Study on Dispersivity of Heavy Metals in Undisturbed Soil Columns In and Around Peenya Industrial Area, Bengaluru, India

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Abstract

This paper analyses the effect of heavy metal tracers on the one-dimensional transport of pollutants through the undistributed soil columns done in the laboratory, and experimental data is compared with analytical data. In this study, the advection-dispersion equation is used analytically through 'Mathematica' to evaluate the transport of pollutants. It considers the heavy metal contaminants by considering the input concentrations of pollutants that vary with time and depth. The experiment test results regarding breakthrough curves were analysed, revealing essential patterns in heavy metal migration. The current investigation is to find the dispersion coefficient in and around the industrial area for four heavy metals, i.e., four undisturbed soil columns at station 1(Inside) and four undisturbed soil columns at station 2 (outside). The hydrodynamic dispersion co-efficient 'D' when Chromium (Cr), Nickel (Ni), Zinc (Zn) and Copper (Cu) solution was passed through 20cm soil column (each metal per column)outside industrial area was 3.57 m^2/year, 1.99 m^2/year,10.84 m^2/year, and 3.49 m^2/year and the solution was passed through 20cm soil column(each metal per column) inside industrial area 5.22 m^2/year, 2.2 m^2/year, 8.08 m^2/year, and 6.57 m^2/year. According to the soil column experiment, the lowest mobility is observed in clay soil (Inside the Peenya Industrial Area) rather than in sandy loam soil (outside the Peenya Industrial Area). These findings enhance our understanding of heavy metal pollution and provide a basis for predicting and managing such pollution in industrial areas. The 'Mathematica' used in the present research helps predict the future effects of heavy metal pollution in the study region, thereby equipping us with the knowledge to take proactive measures.

Keywords: *Heavy Metal, Mobility, Undistributed, Breakthrough Curves (BTC), Soil Columns, Peenya Industrial Area (PIA), Groundwater contamination, Hydrodynamic dispersion.*

Introduction

Soil and water are essential resources for life, but human activity is gradually compromising their quality. Urbanisation, industrialisation, and human activities affect water quality. Water contamination threatens ecosystems, long-term ecological stability, human health, and economic development. Emerging water pollutants from various industries contribute significantly to water pollution and directly or indirectly affect water quality, increasing vulnerability to groundwater pollution. Industrial Effluents contain high levels of toxic heavy metals and are the primary source of surface water, groundwater, and soil pollution [1]. Industrial wastewaters are generated through various multidimensional industrial activities. Industrial wastewater can be classified as chemical, electronic, petrochemical, and food processing, containing high BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), Total solids, TDS (Total Dissolved Solids), TSS (Total Suspended Solids), Inorganic ions, and Non-biodegradable contaminants. Environmental effects from industrial wastewater discharge include improper management of hazardous waste, disposal of heavy metals, and water quality degradation. The pollutants can enter aquifers through various pathways, including leaching, recharge, surface runoff, and leakage, ultimately affecting groundwater quality and posing risks to ecosystems and public health. Gaseous emissions from urban transport systems and industrial exhausts are another primary source of groundwater pollution caused by atmospheric conditions. Groundwater pollution can also arise from air deposition, contaminating soil in urban areas. As contaminants permeate the soil layers and move to groundwater reservoirs, they harm water quality and human health [2,3]. The study aims to identify the major patterns of heavy metal behaviour in soil columns. The study objective is to compare the rigorous laboratory experiments and a comprehensive analysis, providing crucial insights into the transfer of contaminants through undisturbed soil columns. In this study, the advection-dispersion equation is used analytically through 'Mathematica' to evaluate the transport of pollutants, which considers the heavy metal contaminants by considering the input concentrations of pollutants that vary with time and depth.

Heavy metals are elements with relatively high densities (5.3 to 7 g/cm^3) and atomic weight. Even small doses can have serious consequences. Examples of HMs are Mercury (Hg), Cadmium (Cd), Lead (Pb), Chromium (Cr), Arsenic (As), Iron (Fe), Manganese (Mn), Nickel (Ni), Zinc (Zn) & Copper (Cu). They pose health and environmental risks due to their properties, toxicity, nonbiodegradable, and bioaccumulation potential throughout the food chain[1]. Globally, heavy metals in soil and water seriously threaten public health and the environment. Numerous human and natural processes contribute to accumulating these hazardous elements in the environment, which causes pollution. Bioaccumulation means an increase in chemical concentration in a biological organism. Unscientific industrial waste management practices increase heavy metal concentrations, cause metal leaching, and ultimately cause soil and groundwater pollution. Heavy metals can also enter soil from acidic rain and release them into streams, lakes, rivers, and groundwater [4,5].

Soil pollution is caused by both intended and unintended activities, such as on-site industrial pollution, inadequate waste management, mining activities, intentional applications of materials to soil, and atmospheric depositions. Various anthropogenic activities, such as industrialisation, urbanisation, and agricultural practices, lead to the accumulation of pollutants like petroleum products, heavy metals, pesticides, and excessive nutrients in soils. This contamination negatively impacts soil engineering properties, affecting settlement, shear strength, permeability and blocking soil pores. Soil contamination by heavy metals and pesticides also threatens food safety, ecosystems, and public health, necessitating immediate remediation efforts to mitigate harm and ensure sustainability [5,6].

Soils may become contaminated by dumping heavy metal wastes and metalloids through emissions from the rapidly expanding industrial areas, disposal of high metal wastes, leaded gasoline and paints, sewage sludge, pesticides, spillage of petrochemicals, and atmospheric deposition. Problems arise from the leaching of heavy metals from industrial sites. Metal ions are dispersed throughout the environment by water's surface, subsurface, lateral, and vertical motion. Several factors influence heavy metal migration, including soil classification, mineralogy, texture, and leachate composition. It also depends on the season, time, amount of rainfall, temperature, acid rainfall, airborne dust, and other anthropogenic activities.

The transport of industrial chemicals through soils affects groundwater quality [7]. The transport mechanisms of heavy metals through soil have created significant interest to environmental and soil scientists because of the possibility of groundwater contamination through metal leaching. Many soils generally contain heavy metals with varying concentrations depending on the surrounding geological environment, natural and anthropogenic activities [8]. Metal transport is not only dependent on the physiochemical properties of the metals but mainly on the physical and chemical properties of the soil, such as soil organic matter content, clay fraction content, mineralogical composition, and pH, all of which collectively determine the binding ability of soil [9,10].

