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Releasing pollutants in the soil depth under the conditions of irrigation with municipal wastewater in different situations

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ABSTRACT
Due to the enormous amount of wastewater produced due to urbanization and industrialization, as well as the health and environmental risks associated with wastewater, it is essential to estimate the number of pollutants it generates accurately. This study aims to determine the rate (%) of all types of pollutants in wastewater transferred from the soil. The experiment utilized 16 polyethylene columns with a height of 200 cm and an inner diameter of 15 cm. Six 7-day intermittent flooding experiments were conducted. Three times every 21 days, a continuous and intermittent flooding method was used to dispose wastewater. Magnesium exhibited the highest transfer rate (%) among cations (73.46%), while sodium the lowest (39.76). Chlorine displayed the highest transfer rate among anions (60.85%), while bicarbonate the lowest (32.12%). In the cases of other pollutants, nickel revealed the highest (72.19%), while phosphorus the lowest (2.82%), indicating that the soil can retain phosphorus. In conclusion, examining various methods and comparing the results, plays a significant role in achieving optimal methods and estimating more accurate results.

Keywords: Wastewater, pollutants, continuous flood, intermittent flood
Article type: Research Article.

INTRODUCTION
Pollution is one of the significant environmental issues that has led to the destruction of water, soil, and air (Zhang *et al.* 2021). The risk of soil and water pollution is comparable to that of air, however, due to their intangibility and incomprehensibility to non-specialists, they are less significant (Wan *et al.* 2022). Soil and water resources exhibit direct and indirect effects on public health, making it crucial to protect them and ensure their sustainability (Zinchenko *et al.* 2021). Increased concern over the accumulation of pollutants in soil and water has resulted from the development of industry and the release of chemicals used on earth (Li *et al.* 2020). The accumulation of pollutants such as cations, anions, nitrogen, phosphorus, TOC (total organic carbon), nickel, etc., in the water and soil resources of industrial areas, is one of the most critical environmental issues that endanger the lives of plants, animals, and humans (da Silva Paes *et al.* 2022). It has been demonstrated that these pollutants display harmful effects on living organisms, including disruption of biological activities and adverse effects on plants and humans

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due to their entry into the food chain (Bai *et al.* 2019). Industrial pollution is one of the most widespread forms of pollution in terrestrial and aquatic ecosystems (Z. Wang *et al.* 2020). In recent decades, large quantities of pollutants such as cations, anions, and heavy metals have entered the environment due to the expansion of the industrial sector and noncompliance with environmental regulations (Kumar *et al.* 2022). Some of these pollutants are decomposed and removed by microorganisms in water, soil, or under the influence of physical and biological factors. However, most of them accumulate in the environment and pose a great risk to human and animal health (Kang *et al.* 2019). Monitoring the contamination of soils and underground water sources is one of the appropriate methods for remediating contaminated land promptly (Azizi *et al.* 2022). Pollution of agricultural soils may cause soil structure irregularities, alterations in plant growth patterns, and even harm human and community health (Gholoubi *et al.* 2019). In addition, underground water sources are the world's largest accessible freshwater reserves (Wang *et al.* 2020). Recognizing underground water quality as one of the most vital and vulnerable sources of water supply over the past few decades is a no-brainer (Ran *et al.* 2022). Moreover, the increasing population and demand for water use for various purposes, including agriculture, drinking, and industry, necessitate the development of studies and evaluations in the water sector (Liu *et al.* 2018). Due to the adverse effects of underground water pollution on the environment and human health, it is crucial to investigate these resources in terms of the type and amount of pollution, as well as the quality management of water resources (Harms *et al.* 2021). Furthermore, polluted water, even in concentrations below the permissible limit, can gradually accumulate pollution in the soil and plants (Zhao *et al.* 2019). In recent years, the effort to properly dispose wastewater has become crucial due to the enormous volume of wastewater produced. Due to the limited water resources and the enormous amount of wastewater produced in various regions of the world, there is a need for an economically and efficiently viable wastewater treatment method (Kebonye *et al.* 2022). Studies indicate that discharging sewage into the soil is one of the most effective methods of sewage disposal. The high concentration of organic matter in wastewater, the favorable effect of these substances on various soil properties, and the availability of soil are among the most important reasons for discharging wastewater into the soil (Jasim & Aljeboree 2021). In addition, the soil complex physical, chemical, and biological properties play a significant role in enhancing the quality of all types of pollutants, including sewage (Qi *et al.* 2020). By passing wastewater through the unsaturated zone of the earth, it is possible to almost entirely separate floating solid particles, biodegradable materials, and microorganisms, leading to their significantly-reduced concentrations (Sari *et al.* 2018). The contamination of water sources, especially groundwater, soil, and plants, results from the improper management of the wastewater discharge for various purposes in the soil (Ogoko, 2019). The physical, chemical and biological characteristics of the soil, the type of wastewater and its degree of purification, the conditions of wastewater use such as the method of wastewater application, topography and climatic conditions, the type of vegetation, and the level of underground water are among the factors that influence the soil effectiveness in wastewater treatment (Xu *et al.* 2022). To determine the efficacy of soil in wastewater treatment, it is necessary to collect data about the local mechanisms of solute transfer and pollutant accumulation. Consequently, it is necessary to understand the soil efficacy in treating various wastewater components. In the present study, the effect of the amount of wastewater treatment and the method of wastewater application on the ability of purifying certain elements in wastewater has been examined through the study of the transfer of polluting substances to the depth of the soil over time. Investigating the types of pollutants at various intervals and times is one of the novel aspects of this study.

