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Impact of Long-Term Irrigation with Yamuna River Polluted Water on Soil Properties in Semi-Arid Ravines of Western UP

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ABSTRACT

The impact of long-term irrigation (>15 years) with polluted Yamuna river water (T_2) vi's-à-via groundwater (T_1) on physico-chemical characteristics of degraded ravine soils in outside-urban zones of three adjacent districts of UP (viz., Mathura, Agra and Etawah) was assessed. Mean bulk density of soil decreased from 1.37 g/cm^3 to 1.24 g/cm^3 and 1.43 g/cm^3 to 1.33 g/cm^3 at 0-15 cm and 15-30 cm depths, whereas, mean porosity increased from 48% to 53% in 0-15 under T_2 over T_1, respectively. Mean pH decreased significantly at both the soil depths under T_2 over T_1 site. Mean organic carbon and micronutrient concentrations, i.e., available P, K and Mg increased by 2.0, 6.4, 1.6,1.28 and 1.6, 3.8, 1.23, 1.2 times in the top and lower soil depths, respectively, however, available N and Ca concentrations remained unchanged at 0-15 cm and 15-30 cm, respectively. Total Fe, Mn, Zn, Cu and Pb increased significantly both in 0-15 cm (i.e., 2.25, 1.6, 2.4, 3.8 and 4.0 times, respectively) and 15-30 cm (i.e., 1.65, 2.22, 3.31, 3.20 and 1.20 times, respectively) depths. Mean Cd and Cr concentration were significantly higher at 15-30 cm depth than 0-15 cm under T_2 over T_1. This study suggests long-term use of polluted water, if falling under irrigation water quality guidelines, to improve soil properties in semi-arid ravine tracts of Uttar Pradesh, India.

Keywords Polluted water, Ravine soil, Soil properties, Wastewater irrigation, Yamuna river.

INTRODUCTION

Ravines, a highly degraded dry landscape are characterised by variety of edaphic, topographic and climatic constraints which spread over 4.3 million ha in India with the major part (1.23 Mha) in Uttar Pradesh state along the river Yamuna and Chambal (Soni *et al.* 2018). Yamuna ravines are poorly fertile, hence for productive uses requires corrections in deficiency of soil organic carbon, nutrients, water retention potential, aggregate stability, soil structural

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durability reducing nutrient leaching (Dey *et al.* 2018) and optimising microbial decomposition for nutrient release from organo-metallic complexes.

The water quality of Yamuna river all along the stretch of Mathura, Agra and Etawah districts is severely deteriorated due to higher levels of nutrients, organics and heavy metals on account of a major chunk of untreated wastewater being drained from urban and industrial sources (CPCB 2012). The recent studies on Yamuna river water quality show that outside-urban zones it varied within slight to moderate restrictive use for irrigation water quality throughout the year according to FAO guidelines (Pal *et al*. 2017a, b, c, Pal *et al*. 2018). Irrigation with wastewater containing optimum levels of chemical constituents can improve physical, chemical and biological properties of soil (George *et al.* 2017). However, wastewater irrigation uses can also be associated with several short-term and long-term risks like soil pH imbalance, excessive salts build up, increase in the sodium adsorption ratio (SAR), clay dispersion, soil structural degradation, pore blockage, reduced hydraulic conductivity and heavy metal accumulation (Khalid *et al.* 2018).

Nevertheless, polluted water of Yamuna river is intensively used for irrigation semi-arid region of Western UP, but no study has yet been done to assess the long-term impact of Yamuna river polluted water irrigation on soil properties. Therefore, this study was undertaken to evaluate the impact of long-term (>15 years) irrigation with Yamuna river polluted water (outside-urban zones) on soil physico-chemical properties as compared to groundwater irrigation on semi-arid ravine soils outside the urban zones of Mathura, Agra and Etawah districts in UP.