Hamed Mahdipanah, Askari Tashakori, Samad Emamgholizadeh, and Eisa Maroufpoor [11] conducted a study on the determination of the dispersion coefficient in layered soils. Experiments were performed on homogeneous soil and layered heterogeneous soil with three layers. The present research attempted to determine the effects of parameters on Breakthrough Curve (BTC) and dispersivity values by considering different flow velocities and concentrations, pretending the porous media or aquifers in the layered form, and using mixed methods sampling. The results concluded that the dispersion coefficient for layered heterogeneous soils was 1.96 times less than that of homogeneous soils, indicating the amount of dispersion coefficient in soil changes with the contaminant concentration. Wan Zuhairi W.Y, Abdul Rahim Samsudin, & Nurita Ridwan's [12] study was focused on the Column experiment. It is a very useful apparatus that can be used to study the migration and attenuation of heavy metals through a compacted soil column. This study conducted a column experiment on some natural soils from the Selangor area in Malaysia using different types of heavy metals, namely Cu, Pb, Ni, and Zn. The study has revealed that soils have different capacities to retain heavy metals and very much depend on their physical and chemical properties. The affinity or selectivity of HMs for sorption (or retention) also varies in different types of soils, as proven by the study.

Zhao Wang and Guangyu Lei [13] conducted a study of the Soil column permeability experiments in the laboratory to study the transport characteristics of five heavy metal ions of Mn, Ni, Cd, Cr, and Cu in saturated loess, sandy soil, and compound soil. The results show that the soil texture and the characteristics of heavy metal ions have a common effect on the migration of heavy metal ions. Heavy metal ions in loess do not migrate easily and can be adsorbed on the surface or shallow surface for a long time. It is not easy to cause deeper contamination of groundwater. However, it causes surface runoff to migrate laterally to rivers or other areas and expands the pollution area. The study shows that any type of heavy metal from mining areas with a high content can cause environmental pollution and adverse effects.

Wan Zuhairi W.Y. & Nurita R. [14] performed the soil column study to investigate the retention capability of three soil types in Malaysia, namely marine clay (SBMC), weathered metasediments (HMS) and river alluvium soil (ARA). All soil columns were tested against four types of heavy metals, i.e. copper, lead, nickel, and zinc. The breakthrough curves show that the SBMC has better retention capability on heavy metals than other soils, indicating less migration of heavy metals through the SBMC soil column. The study discovered that heavy metals entered the soil columns and were retained predominantly at the top 30 mm. Mohamed Rashad and Faiz F. Assaad and Elsayed A. Shalaby [15], undertook their study within the soil's plough layer (0-20 cm depth) from two sites near two municipal solid waste dumpsites in Alexandria, Egypt. Column leaching experiments provided valuable information on labile metal pools and the significance of slow reaction kinetics in metal leaching. The results from the study recognised that the cumulative amounts of metal cations released are poorly defined because they can include metal cations released from high-affinity sorption sites on organic matter and oxides.

M.J. Sanchez-Martin, L. F. Lorenzo, and M. Sanchez-Camazano [16] investigated the leaching of Pb, Cd, Zn, and Cu in three representative packed soil columns collected within the zone affected by the spill from a pyrite mine in Aznalcollar (Sevilla, Spain). The study's results discovered that the relative mobilities of the different toxic elements in the columns are Cd> Zn> Cu> Pb. Results also showed that the soils themselves have a good capacity for immobilising the soluble fraction of the elements from the spilt mud. C. M. Niranjan, J. Raji and S.R. Sudheendra [17] investigated the effect of radioactive tracer on the one-dimensional transport of pollutants through the unsaturated porous media and compared it with experimental data. In their study, the advection-dispersion equation is used analytically to evaluate the transport of pollutants, which considers the decay of radioactive contaminants by considering input concentrations of pollutants that vary with time and depth. The solution is obtained with the Laplace transform and moving coordinates to reduce the linear partial differential equation to an ordinary one. Duhamel's theorem is applied using experimental data to receive the complementary error function solution. The outcomes from the research help in the possibilities of applied chemicals leaching through over-irrigation, thereby resulting in groundwater contamination by fertilisers.

Study Area

Peenya Industrial Area (PIA) is the most significant industrial Zone in Bengaluru, Karnataka, India. The Peenya Industrial estate lies in Bengaluru city's north part between latitude 13^0 1’ 42" N and longitude 77^0 30’ 45" E. The Industrial Area is crossed by national highway NH 4, which runs between Bengaluru and Mumbai. It was established in the late 1970s by the KSIDC-Karnataka Small Industrial Development Corporation and has divided the PIA region into 3 Stages. Further, the Karnataka Industrial Development Board has subdivided the 40 km^2 PIA region into four phases: phases 1, 2, 3, and 4 for development and monitoring. BBMP- Bruhat Bangalore Mahanagara Palike will have authority over the

Peenya industrial sector [18]. The PIA comprises about 2,100 types of Industries, including small and medium-scale [19]. Peenya Industrial sector employs around 5,00,000 people. The small and medium-sized industries include pharmaceutical formulations, chemicals industries, polymers industries, leather industries, electroplating industries, lead processing, textile dying, galvanising, degreasing, spray painting, phosphating, pickling industries, anodisation, garment washing, powder coating, plating, and allied industries. Both central and state governments recognise the Peenya Industrial Area (PIA) as the primary hub of Karnataka State's industrial activity and a substantial provider of manufactured goods that are well-regarded for their quality in domestic and international markets. Figure 1. shows the spatial Location map of the study area.

