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Chapter [10]

Effect of untreated wastewater on soil quality: A case study in Ranipur Rao watershed in Haridwar region (Uttarakhand), India

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Abstract

The current study seeks to assess the sustainability of soil by identifying the effect of wastewater on soil nutrient quality by using the nutrient index approach in different land uses in Ranipur Rao Watershed in the Haridwar region of Uttarakhand state. The vast majority of the wastewater produced in urban areas is treated proceeding to irrigation, while in low-income nations wastewater treatment is not important. Clean water irrigated soil samples from forest area were taken as control. Wastewater irrigated soil samples were taken from industrial and agricultural areas. Soil organic carbon (%) of soil ranged from 0.70-0.84 at clean water irrigated sites in the forest area. Whereas, 0.48-0.75 at wastewater irrigated sites in the industrial area and 0.53-0.79 at wastewater irrigated sites in the agricultural area. The content of available nitrogen in soil of agricultural wastewater irrigated area indicates high status as compared to industrial and forest areas. The circumstance consequently requests the selection of fitting administration rehearses to support the fruitfulness status in study territory. These practices may include such practices as site-specific nutrient management, increased use of organic nutrient sources, sustainable land use and cropping systems, and appropriate agronomic practices.

Keywords Land use, Nutrient index, Soil fertility, Wastewater, Watershed management

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Abbreviations: %: Percent, GPS: Geographical Positioning System, pH: Potential of Hydrogen, EC: Electrical Conductivity, cm: Centimeter, mm: Millimeter, AN: Available Nitrogen, AP: Available Phosphorus, AK: Available Potassium, AS: Available Sulphate, Ca: Calcium, Mg: Magnesium, Zn: Zinc, Cu: Copper, Fe: Iron, Mn: Manganese, SNI: Soil Nutrient Index, dS/m: DeciSiemens per metre; meq/100g: Milliequivalent/100gram; SD: Standard Deviation, gm: Gram.

Introduction

The population in the world is currently growing at a rate of around 1.05% per year (down from 1.08% in 2019, 1.10% in 2018, and 1.12% in 2017). The current average population increase is estimated at 81 million people per year (Tilley *et al*., 2014). In developing countries, the increasing requirement for freshwater in agricultural production is not limited to, But needs per person and also supplies the needed irrigate resources industry needs and priorities of the urban communities in these areas (Mohson and Ali, 2017). The discharge of raw sewage in the environment, contaminating the quality of surface and groundwater streamflow (Abedikoopayee *et al.,* 2003; Karimzadeh *et al.,* 2012). So, the use of treated wastewater in agricultural areas decreases the use of water, which in addition to other practices, such as household works like bathing, washing, and maybe drinking (Alikhales and Smalzadeh, 2010; Kumar *et al*., 2018).

The vast majority of the wastewater produced in urban areas is treated proceeding to irrigation, while in low-income nations wastewater treatment is not important. Thus the combination of treated, partially treated, and untreated wastewater is commonly used for agricultural purposes (Hussain *et al.,* 2002). The World Health Organization estimates that nearly 20 million hectares throughout the world are irrigated using untreated wastewater (WHO, 1989).

In wastewater, the occurrence of organic, inorganic, and microbial contaminants is an earlier stage of depuration is necessary before reuse in irrigation. To evade the contamination of soil, crops, and adjacent water resources and accordingly the dispersion of waterborne diseases or the degradation of soil. The extent to which wastewater has to be treated before irrigation depends on the limitations established in local or international water quality criteria for irrigation (Kretschmer *et al*., 2002). Soil, the source of life, is the most essential and valuable natural resource which is not renewable quickly. Soil quality is a measure of the form of soil components with the necessities of at least one biotic species as well as to human need or use (Johnson *et al*., 1997). Soil fertility is a dynamic natural property that can alter through the impact of natural and human-derived factors (Kavitha and Sujhata, 2015). Changes in soil properties in different land use maybe because of dynamic collaborations among ecological factors like weather, parent material, geography, and land use, and land cover (Bharti and Kamboj, 2018). The fertility of the soil is determined by the presence or absence of nutrients which have agronomic importance (Lone *et al*., 2016). Soil nutrient composition plays a key role in determining the goodness of the soil. Healthy soil will have all the essential elements in the right proportions to support healthy plant growth throughout its life cycle (Art Efretuei, 2016). Degradation of soil quality has posed a threat to agricultural productivity, economic growth, and a healthy environment on a global scale (Eswaran *et al*., 2001). Different types of wastewater use in different land-use irrigation that also affect the biodiversity of soil (Bharti and Kamboj, 2020).