MATERIALS AND METHODS

The present study was conducted in the Faculty of Agriculture Research Laboratory at the University of Diyala over 126 days, with consideration given to the type of wastewater and the method of its use as continuous and intermittent flooding. In the experiment, 16 polyethylene columns were employed. The column height and their inner diameter were 200 cm and 15 cm respectively. Appropriate membranes were used to reduce the lateral movement of water at the end of the columns, preventing water from escaping the containers designed to collect the drain water. Then, a layer of plastic mesh was stretched to give the end section sufficient strength. This study separated coarse soil particles to create more uniform soil. Examining the soil gradation curve revealed that 17% of the original soil sample is composed of particles larger than 3 mm. Based on the agricultural classification, this soil was classified as sandy loam. Table 1 lists the physical and chemical characteristics of the desired soil. The amount of soil required to fill the columns was calculated based on the soil specific mass, and it was added gradually throughout several stages without any unique compaction. The final soil height was 160 cm after fine sand was poured at approximately 10 cm. The 40 cm-tall space atop the columns was considered as free depth for adding sewage.

Table 1. Specifications of the soil sample used

Parameter	unit	value
Sand	%	53.42
Silt	%	28.61
Clay	%	17.97
Porosity	%	43.72
Special dry mass	g cm^{-3}	1.76
Specific mass of saturation	g cm^{-3}	2.14

In order to produce effluent from raw sewage, the treatment system consisted of an aeration lagoon with complete mixing. The volume of wastewater required to flood the soil, based on its porosity percentage and total volume, was calculated to be approximately 4 L. Taking into account the evaporation of wastewater from the surface of the soil and the need to pass the same volume of wastewater through all the columns, if acceptable results are obtained in terms of the amount of transfer of substances in the wastewater to the depth of the soil. In natural conditions, better results are obtained due to the integrity and continuity of soil and land. In other words, an effort was made to consider the experiment's worst and most critical conditions. In continuous use conditions, wastewater was used at the level of the soil columns all at once, and water was collected after 21 days. In intermittent application, the same volume of wastewater (4 L) was divided into three parts and used every seven days. As in the conditions above, drainage water was collected. So that, after 21 days, a constant volume of sewage passed through all the columns. Drain water samples were collected and transported to the laboratory for chemical analysis in each of the six 21-day periods during which the experiment was conducted. Before the experiment, soil solution parameters such as pH, the concentration of soluble cations (sodium, potassium, calcium, and magnesium), soluble anions (chlorine, carbonate, bicarbonate, and sulfate), and other elements such as nitrogen, phosphorus, total organic carbon, and nickel were measured. These parameters were measured in wastewater and drainage samples during each test period. Table 2 presents the chemical quality of the examined wastewater.