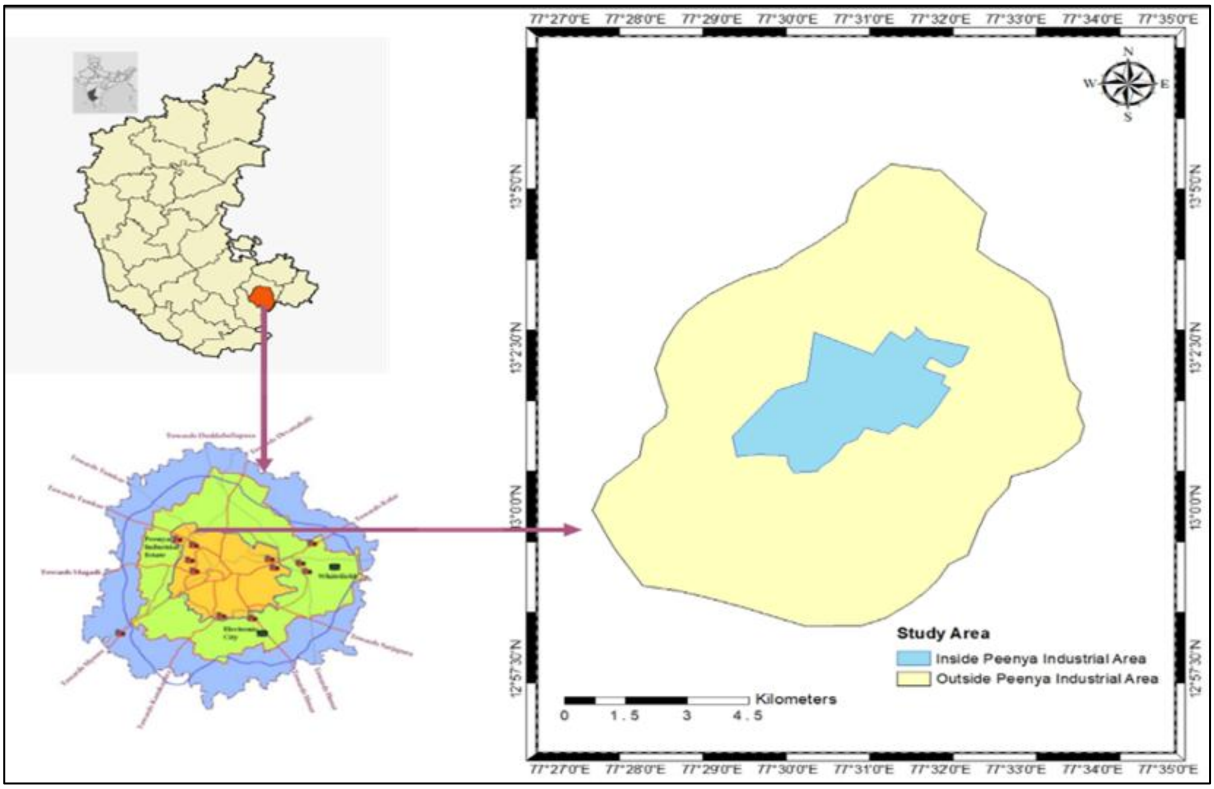

Figure 1: Location Map of Study Area

Topography, Climate and Rainfall

The PIA comes under Bangalore North Taluk and is underlain by banded gneissic complexes and granites of the Archaean age. Both rock types are weathered. The western part of this ridge's drainage flows and joins the Arkavathi, while the eastern plains drain towards the South Pinakini [19]. Over the past 50 years, the research area has received an average of 923 mm of rainfall annually [19]. Most rainfall is received during the southwest monsoon between June and September. September is the wettest month, and January is the driest month. The atmospheric temperature varies between 14° to 34° Celsius. The lowest recorded temperature was 7.8° Celsius, while the highest was 38.9° Celsius. Near the Peenya industrial sector, the Air Quality Index factor varies from satisfactory to moderately polluted.

Hydrogeology, Geology, and Soil

Peninsular gneissic rocks, such as granites, gneisses, and migmatites, are responsible for forming significant aquifers in the metropolitan areas of Bengaluru. The rock, often magmatite, combines igneous and metamorphic rocks [19]. The composite Migmatite rock comprises a metamorphic host material veined or streaked with granite. There are phreatic conditions in the north groundwater of Bengaluru. The weathered zone and the fresh gneisses and granite rock that lie underneath it comprise the whole aquifer system in this region. Depending on the location, the PIA weathering thickness might range from

20 to 24 meters. The groundwater depths before the monsoon season vary from 3.20 meters to 57.38 meters bgl (below ground level), whereas groundwater depths range from 2.50 meters to 37.50 meters bgl after the monsoon season. The soil composition around Bengaluru varies from red loamy to laterite soils. Red sandy soil is typical in the Peenya industrial region. These sandy soils offer good penetration rates, a reasonable water-holding capacity, and a light texture. There are three different types of soils in the research area: sandy clay loamy, sand loamy, and loamy sand. Figure 2. shows the geology map of the study area.

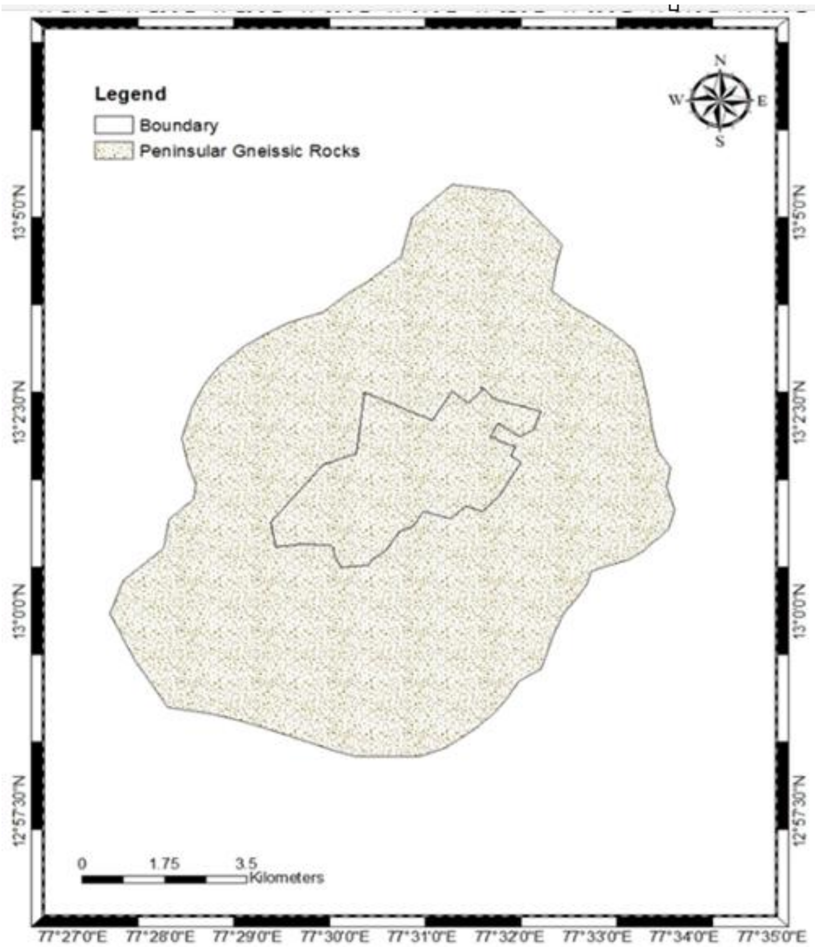

Figure 2: Geology Map of Study Area

Methodology

Soil column studies are a valuable method for investigating the behaviour and movement of heavy metals in soils. Soil column studies provide crucial insights into how heavy metals behave in soil environments and help to develop effective strategies for managing soil contamination and protecting ecosystems. Soil column studies are designed to simulate the natural conditions of soil and its interaction with contaminants, such as heavy metals. The study objectives: 1. To study the major patterns of heavy metal behaviour in soil columns. 2. The Mathematical Software Ttool used in the present research is to help predict future heavy metal pollution in the study region [20,21,22].