MATERIALS AND METHODS

Experimental sites description

A total of six sites situated close to the Yamuna river banks lying outside-urban zones in three districts of UP (viz., Mathura, Agra and Etawah) were selected. Two sites (viz., T_1: Ground water irrigated and T_2: Yamuna river water irrigated) were located in each district. In each T_1 and T_2 sites two and five agricultural fields, respectively, were selected for soil sampling (Fig.1). A careful selection of these sites receiving similar soil management practices was done

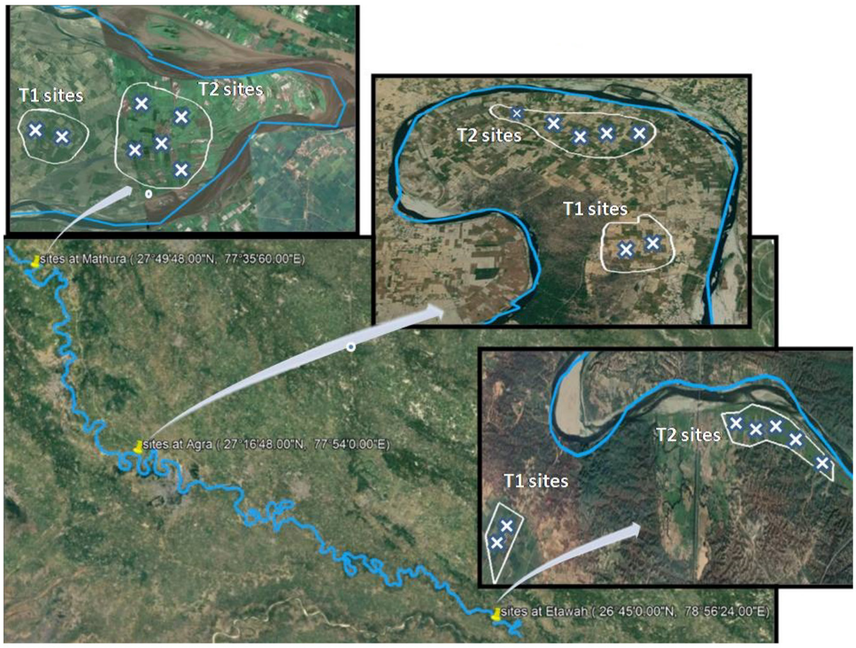


Fig. 1. Systematic representation of sampling sites (groundwater irrigated: T_1, Yamuna river irrigated: T_2) in Mathura, Agra and Etawah districts (UP), India.

Table 1. Physical and chemical characteristics of soil (0-30 cm) at uncultivated sites in Mathura, Agra and Etawah.

Soil characteristics	Mathura	Agra	Etawah
Bulk density (g/cm^3)	1.5±0.03	1.43±0.01	1.48±0.05
Porosity (%)	43±2.5	46±3.4	44±2.1
pH	7.05±0.41	7.04±0.02	7.02±0.03
EC (dS/m)	0.23±0.02	0.33±0.01	0.21±0.007
OC (%)	0.08±0.007	0.11±0.004	0.14±0.002
Na (cmol/kg)	2.7±0.08	3.3±0.06	2.8±0.04
Available N (kg/ha)	74±4.7	79±8.9	77±2.5
Available P (kg/ha)	5.6±0.5	4.9±0.1	5±0.3
Available K (kg/ha)	118±11.4	120±15.1	126±17.2
Available Ca (kg/ha)	167±8.6	148±6.9	116±5.2
Available Mg (kg/ha)	121±6.7	105±10.3	100±5.1
Pb	0.01±0.001	0.008±0.002	0.005±0.006
Cd	ND	ND	ND
Cr	ND	ND	ND

for the comparison. The entire experimental region has a ravine landscape with a semi-arid climate and a rainy season from July to September. Long-term mean annual minimum and maximum temperature, relative humidity and mean annual precipitation ranged from 19.5 to 33^o C, 34 to 77% and 112 to 725 mm, respectively. Groundwater irrigated sites had never received wastewater irrigation and the other way around. The physico-chemical properties of the 0–30 cm layer of soil from uncultivated sites is represented in Table 1. The soil texture is sandy loam in all the three districts.