Table 2. Chemical quality of investigated wastewater

Parameter	unit	value
Sodium	meq L^{-1}	10.76
Potassium	meq L^{-1}	0.83
Calcium	meq L^{-1}	1.86
Magnesium	meq L^{-1}	2.17
Chlorine	meq L^{-1}	6.42
Carbonate	meq L^{-1}	7.49
Bicarbonate	meq L^{-1}	9.07
Sulphate	meq L^{-1}	3.71
Nitrogen	mg L^{-1}	31.54
Phosphorus	mg L^{-1}	1.83
Total organic carbon	mg L^{-1}	42.27
Nickel	mg L^{-1}	0.179

The transfer percentage factor was used to determine and investigate the number of changes in the transfer of various components in raw sewage and effluent to the depth of the soil during the period of wastewater application. The transfer percentage is the ratio of the average output concentration of each element from the soil column to its average input concentration. The lower percentage of element transfer indicates the soil high capacity to retain that element. High transfer percentage values for each element indicate high dynamics or a low capacity of the soil to retain that element due to its entry in large quantities. In this regard, the trend of changes in the transfer percentage of each desired element in the soil columns throughout the test period has been examined.

RESULTS AND DISCUSSION

Examining the transfer percentage of cations

Cations such as calcium, magnesium, and potassium do not directly threaten human health or the environment, and their leaching from the soil can indicate the removal of beneficial elements. In addition, since divalent cations play a positive role in the soil, their removal can affect the physicochemical properties of the soil. During the experiment, the transfer rate (%) of each dissolved cation from the soil columns is depicted in Fig. 1. Using a greater quantity of wastewater over time, the transfer proportion in the drainage of the soil has increased. Therefore, altering their value over time is continuously accelerating.