Laboratory Tests

Thin-walled steel cylinders are used to construct soil columns. The lower end of the steel pipe was sharpened to reduce compaction inside the column and easily facilitate pipe insertion into the soil. The eight steel cylinders 20cm in height and 10cm in diameter were coated with vegetable oil, inserted at the sampling sites, and collected undisturbed (4 soil samples Inside PIA and another 4 outside PIA). The soil columns are labelled, sealed, and transported in a plastic box to the laboratory. The experimental investigation was carried out on Eight undisturbed soil samples with four different heavy metals. The undistributed soil represents natural conditions. Soil columns are typically constructed in steel cylinders to allow observation of the movement of contaminants. The upper part of the steel column is open, and the outlet hole has evenly meshed at the bottom; a layer of filter paper is laid on the lower ends of the soil column to collect the effluent from the column and to prevent outflux of particles. The soil columns were hung to a steel stand with a hook provided to the stand, as shown in Figure 3.

Methodology for Experimentation

There are two stages of leaching for the column test:

1. Column leaching using deionised water.
2. Column Leaching using a test solution.

The tracer solutions employed were deionised water and aqueous heavy metals solutions. The composition of the aqueous heavy metals test solutions was prepared by dissolving heavy metals in deionised water to obtain a concentration of Chromium: 500 mg/l, Nickel: 560 mg/l, Copper: 400 mg/l, and Zinc: 516 mg/l as this metal were found in higher concentration in the soils tested at same locations during earlier studies conducted for soil [23]. Deionised water having a low pH simulates rainwater percolation through the soil column until all the heavy metals present in the soil are washed out.

Figure 3: Soil Column Experiment

Breakthrough curve (BTC):

The breakthrough curve measures the adsorbate concentration in the fluid phase at the column's exit as a time function. It is a plot of the test duration against the adsorbate concentration in the effluent stream of a liquid with the adsorptive. It is a critical tool for understanding how contaminants migrate and evaluating soil remediation techniques. Breakthrough curves help model and predict the transport and behaviour of contaminants in soil and groundwater systems. Researchers can assess the effectiveness of soil treatments or amendments by comparing breakthrough curves before and after applying remediation techniques. These curves ensure that soil and groundwater contamination levels meet regulatory standards and guidelines. The data obtained from breakthrough curves can guide the design of soil treatment or remediation strategies to manage and mitigate contamination effectively [24, 25].

Application of Mathematica for predicting the transport of heavy metals to groundwater

In recent years, the advection-diffusion equation has drawn considerable attention from hydrologists, civil engineers, mathematical modellers, and environmental scientists researching the migration and characteristics of trace metals in soil. The advection-diffusion equation describes the solute transport caused by the combined effect of diffusion and convection in a medium [11, 17, 26].

Dispersivity is an assessed characteristic in soil porous mediums used to examine the transfer of pollutants to groundwater. Determination of the longitudinal dispersion coefficient in the laboratory is typically done using the analytical solution to the one-dimensional dispersion equation. The solution for the dispersion equation is given by:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - u\frac{\partial C}{\partial z}$$

Where *C* is the constituent concentration in the soil, the solution, *t* is the time in minutes, *D* is the hydrodynamic dispersion coefficient, *z* is the depth, and *u* is the average porewater velocity.

Using Fried and Cumbarnous's [27] equation given below and the experimental data about soil columns containing tracer metals, the dispersion coefficient values were calculated:

$$D = \frac{1}{8}\left[\frac{z - vt_{0.16}}{\sqrt{t_{0.16}}} - \frac{z - vt_{0.84}}{\sqrt{t_{0.84}}}\right]^2$$

where $t_{0.16}$ and $t_{0.84}$ are the times required for the concentration ratios of $C/C_0=0.16$ and $C/C_0=0.84$, respectively, to reach a particular distance z.

Metal transport depends not only on the physiochemical characteristics of the metals but also primarily on the physical and chemical characteristics of the soil, including its pH, organic matter content, clay fraction, mineralogical composition, and other factors that define the soil's binding ability [28].

Results and Discussion

The results of soil column experiments using deionised water will illuminate the quantum of metal leached out of the soil. The input to the soil column is drawn from the constant tank containing the tracer and allowed over the column drop by drop. Then, after the soil becomes saturated, the tracer comes out as leachate from the bottom end of the soil column, and the time elapsed is recorded. The collected leachates were subjected to chemical analysis, and breakthrough curves were constructed and discussed in the present section. The soils from the study sites were sampled and subjected to essential physical and chemical tests using standard test procedures.

Table 1 below presents the physical and chemical properties of the soils in the study area. Results show that all the soil samples collected from Inside PIA (Station 1) is clay soil and all soil samples outside (Station 2) the PIA is a sandy loam type.

Table 1: Physical and Chemical results of soil tests

Soil Sample	Latitude	Longitude	pH (1:5)	ECe (dS/m)	CEC (cmol/kg)	OM (%)	OC (%)	sand (%)	silt (%)	clay (%)	Soil structure
Station 1 (Inside PIA)	13.0256417	77.5136416	7.59	0.26	30.43	1.032	0.6	35.56	16.12	48.32	clay soil
Station 2 (Outside PIA)	12.990593	77.491051	6.55	0.08	13.78	1.24	1.17	69.68	18	12.32	sandy loam

CEC (Cation Exchange Capacity): This measures the soil's capacity to attract and hold positively charged ions (cations) like calcium, magnesium, potassium, and sodium, which are essential for plant growth; higher CEC indicates the soil can retain more nutrients.

OM (Organic Matter): This refers to the percentage of decomposed plant and animal material in the soil, which plays a crucial role in improving soil structure, water retention, and nutrient availability.

OC (Organic Carbon): This is a specific component of organic matter, representing the carbon content within the decomposed organic material.