Water sampling and analysis

Groundwater and Yamuna river water samples used for irrigation were taken in three seasons viz., winter, summer and post-rainy from near soil sampling sites in Mathura, Agra and Etawah districts. Samples of 10 liters were stored in polyethylene bottles, pre-washed with nitric acid (1%) and stored at 4 ºC until analysis. Then, pH, electrical conductivity (EC) and other chemical parameters including heavy metals were measured according to standard methods (APHA 2012). The various physico-chemical parameters were averaged for three seasons to give representative characteristics of groundwater and Yamuna river water used for irrigation in three districts.

Soil sampling and characterization

The representative soil samples from the irrigation area were collected in a clean polyethylene. In order to assess long term impact of irrigation with polluted Yamuna river water, soil samples were taken from 0-15 cm and 15-30 cm depths with an auger before sowing of wheat crops and sieved (2 mm) after air drying for soil chemical analysis. All soil samples were collected in three replicates. Bulk density of soil samples (BD) was determined in undisturbed core soil samples using cylindrical BD cores. The total porosity of soil samples was estimated from bulk density assuming a particle density of 2.65 mg/m^3. Soil texture was dete~~rmined by~~ hydrometer method. Soil pH, electrical conductivity (EC), total organic carbon, available nitrogen (N), available phosphorus (P), exchangeable cations (Na, K, Ca and Mg) were determined through standard procedure. Sodium absorption ratios (SAR) were calculated according to the following equation:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca} + \mathrm{Mg})/2}}$$

Digestion of soil samples for heavy metals determination

0.5 g of each dried and sieved soil samples were digested with nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) using method 3050B of USEPA (1996), and the digested solution was diluted to 50 ml with ultrapure water. The digested solution was transferred to a flask and diluted with ultrapure water (Ma *et al*. 2016). The concentrations of heavy metals (Pb, Cr and Cd)

Table 2. Characteristics of Yamuna river water and groundwater used for irrigation at experimental sites in three districts viz., Mathura, Agra and Etawah (UP).

Parameters	Yamuna river water			Groundwater		
	Mathura	Agra	Etawah	Mathura	Agra	Etawah
pH	7.45±0.02	7.36±0.06	7.25±0.04	7.4±0.03	7.6±0.01	7.3±0.04
EC (dS m^{-1})	2.19±0.01	2.2±0.03	1.55±0.06	3.45±0.12	4.3±0.21	4.8±0.22
BOD (mg l^{-1})	15.8±1.2	14.1±1.5	8.2±1.6	-	-	-
Na^+ (meq l^{-1})	9.42±0.34	10.96±0.21	6.9±0.07	18.67±0.22	20.2±0.32	17.8±0.35
K^+ (meq l^{-1})	0.41±0.04	0.49±0.02	0.56±0.01	0.12±0.003	0.32±0.01	0.41±0.03
Ca^{2+} (meq l^{-1})	4.1±0.02	4.2±0.03	3.5±0.8	4.2±0.06	4.7±0.06	5.6±0.01
Mg^{2+} (meq l^{-1})	1.4±0.05	1.23±0.01	1.0±0.06	6.8±0.04	6.2±0.6	7.5±0.2
CO_3^{2-} (meq l^{-1})	1.2±0.04	1.9±0.01	1.4±0.05	1.87±0.01	2.1±0.03	2.5±0.04
HCO_3- (meq l^{-1})	1.63±0.06	1.75±0.03	0.76±0.01	3.87±0.07	4.2±0.08	5.1±0.02
Cl^- (mg l^{-1})	122±3.21	145±7.30	80±4.25	2.21±0.03	3.3±0.02	4.2±0.31
NO_3- (mg l^{-1})	5±0.05	4.2±0.06	2.1±0.03	0.43±0.05	0.51±0.02	0.62±0.03
PO_4^{2-} (mg l^{-1})	1.9±0.04	1.9±0.02	1.5±0.05	0.37±0.2	0.43±0.07	0.67±0.02
SAR	5.6±0.08	6.6±0.03	4.5±0.07	8.0±0.46	8.67±0.03	6.85±0.25
Pd (mg l^{-1})	0.006±0.03	0.007±0.06	0.004±0.01	-	-	-
Cd (mg l^{-1})	0.001	0.001±0.001	-	-	-	-
Cr (mg l^{-1})	0.008±0.001	0.015±0.003	0.005±0.001	-	-	-

