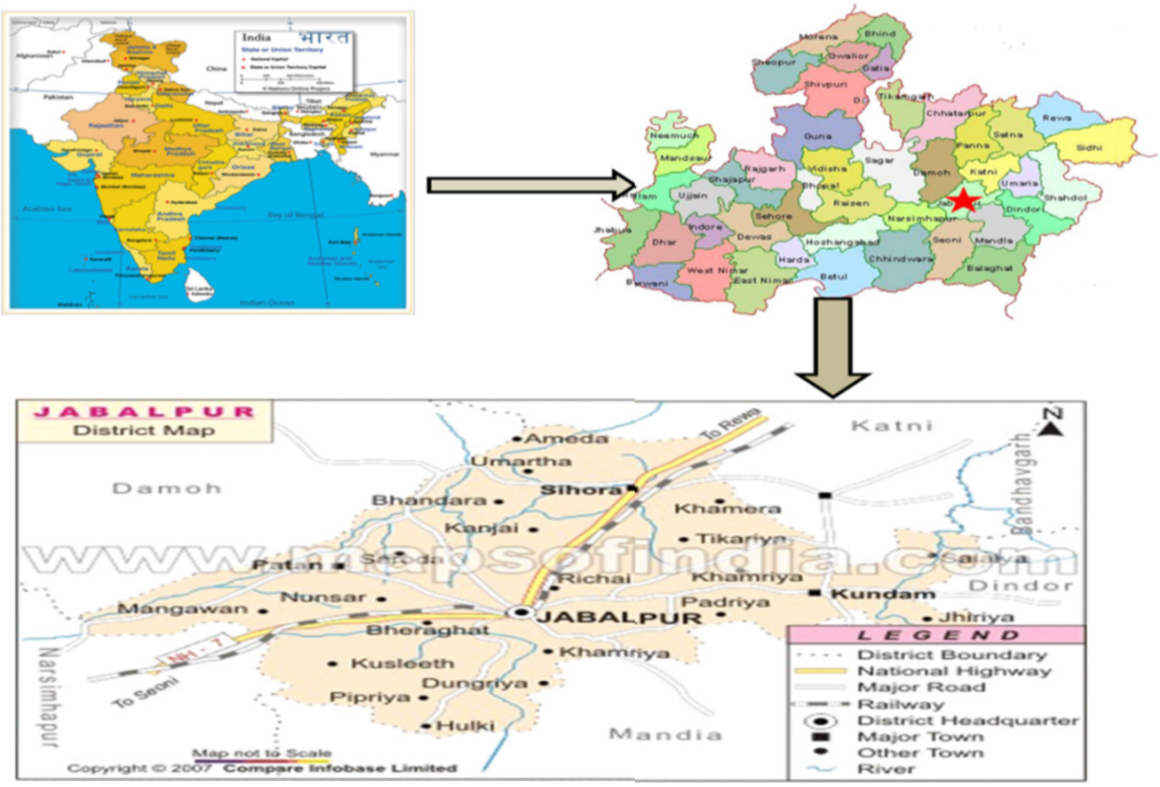

Figure 1. Location map of the study area.

climate and is located on the Kymore plateau and Satpura hills in the agro-climatic area at 2309" latitude and 79058" E longitude, at an altitude of 411.78 m above mean sea level, with hot, dry summers and chilly, rainy winters. The temperature drops below freezing point in the winter and reaches as high as 460 degrees in the summer, making the environment of this location rather harsh. The study area's location map is depicted in Fig. 1.

Sampling: During the pre-monsoon season of 2018, water samples from industrial waste (vehicle nala) were collected from open wells, bore wells, and tube wells. In a plastic container, a sample of water was collected. As specified in Standard Methods for the Examination of Water and Wastewater, all samples were collected, maintained, and stored for analysis [17]. Before seeding, a 30 cm deep soil sample was taken from the research area with a hand auger.

