Profitability and Health Risk Estimation of Rice Cultivation under Wastewater Irrigation from Natural Drainage

Arti Yadav*, Pawan Kumar Yadav, Shalini Srivastava*, Pramod Kumar Singh*, Vandana Srivastava* and D. N. Shukla*

* Bhargava Agricultural Laboratory, Department of Botany, University of Allahabad-211002,
Uttar Pradesh, India.

Abstract- The paper reports the results of an empirical study on the profitability of rice cultivation in the rural areas of Allahabad by wastewater irrigation from natural drainage. The results show that plots using wastewater containing organic nutrients earn higher profits than those using groundwater. However, we also find the profitability of plots using wastewater negatively affected by the presence of heavy metals such as Fe, Mn, Cu, Zn, Pb and Ni that are found in the water and soil. Of the two opposing effects of wastewater irrigation, the positive effects of organic nutrients outweigh the negative effects of heavy metal toxicity. The soil along the sides of the wastewater channel shows higher productivity and concentration of heavy metals than the crops away to it but lies within the safe limits of WHO/ FAO. The order of metal contents was found to Fe > Zn > Mn > Ni > Cu > Pb in contaminated irrigation water, and the average abundance order of heavy metal contents in soil are: Fe>Mn>Zn>Cu>Pb>Ni. Very strong positive correlation observed for Cu (r^2 = 0.984; P<0.01) and strong positive correlation for Mn (r^2 = 0.698; P<0.01) while other heavy metals show moderate positive correlation (r^2, 0.36 to 0.67; P<0.05) between the concentration in wastewater and their availability in the soil of the study area.

The Study reveals that there is significant relation between the concentrations of the metals in soil to the concentration of metals in water used for irrigation, but no significant relationship for its transfer to the rice. The low concentration of metals in the soil may be ascribed to its continuous removal by rice grown in the study areas. Daily intake values of heavy metals through consumption of wastewater fed rice are below the recommended oral dose of metal for adult. Consumption of food crops contaminated with heavy metals are a major food chain route for human exposure, but it can safe to state that irrigation of agricultural land of rural areas of Allahabad with wastewater has not led any contamination of food crops with heavy metals. This study regarding DIM (Daily intake of metals) suggest no potential health risk for adults and children with respect to amount of daily intake of heavy metals through ingestion of wastewater irrigated rice crops. However, the concentrations of heavy metals in soil and rice grains were still below the maximal levels, as stipulated by Indian Prevention of Food Adulteration Act (PFA, 1954) and World Health Organization (WHO, 1993) guidelines. IFFCO Phulpur is not discharging its effluent outside the company premises but chances of heavy metals contaminations of crops may occur if the rural drainage system get link to any industrial discharge or any other source of contamination. These results support both efforts to conserve the natural drainage, which will generate a number of ecological benefits, as well as to regulate the discharge of wastewater into the water from households and runoff that are located upstream.

Index Terms- Contamination, Heavy Metal, Daily Intake of Metal, Health Risk, Wastewater Irrigation, Natural Drainage, Bairagiya drain, Allahabad.

I. Introduction

Use of wastewater in agriculture undoubtedly helps to recycle useful nutrients through the food chain. But it also poses risks simultaneously for human health and for the profitability of the cultivated crop because of the possible presence of toxic elements in the irrigation water. Though the presence of heavy metals in small quantities is 'natural' in the water and soil, their elevated concentrations kill micro-organisms that are beneficial to plant growth. As Alloway points out (1995), Chromium (Cr), Zinc (Zn), Cobalt (Co), Copper (Cu) and Manganese (Mn) in small quantities are good for plant growth but the presence of metals like Lead (Pb), Cadmium (Cd) and Mercury (Hg) are always a cause of concern above a certain level. Of these, Pb and Cd, being heavier metals, work at the root and stem of the plant to destroy them while Hg being lighter gets easily transported to the grains. The metal mobilization and plant uptake would be restricted by the alkaline pH of the soil.