were determined in soil digested solutions by Inductively Coupled Plasma (ICP) Spectrophotometer.

Statistical analysis

In order to assess the effects of Yamuna river polluted water irrigation on soil properties in contrast to groundwater irrigated, one way ANOVA was used to find statistical significance at 0.05 probability level. The SPSS statistical package (SPSS Inc., Chicago, Illinois) was used for the analysis.

RESULTS AND DISCUSSION

Yamuna river water characteristics

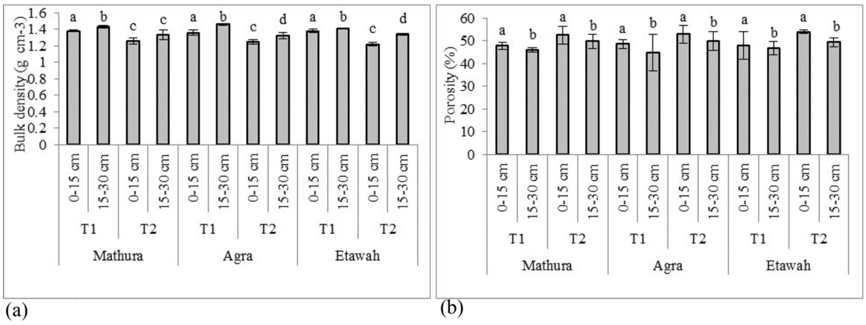
Data on the mean values of physico-chemical characteristics of Yamuna river water used for irrigation shows that pH of river water was slightly alkaline (7.35-7.45) (Table 2). EC and SAR together as well as concentrations of HCO_3- and Cl^- shows that river water quality was under slight to moderate degree of restriction for use as per FAO irrigation water quality guidelines (Ayers and Westcot 1994). However, all nutrients (Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^{2-}, Cl^-, NO_3-, PO_4^{2-}) and heavy metals (Fe, Mn, Zn, Cu, Pb, Cd and Cr) concentrations in river water were below safe limits with no restriction for use as irrigation water.

Impact on soil bulk density and porosity

The average bulk density of soil significantly ($p < 0.05$) decreased by 0.9 times (from 1.37 to 1.24 g cm^{-3}) and 0.93 times (from 1.43 to 1.33 g cm^{-3}) in 0-15 cm and 15-30 cm soil depths, respectively, at T_2 sites compared to T_1 sites. Concomitantly, average porosity significantly increased by 1.1 times (from 48.2 % to 53.0 %) in 0-15 cm soil depth at T_2 sites over T_1 (Fig. 2). However, no significant changes were observed in porosity at 15-30 cm soil depths. This slight decrease in bulk density at T_2 sites could be attributed to the effect of organic substances that increased soil aggregates and improved soil structure (Abd-Elwahed 2018). In contrast, soil porosity reduction and bulk density increase have been found with wastewater irrigation due to accumulation of organic matter (Coppola *et al.* 2004).