Maintaining soil health and sustainable agricultural production, replenishment of macro and micronutrients, and addition of soil amendments is a must in the soil to obtain good crop yields. If their status in the soil is known before the crop is sown, it provides a sound basis for determining the nutrient requirements for the desired production (Amara *et al*., 2016*)*. The extent of the beneficial impacts depends on the local conditions of the specific project. The fundamental negative part of reusing treated and untreated wastewater in agricultural areas is the contamination of soil systems, the likely defilement of yields and water resources, and the intrinsic risk of harmful impacts that pollution stances to the unprotected living beings (Juan *et al*., 2014). Nowadays, under freshwater scant conditions, it becomes almost obligatory for farmers to consider and use any sources of water, especially in many regions (Kumar *et al*., 2020).

So, Adoption of appropriate land use management practices and land use planning would help to minimize the degradation in soil physical quality and would ensure sustainable crop production and productivity (Ramesh *et al*., 2008). Therefore, this investigation was made to study the effect of wastewater on the soil in different land use in district Haridwar (Uttarakhand). The nutrient index was calculated to show the level of contamination in soils at wastewater-irrigated different land-use sites.

Study area

The present study was carried out in three different land-use types i.e. forest area, industrial area, and an agricultural area in Ranipur Rao seasonal hill river watershed area in the Haridwar region (Uttarakhand). The selection of the study area was based on their land-use patterns and type of irrigation in the land.

Sample collection, preparation, and preservation

The soil samples were collected from 0-15 and 15-30 cm. depth with the help of an auger from March 2017 to February 2018, using the GPS locations in 3 different areas. Composite soil sampling was done inside each land-use area and mixed thoroughly following a standard method for sample preparation (Andreas and Berndt, 2005). All the collected soil samples were air-dried after analyzed pH and EC and then soil samples were dried in shade, crushed with motor and pestle, and then sieved through a 2.0 mm sieve. The dried soil samples were stored for further analysis of the physical, chemical, and nutrient characteristics of soil samples.

Physico-chemical and nutrient analysis of soil

A total of 13 physico-chemical and nutrient characteristics, pH, electrical conductivity, organic carbon, available nitrogen, available phosphorus, available potassium, available calcium, available magnesium, available sulphate, available zinc, available iron, available manganese, and available copper were analyzed in the laboratory, following the standard methods (Jackson, 1958; Trivedy and Goal, 1998; Anderson and Ingram, 1993; Behera, 2014).

Soil nutrient index determination:

To evaluate the fertility status of soils in the study area, different soil physico-chemical characteristics that affect nutrient availability including pH, electrical conductivity, available N, P, K and S, exchangeable Ca and Mg, and available micronutrients (Zn, Cu, Fe, and Mn) were calculated based on the specific rating chart (Table 1) modified from Brajendra *et al.* (2014). Soil nutrient index (SNI) was worked out to depict the available status of each macronutrient at a series level by using the formula proposed by Parker's *et al*. (1951):

$$\mathrm{SNI} = \frac{(\mathrm{Nl} \times 1) + \mathrm{Nm} \times 2 + \mathrm{Nh} \times 3}{2\mathrm{Nt}}$$

Table 1. Rating chart for soil test values and their nutrient indices.