Analytical methods: Wastewater samples were processed for examination using a temperature programme based on the Milestones Cookbook of microwave application notes for MDR technology and an acid digestion beforehand. Na and K contents were determined using the atomic emission method, Fe, Al, Cu, and Mn contents were determined using the atomic absorption spectroscopy method, and chloride (Cl), sulphate (SO_4), nitrite, and nitrate contents were determined using the ionic chromatography method in wastewater and drinking water samples. The APHAAWWA-WPCF method [17] was used to determine N-Kjeldahl, total P, BOD5, COD, electrical conductivity, carbonate and bicarbonate, IC (inorganic carbon), and TOC (total organic carbon).

The pH and electrical conductivity (EC) in saturation extract (1:2.5 suspension of solid in water), pH with a previously calibrated pH meter [18], EC with a previously calibrated conductive meter [19], organic matter content with the Walkley and Black method [20], total nitrogen (N) by the Kjeldahl procedure, and available phosphorus (P) by the Kjeldahl procedure [21] were determined. According to Milestones Cookbook of microwave application notes for MDR technology, the soil was acid digested for various parameters and metal measurements. Na and K were afterwards determined using atomic emission spectroscopy in an atomic absorption spectrometer, while Ca, Mg, Fe, Zn, Mn, Cu, Ni, Cr, Cd, As, Hg, and Pb were determined using atomic absorption spectroscopy in an atomic absorption spectrometer [22].

Results and Discussion

Physical properties of water at source: Physical properties of waste water obtained from industrial waste (Nala near Vehicle factory) were evaluated for pH and electrical conductivity (Table 1).

The pH scale measures the acidity or alkalinity of water as well as the concentration of hydrogen ions. The pH has no direct negative impact on one's health. Trihalomethanes, which are poisonous, are formed when the pH is too high. Corrosion begins in pipes when the pH falls below 6.5, releasing hazardous metals such as Zn, Pb, Cd, and Cu. The pH value of water sample of the Vehicle Nala is 7.42. This value is within the prescribed limit of WHO and also in safe range of pH for irrigation water i.e 6.5-8.5.

Electrical conductivity (EC) is a quick way to figure out how much ionized stuff is in a given amount of water. The water recovered from the Vehicle Factory Nala has an average EC of 1.11 dS/m, which is in the High category according to USSSL but suitable for irrigation.

Table 1. Physico-chemical properties of waste water at surface and ground water.

Parameters	Units	At Source	Ground water	Percentage Change
pH		7.42	7.47	-0.66
EC	(dS/m)	1.11	1.11	0.26
Cu	(mg/l)	0.4	0.18	55
Cr	(mg/l)	0.08	0.03	62.5
SO_4	(mg/l)	47	31.57	32.89
Fe	(mg/l)	0.52	0.18	65.38
NO_3	(mg/l)	0.45	0.27	40
Chloride	(mg/l)	75	44.71	40.38
TH	(mg/l)	280	232.85	16.83
TA	(mg/l)	710	530.85	25.23
Na	(mg/l)	130	109	16.15
Cl	(mg/l)	0.67	0.53	20.89
Br	(mg/l)	2.01	1.68	16.41
Iodine	(mg/l)	1.08	1.01	6.48
NH_4-N	(mg/l)	4.12	2.57	37.62
PO_4	(mg/l)	3.16	1.42	55.06
Si	(mg/l)	4.26	3.04	28.63
NO_2-N	(mg/l)	0.01	0.001	90
Su	(mg/l)	0.02	0.02	0
Zn	(mg/l)	0.86	0.38	55.81
RSC	(me/l)	4.3	2.98	30.69
SAR	millmole/l	1.09	1.01	7.92

Chemical properties of waste water: Chemical properties of waste water obtained from Industrial waste (Nala near Vehicle factory) are presented in Table 1.