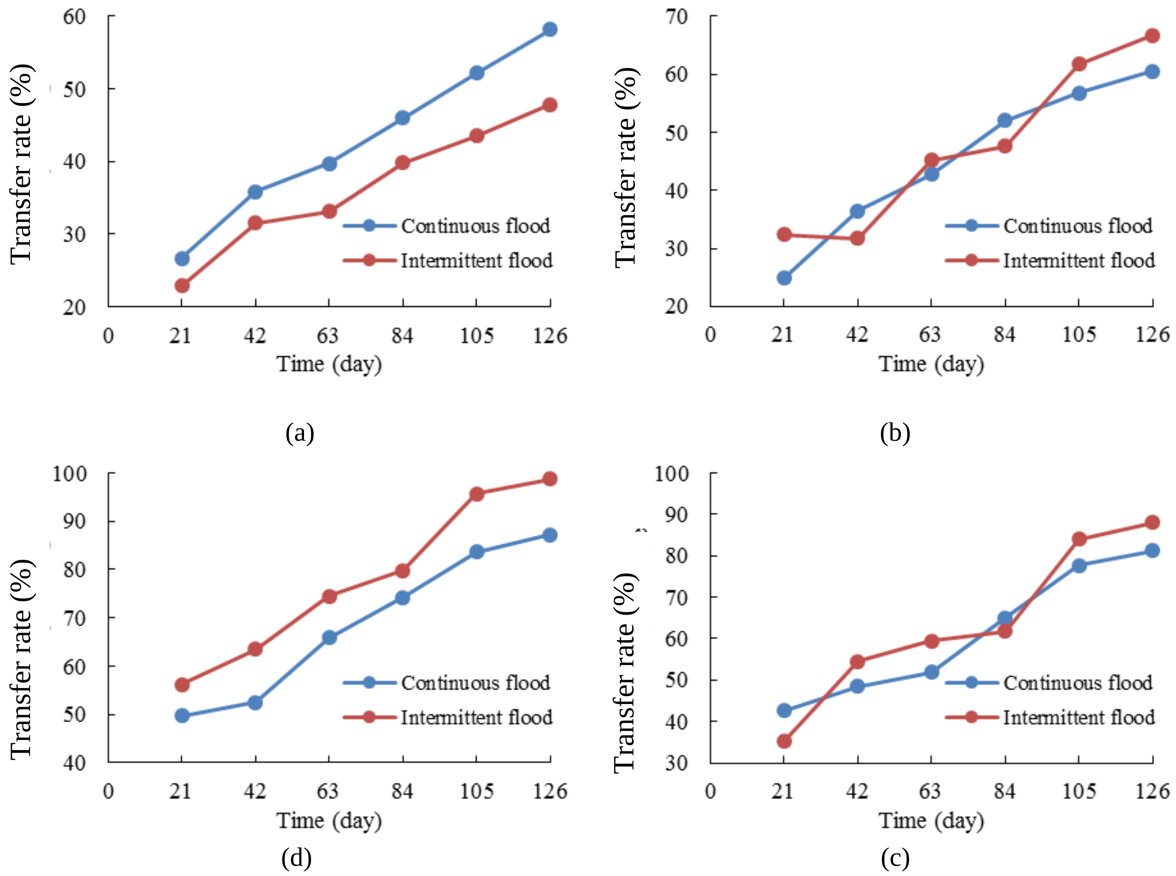

Fig. 1. Transfer percentage of cations in continuous and intermittent flood conditions: (a) sodium, (b) potassium, (c) calcium, (d) magnesium.

The less organic matter in wastewater, the more quick its moving through the soil and transport more cations. In addition to directly affecting a portion of the soil pores, a great deal of organic matter, especially floating sewage, significantly impacts the soil pores. In addition, indirectly, by stimulating the activity of soil microorganisms and increasing their microbial production, it obstructs a portion of the soil pores, resulting in a gradual decrease in sewage infiltration. In intermittent sewage movement, the average transfer rate (%) of all dissolved cations (except sodium) to the outflow water drain is more significant than in the continuous condition. However, this effect is statistically significant only for the transfer rate of magnesium in the harvest ($p < 0.05$). During the test period, the average transfer percentage of sodium, potassium, calcium, and magnesium cations from the soil columns were 39.76, 46.57, 62.49, and 73.46, respectively. It can be seen from a comparison of the transfer rate that the transfer rate of divalent cations is greater than that of monovalent cations (Houle *et al.* 2020). The potassium transfer rate is justifiable, since its concentration is low in soil and wastewater. Although a large amount of sodium compared to calcium and magnesium cations in the incoming wastewater, its low transfer percentage from the soil indicates that the discharge of sodium-rich wastewater disrupts the natural balance of soil cations and results in the replacement of sodium with cations (Rosenstock *et al.* 2019). Other elements, particularly calcium and magnesium at the soil surface, are now exchangeable. Due to leaching, more divalent cation entered the soil solution and was transferred. From the comparison of transfer rate, it can be concluded that calcium has been transferred at a higher rate than magnesium.

Examining the transfer percentage of anions

In general, it is necessary to monitor the concentration of anions in wastewater, since their high concentrations reduce the quality of soil, surface, and groundwater. So that, the reaction of carbonate and bicarbonate with dissolved calcium and magnesium increases sodium exchange and reduces the soil permeability. By forming bonds with heavy metals, inorganic anions in the soil solution also affect their absorption in the soil. According to Fig. 2, the rate of change in the rate of dissolved anions transported in the drainage of water leaving the soil constantly rises. Significantly more carbonate and sulfate were transferred under continuous application conditions when wastewater was applied ($p < 0.05$).