Soil property	Unit	Range		
Soil pH	pH unit	< 6.0 (Acidic)	6.1-8.0 (Neutral)	>8.0 (Alkaline)
Electrical conductivity	dS/m	<1.0 (Normal)	1.0-2.0 (Critical)	>2.0 (Injurious)
Organic Carbon	%	<0.5 (Low)	0.5-0.75 (Medium)	>0.75 (High)
Available Nitrogen (N)	kg/ha	<280 (Low)	280-560 (Medium)	>560 (High)
Available Phosphorus (P_2O_5)	kg/ha	<10 (Low)	10-25 (Medium)	>25 (High)
Available Potassium (K_2O)	kg/ha	<110 (Low)	110-280 (Medium)	>280 (High)
Available Sulphur (S)	Ppm	<10 (Low)	10-30 (Medium)	>30 (High)
Exchangeable Calcium (Ca)	meq/100g	<1.5 (Low)	1.5-4.5 (Medium)	>4.5 (High)
Exchangeable Mg	meq/100g	<1.5 (Low)	1.5-4.5 (Medium)	>4.5 (High)
Available Zinc (Zn)	Ppm	<0.6 (Low)	0.6-1.0 (Medium)	>1.0 (High)
Available Manganese (Mn)	Ppm	<0.07 (Low)	0.07-0.2 (Medium)	>0.2(High)
Available Iron (Fe)	ppm	<4.5 (Low)	4.5-5.5 (Medium)	>5.5 (High)
Available Copper (Cu)	ppm	<0.07 (Low)	0.07-0.2 (Medium)	>0.2(High)
Nutrient Index	Index	I	II	III

Table 2. Nutrient index with range and remarks.

Nutrient Index	Range	Remarks
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Where, Nt = total number of samples analyzed for a nutrient in any given area; Nl = number of samples falling in the low category of nutrient status ; Nm = number of samples falling in the medium category of nutrient status; Nh = number of samples falling in the high category of nutrient status ; An SNI value less than 1.67, between 1.67 to 2.33, and more than 2.33 indicates low, medium, and high fertility status of soil, respectively (Table 2).

Soil nutrient index of three different land-use areas was evaluated regarding pH, Organic Carbon, primary and secondary nutrients, and micronutrients, for example, Fe, Zn, Cu, and Mn. The results obtained are presented in Tables 3-6, and discussed in the following headings.

Effect of wastewater on soil pH

During the study year (2017–2018), soil from clean water-irrigated sites, i.e., forest area, showed pH values ranged from 5.78-6.76, whereas in wastewater irrigated sites i.e. industrial and agricultural area soil pH ranged from 5.72-6.90 and 7.0-7.67 (Table 3). Wastewater is a source of acidic constituents and diminishes the soil pH because of the decay of organic matter and materialization of organic acids containing elements in the soil system. (Vaseghi *et al*., 2005; Khai *et al*., 2008). The Forest area also showed slightly acidic pH because of the decomposition of plant litter residues. This indicates a low status of pH in the forest and industrial area and medium status in an agricultural area (Table 6). The fertility rating of the pH of agriculture was medium due to the continuous application of different types of fertilizers.

Effect of wastewater on soil electrical conductivity

Electrical conductivity (dS/m) of soil ranged from 0.36-0.85 at clean water irrigated sites in the forest area. Electrical conductivity ranged from 0.51-0.65 at wastewater irrigated sites in the industrial area and 0.64-0.89 at wastewater irrigated sites in an agricultural area (Table 3). The soil nutrient index of electrical conductivity indicates the medium status in all land use areas.

Effect of wastewater on soil organic carbon

Soil organic carbon (%) of soil ranged from 0.70-0.84 at clean water irrigated sites in the forest area. Whereas, 0.48-0.75 at wastewater irrigated sites in an industrial area and 0.53-0.79 at wastewater irrigated sites in an agricultural area (Table 3). This indicates the medium status of soil organic carbon

Table 3. Descriptive status of measured soil properties in Ranipur Rao watershed.

