Indian Journal of Ecology (2023) 50(2): 526-531
DOI: https://doi.org/10.55362/IJE/2023/3930

Manuscript Number: 3930
NAAS Rating: 5.79

Assessment of Wastewater Quality Discharged from Common Effluent Treatment Plant (CETP) and its Impact on Irrigated Soil around Jajmau, Kanpur, India

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Abstract: The present study is undertaken to assess the concentration of heavy metals (Cu, Cd, Cr, Zn, Fe, Ni, Mn and Pb) in treated wastewater discharged from the Common Effluent Treatment Plants (CETPs) and in the wastewater-irrigated soil around Jajmau in Kanpur, Uttar Pradesh. The wastewater irrigation applied for a long time had a severe effect on irrigated soil and human health. High concentrations of HMs were reported both in collected wastewater samples (Fe>Zn>Mn>Cr>Cu>Cd>Ni>Pb) and soil samples (Fe>Zn>Cr>Cu>Ni>Mn>Pb>Cd) from the agriculture fields. The physicochemical characteristics of wastewater are analyzed using parameters such as color, pH, temperature, BOD, COD, TDS, EC, TN, sulfate, phosphate, potassium and chloride. For the assessment of the physicochemical properties of soil, pH, soil texture, soil moisture, EC, SOM, TOC, available nitrogen, available sulfate, available phosphorus and available potassium were considered. The study will be beneficial for providing the theoretical and statistical data to support wastewater treatment and the merits and demerits of reusing wastewater for irrigation. The outcome is also important in view of the safe and sustainable use of treated wastewater for irrigation, reducing the pressure on freshwater resources and supporting the growth of agriculture while protecting public health and the environment.

Keywords: Wastewater irrigation, Reuse, Farmers profile, Physicochemical characteristics, Soil properties, Heavy metals

Freshwater is not only a valuable natural resource that maintains the survival and development of society but is also considered an essential element of the ecosystem (Smol et al 2020). Worldwide, due to the massive scale of industrialization, urbanization and increasing population, freshwater resources are declining rapidly. Therefore, the situation needs urgent action to scale up efforts in restoration, recycling and reuse to lessen the existing load on freshwater resources (Pratap et al 2023). The recycling and reuse of treated wastewater for agriculture production reduces the demand for freshwater that needs to be extracted from natural resources (EPA 2012, Pratap et al 2021). Over 97% of all the water on earth's surface is saline present in the oceans and the remaining 3% is available as freshwater. Considering accessible freshwater, out of this only 1% is available for human consumption in the form of groundwater, rivers, lakes, streams and reservoirs and the rest 2% is frozen in the form of polar ice caps (Angelakis et al 2021). Due to improper treatment and disposal facilities, most of the industrial effluents are discharged without appropriate treatment processes into the nearby waterbodies or passed through unlined channels resulting in the contamination of freshwater resources. In the past, many developed countries have understood the strategic significance of wastewater recycling and reuse. In 1973, World Health Organization (WHO) published health guidelines for the safe use of wastewater for agricultural irrigation which initiated the application of treated wastewater for irrigation that should be followed strictly (WHO 2006). The Food and Agriculture Organization (FAO) has also issued two technical reports about wastewater treatment and irrigation and effluent quality control on the basis of the current situation of wastewater irrigation worldwide (FAO 1992, Pratap et al 2023).