Copper (Cu): The higher concentration of Cu can be related to anemia, digestive disturbance, liver and kidney damage, bitter and metallic taste, blue green or plumbing fixture diseases. The copper in Vehicle Factory is 0.40 mg/l. The copper is within the permissible limit as per WHO.

Chromium (Cr): Cr causes skin irritation, ulcers, lung tumors, gastrointestinal consequences, nervous system damage, and circulatory system harm. In the water recovered from the Vehicle Nala, a value of Cr (0.08 mg/l) was detected.

Sulphate: Drinking water with a sulphate level of more than 400 mg/l has a bitter, medicinal flavor and can produce gastric discomfort and catharsis. The SO_4 value of the Vehicle Nala's water sample (Table 1) is 47 mg/l. This SO_4 level is within the WHO's recommended range.

Iron (Fe): Fe occurs in water either as ferrous Fe or as ferric Fe. Plant growth, especially vegetable growth, benefits from a tiny amount of Fe. Large quantities cause unpleasant, metallic, bitter taste and favour the slimy growth of iron bacteria. The value of Fe (0.52 mg/l) was recorded (Table 1) in the water obtained from the Vehicle Factory. The iron concentration of water sample is within the permissible limit as per WHO.

Nitrate (NO_3): Nitrate is a contaminant found in ground water as a result of sewage percolation under the surface. Organic sources of nitrate, as well as industrial and agricultural pollutants, are found in natural water. Nitrate encourages growth of organism like algae that cause undesirable taste and odour. The nitrate concentration in excess of 45 ppm may cause methenoglobinemia in infants (blue babies). The highest value of NO_3 is 0.45 mg/l for Vehicle Factory. The nitrate concentration is within permissible limits as per WHO. Presence of nitrate in water indicates the final stage of mineralization. The increase in nitrate nitrogen in the effluent is undesirable as it pollutes the ground water. The higher nitrate nitrogen content in the water causes eutrophication.

Chloride: Chloride is a minor constituent of the earth's crust but a major dissolved constituent of most natural waters. Corrosion of metals in the distribution system is accelerated by high chloride concentrations. The chloride concentration of a Vehicle Factory water sample is 75 mg/l. According to WHO, the chloride content is within the allowed range.

Total hardness (TH): Hardness refers to the feature of water that prevents soap from lathering. The total hardness of water is due to presence of cations Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and anions HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-. Human cardiac disease is influenced by water hardness. The value of TH (280 mg/l) was recorded.

Total alkalinity (TA): Hydroxide, carbonate, and bicarbonate are the main sources of alkalinity in natural water. Alkalinity is not detrimental to humans in and of itself. The water sample has a total alkalinity of 710 mg/l. Water sample from Vehicle Factory has shown higher as per the permissible limit as prescribed by WHO.

Sodium (Na): Sodium is an important element when salinity or total dissolved solids (TDS) are considered in the use of water. Many irrigation water quality criteria like SAR, sodium percent are based on the sodium. According to the National Academy of Science, greater sodium levels are linked to cardiovascular disease and pregnancy-related toxaemia in women. Water sample of Vehicle Factory is found within the permissible limit given by WHO.

Residual sodium carbonate (RSC): The RSC of Vehicle Factory is 4.30 meq/l and given in Table 1. The RSC value for Vehicle Factory comes under high category as per IS: 11624 – 1986, but it is fair for irrigation purpose. The RSC content of water depends upon the carbonate and bicarbonate contents of water and the concentrations of calcium and magnesium.

Sodium adsorption ratio (SAR): The SAR of Vehicle Factory is 1.09 millimole/l. The SAR of water depends on the sodium content of water and total hardness of water. The SAR of water sample is low class (less than 10 USSSL). Than SAR point of view water sample are excellent for irrigation purpose.

Other parameters and micro nutrients: Some of the other parameters and micro nutrients like chlorine, bromine, iodine, ammonium nitrogen, phosphate, silica, nitrite, sulfite and zinc are presented in Table 1.