Soil reaction (pH)					
	Percent of samples falling within range				
Land use areas	**<6.0 (Acidic)**	**6.0 - 8.0 (Neutral)**	**>8.0 (Alkaline)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	5.78-6.76	6.3 ± 0.33
Industrial area	33.33	66.66	0	5.72-6.90	6.27 ± 0.48
Agricultural area	0	100.0	0	7.0-7.67	7.25 ± 0.26
Electrical conductivity					
Land use areas	**<1.0 dS/m (Normal)**	**1.0-2.0 dS/m (Medium)**	**>2.0 dS/m (High)**	**Range**	**Mean ± SD**
Forest area	100	0	0	0.36-0.85	0.60 ± 0.19
Industrial area	100	0	0	0.51-0.65	0.57 ± 0.05
Agricultural area	100	0	0	0.64-0.89	0.74 ± 0.08
Organic carbon					
Land use areas	**<0.5% (Low)**	**0.5-0.75% (Medium)**	**>0.75% (High)**	**Range**	**Mean ± SD**
Forest area	0	66.66	33.33	0.70-0.84	0.74 ± 0.05
Industrial area	16.7	83.33	0	0.48-0.75	0.60 ± 0.10
Agricultural area	0	83.33	16.7	0.53-0.79	0.65 ± 0.10
Exchangeable Ca					
Land use areas	**<1.5 meq/100g (Low)**	**1.5-4.5 meq/100g (Medium)**	**>4.5 meq/100g (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	2.65-3.35	2.99 ± 0.29
Industrial area	0	16.7	83.33	3.77-6.80	4.88 ± 1.04
Agricultural area	0	83.33	16.7	3.90-4.65	4.25 ± 0.27
Exchangeable Mg					
Land use areas	**<1.5 meq/100g)**	**1.5-4.5 meq/100g (Medium)**	**>4.5 meq/100g (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	1.89-3.55	2.55 ± 0.58
Industrial area	100	0	0	0.51-1.45	1.10 ± 0.33
Agricultural area	0	66.66	33.33	3.54-4.66	4.13 ± 0.45

in all land use areas. Due to wastewater irrigation, higher organic concentration can adverse effects on soil porosity and make anaerobic environments in the plant root zone.

Effect of wastewater on soil calcium and magnesium

Exchangeable calcium (meq/100gm) of soil ranged from 2.65-3.35 at clean water irrigated sites in the forest area. Whereas, 3.77-6.80 at wastewater irrigated sites in the industrial area and 3.90-4.65 at wastewater irrigated sites in an agricultural area (Table 3). This indicates the medium status of soil exchangeable calcium in forest and agricultural areas and high in the Industrial area due to the accumulation of calcium deposits through industrial and municipal wastewater irrigation. Soil

Table 4. Descriptive status of macronutrients in Ranipur Rao watershed.

Nitrogen (N)					
Location	**Percent of samples falling within range**			**Range**	**Mean ± SD**
	<280 Kg/ Ha (Low)	**280-560 Kg/Ha (Medium)**	**>560 Kg/Ha (High)**		
Forest area	0	66.66	33.33	281.2-573.88	429.2 ± 41.9
Industrial area	100	0	0	110.14-70.15	193.8 ± 68.86
Agricultural area	0	83.33	16.66	282.3-582.96	267.4 ± 39.4
Phosphorus (P_2O_5)					
Location	**<10 Kg/Ha (Low)**	**10-25 Kg (Medium)**	**>25 Kg/Ha (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	13.76-22.39	17.91 ± 3.37
Industrial area	33.33	66.66	0	8.96-13.74	10.25 ± 2.01
Agricultural area	0	100	0	17.85-22.23	19.8 ± 1.69
Potassium (K_2O)					
Location	**<110 Kg/ Ha (Low)**	**110-280 Kg/Ha (Medium)**	**>280 Kg/Ha (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	119.65-152.32	134.1 ± 14.07
Industrial area	100	0	0	78.32-95.14	86.81 ± 6.67
Agricultural area	0	100	0	125.32-168.65	140.7 ± 17.36
Available sulphur (S)					
Location	**<10 ppm (Low)**	**10-30 ppm (Medium)**	**>30 ppm (High)**	**Range**	**Mean ± SD**
Forest area	0	100	0	11.89-19.88	14.56 ± 3.32
Industrial area	0	0	100	53.14-75.88	62.83 ± 7.77
Agricultural area	0	0	100	31.71-42.88	37.63 ± 4.27