Column leaching using deionised water:

Four undisturbed soil columns inside the Peenya industrial area undergo column leaching separately for 4 tracer elements i.e., First Column for Cr, second column for Ni and likewise using deionised distilled water for nearly 240 hours. At 120 h, the concentration almost becomes zero for Cr and Ni, Zn at 234h (Figure 4a, 4b, 4c), and Cu at 178h (Figure 4d).

Similarly, Column leaching using deionised distilled water takes nearly 240 hours for four undisturbed soil columns outside the PIA. At 120 h, the concentration almost becomes zero for Cr and Ni, Zn at 222h (Figure 5a, 5b, 5c), and Cu at 174h (Figure 5d).

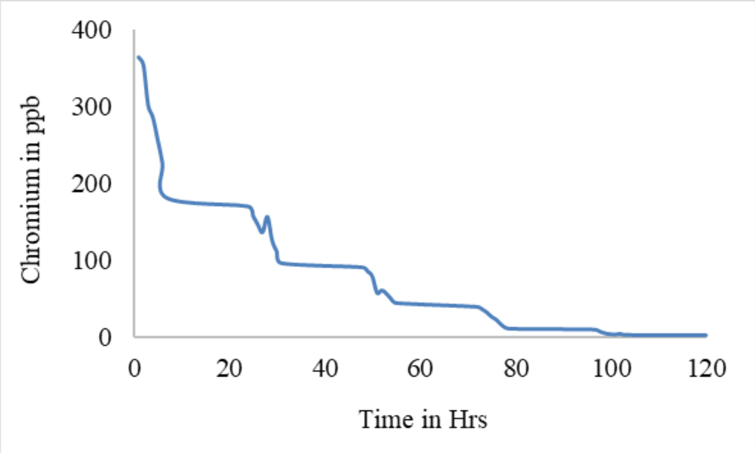

Figure 4a: Deionised water graph of Chromium Inside Peenya Industrial Area (PIA)

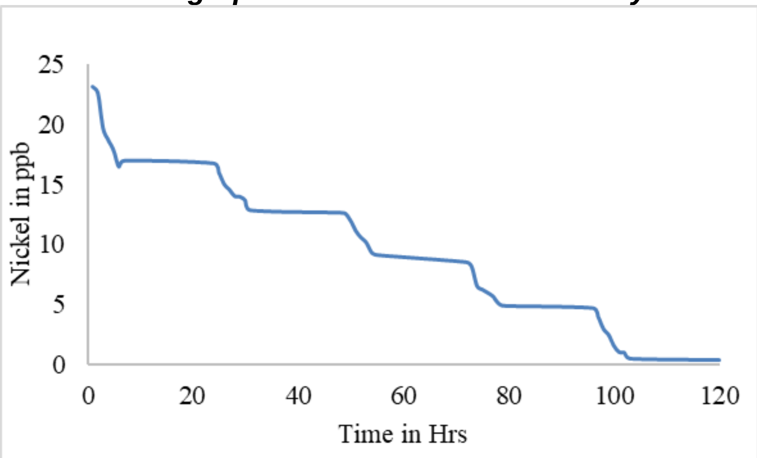

Figure 4b: Deionised water graph of Nickel Inside Peenya Industrial Area (PIA)

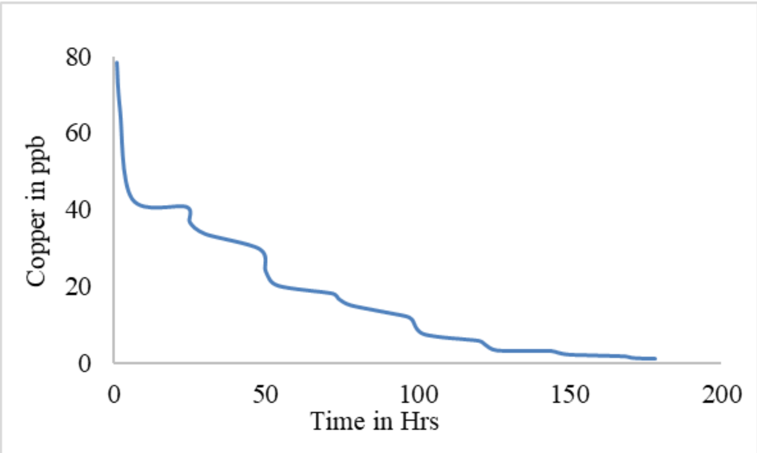

Figure 4c: Deionised water graph of Copper Inside Peenya Industrial Area (PIA)

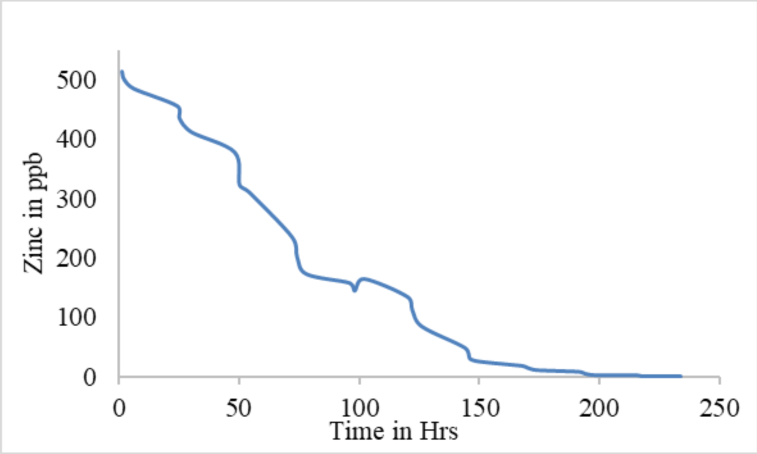

Figure 4d: Deionised water graph of Zinc Inside Peenya Industrial Area (PIA)

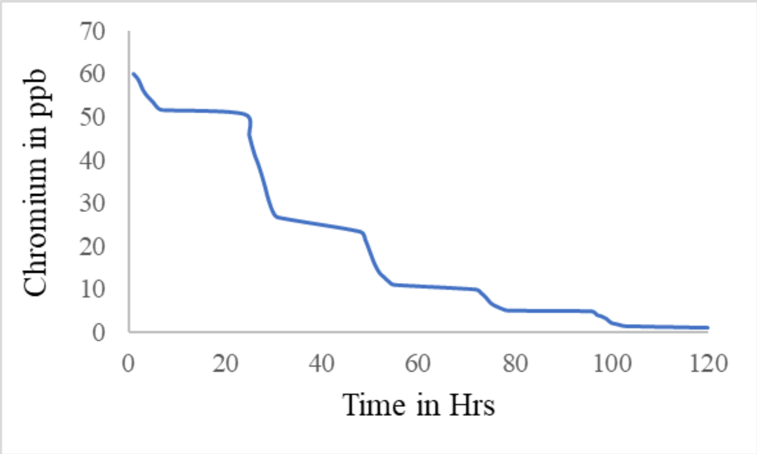

Figure 5a: Deionised water graph of Chromium Outside Peenya Industrial Area (PIA)