Effect on ground water due to polluting source: Water quality analysis of waste water has been discussed in the previous section. When this water is applied over a field as irrigation or percolate down right from the source itself causes contamination to ground water in long term. The intensity of contamination depends mainly on intensity of impurity of waste water at the source, the length of time for which this problem exists and the strata of soil through which it passes before joining the ground water. In order to assess the effect on ground water quality. Ground water samples from near open well, hand pumps and tube wells were collected and analyzed.

It is suspected that the ground water might have got polluted due to the polluting sources; therefore the physico-chemical properties of ground water were determined. The possible effect on ground water due to source was calculated in terms of percentage reduction change as:

$$Percentage\ Change = \frac{(Ps-Pg)}{Ps} * 100 \quad (1)$$

where, Ps = Value of parameter in sources, Pg = Value of parameter in ground water.

Physical properties of ground water: Physical properties of waste water obtained from industrial waste (Nala near Vehicle factory) are presented in Table 1.

pH: The pH value of ground water 7.47 (Vehicle Factory) was increased against at the sources with 7.42. All these values come under the permissible limits as per WHO standard.

Electrical conductivity: The EC value registered same in ground water and surface water (1.11 dS/m).

Chemical properties of ground water: Chemical properties of ground water obtained from Industrial waste (Nala near Vehicle factory) are presented in Table 1.

Copper: The value of copper was 0.18 mg/l in ground water sample, which is 55% lesser than in the waste water source. The safe limit of copper 0.05-1.5 mg/l suggest that ground water of these sites falls under safe category for copper point of view.

Chromium: The value of chromium was 0.03 mg/l in ground water sample, which is 62.5% lesser than in the waste water sources. The safe limit of chromium is 0.05 mg/l and suggests that ground water of these sites comes under the safe category.

Sulphate: The value of sulphate was recorded 31.57 mg/l which is 32.89% lesser than the waste water source (Table 1). All samples come under the permissible limit as per Standard of WHO and suggest that ground water of these sites is under the safe category for sulphate point of view.

Iron: Iron in the ground water sample was 0.18 mg/l. These ground water samples showed 65.38% lesser values than the waste water at source (Table 1). The safe limit of iron is 0.3-1.0 mg/l and suggest that ground water of the locality under the safe category in iron point of view.

Nitrate: The NO_3 concentration was maximum 0.27 mg/l in ground water. The percentage reduction change in the NO_3 was 40% . All samples of ground water falls under the permissible limits. The safe limits of NO_3 is 45-100 mg/l.

Chloride: The value of chloride in ground water sample was 44.71 mg/l. The percentage reduction change in ground water from source is 40.38. The safe limit of chloride is 250-1000 mg/l.

Total hardness: The value of total hardness in the ground water was 232.85 mg/l. The percentage reduction change from 16.83% was obtained. All ground water samples come under the permissible limit (300-600 mg/l) as per WHO standard.

Total alkalinity: The concentration of total alkalinity of ground water sample was 530.85 mg/l. The ground water sample was 25.23% lesser than the waste water source. The safe limit of TA is 200-600 mg/l.

Sodium: The concentration of sodium in ground water sample was 109 mg/l. This value is 16.15% lesser than the waste water at source (Table 1). The permissible limit of Na is 200 mg/l.

Residual sodium carbonate: The RSC value of ground water sample was 2.98 me/l. The percentage change is 30.6% (Table 1). As per CGWB and CPCB (2000) the value of RSC is low, which comes under the good class of water for irrigation point of view.

Sodium adsorption ratio: The SAR value of ground water sample was 1.01 millimole/l (Table 1). The percentage change is 7.3%. According to CGWB and CPCB (2000) ground water samples are excellent quality for irrigation point of view.