Impact on the soil pH and salinity

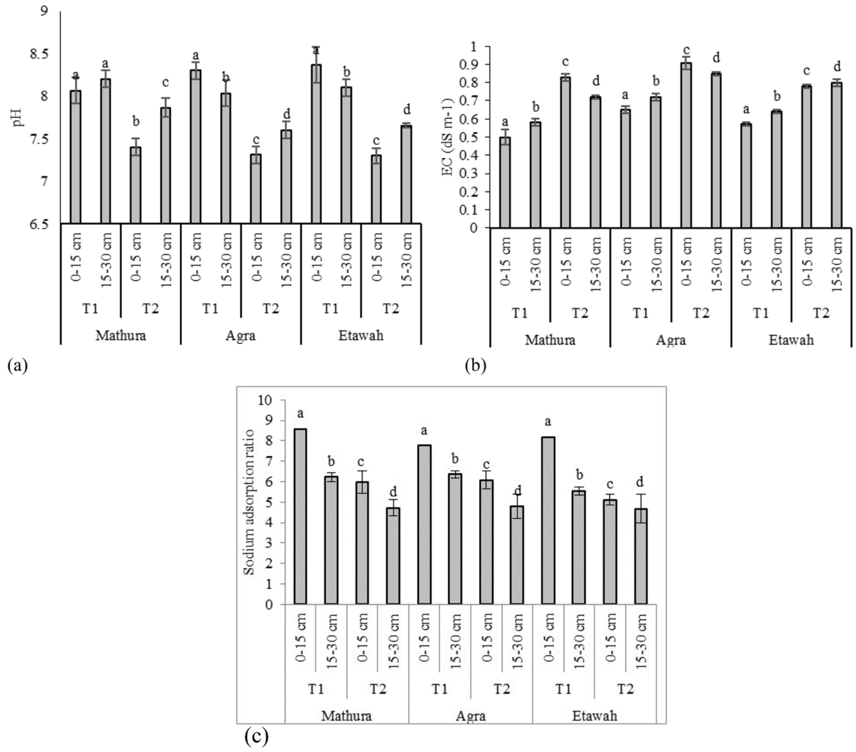
Soil pH is an important parameter as it governs the availability of nutrients to the crops by affecting their charge. The pH in ravine soil under semi-arid climate were alkaline (at T_1 sites) ranging from 8.0 to 8.3 in both the soil depths (Fig. 3a). The pH was significantly ($p < 0.05$) lower in both the soil depths at T_2 sites as compared to corresponding depths at T_1 sites. The pH reduction in the top soil layer at T_2



(a) (b)

Fig. 2. Bulk density (a) and porosity (b) changes in soil profile. Different alphabetical letters indicate significant difference at $p<0.05$.

sites was significantly more as compared to lower soil layer which might be due to oxidation of organic matter in comparatively well aerated top soil layer. Even, long-term studies conducted on wastewater irrigation for >80 and >15 years also made similar observations (Elgala *et al.* 2003 and Angin *et al.* 2005). Higher ammonium ions in wastewater undergo nitrification in the soil releasing high concentration of free hydrogen ions and consequently lowering the soil pH (Vazquezmontiel *et al.* 1996). The other possible reason for reduction in soil pH could be the decomposition of organic matter and production of organic acids in soils irrigated with Yamuna river polluted water. Contrarily, some researchers reported a slight



(a) (b)

(c)

Fig. 3. pH (a), electrical conductivity (EC), b) and sodium adsorption ratio c) changes in soil profile. Different alphabetical letters indicate significant difference at $p<0.05$.