As a vast agricultural country, India's agriculture sector consumes an extensive amount of freshwater, accounting for more than 70% of the total freshwater consumption. Although India accounts for only 2.2% of the global land, it has 4% of the world's water resources and 16% of the world's population (Pratap et al 2021). Unfortunately, in India, the state of Uttar Pradesh alone is discharging more than half of the heavy metals (HMs) into rivers and streams, with partial or untreated effluent discharged into them. Kanpur, one of the biggest mechanical and business-focused industrial hubs in northern India, has over 800 industries involved in the manufacturing of goods and products. The industrial area of Jajmau in Kanpur alone has more than 400 tanneries engaged in chrome tanning processes and is home to the biggest manufacturer of leather footwear and leather goods (Gupta et al 2018). According to estimates, about 80-90% of tanneries use chromium sulfate in tanning processes, which generates large volumes of toxic effluents that require advanced treatment processes. Tannery wastewater is heavily contaminated with high levels of HMs such as copper, cadmium, chromium, zinc, iron, nickel, manganese, and lead. Although a Common Effluent Treatment Plant (CETP) operates to treat industrial effluent, the treated effluent has been continuously used for irrigation of nearby farming lands for the last four decades. The wastewater-irrigated area covers around 1800 hectares of agricultural land and approximately 10 villages. The long-time application of wastewater irrigation has contaminated the irrigated soil and crops by a huge margin. By consuming these crops, serious health hazards have been reported among consumers (Gupta et al 2018). It has been previously stated by CLRI, Madras (Central Leather Research Institute) that a single tannery can cause pollution of groundwater around a radius of 7 to 8 km (CLRI 1990). Discharged effluent if allowed to percolate into the soil to the groundwater for a long-time could seriously affect the soil profile and the groundwater of the locality making it unfit for drinking, bathing, irrigation and other uses (Mukherjee et al 2020). So, the objectives of this study are to assess the quality of discharged effluent and its suitability for irrigation purposes in reference to the physicochemical properties of effluent and irrigated soil. The present study also deals with the application of wastewater irrigation and its effects on human and environmental health. These specific objectives are designed to promote the sustainable application of wastewater irrigation in India and provide theoretical and statistical support by reusing through high-efficiency treatment of wastewater.

MATERIAL AND METHODS

Site description: The selected site is located on the right bank of the Ganga River at Jajmau (26º24′22″ N latitude and 80º26′12″ E longitude) in Kanpur, U.P. India and is chronically polluted with HMs. A number of industrial units such as tanneries, leather manufacturing industries, cotton and textile mills, chemicals, paints, plastics, fertilizers and arms manufacturing factories are situated there. Specifically, Kanpur is one of the biggest exporting centers of tanned leather of the Ganga alluvial plain. A Common Effluent Treatment Plant (CETP) is situated in the Jajmau area that receives wastewater from the cluster of industrial units located around it. The wastewater treatment is carried out throughout the year and discharged effluents were conveyed to farms through an 8 km long canal where farmers reuse this wastewater for crop irrigation. From this long canal, farmers have made different branches of small canals and diverted them into their agricultural land. Surface irrigation method applied by the farmers for the irrigation of their crops in which wastewater is distributed over the soil surface by the open flow. At the selected site mainly cereals (rice and wheat) and vegetables (potato, onion, beetroot, cabbage, spinach, cauliflower and mustard) crops are grown by the farmers. The study site is situated in the humid subtropical climatic zone and the year is divided into three seasons: the winter season (November-February), the summer season (March-June) and the monsoon season (July-October).

Collection of wastewater and soil samples: The wastewater and soil samples were collected from the selected sites at regular intervals of 30, 60 and 90 days. Wastewater samples were collected in clean plastic containers (5 l) and soil samples were collected from horizon 'A' soil profile (0-20cm depth) which is usually contaminated with HMs. The collected wastewater samples were immediately brought to the laboratory, stored at 4ºC and used for the physicochemical and HMs analysis. The soil samples were collected in self-locking, double-sealed polythene bags and carried to the laboratory for further analysis. Soil samples were oven dried for two days at 70°C and finely powdered and sieved into 250 mm mesh size for physicochemical and HMs analysis. It is seen that the analytical values are above the standard range of certified values of reference materials.

Physicochemical (PC) characteristics and HMs analysis of wastewater and soil samples: The collected wastewater samples were analyzed in three replicates for physicochemical characterization to define the pollution profile of wastewater as per the standard protocols outlined in the Standard Methods for Examination of Water and Wastewater (APHA 2017). Collected soil samples were air-dried, ground to pass through a 2 mm size sieve and stored in plastic bags for further analysis. The samples were analyzed for different physicochemical properties as per the standard procedure. The soil pH was estimated by pH meter in the saturation medium as described by McNeal 1983. The same saturation medium was used for the estimation of electrical conductivity using a conductivity meter. Soil organic matter was estimated by the Walkley-Black method (Jackson 1967). Available nitrogen was estimated by the Kjeldahl method (Bremner and Mulvaney 1982) and available sulfate and phosphorous were determined by Olsen's method using a UV-visible spectrophotometer (Olsen and Sommers 1982). Available potassium was estimated by using a flame photometer as per the standard method. Furthermore, the Inductively Coupled Plasma Mass-Spectrophotometer (ICP-MS) was used for the detection of HMs (Cu, Cd, Cr, Zn, Fe, Ni, Mn and Pb) in collected wastewater and soil samples (Table 1).