exchangeable magnesium (meq/100gm) of soil ranged from 1.89-3.55 at clean water irrigated sites in the forest area. Whereas, 0.51-1.45 at wastewater irrigated sites in the industrial area and 3.54-4.66 at wastewater irrigated sites in an agricultural area. This indicates the medium status of soil exchangeable magnesium in forest and agricultural areas and low in the Industrial area. Notably, wastewater irrigation alters the cation concentration in the soil which affects the nutrient and metal stability among solid and liquid phases of the soil system (Khalid *et al*., 2017b). However, the effect depends on the absorption of these cations in the applied wastewater (Table 5).

Effect of wastewater on soil macronutrient elements

AN, AP, AK, and AS are essential nutrients for plant growth. The contents of these elements were analyzed and were shown in Table 3. The content of AN in the soil of agricultural wastewater irrigated area indicates high status as compared to industrial and forest areas (Table 4-6). In wastewater irrigated soils, organic nitrogen is transformed into nitrates by soil microorganisms to a greater extent than that

Table 5. Descriptive status of available micronutrients in Ranipur rao watershed.

Zinc (Zn)					
	Percent of samples falling within range			**Range**	**Mean ± SD**
Location	**<0.6 ppm (Low)**	**0.6-1.0 ppm (Medium)**	**>1.0 ppm (High)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	0.54-0.988	0.77 ± 0.17
Industrial area	16.7	50	33.33	0.50-1.54	0.91 ± 0.35
Agricultural area	33.33	33.33	33.33	0.47-1.25	0.86 ± 0.30
Manganese (Mn)					
Location	**<0.07 ppm (Low)**	**0.7-0.2 ppm (Medium)**	**>0.2 ppm (High)**	**Range**	**Mean ± SD**
Forest area	66.66	33.33	0	0.06-0.11	0.07 ± 0.59
Industrial area	50	33.33	16.7	0.05-0.23	0.18 ± 0.83
Agricultural area	0	66.66	33.33	0.09-0.22	0.16± 0.44
Iron (Fe)					
Location	**<4.5 ppm (Low)**	**4.5-5.5 ppm (Medium)**	**>5.5 ppm (High)**	**Range**	**Mean ± SD**
Forest area	83.33	16.7	0	0.31-0.61	0.44 ± 0.10
Industrial area	50	16.7	33.33	4.26-5.86	4.49 ± 1.18
Agricultural area	16.7	50	33.33	4.19-5.89	4.94 ± 0.65
Copper (Cu)					
Location	**<0.07 ppm (Low)**	**0.7-0.2 ppm (Medium)**	**>0.2 ppm (High)**	**Range**	**Mean ± SD**
Forest area	16.7	83.33	0	0.02-0.20	0.08 ± 0.03
Industrial area	0	66.66	33.33	0.14-0.23	0.17 ± 0.02
Agricultural area	16.7	83.33	0	0.05-0.19	0.15 ± 0.17

observed in non–irrigated agricultural soils (Ramirez *et al*., 2002). This indicates the high status of AP in forest areas as compared to wastewater irrigated sites. AK was higher in agricultural areas as compared to the forest and industrial areas. AS indicates the high status in industrial areas due to the accumulation of sulphate deposits through various industrial plants. Industrial and domestic wastes of the industrial area (SIDCUL and BHEL) are discharged into the seasonal river Ranipur Rao, Haridwar that leads to the change in nutrient status of soil in the adjoining areas (Kamboj *et al*., 2013).
This indicates that wastewater irrigation will be of benefit to soils in elevating some of the nutrient elements. Forest planting, especially the use of wastewater for irrigation, can effectively elevate soil nutrient contents, improving soil fertility (Peiyue *et al*., 2014).