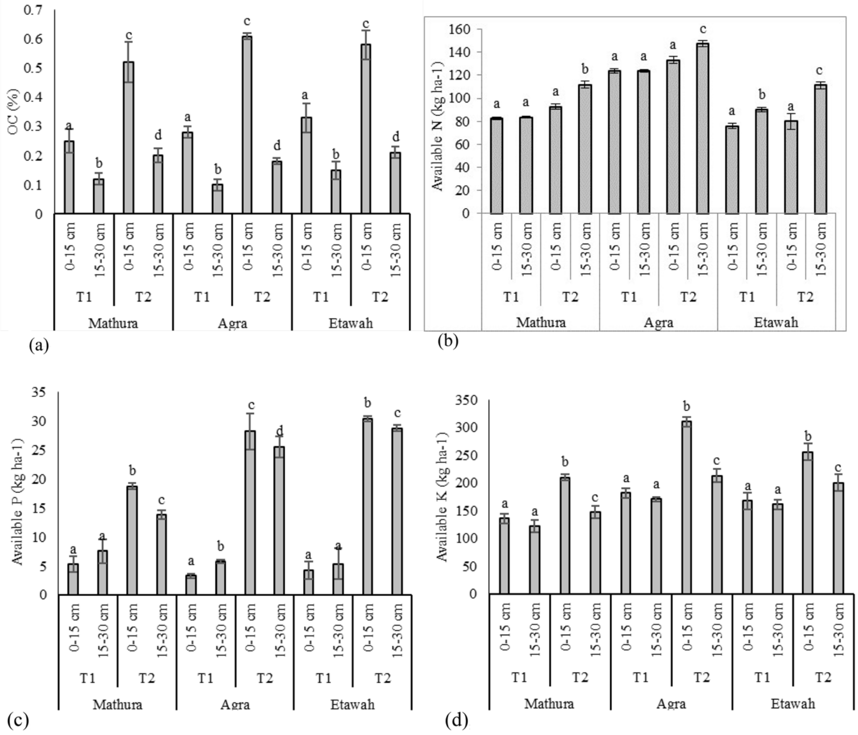


Fig. 4. Soil organic carbon (SOC), (a) available N (b) available P (c) available K (d) changes in soil profile. Different alphabetical letters indicate significant difference at $p<0.05$.

increase of soil pH due to high content of HCO_3-, salinity and nutrients in wastewater (Becerra-Castro *et al.* 2015, Biswas and Mojid 2018).

The average EC of soil at T_2 sites increased significantly ($p < 0.05$) by 1.47 (from 0.57 to 0.84 dS m^{-1}) and 1.22 (from 0.65 to 0.79 dS m^{-1}) times at 0-15 cm and 15-30 cm depths compared to T_1 sites, respectively (Fig. 3b). The higher EC increase in top layer compared to lower layer could be due to higher accumulation of anions or increase in soluble salts (Fuller *et al.* 1995). Nevertheless, EC values ranged between 0.78-0.91 dS m^{-1} and 0.72-0.85 dS m^{-1} at T_2 sites which are below 2 dS m^{-1} threshold for most crops, except saline tolerant plants. The significant increase in soil EC on wastewater irrigation has also been reported earlier (Yasin *et al.* 2017).

Excess Na^+ ions adversely affect soil structure and infiltration, however, SAR is a preferred representation of Na^+ content in soil. Our results showed that there was a significant difference of SAR in both the soil layers between those irrigated with groundwater and Yamuna river water (Fig. 3c). In the 0-15 cm soil layer, the average SAR in plots at T_2 sites decreased by 0.70 times over T_1 sites (from 8.17 to 5.73). In the 10-20 cm soil layer, the average SAR in the plots at T_2 sites decreased by 0.78 times (from 6.04 to 4.73). Under semi-arid regions there are excess salts build up in soils due to water deficit, arising from the fact that the annual evapotranspiration rate exceeds the precipitation rate. Therefore, irrigation with Yamuna river water, which contained proportionally lower Na^+ vs, Ca^{2+} and Mg^{2+}, decreased sodium adsorption ratio (SAR) in naturally salt rich soil at T_2 sites due to displacement of Na^+ ions by Ca^{2+} and Mg^{2+} ions and leaching of excess of these cations. Accumulation of a portion of leached Na^+ ions in subsurface soil layers counteracts the washing effect of irrigation, which was a reason for a lesser decrease of SAR in 15-30 cm soil layer at T_2 sites over T_1. The decrease in SAR of soils irrigated with wastewater under arid