Statistical analysis: All the experimental data were statistically analyzed using MS Excel software and the mean of three values was calculated against the critical difference (CD) at a 5% level of significance.

Quality control and quality assurance: According to the Environmental Protection Agency (EPA), the samples for heavy metals were ensured for the analytical quality data through repeated analysis (n=3) (EPA 2012). The experiment was performed for three months and wastewater and soil samples were collected randomly from the selected sites. All the collected samples were analyzed in three replicates and the reported values are the mean of three replicates ±SE.

RESULTS AND DISCUSSION

Farmers' profile: Most of the farmers in the study area are not much aware of the possible health and environmental impacts of wastewater irrigation. This may be followed due to the lack of alternative irrigation water resources and easy accessibility of wastewater. Most of the interviewed farmers were male but some females were also involved in agricultural practices. The literacy rate of the farmers being interviewed was very low and most of them did not know about the health impacts of wastewater irrigation. The age of survey respondents was between 20 to 60 years and most of them were about 40-50 years old. Farmers had similar views about the history of reusing wastewater for irrigation and the majority (60-70%) of them reported that they have been using wastewater for irrigation for the last four decades. The results of this study indicate that a low literacy rate and lack of information among the farmers could be the main reasons behind the application of untreated and partially treated wastewater for irrigation.

Physicochemical characteristics of wastewater samples: The physicochemical parameters such as color, pH, temperature, biochemical oxygen demand (BOD),

Table 1. Physico-chemical characterization of wastewater and soil samples

Parameters	30 days	60 Days	90 days
Wastewater			
Color	Black	Black	Black
pH	8.13±0.06	8.03±0.15	8.17±0.06
Temperature	27.33±0.58	29.67±0.58	32.33±0.58
BOD (mg L^{-1})	261.00±4.58	274.67±4.04	289.67±4.51
COD (mg L^{-1})	931.33±5.69	980.33±6.66	993.67±3.21
TDS (mg L^{-1})	279±2.08	238.33±3.06	229.67±4.51
EC (mS/cm)	0.56±0.00	0.48±0.01	0.46±0.01
Total Nitrogen (mg L^{-1})	221.33 ±6.02	256.66±4.16	274.33±4.50
Sulfate (mg L^{-1})	1232.33±7.63	1260.33±6.02	1278.33±5.03
Phosphate (mg L^{-1})	513.66±5.03	531.66±5.50	554.33±7.02
Potassium (mg L^{-1})	165.33±3.05	174.33±3.51	181.33±2.08
Chloride (mg L^{-1})	116.33±2.51	122.33±3.51	126.33±3.05
Soil			
pH	8.03±0.12	8.07±0.15	8.10±0.10
Sand (%)	54.00±1.00	54.33±0.58	56.00±1.00
Silt (%)	32.67±0.58	33.67±1.15	35.00±1.00
Clay (%)	14.00±1.00	13.67±2.08	9.00±1.00
Moisture (%)	77.48±0.65	73.59±0.45	71.65±1.40
EC (mS/cm)	2.03±0.01	3.08±0.05	3.05±0.9
SOM (%)	1.11±0.03	1.25±0.06	1.34±0.05
TOC (%)	2.12±0.03	1.96±0.06	2.21±0.02
Available Nitrogen (mg kg^{-1})	2.17±0.03	2.25±0.03	2.35±0.04
Available Sulphate (mg kg^{-1})	9.13±0.02	9.27±0.06	9.44±0.09
Available Phosphorus (mg kg^{-1})	4.16±0.03	5.13±0.05	5.28±0.06
Available Potassium (mg kg^{-1})	7.34±0.05	7.43±0.15	7.55±0.09

± Standard Deviation

chemical oxygen demand (COD), total dissolved solids (TDS), electrical conductivity (EC), total nitrogen (TN), sulfate, phosphate, potassium, and chloride of wastewater was measured which showed that the wastewater irrigation applied for a long time had a severe effect on irrigated soil and human health (Table 1).