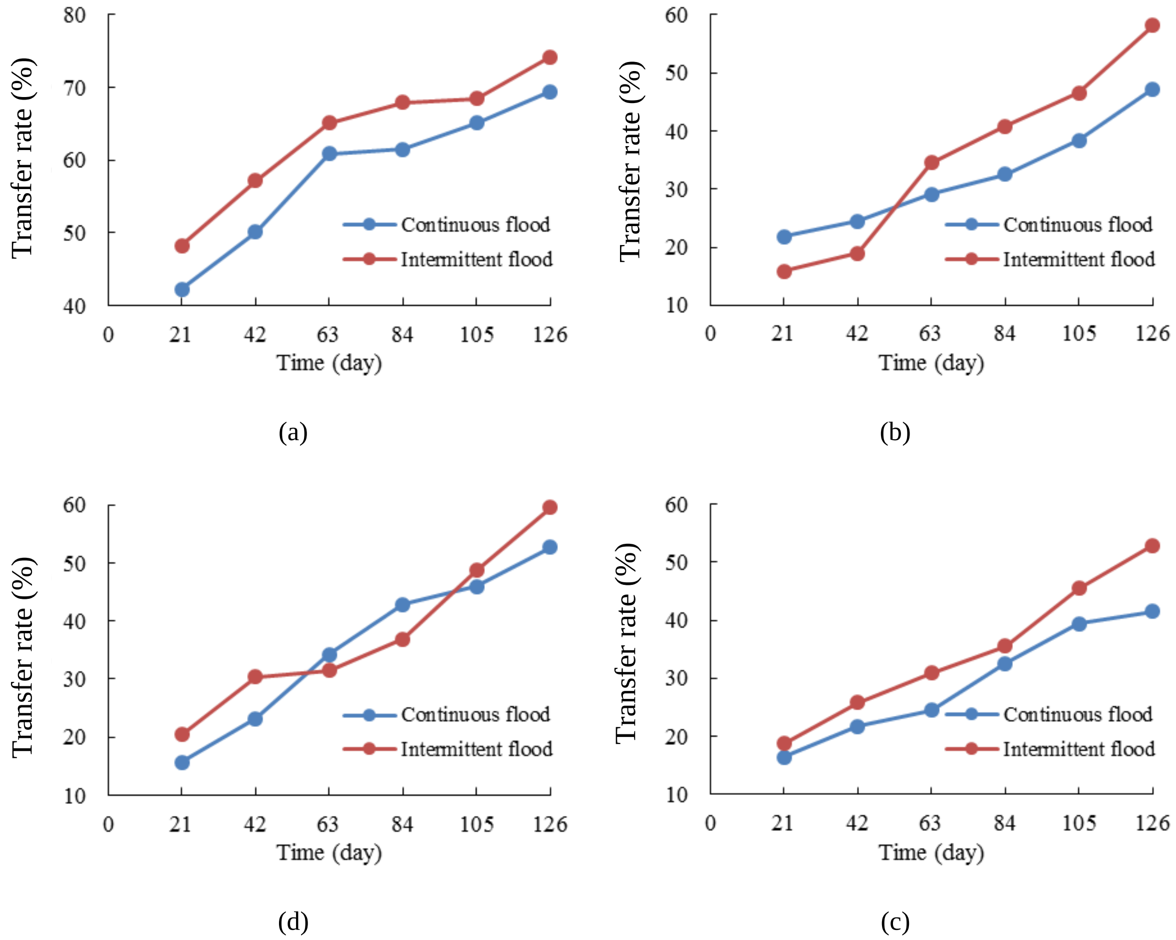

Fig. 2. Transfer rate (%) of cations in continuous and intermittent flood conditions: (a) chlorine, (b) carbonate, (c) bicarbonate, (d) sulfate.

Regardless of the wastewater application method, the average transfer rate of chlorine, carbonate, bicarbonate and sulfate anions from soil columns were 60.85, 34.03, 32.12, and 36.84%, respectively, exhibiting that chlorine had the highest transfer rate, while bicarbonate the lowest (Hussain *et al.* 2022). Since the chlorine anion has no effect on the soil physical conditions and is not typically absorbed by the soil solids, it is highly mobile.