A recent study by Nawaz et al. (2006) studied the effect of water containing heavy metals on yield, yield components and heavy metal contents in paddy and straw. They looked at three varieties of rice and soil at three different sites in the district of Sheikhupura near the bank of Nallah Daik where the crop is irrigated with water from Nallah Daik in Pakistan. This study showed contamination by the two heavy metals Cu and Cd to be within safe limits in the soil. Moreover, although they observed a minor accumulation of these metals in the plant parts, they found it to remain within the permissible limit. A study by Fazeli et al. (1998), who investigated the degree of accumulation of seven heavy metals (Cu, Zn, Pb, Co, Cd, Cr and Ni) in the soil and in different plant parts of paddy irrigated by paper mill effluents near Nanjangud, Mysore district, Karnataka in India, also found remarkably low concentrations of heavy metals (except Zn) in the seeds of paddy although this was not the case for the roots and leaves. Further, the crop seemed able to tolerate the presence of the heavy metals in the polluted water without suffering much damage. A study by Wang et al. (2003), on the other hand, has estimated the status of trace elements in paddy soil and sediments in the Taihu Lake region in China. It showed Zn, Cu and Pb to be the main pollutants in the experiment sites and the rapid development of village/township industries to be the primary cause of severe environmental pollution in the Taihu Lake region, especially of irrigation river sediments. Markandya and Murthy (2000), in their study of the Kanpur-Varanasi region in India, found that though the mean levels of Cd, Cr, Ni and Pb in the soils were above their respective tolerable limits for agricultural crops, since the pH of the receiving soil was alkaline, their effects were less harmful than expected. They also noted the positive effect on agricultural yield of nutrients present in partially treated wastewater when compared with crops grown using groundwater.

In contrast with the studies discussed above, the primary objective of our study taking the Bairagiya drain as its study site is to investigate the effect of wastewater toxicity on the livelihood options of farmers involved in rice cultivation in the region. Therefore, we study whether wastewater cultivation has had a negative impact on the profitability of rice cultivation in this region rather than the impact of heavy metals on yield and the plant body. We consider this important as farmers may adopt a number of measures like pollutant-resistant varieties of seeds, fertilizers and pesticides in order to cope with the negative externality posed by toxicity so that higher yield is achieved at lower profits. But if this indeed happens, the livelihood support provided by the Wetlands will be reduced and the pressure for its conversion into more economically beneficial projects will build up. In the case of the Bairagiya drain, some studies have already noted the presence of heavy metals in the vegetables produced in the region. Our study estimate the effects of the toxicity of wastewater on the profitability of rice cultivated in the region.

II. RESEARCH METHODOLOGY

Study area

The study was carried out around Bairagiya drain, north side of the River Ganga and 30 kilometers east of Allahabad city of Uttar Pradesh, State of India from December 2012-June 2013. Bairagiya drain flows from Phulpur (25°32'31.90"N 82°02'24.05"E) to Rasulpur (25°18'58.48"N 82°05'00.43"E). Six sampling sites in downstream and one control site were considered for the study shown in the map (Fig. 1). Bairagiya drain is a natural drainage which drains the runoff and wastewater from different villages in downstream till it joins the river Ganga. It originates from a village pond of Phulpur and not linked to any industrial discharge in its course. IFFCO fertilizer manufacturing plant is located 7 kilometer downstream from the origin of the drain and no evidence of effluent discharge from the manufacturing plant was found during this period. The rice samples grown in the area are considered for study, most of the Crop samples cultivated in these sites are supplied to the wholesale Crop sample markets in Allahabad city and rest of enter the local markets. Kajipur Fatuha (25°25'19.38"N 82° 3'23.53"E) a Crop sample cultivating agricultural land 3.2 km from sampling site 4 with no history of wastewater use was chosen as the control site.