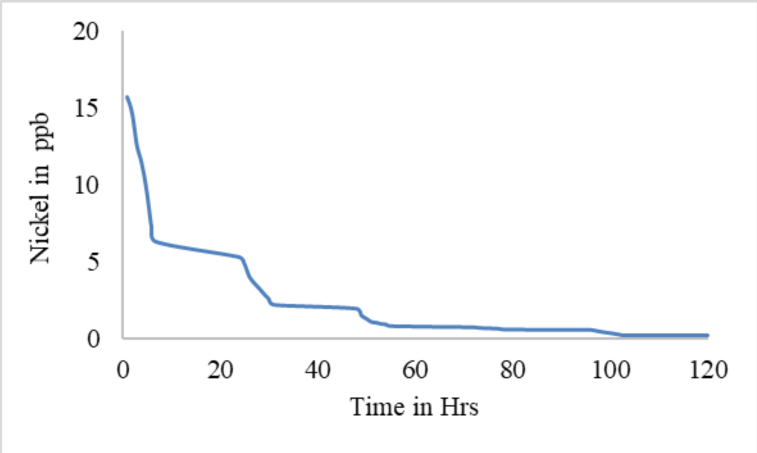

Figure 5b: Deionised water graph of Nickel Outside Peenya Industrial Area (PIA)

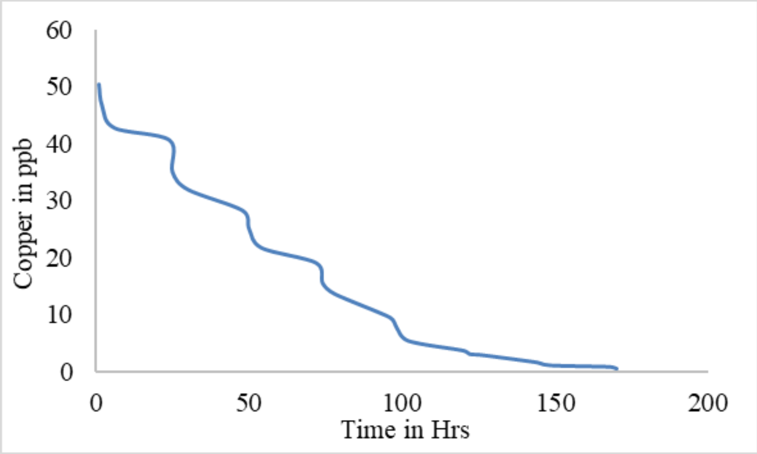

Figure 5c: Deionised water graph of Copper Outside Peenya Industrial Area (PIA)

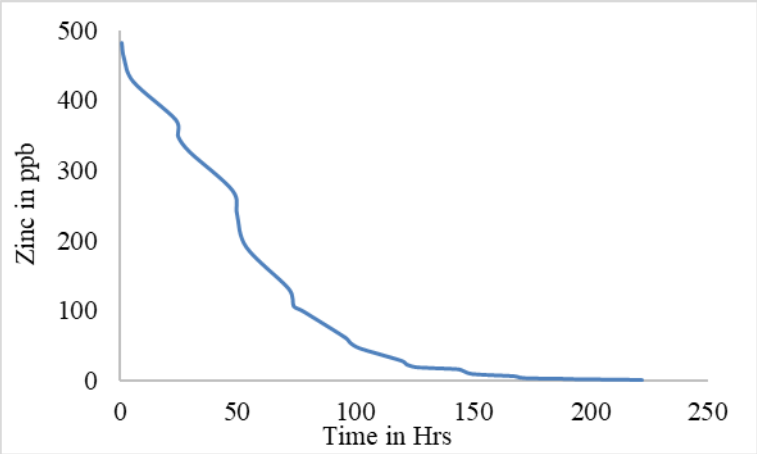

Figure 5d: Deionised water graph of Zinc Outside Peenya Industrial Area (PIA)

Column Leaching using a test solution

Statistical analysis of data and replication of leaching experiments are required to ensure reliability. Synthetic heavy metals solution of Heavy metals of Cr, Ni, Zn and Cu is passed through the unsaturated soil columns collected Inside and Outside the PIA till the soil adsorption capacity is exhausted, and Breakthrough curves (BTC) are plotted. Breakthrough curves are plotted between relative concentration and time. Figures 6(a, b, c, d) and 7(a, b, c, d) show the BTCs of Ni, Cr, Zn and Cu for soils collected inside and outside the PIA.

In summary, the migration processes of four metals in four soils inside the PIA are slower than those outside the PIA. The soil sample collected from inside the PIA is a clay soil type, and the CEC and OM values are high compared to soil collected outside the PIA. The affinity of heavy metals adsorption can be ranked Cu>Zn>Ni>Cr. According to the studies, heavy metal ions are not easier to migrate in clay soil than in sandy soil. The lowest heavy metal mobility is observed in clay soil (inside PIA) compared to sandy loam soil (outside PIA). Because the total surface area for adsorption is slightly higher in clay soil than in sandy loam soil [28,29]. As a result, there is a higher chance of topsoil pollution, and due to surface runoff, it migrates laterally to surface water or other areas and expands the area of pollution. The penetration rates of heavy metals were low at high cation exchange capacity and organic matter. The soil sample collected from inside the PIA is a clay soil type. For the same reason, it is difficult to cause deeper groundwater contamination inside the PIA. However, groundwater pollution exists inside the PIA because of the direct discharge of industrial pollutants into bore wells and improper industrial waste management.