Other parameters and micro nutrients: Element of halogen group i.e. Cl, Br and iodine decreased when percolate down to the ground water (Table 1). There was considerably decrease in NH_4-N and NO_2-N was leached down to the ground water, the soil prevailing was capable of filtering about 18-90% of this material. The NH_4-N decreasd from 37.62% (Table 1). The NO_2-N was reduced 90% in the ground water samples collected from Vehicle Factory. The PO_4 concentration was 1.42 mg/l in ground water. The percentage change in the concentration of PO_4 was 55.06%. The Si concentration was 3.04 mg/l in ground water. The percentage change in the concentration of Si was 28.63%. The value of Zn was same as ground water as well as water source. The Zinc concentration decreased in the ground water sample in comparison to the waste water source.

Water quality refers to the physical, chemical and biological qualities of a water supply that impact its acceptability for a certain use. Specific purposes require different levels of quality, and a water supply is seen more acceptable if it gives better outcomes or creates fewer difficulties than an alternative water supply[23] . The kind and quantity of dissolved salts in irrigation water can have a significant impact on its quality. Ayers and Westcot [24] provide guidelines for evaluating water quality for irrigation in Table 2. These recommendations are practical and have been used successfully in irrigated agriculture for analysing surface water, groundwater, drainage water, and wastewater constituents [25].

Soil impairment due to waste water irrigation: Soil samples were collected from areas where irrigation from different polluting sources is in practice. The physico-chemical properties of these samples were determined. The results obtained from different test

Table 2. FAO recommendations for maximum concentration in irrigation water[24].

Parameter	Max. value	Parameter	Max. concentration (mg/l)
pH	6.5-8.5	Cadmium	0.01
EC (dS/m)	3.0	Chromium	0.10
Total dissolved solids (mg/l)	2000	Cobalt	0.05
HCO_3 (mg/l)	600	Copper	0.10
SO_4 (mg/l)	1000	Iron	5.0
Cl (mg/l)	1100	Manganese	0.2
Mg (mg/l)	60	Nickel	5.0
Na (mg/l)	90	Lead	2.0
SAR (mmol/l)	<10 excellent, 10-18 good 18-26 fair, >26 poor		

Table 3. Physico-chemical properties of soil.

Parameters	Units	Soil Depth	
		0 cm	30 cm
pH	-	8.0	7.5
EC	(dS/m)	0.9	0.4
OC	(g/kg)	9.7	15.0
Av.N	(ppm)	310.0	405.0
Av.P	(ppm)	28.6	31.3
Av.K	(ppm)	578.5	490.6
Av.S	(ppm)	4.2	4.2
Zn	(ppm)	20.9	20.1
Fe	(ppm)	10.3	14.3
Mn	(ppm)	15.0	3.1
Cu	(ppm)	971.0	856.0
TA	(ppm)	125.0	110.0
Na	(ppm)	87.0	65.0
NH_4-N	(ppm)	59.0	63.0
NO_3-N	(ppm)	27.8	29.3

Table 4. Soil parameters limits.

Class	OC (g/kg)	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (mg/kg)
Low	<5	<250	<10	<200	<10
Medium	5-7.5	250-500	10-20	200-400	10-20
High	>7.5	>500	>20	>400	>20

Critical limits: Zn = 0.5 mg/kg, Cu =<0.5 mg/kg, Fe = 2.5 - 4.5 mg/kg, Mn = 3.5 mg/kg

samples were compared with standard norms presented in Table 4. Salient results are presented in Table 3.

pH: The pH value of soil is an important parameter, which need to be controlled for the maintenance of the soil fertility as it is directly influenced by availability of nutrient. Brady [26] has specified that slightly acidic and slightly alkaline condition is supposed to be best from fertility point of view. The pH value was 8.0 for surface soil and at 30 cm depth 7.5.

Electrical conductivity: Electrical conductivity of soil is related to the total dissolved salt content and is therefore a reliable index of salization. The EC value was found 0.85 dS/m at the surface of soils. At 30 cm depth the value of EC was slightly lower.