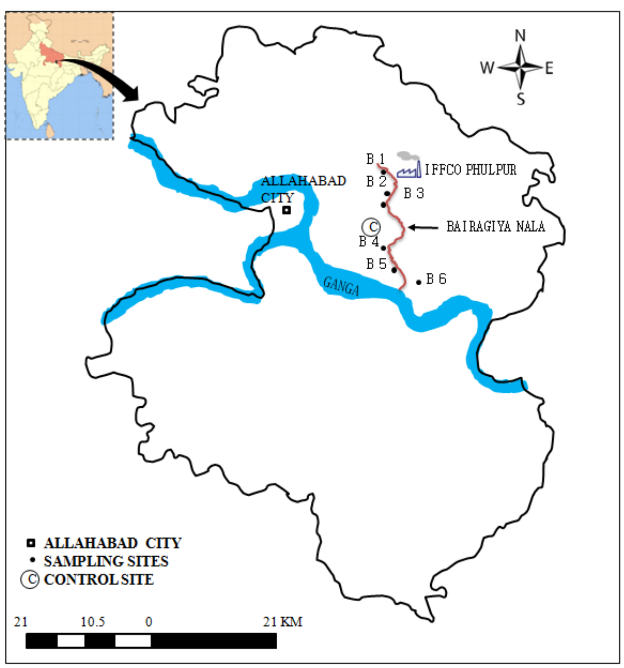

Figure 1: Map of Allahabad District showing sampling sites along the Bairagiya

Method of Study

Crop samples are collected randomly in triplicate from six sites of wastewater irrigated agricultural land of Iffco Phoolpur industry area and five sites downstream of the Bairagiya drain, along with the control site during the months from December 2012-June 2013. For metal analysis only the edible parts of Crop samples were used. All samples were collected and put in clean polythene bags according to their type and brought to the laboratory for preparation and treatment as soon as possible. In each plant sample 6-8 Crop sample plants of the same species were collected at random from the fields of the sampling sites by hand using vinyl gloves carefully packed into polyethylene bags and the whole plants body was brought to the laboratory. The cleaning (removal of soil) of Crop samples was performed by shaking and also by means of a dry pre-cleaned vinyl brush. Then the whole plant bodies were divided into different parts and non-edible portions were removed.

The edible parts of the Crop sample were washed with tap water several times and subsequently dipped in 0.01N HCl acid, for 5 minutes followed by thorough washing in distilled water to remove airborne pollutants. Then the samples were cut into 2 cm pieces and dried in a hot air oven at 70-80^oC till the constant weight was achieved. The dried samples were grounded in a stainless still blender and then passed through a 2-mm size sieve. Soil samples from the surface soil to a depth of 12cm around each plant root zone were collected simultaneously from the field with the plants. The soil samples were air dried at room temperature finally powdered, and sieved through a 2-mm nylon mesh to remove large debris, stones and pebbles. Then the samples (500 gm of soil) were dried at 105^oC for 2 hour to remove all the moisture content and homogenized for analysis. The dried samples were wet digested according to standard protocols. For water sampling, three replicate polythene bottles (acid washed) of capacity 100 ml were immersed one by one at an interval of 15 seconds into the water of Bairagiya drain that was being used for irrigation purpose, and immediately after filling, 1ml of concentrated HNO3 was added to the water and the bottles were brought back to the laboratory and digestion was completed within a week.

For heavy metal analysis fifty milliliters of contaminated water sample was digested with 10 ml of concentrated HNO_3 at 80^oC until the solution became transparent (APHA 1985). The solution was filtered through Whatman no. 42 filter paper and the filtrate was diluted to 50 ml with distilled and dehumanized water. One gram each of soil and Crop sample samples were digested (wet acid digestion) with 15 ml of concentrated HNO_3, H_2SO_4, and $HCIO_4$ in 5:1:1 ratio at 80◦C until a transparent solution was obtained (Allen et al. 1986). The digested samples of water, soil, and Crop samples were filtered through Whatman no. 42 filter paper and the filtrates were diluted to 50 ml with distilled water. All samples were stored at ambient temperature before analysis. All reagents used were Merck, analytical grade (AR), including standard stock solutions of known concentrations of different heavy metals. Trace elements concentrations in water, soil, and in Crop sample samples were estimated by an atomic absorption spectrophotometer (Perkin Elmer AAnalyst 300). Blank samples were analyzed after six samples. Concentrations were calculated on a dry weight basis. All analyses were replicated three times. The precision and analytical accuracy were checked by analysis of standard reference material, NIST-SRM 2709 for soil, NIST-SRM 1570 for water, and NBS-SRM 1573 for plant samples. The results were found to be within 2% of certified values for every heavy metal. Statistical summary and correlation analysis was performed using Microsoft Excel (version 2007).