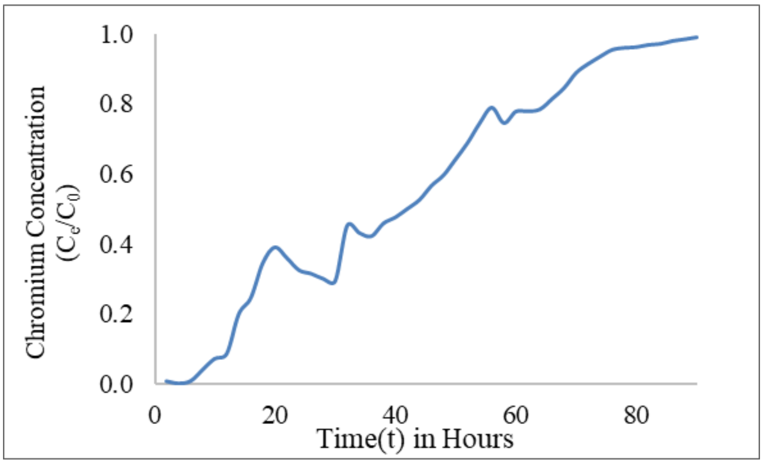

Figure 6a: Break Through Curve of Chromium Inside Peenya Industrial Area (PIA)

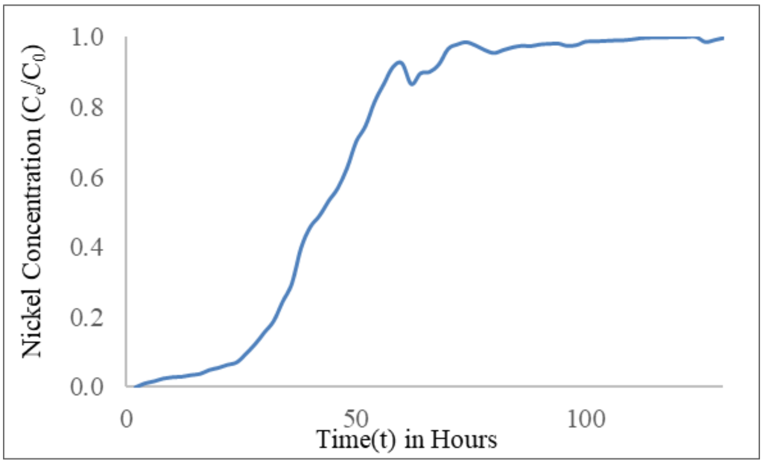

Figure 6b: Break Through Curve of Nickel Inside Peenya Industrial Area (PIA)

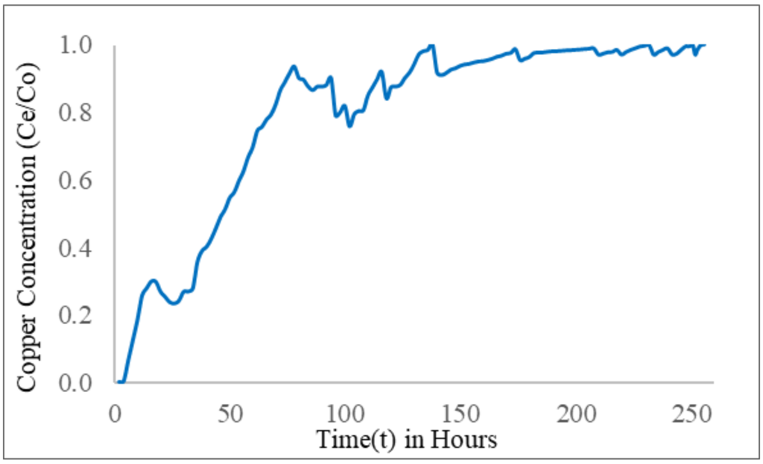

Figure 6c: Break Through Curve of Copper Inside Peenya Industrial Area (PIA)

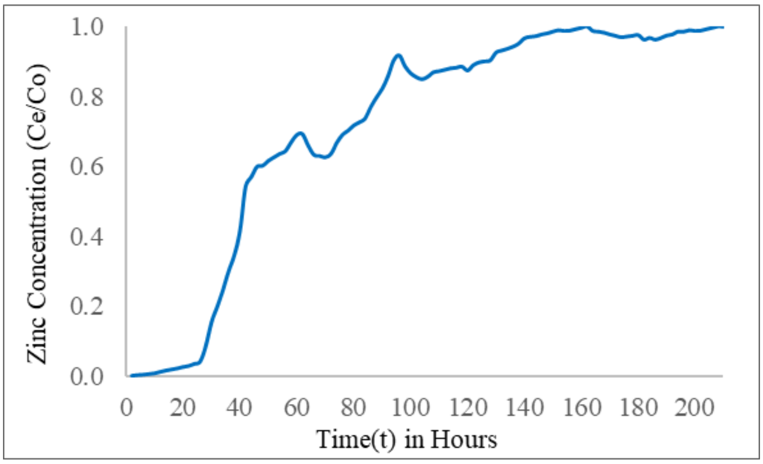

Figure 6d: Break Through Curves Copper Inside Peenya Industrial Area (PIA)

The migration processes of 4 metals in 4 soils outside the PIA differ in the same soil conditions. The soil sample collected from outside the PIA is a sandy loam type of soil and clay soil found inside the industrial area. The mobility of Cr in the soil column is higher than that of other metals in the soil column. The behaviour of Ni percolates from soil samples was very similar to that of Cr. Ce/Co values increased with the number of days. The mobility of Zn is low compared to other metals, such as Cr and Ni, in the soil column. The mobility of Cu in the column is low compared to three metals, Cr, Ni and Zn, in the soil column. The affinity of heavy metals sorption can be ranked Cu>Zn>Ni>Cr. BTCs show retention of heavy metals in the case of Cu and Zn metals and greater mobility in the case of Cr and Ni by soil column. The environmental impact of Heavy Metal contamination strongly depends on the metal specification, mobility, type of soil, and physical and chemical properties of soil. According to the findings, the soil sample taken from outside the Peenya industrial area is a sandy loam soil type. According to studies, heavy metal ions migrate more easily in sandy soil than loess. Also, the CEC and OM values of the sandy loam soil are low. Therefore, the penetration rates of heavy metals were high at low cation exchange capacity and organic matter. This is why metal infiltrates deep into the soil or groundwater and causes pollution.