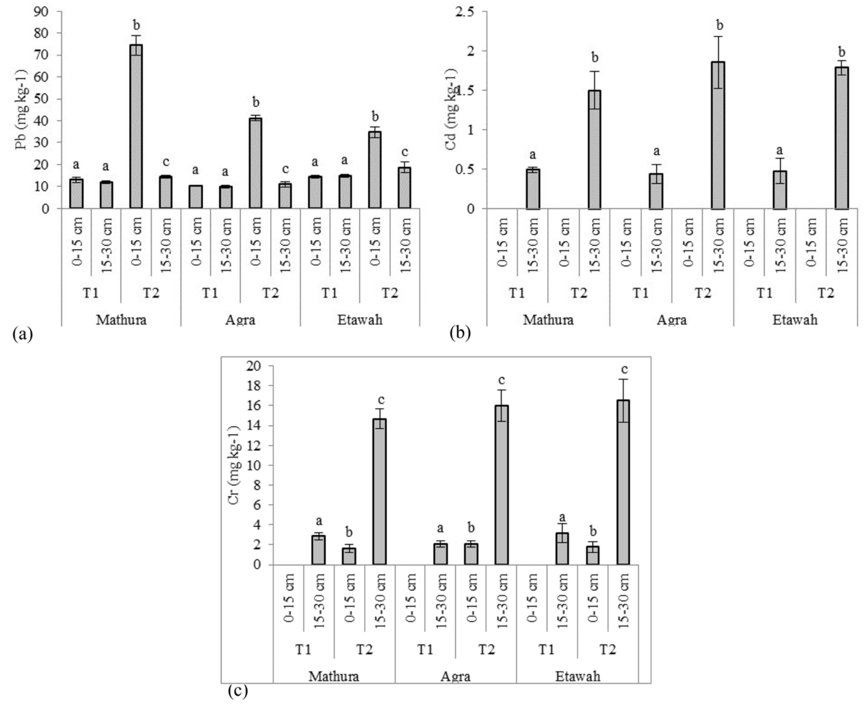


Fig. 5. Total heavy metals viz., Pb (a), Cd (b) and Cr (c) changes in soil profile. Different alphabetical letters indicate significant difference at p<0.05.

and semi-arid conditions is in compliance with earlier study (Oliveira *et al*. 2016).

Impact on the soil macronutrient status

The average soil organic carbon (SOC) at T_2 sites was significantly increased ($p < 0.05$) by 2 times (from 0.27 to 0.57%) in 0-15 and 1.62 times (from 0.12 to 0.2%) in 15-30 cm depths, compared to T_1 sites, whereas it decreased significantly with depths at both T^1 and T_2 sites (Fig. 4a). Similar results were obtained by other researchers who attributed the organic carbon accumulation in upper layers to the wastewater irrigation (Abbas and Bassouny 2018, Elcossy *et al.*2020). Chen *et al.* (2015) found 1.5 times higher SOC in the top soil layer (0-10 cm) whereas noted a large, but insignificant increase in sub-surface soil (10-20 cm) indicating that it might be affected by other factors like soil properties and wastewater quality. The higher SOC at T_2 sites compared to T_1 sites was due to the presence of degradable and compostable substances (Dubey *et al.* 2010).

Several researchers reported accumulation of available N, P and K in the soil irrigated with wastewater owing to high levels of these nutrients in the wastewater applied (Matheyarasu *et al.* 2016, Bastida *et al.* 2019, Abd-Elwahed 2019). In this study, we recorded a significant increase ($p<0.05$) by 1.25 times (from 99 to 123.6 kg ha^{-1}) in the average concentration of available N at 15-30 cm depth at T_2 sites compared to T_1 indicating appreciable amount of NO_3—N in Yamuna river polluted water. However, insignificant changes were observed in the content of available N in 0-15 cm depth which could be attributed to the uptake of excess NH_4+ and NO_3- ions by plant roots (Duncan *et al.* 2009) as well as leaching of these highly mobile ions in sandy loam soil where infiltration rate is very high (1.77 to 2.2 cm hr^{-1}), this could also be the reason for higher accumulation of available N in sub-surface soil layer (Fig. 4b). The average concentrations of available P and K in T_2 site soils increased significantly on an average by 6.4 times (4.2 to 25.8 kg ha^{-1}) and 1.6 times (from 161 to 258 kg ha^{-1}), respectively, at 0-15 cm depth, whereas by 3.6 times (6.24 to 22.68 kg ha^{-1}) and 1.23 times (151 to 187 kg ha^{-1}), respectively, at 15-30 cm depth (Fig. 4c-d). Matheyarasu *et al.* (2016) reported 2, 3.4 and 16.6 times higher content of available N, P and K in long-term abattoir wastewater irrigated soils. Abegunrin *et al.* (2016) observed significant and insignificant changes in the content of available K under irrigation with different wastewaters suggesting the impact on the nutrient status of soil are largely governed by wastewater characteristics.