III. RESULT AND DISCUSSION

1. Heavy metal concentrations in irrigation water

The heavy metal content in Bairagiya drain is below the recommended maximum concentration specified by FAO for irrigation and also below the limits of drinking water quality for livestock which makes it fit for use in irrigation and animal husbandry. Out of six elements examined in the wastewater used for irrigation in the study area, concentration of Fe was highest (0.4858 mg/l, SD: 0.00160) while Pb was lowest (0.0041 mg/l, SD: 0.00044) and mean concentration of other metals are; Cu (0.00737 mg/l, SD: 0.00025), Mn (0.48584 mg/l, SD: 0.00047), Zn (0.09239 mg/l, SD: 0.00051) and Ni (0.01692 mg/l, SD: 0.00379). The mean metal concentrations of wastewater irrigation in Bairagiya drain region are less than from different parts of India where wastewater irrigation is a practice. Such as suburban areas of Varanasi, Uttar Pradesh (Sharma et al. 2007, 2006), Titagarh, West Bengal (Gupta et al. 2008), Ramgarh Lake, Gorakhpur, Uttar Pradesh (Singh et al. 2011) Nagpur, Maharashtra (Singh et al. 2012) and in urban area of Naini Allahabad Uttar Pradesh (Yadav et al. 2013).

2. Heavy metal concentrations in Soil

The concentration of heavy metals (mg/Kg dry soil) in agricultural soils of study area in (Table 2) ranged from 0.83-1.36 for Cu, 11.02-16.12 for Fe, 5.97-14.88 for Mn, 1.26-1.93 for Zn, 0.032-0.043 for Pb and 0.004-0.014 for Ni. Fe has the highest mean concentration recorded in soil fallowed by Mn Cu, Zn, Pb, and Ni. The extent of metals observed in agricultural soil of the fields in the present investigation is below the permissible levels and lower than those reported by different authors like Kabata-Pendias and Pendias (1992) Temmerman et al. (1984), Gupta et al. (2008), Singh et al. (2012) and by Sharma et al. (2007) of use of urban wastewater for irrigation in fields. However, Cu concentration in soil was also lower than the previous result obtained by Thandi et al. (2004) (2.5-133.3 mg/Kg) and of Mapanda et al. (2005) (7.00-145 mg/Kg) in Zimbabwe and those of Wong et al. (2002) in agricultural soil of China. This variation of result might probably be due to the variations of heavy metal concentrations in irrigation water and other agronomic practices of the respective area. The concentration of heavy metals in the soil is far low to the recommended maximum concentration of WHO, this may be ascribed to its continuous removal by vegetables grown in the designated areas.

Table 1: Heavy metal concentrations (mg/l) in wastewater of Bairagiya drain (n=36)

Metals	Mean	Minimum	Maximum	Stn.dev	Recommended maximum concentration[a]	Livestock Drinking Water
Cu	0.00737	0.00706	0.0078	0.00025	0.2	0.5
Fe	0.48584	0.4835	0.4885	0.00160	5	NA
Mn	0.02402	0.0232	0.0245	0.00047	0.2	0.05[b]
Zn	0.09239	0.09186	0.0932	0.00051	2	24
Pb	0.00416	0.00366	0.0048	0.00044	5	0.1[c]
Ni	0.01692	0.011	0.023	0.00379	0.2	NA

Source: National Academy of Sciences (1972), Pratt (1972) and FAO

a. The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

b. Insufficient data for livestock. Value for human drinking water used.

c. Lead is accumulative and problems may begin at a threshold value of 0.05 mg/l.