Organic carbon: Soils of near Vehicle Nala have high organic carbon both on the surface and at the depth below 30 cm.

Available nitrogen, potassium and phosphorus: Soils irrigated by waste were moderate in nitrogen at surface and 30 cm depth. The value of nitrogen was 310 ppm (at surface) and 405 ppm (30 cm depth). Similarly, soils near Vehicle Factory Nala is sufficiently high in potassium and phosphorus at surface and 30 cm depth. Soils irrigated by waste water of Vehicle Factory Nala were low in sulphur as it ranges below 10 ppm.

*Micro nutrient sand other parameters:*The waste water irrigated soils showed sufficient values of zinc, iron and manganese. Higher values of Zn, Mn, Cu, Na, TA were at surface than at the 30 cm depth, while Fe, NH_4-N, NO_3-N had higher values at 30 cm depth than surface soil.

Conclusions

The physical and chemical properties of soils are affected by long-term wastewater irrigation. The results demonstrated a considerable decrease in pH, EC and micronutrients when compared to surface waste water and ground water. In order to conserve non-renewable resources, soil deterioration in semi-arid areas must be addressed. As a possible source of nutrients, wastewater irrigation can be utilized as an organic fertilizer to improve the physical and chemical qualities of soils. The buildup of immobile heavy metals in soils is a key drawback of wastewater irrigation. Heavy metal contamination should be researched further to establish the lingering effects of wastewater before it is used for land restoration or as a fertilizer. In order to achieve sustainable agriculture, consistent assessments of both irrigation water and irrigated soils are required to avoid the detrimental impacts of applied wastewater. Furthermore, in order to attain improved soil qualities in the research region, remediation procedures and management plans are required.

Declarations

Ethics Approval and Consent to Participate: Not applicable.
Consent for Publication: Not applicable.
Competing Interests: The authors declare that they have no competing interests.

References

[1]Friedel, J.K., Langer, T., Siebe, C. and Stahr, K. 2000. Effects of long-term wastewater irrigation on soil organic matter, soil microbial biomass and its activities in central Mexico. Biol. Fertil. Soils **31**:414-421.

[2]Couillard, D. 1995. Dynamics of municipal wastewater sludges on forest land. J. Environ. Systems **24**(1):25-46.

[3]Ganjegunte, G., Ulery, A., Niu, G. and Wu, Y. 2018. Organic carbon, nutrient, and salt dynamics in saline soil and switchgrass (*Panicum virgatum* L.) irrigated with treated municipal wastewater. Land Degrad. Dev. **29**(1):80–90.

[4]Ofori, S., Puškácová, A., Ru•icková, I. and Wanner, J. 2021. Treated wastewater reuse for irrigation: Pros and cons. Sci. Total Environ. **760**: 144026.

[5]Magesan, G.N., Williamson, J.C., Sparling, G.P., Schipper, L.A. and Lioyd-Jones, A.R. 1999. Hydraulic conductivity in soils irrigated with wastewaters of deferring strengths: Field and laboratory studies. Aust. J. Soil Res. **37**:391–402.

[6]Pomares, F., Roca, J., Tarazona, F. and Estale, M. 1984. Aerobically digested sewage sludge as N and P fertilizer. In Processing and use of sewage sludge. Dordecth: Reidel. (Commission of the European Communities). pp. 313-315.

[7]Sommers, L.E. 1977. Chemical composition of sewage sludges and analysis of their potential use as fertilizers. Environ. Qual. **6**:225-229.

[8]Seaker, E.M. 1991. Zinc, copper, cadmium and lead in minespoil, water and plants from reclaimed mine land amended with sewage sludge. Water Air Soil Poll. **57-58**:849-859.

[9]Pescod, M.B. 1992. Wastewater treatment and use in agriculture. FAO Irrig. Drain. Pap. 47, Rome, Italy.