Physicochemical characteristics of soil samples: Long-term wastewater irrigation and the presence of reported HMs clearly indicate that the discharged effluent is not suitable for the irrigation of soil. The worst thing is that these elements have been far beyond the ability of soil self-purification causing serious pollution and changes in soil physicochemical characteristics. The pH of collected soil samples was found to be alkaline between the range of 8.32-8.10. Once the pH value varies drastically, the soil physicochemical properties would be changed accordingly which affects the existing composition and availability of soil nutrients directly. The availability of soil organic matter is not only related to natural environmental conditions but also depends on the supply of organic matter through irrigated wastewater. Available nitrogen, available sulfate, available phosphorus and available potassium had significantly increased because of long-term wastewater irrigation that accumulated in the upper soil layer (0-20 cm) (Table. 1). Available nitrogen is an essential nutrient for crop growth and the continuous supply of nitrogen with wastewater affects soil productivity.

Heavy metals concentration in different wastewater samples: Interviewed farmers showed concerns about the hazards of wastewater irrigation. Further, analytical results showed the presence of HMs above the acceptable limits in wastewater and their bioaccumulation in soil systems. Particularly Cr, Zn, Fe, Ni, Mn and Pb were found in wastewater samples above the permissible limits (Fig. 1) (WHO 2006). Higher concentrations of HMs in collected wastewater samples might be the outcome of treated or partially treated industrial effluents discharged by CETP and its application for growing crops over a long period that has built up HMs in the soil systems.

Heavy metal concentration in soil samples: Long-term wastewater irrigation results in HMs contamination of soil up to a toxic level which in turn leads to the degradation of soil productivity. This concentrations of HMs higher than the recommended permissible limits in collected soil samples irrigated with wastewater. However, the severity of wastewater irrigation depends on its source, composition, treatment before use and management at the farm levels. Very high concentrations of Fe, Zn, Cr and Cu were in the collected soil samples (Fig. 2) (WHO 2006). Higher concentrations of HMs were observed in the upper soil layers of the selected locations (0-20 cm). Physicochemical properties such as soil pH, texture, EC and SOM play a great role in HMs contamination of wastewater-irrigated soil. In general, long-term wastewater irrigation would be responsible for the adsorption of HMs in soil particles resulting in soil HMs pollution which has become the most serious hazard for human health and the environment. Ultimately, these HMs are dangerous to human health through various food chains.

The long-term application of wastewater irrigation may alter the physicochemical properties and microbiota of irrigated soil which may further deteriorate land fertility and crop productivity. The physicochemical analysis of wastewater and soil samples of this study has revealed that the pH and EC values were higher due to the presence of a high concentration of organic and inorganic salts. Several other findings reported the threats of wastewater irrigation and their impacts on the soil profile by affecting pH, salinity, nutrient availability, organic matter content and microbial diversity (Jaramillo and Restrepo 2017, Pratap et al 2021). The continuous practice of wastewater irrigation resulted in the accumulation of HMs in the irrigated soil and subsequently in crops growing therein (Shahid et al 2017).

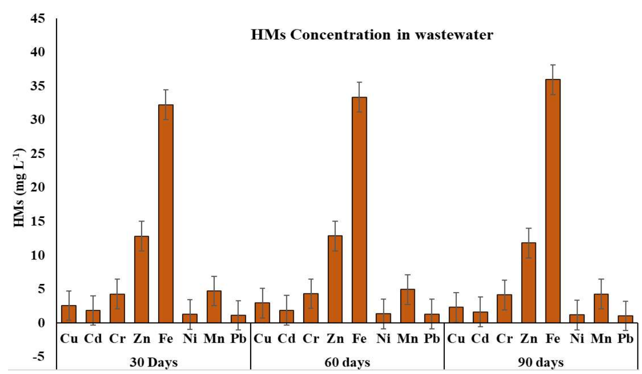

Fig. 1. Heavy metals concentration in collected wastewater samples

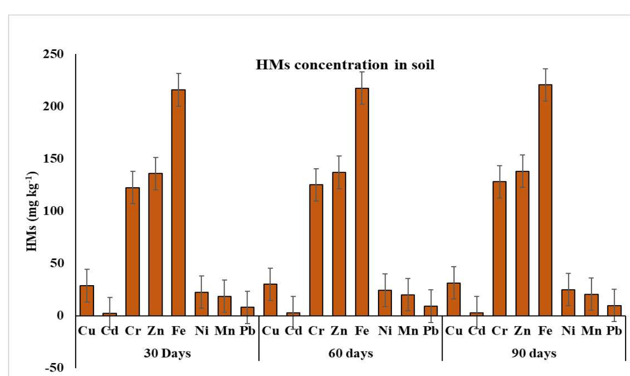

Fig. 2. Heavy metals concentration in collected soil samples

The high concentration of HMs (above the permissible limit) is mainly due to the condensation process which takes place during the tanning process in tannery industries. Reuse of this wastewater for crop irrigation leads to health risks to farmers and consumers via food chain and the environment. The transfer of HMs from wastewater to irrigated soil primarily via the absorption process. The absorption of HMs such as Fe, Zn, Cr and Cu within soil depends upon pH, temperature, organic matter, nutrient availability and available moisture content (Wang et al 2017, Pratap et al 2021).