Table 2: Concentration of heavy metals in soil (mg/Kg dry soil) irrigated with wastewater of Bairagiya drain in rural area, Allahabad (n=36).

Metals	Mean	Minimum	Maximum	Stn.dev	Recommended maximum concentration[a]	Limits of MoEF[b]
Cu	1.0716	0.83	1.36	0.1904	140	200
Fe	14.0033	11.02	16.12	2.2583	NA	NA
Mn	9.9416	5.97	14.88	3.8456	NA	1800
Zn	1.62	1.26	1.93	0.2422	300	150
Pb	0.0386	0.032	0.043	0.0039	300	200
Ni	0.011	0.004	0.014	0.0041	75	100

a WHO (2007).

b The Environmental Management Act (Soil Quality Standards) Regulations, 2007.

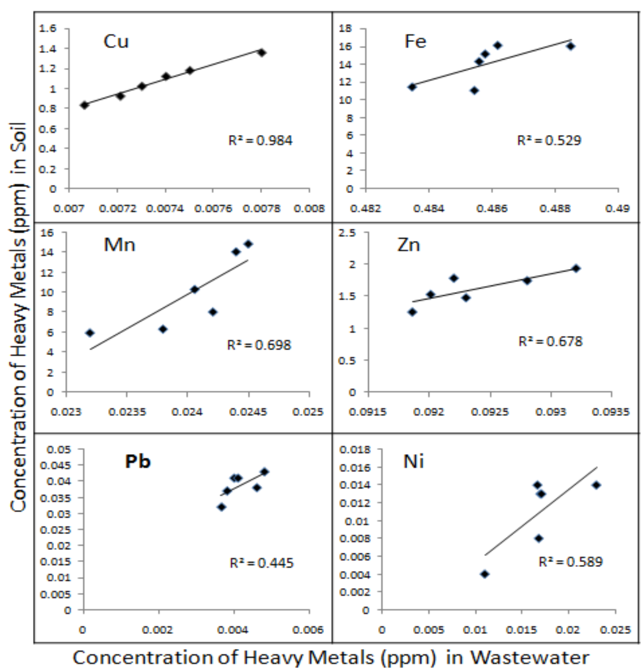

Figure 2: Relationships between heavy metal concentrations in wastewater and soil

ISSN 2250-3153

Very strong positive correlation observed for Cu (r^2 = 0.984; P<0.01) and Strong positive correlation for Mn (r^2 = 0.698; P<0.01) while other heavy metals show moderate positive correlation (r^2, 0.36 to 0.67) (Mason et al 1983) between the concentration in wastewater and soil of the study area (Fig. 2) which signifies the transportation of these heavy metals from the wastewater to soil through irrigation.

3. Heavy metal concentrations in Rice and Rice productivity

Concentrations of heavy metals in rice were within the safe limit of WHO and Indian standard (Awashthi, 2000). The mean concentrations of heavy metals in the rice plant parts (Table 3 and Fig. 3) showed that all the studied metals were present and most of the metals accumulated in the roots than other parts. The Cu, Zn, and Mn also accumulated at its highest concentration in roots of the rice plant and followed by straw and grains (Fig. 4). Most metals that were found abundantly in the paddy plants were nutrients like Fe, Mn, Zn, and Cu that are required for various enzyme activities and play important roles in photosynthesis and growth of the plant (Tripathi, Raghunath, and Krishnamoorthy 1997; Hopkins 1999).