[10]Mukherjee, S. and Nelliyat, P. 2007. Ground Water Pollution and Emerging Environmental Challenges of Industrial Effluent Irrigation: A Case Study of Mettupalayam Taluk, Tamilnadu; Madras School of Economics Working Paper 52 p. Available online: https://ssrn.com/abstract=1021153 (accessed on 9 August 2021).

[11]Hajjami, K., Ennaji, M.M., Fouad, S., Oubrim, N., Khallayoune, K. and Cohen, N. 2012. Assessment of helminths health risk associated with reuse of raw and treated wastewater of the Settat city (Morocco). Resour. Environ. **2**:193–201.

[12]Yadav, R.K., Goyal, B., Sharma, R.K., Dubey, S.K. and Minhas, P.S. 2002. Post irrigation impact of domestic sewage effluent on composition of soils, crops and groundwater: a case study. Environ. Int. **28**:481–486.

[13]Tarchouna, L.G., Merdy, P., Raynaud, M., Pfeifer, H.R. and Lucas, Y. 2010. Effects of long-term irrigation with treated wastewater. Part I: Evolution of soil chemical properties. Appl. Geochem. **25**:1703–1710.
[14]Saliba, R., Callieris, R., D'Agostino, D., Roma, R. and Scardigno, A. 2018. Stakeholders' attitude towards the reuse of treated wastewater for irrigation in Mediterranean agriculture. Agric. Water Manag. **204**: 60–68.
[15]Barber, L.B., Rapp, J.L., Kandel, C., Keefe, S.H., Rice, J., Westerhoff, P., Bertolatus, D.W. and Vajda, A.M. 2019. Integrated assessment of wastewater reuse, exposure risk, and fish endocrine disruption in the Shenandoah River watershed. Environ. Sci. Tech. **53**:3429–3440.
[16]Abd-Elwahed, M.S. 2018. Influence of long-term wastewater irrigation on soil quality and its spatial distribution Ann. Agric. Sci. **63**(2):191-199.
[17]APHA-AWWA-WPCF 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. American Public Health Association, Washington DC. USA.
[18]Peech, N. 1965. Hydrogen ion activity. In Black, C. A., Evans, D. D., White, J.L., Ensminger, L.E. and Clark, F.E. (eds). Methods of Soil Analysis.American Society of Agronomy, Madison, Wisconsin, pp.914-926.
[19]Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. In Sparks, R.L.(ed.). Methods for Soil Analysis, Part 3: Chemical Methods. Soil Science Society of America, Madison, pp. 417-435.
[20]Nelson, D.W. and Sommers, L.E .1996. Total carbon, organic carbon, and organic matter. In Page, A. L. *et al.*(ed.). Methods of Soil Analysis, Part 2. 2nd edn. Agronomy **9**:961–1010. Am. Soc. of Agron., Inc. Madison, WI.
[21]Olsen, R.L. and Dean, L. 1965. Phosphorus. In Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E.and Clark, F. E. (eds). Methods of Soil Analysis. American Society of Agronomy, Madison, Wisconsin, pp. 1035-1049.
[22]MAPA 1994. Ministerio de Agricultura, Pesca y Alimentacio´n, Me´todos oficiales de ana´lisis. Tomo III. Ed. MAPA, Madrid.
[23]Lockett, A.M. 2008. Impact of reuse water on golf course oil and turfgrass parameters monitored over a 4.5 year period. HortScience **43**:1942–2274.
[24]Ayers, R.S. and Westcot, D.W. 1985. Water quality for agriculture. Irrigation and Drainage Paper 29 (Rev. 1) Food and Agriculture Organization (FAO) of the United Nations. Rome, Italy.
[25]Quian. Y.L. and Mecham, B. 2005. Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways. Agronomy Journal **97**:717–721.
[26]Brady, N.C. 1984. The Nature and Properties of Soils. 9th edn. Macmillan Publishing Company, New York, 750 p.