Impact on heavy metal distribution in soil profile

The long-term impact of wastewater irrigation on soil heavy metal content is reflected through its total heavy metal content (Massas *et al.* 2013). The total heavy metals concentrations in soils at T_2 sites (as well as T_1 sites) located in three districts were significantly different which could be due to variation in local meteorological conditions and history of cultivation. The average concentrations of total Pb increased significantly at 0-15 cm (i.e., 2.25, 1.6, 2.4, 3.8 and 4.0 times, respectively) and 15-30 cm (i.e., 1.65, 2.22, 3.31, 3.20 and 1.20 times, respectively) depths under T_2 site soils as compared T_1 sites which can be ascribed to presence of their appreciable amount in Yamuna river water (Figs. 5 a-e). The concentrations of Pb were significantly higher in the top soil layer as compared to subsurface soil layer which can be ascribed to binding with higher organic C in the top layer. However, Cd were not detected in 0-15 cm soil depth at both T_1 and T_2 sites which could be due to very poor concentrations in Yamuna river water used for irrigation. However, its average concentration was 3.67 times higher in 15-30 cm depth at T_2 sites as compared to T_1 probably due to leaching (Fig. 5f). Similarly, Cr was absent in 0-15 cm depth in T_1 sites only and increased to 1.86 mg kg^{-1} at T_2 sites, whereas, it was 5.8 times higher in 15-30 cm depth at T_2 sites as compared to T_1 (Fig. 5g). The differential leaching behavior of heavy metals could be due to the differences in their affinity to negatively charged soil particles and organic matter (electronegativity series order: Pb> Cd> Cr). Studies have shown accumulation of heavy metals more in the top soil layer (Li *et al.* 2014). An increase in heavy metal content in soils irrigated with wastewater on long-term has also been reported earlier (Chaoua *et al.* 2019). The concentrations of all the heavy metals analyzed in soils at T_2 sites were found within permissible limits (Table 3). Long-time continuous uptake of heavy metals by food crops grown at T_2 sites and leaching into the deeper layers of soil was a probable reason for low concentration of heavy metals than permissible limits.

Table 3. Guidelines for safe limits of heavy metals (WHO/FAO, 2007).

Sample	Pb	Cd	Cr
Irrigation water (mg l^{-1})	5	0.01	0.1
Agriculture soil (mg kg^{-1})	100	3	100

CONCLUSION

The Yamuna river polluted water quality complied slight to moderate restriction on irrigation use category outside the urban zones according FAO guidelines. Irrigation with Yamuna river water in ravine soils improved soil fertility and wheat productivity without compromising their quality. Since, heavy metals (Fe, Mn, Zn, Cu, Pb, Cd and Cr) in Yamuna river water were below permissible limits of irrigation water quality standards (FAO), therefore, its application did not increase soil heavy metal content to hazardous levels even in the long-term applications. Thus, the study suggests that the stretch of polluted rivers outside the urban zones can be identified meeting irrigation water quality standards and hence, can be used for long-term irrigation which offers most cost-effective and technically viable solution to improve soil fertility and crop productivity if used wisely with precaution.

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