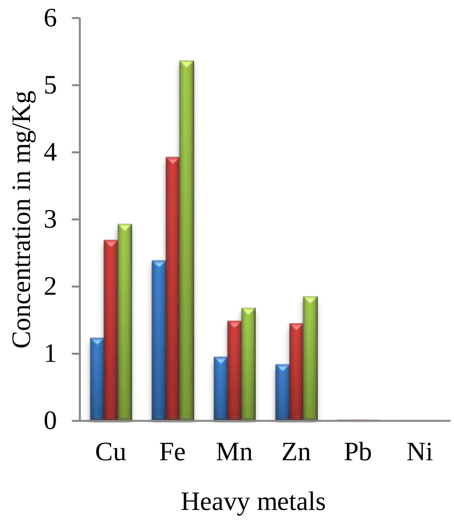

Figure 3

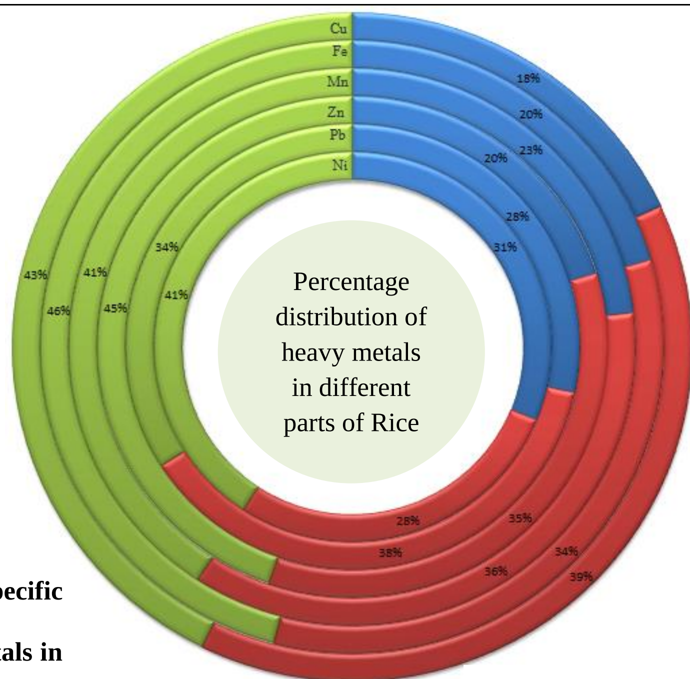

Figure 3: Concentration of metals and their specific distribution in different parts of Rice plant
Figure 4: Percentage distribution of heavy metals in different parts of Rice

Figure 4

Table 3: Mean Heavy metal concentration (mg/Kg dry weight) in Rice grown in wastewater irrigated rural land of Allahabad

	Cu	Fe	Mn	Zn	Pb	Ni
Grain	1.24	2.39	0.95	0.84	0.015	0.0052
Straw	2.69	3.93	1.49	1.45	0.02	0.0047
Root	2.93	5.37	1.68	1.85	0.018	0.0068

Table 4: Comparison between rice plants irrigated with normal well water and wastewater of Bairagiya Drain

Targets	Control	Wastewater irrigated
Rice plant Size (m)	0.98	0.98
Rice plants in 1 cluster	10	10
Rice ears in 1 cluster	6.5	7
Average productivity (Kg/m2)	0.83	0.85

Growth and development of rice plants irrigated by wastewater and normal well water compared in table 4. The average productivity of wastewater irrigated is higher than that of irrigated with well water. This due the fact that wastewater has high concentration of nitrogen, phosphorus, and organic matter in comparison to well water.

4. Daily intake of metals

The daily intake of metals (DIM) was determined by the following equation:

$$DIM = mc \times cf \times di / bw$$ (Gupta et al. 2008)

where, "mc" is the metal concentration in vegetables (in milligrams per kilogram) on dry weight basis, cf or the conversion factor of 0.085 was used to convert fresh weight of the vegetables to dry weight as mentioned by Rattan et al. (2005) and "bw" in the equation denotes the body weight (in kilograms). The average daily vegetable intake for adult and children were considered to be 0.345 and 0.232 Kg person/day, respectively, while the average adult and child body weights were considered to be 55.9 and 32.7 Kg, respectively as reported in previous studies (Ge 1992; Wang et al. 2005).