A study carried out on wastewater irrigation through the polluted water of Musi River at Hyderabad, Telangana, India, showed the translocation of HMs at different trophic levels (Qadir et al 2010). The arid and semi-arid northern and central part of Mexico uses reclaimed wastewater to irrigate their crops. Moreover, the Tula Valley, one of the largest areas of the world covering more than 90,000 hectares of agricultural land is using treated wastewater for agricultural production (Navarro et al 2015). In India, several regions reuse treated or partially treated wastewater for the irrigation of agricultural crops. Finally, the exposure of HMs from crops to human beings takes place directly via dietary intake of wastewater-irrigated crops, especially green vegetables (Woldetsadik et al 2017). Previous studies indicated that wastewater irrigation resulted in serious hazards for the environment such as HMs pollution of the soil and groundwater. Long-term wastewater irrigation may significantly affect the groundwater through leakage of salty and HMs-rich wastewater making them unfit for human consumption (Jaramillo and Restrepo 2017, Pratap et al 2021). They can cause serious threats to human health if used for drinking, cooking and domestic purposes. HMs could also enter into freshwater bodies through runoff and potentially affect aquatic ecosystems (Pratap et al 2023). This study may be useful in planning a safe cropping system for such HMs-contaminated agricultural fields as well as the management and safe disposal of such wastewater to avoid contamination of fertile agricultural fields. Reusing treated wastewater in India for the irrigation of more than 1.5 million hectares of agricultural land annually could reduce the pressure on freshwater resources. However, recycled wastewater also carries adverse effects on soil and crops, the environment and human health. Therefore, continuous improvement in wastewater treatment technologies and stricter monitoring approaches are urgently required to promote reuse of treated wastewater for crop irrigation in India (Qadir et al 2010, Pratap et al 2021).

CONCLUSIONS

The specific objectives have been designed to promote the sustainable application of wastewater irrigation in India and provide theoretical and statistical support for the reuse of wastewater through high-efficiency treatment. The idea is to (a) encourage the adoption of advanced treatment technologies for efficient and effective wastewater treatment, (b) create awareness among farmers and the local community about the safe and sustainable use of treated wastewater for irrigation, (c) assess the quality of treated wastewater and its impact on soil, crops, and groundwater, (d) identify potential health risks associated with the use of untreated or partially treated wastewater for irrigation, and (e) develop guidelines and regulations for the safe and sustainable use of treated wastewater for irrigation. In India, encountering the problems of water scarcity and the high cost of fertilizers, wastewater could be used for irrigation. Starting from the sources of wastewater generation, the quality aspect should be considered strictly at treatment plants which could strengthen the quality of discharged wastewater. For the individual, the health risks of wastewater irrigation should be extensively published enhancing awareness of environmental and human health hazards. The reuse of wastewater for irrigation practices has gained importance worldwide due to limited water resources and the very high cost of wastewater treatment technologies. Wastewater contains a high amount of organic matter, nutrients and HMs which are toxic to soil, crops and human health beyond a certain limit. The indiscriminate long-term use of wastewater for crop production could result in HMs contamination that may become hazardous for the farmers and consumers. Wastewater-irrigated soil may accumulate HMs in sufficient amounts to cause chronic diseases in farmers and local people who have been consuming these HMs accumulated crops. Results indicate that the reuse of wastewater with appropriate treatment processes could increase the water resources for irrigation which may be beneficial for agricultural production. Therefore, wastewater irrigation needs to consider the actual situation at selected sites carefully and strict treatment protocols should be considered to achieve safe and effective reuse of wastewater for irrigation.

ACKNOWLEDGMENT

The authors acknowledge the support and the necessary facilities provided by the Department of Environmental Science, Babasaheb Bhimrao Ambedkar University, Lucknow in carrying out this research work.

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Received 10 December, 2022; Accepted 26 February, 2023