Examining the transfer percentage of other pollutants

Significant amounts of nitrogen are added to the soil due to sewage discharge, which depends on the amount of nitrogen in the sewage. Nitrate is one of the forms of nitrogen. Due to its negative charge, the nitrate ion is highly dynamic, and its movement is similar to that of water in the soil. If plants or microorganisms do not absorb nitrate, it will quickly enter the water and pose health risks. Phosphorus is a critical nutrient in the occurrence of the eutrophication phenomenon, and its transfer to surface and subsurface waters results in a decline in water quality. Bioaccumulation is a property of organic compounds resistant to decomposition, which are toxic to soil microorganisms and plants and carcinogenic to humans. The presence of TOC in the soil solution can alter the oxidation and reduction potential of the soil and increase the dynamics of heavy metals in the soil depths. In addition, the preferential bonding of soluble organic compounds with calcium and magnesium results in a more excellent dispersion of soil particles. Heavy metals such as nickel are frequently used in various urban settings and can enter the sewage system through water consumption. The transfer of the specified pollutants over time is depicted in Fig. 3.

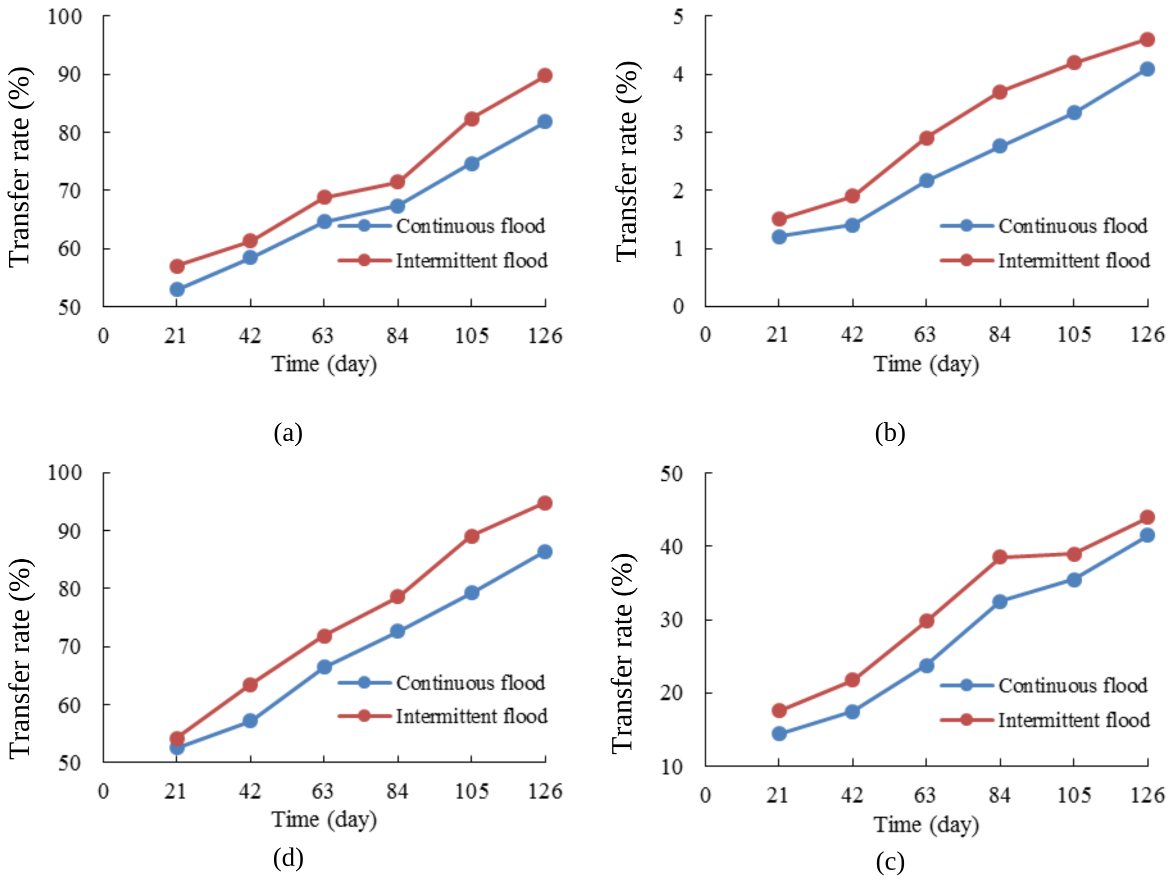

Fig. 3. Transfer rate (%) of cations in continuous and intermittent flood conditions: (a) nitrogen, (b) phosphorus, (c) TOC, (d) nickel.