Dietary intakes of heavy metals for adult the consumption of vegetables are in the safe oral reference RfD limit such as for Cu (0.529 µg/Kg/Day), Fe (3.626 µg/Kg/Day), Mn (1.939 µg/Kg/Day), Zn (0.802 µg/Kg/Day), Pb (0.009 µg/Kg/Day) and Ni (0.003 µg/Kg/Day) respectively. This study shows that the DIM values for heavy metals were low through the consumption of food crops grown with contaminated water to wastewater irrigated vegetables in rural agricultural areas of Allahabad. Oral reference dose (RfD) is an estimate of a daily exposure to human population that is likely to be without an appreciable risk of deleterious effects during a life time (USEPA, IRIS 2006). The RfDs for Cu, Fe, Mn, Zn, Pb and Ni are 0.04, NA, NA, 0.3, 0.004, 0.02 mg/Kg/day, respectively (USEPA, IRIS 2006). The risks can be markedly reduced, however, by appropriately matching plant production systems to effluent characteristics (Snow et al. 1999). High-yielding crops with large amounts of nitrogen in their biomass would be more effective than tree plantations at reducing nitrate leaching. Thus, the findings of this study regarding DIM suggest no potential health risk for adults and children with respect to amount of daily intake of heavy metals through ingestion of wastewater irrigated vegetable crops.

IV. CONCLUSION

This study performed on rice plant samples determined the accumulation of heavy metals in rice plant samples collected during their harvesting period irrigated with wastewater of Bairgiya drain and control water. The concentrations of metals in wastewater were found within the permissible limit. Most of the heavy metals studied were found to accumulate mostly in roots of rice plants, while other parts including the straw and grains contained low levels that are below the permissible limits. The heavy metals in the soil studied were mainly derived from the basic rocks found in the study area and availability of toxic metals to rice plants was found to be low. Soil, plant, and water quality monitoring together with the prevention of metals entering the plant, is a prerequisite in order to prevent potential health hazards of irrigation with wastewater. Heavy metal in wastewater of Bairagiya drain used for irrigation, soil and food crops in the study area of Allahabad were compared with the safe limit provided by WHO (2007), SEPA (2005), FAO /WHO standard (Codex Alimentarious Commission 1984) and Indian standard. Application of sewage water increased the yield of crops compared to irrigation with well water; it also increased total N, P, K and organic carbon of soil (Ladwani et al. 2012; Hamilton et al. 2005; Singh et al. 2012). On the other hand the indiscriminate long term use of wastewater for the crop production could result in the concentration that may become phytotoxic (Ghafoor, 1999). Consumptions of food crops contaminated with heavy metals are a major food chain route for human exposure, but it can safe to state that irrigation of agricultural land of rural areas of Allahabad with wastewater has not led any contamination to food crops with heavy metals. Measures must be taken to reduce heavy metal pollution and nutrient loading of irrigation water and soils to protect the safety of both farmers and consumers.

ACKNOWLEDGMENT

The authors would like to place on record their sincere thanks to UGC New Delhi, for the financial assistance, Environment cell, IFFCO Phoolpur Allahabad and University of Allahabad for the support to complete this research.

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AUTHORS

First Author: Arti Yadav (PhD Scholar), M.Sc. in Environment Science, University of Allahabad, arti.yadav39@gmail.com.
Second Author: Pawan Kumar Yadav, M.Sc. (Tech.) in Environment Science & Technology, pawankumar.active@yahoo.in.
Third Author: Shalini Srivastava (PhD Scholar), M.Sc. (Tech.) in Environment Science & Technology, shalinibhuvns@gmail.com.
Fourth Author: Pramod Kumar Singh (PhD Scholar), M.Sc. (Ag.), University of Allahabad, spramodkumar28@gmail.com.
Fifth Author: Vandana Srivastava PhD, University of Allahabad, vansri.envirotech@gmail.com.
Sixth Author – Prof. D. N. Shukla, PhD, D. Sc., University of Allahabad, dnshukal.deen@gmail.com.
Correspondence Author – Arti Yadav, arti.yadav39@gmail.com and mobile no. +918800345662.