Table 6. Nutrient indices of major and micro nutrients in soils of Ranipur Rao watershed.

Parameters	**Units**	**Forest area**		**Industrial area**		**Agricultural area**	
		Nutrient index	**Fertility rating**	**Nutrient index**	**Fertility rating**	**Nutri-ent index**	**Fertility rating**
pH		1.0	Low	1.66	Low	2.0	Medium
Electrical conductivity	ds/m^{-1}	2.0	Medium	2.0	Medium	2.0	Medium
Organic carbon	%	2.33	Medium	1.83	Medium	2.0	Medium
Available nitrogen	Kg/ha	2.33	Medium	1.0	Low	2.16	Medium
Available phosphorus	Kg/ha	2.0	Medium	1.33	Low	2.0	Medium
Available potassium	Kg/ha	2.0	Medium	1.0	Low	2.0	Medium
Available calcium	meq/100 g	2.0	Medium	2.66	High	2.16	Medium
Available magnesium	meq/100 g	2.0	Medium	1.0	Low	2.34	Medium
Available sulphate	ppm	2.0	Medium	3.0	High	3.0	High
Available zinc	ppm	1.83	Medium	1.0	Low	1.83	Medium
Available iron	ppm	2.16	Medium	1.0	Low	2.16	High
Available manganese	ppm	1.33	Low	2.30	Medium	2.37	High
Available copper	ppm	1.0	Low	2.37	High	2.22	medium

Effect of wastewater on soil micronutrient elements

Zinc is essential in plants for several biochemical processes such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and the maintenance of membrane integrity (Halvin *et al*., 2010). The available zinc content was highest in the industrial area i.e. 1.54 mg/kg. The available manganese content was highest in the industrial area i.e. 0.23 mg/kg i.e. slightly high from safe limits. Iron is a vital micronutrient for almost all living beings. It plays an important role in metabolic processes like DNA synthesis, respiration process, and photosynthesis processes (Raut and Sahoo, 2015). The available iron content was highest in the agricultural area i.e. 5.89 mg/kg. Copper is also an important micronutrient, required for lignin synthesis and acts as a constituent of ascorbic acid, oxidase, phenolase, and plastocyanin in plants (Halvin *et al*., 2010). The available copper content was highest in the industrial area i.e. 0.23 mg/kg. The nutrient index indicates the high status of Cu in the industrial area, it creates several defects in the human system. The low status of Cu, Mn, and medium status of Zn and iron was found in the clean water irrigated forest area. In the agricultural area, Zn indicates medium status. Fe, Cu, and Mn indicate the high status due to wastewater irrigation and recommended fertilizer applied. Long-term irrigation with raw effluents causes amassing of high concentration of heavy metals in soil and therefore in crop plants (particularly leafy vegetables), which can be phytotoxic to crop plants and wellbeing risk to animals and humans.

Conclusion

The results of the current study concluded that long-term application of wastewater in Ranipur Rao Shivalik hill watershed areas, nutrients, and total organic matter increasing in the soils; but there is anxiety related to soil EC increment and the accumulation of possibly toxic elements, like Pb, Cu, and Ni. To avoid unnecessary destructive impacts from the wastewater applied to the soil, regular evaluation of soil quality in such regions is essential. Furthermore, remediation techniques along with management strategy are needed in the study area which is considering a key point for soil quality improvement.

Conflict of interest: Authors declare that they have no conflict of interest.

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