The proportion of nitrogen transferred from the soil has increased over time (Fig. 3). By examining the effect of wastewater application on the rate (%) of nitrogen transfer, it was found that its average transfer rate is significantly higher under intermittent use than under continuous use ($p < 0.05$). The increase in nitrogen-nitrate transfer under intermittent use conditions can be attributed to the continued decomposition of organic matter caused by the release of ammonium and subsequent nitrogen-nitrate production in the soil. Regardless of the method of wastewater application, the average transfer of nitrogen- nitrate from the soil was 69.20%. Due to the soil light texture and large pores, a greater quantity of wastewater has been transferred to the depths of the soil, which accounts for the high nitrogen transfer rate (Jia *et al.* 2019). In addition, conditions have improved for the infiltration of oxygen into the soil and the occurrence of nitrification. Very little phosphorus is transferred to the water drain from the soil, so the average phosphorus transfer from the soil columns was 2.81%, indicating that the soil has significantly influenced phosphorus retention in wastewater (Zhou *et al.* 2018). In the study about the effect of the wastewater application method on the phosphorus transfer rate, it was also found that more phosphorus was transferred when wastewater was applied continuously. The higher phosphorus transfer rate under continuous application reduces the contact between wastewater and soil particles. The results indicated that the rate of TOC transferred to the outflow water drain has increased over time. The ability to remove organic substances from wastewater increases over time, either due to the biological degradation of organic substances or the soil increased capacity to absorb organic substances as they accumulate. Therefore, the increase in TOC over time can be attributed to both the rapid rate of decomposition and the release of organic substances that are resistant to decomposition. The average rate of TOC transferred was 29.64%, exhibiting that soil texture has played a significant role in the high TOC transfer rate. It was concluded that the transport of organic matter to depth is more significant in soils with a light texture than in dense ones (Guo *et al.* 2019). Following the alkaline pH of the soil, nickel has been transferred to the depth of the soil, and the proportion of nickel transferred to the outflow water drain has increased over time. The type of soil texture and the presence of large pores can be one of the most influential factors for increasing the nickel transfer rate from the soil to the water drains as wastewater utilizing rises over time. The movement of a portion of colloidal sediments and clay particles, along with the movement of the soil solution, results in the transfer of heavy metals attached to these particles in soils with large pores. In addition, the transfer of TOC and the process of increasing the rate of its transfer to the depth of the soil over time can also influence the transfer (Gujre *et al.* 2021). In an investigation about the effect of the wastewater application method, it was found that the nickel transfer rate in the intermittent sewage movement is significantly higher ($p < 0.05$) than in the condition of continuous sewage movement. Based on the average transfer rate of nickel from the soil columns (72.19%), it can be concluded that a significant portion of the nickel added by sewage, is accumulated in the soil.

CONCLUSION

From the analysis of the transfer rate values (%) of the examined parameters, it can be concluded that their transfer rate to the soil depth has increased, as wastewater application has continued. The soil has demonstrated a solid capacity to retain phosphorus. However, a significant amount of soluble cations and anions, nitrogen, total organic carbon, and nickel have been lost to the drains. Due to the high rate of nitrogen-nitrate and total organic carbon transfer, the people health will be at risk if the drain water from this soil permeates the underground water, especially the water which supplies the cities with drinking water. As time passes and organic matter decomposes, heavy metals bound to organic matter and TOC in the soil solution rise. In many cases, no significant difference was observed between the continuous and intermittent utilizing of wastewater during the study about the effect of the wastewater use method. However, intermittent utilizing of wastewater is recommended to reduce the dynamics of heavy metals.

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