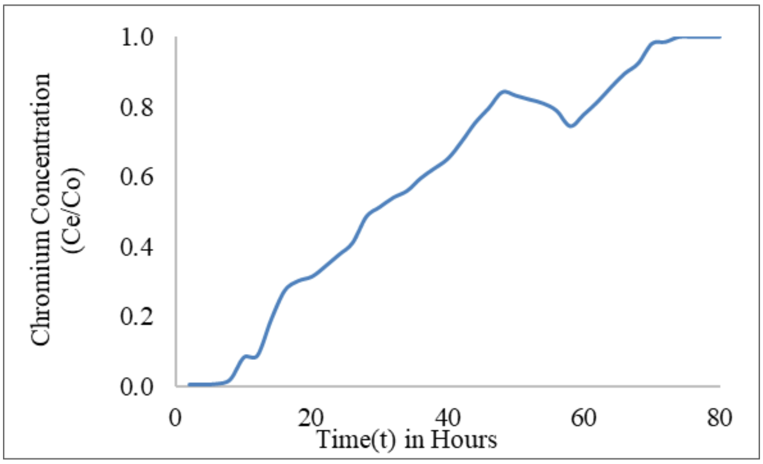

Figure 7a: Break Through Curves Chromium Outside Peenya Industrial Area (PIA)

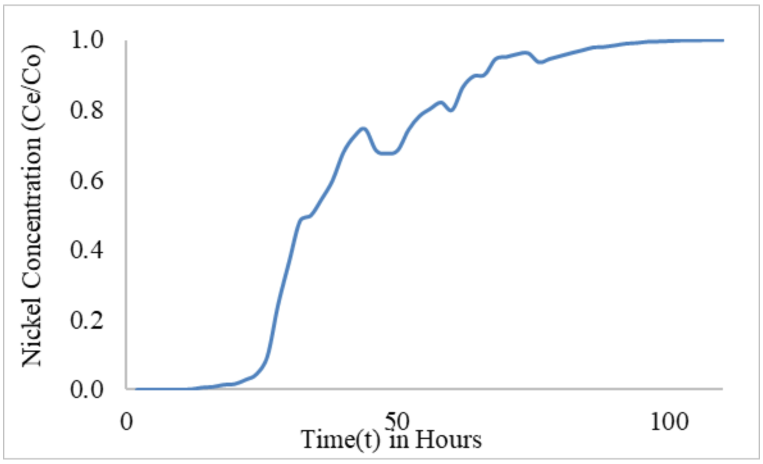

Figure 7b: Break Through Curves Nickel Outside Peenya Industrial Area (PIA)

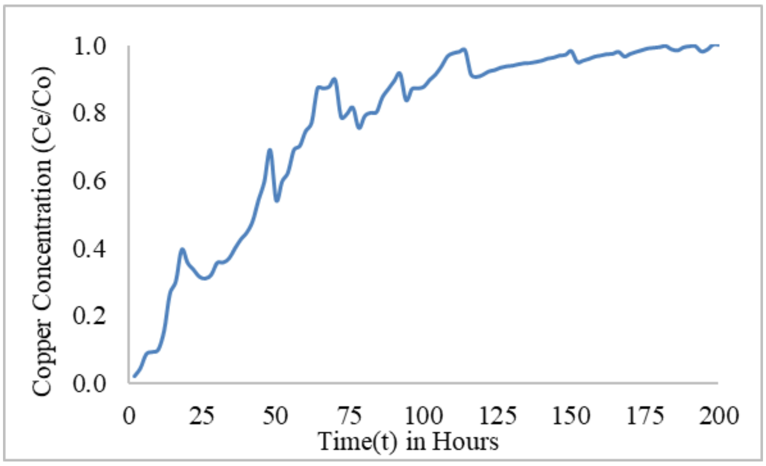

Figure 7c: Break Through Curves Copper Outside Peenya Industrial Area (PIA)

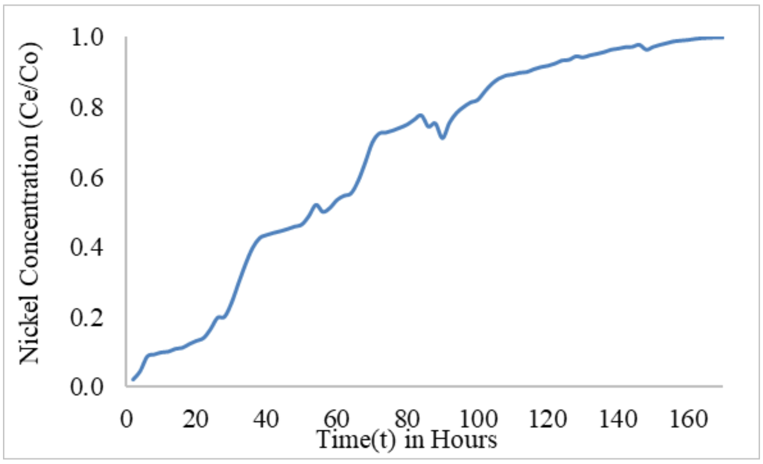

Figure 7d: Breakthrough Curves Zinc Outside Peenya Industrial Area (PIA)

The overall study found that Cr mobility in the soil column is higher than other metals in the soil column in both soils (inside and outside the PIA). Hence, it was proved from the groundwater analysis that Cr concentrations are higher than the standards found in the borewells inside and around the PIA. The penetration time of all metals in sandy loam soil (outside the PIA) is less than that in clay soil (inside the PIA). The study revealed that soils have different capacities to retain heavy metals and depend on their physical and chemical properties.

Water-containing contaminants, like sewage and industrial wastes, seep into the soil matrix from direct flow from overland regions due to runoff. Eventually, the aquifer, a groundwater storage basin, receives this water. It is a source of potable water. Water moves through the soil, mixing, dispersing, and diffusing the contaminants in the flowing flux. The development of more precise and cost-effective models for forecasting the transport and destiny of solutes, frequently from solute sources in the unsaturated soil zone, resulted from this. Fried and Cumbarnous's equation calculated the hydrodynamic dispersion coefficient when the heavy metal solution was passed through a 20 cm soil column, as shown in Table 2. The transport of dissolved contaminates is an essential process in groundwater hydrology. Predicting solute concentrations and illustrating the effects of different transport parameters are usually accomplished by one-dimensional analytical solutions of the governing equations. The application of mathematical models application software like `Mathematica' to predict the transport of heavy metals to groundwater plays a vital role in the study [17]. From the one-dimensional dispersion equation, $C/C_0$ was numerically computed using `Mathematica'.

Table 2: Dispersion coefficient values

Study Site	**Parameter**	**D (m^2 yr^{-1})**	**$t_{0.16}$ (hr)**	**$t_{0.84}$ (hr)**
Station 1 (Inside Peenya Industrial Area)	Chromium Tracer	5.22	15	54
	Nickel Tracer	2.2	25	104
	Zinc Tracer	8.08	20	178
	Copper Tracer	6.57	16	226
Station 2 (Outside Peenya Industrial Area)	Chromium Tracer	3.57	14	56
	Nickel Tracer	1.99	24	86
	Zinc Tracer	10.84	14	136
	Copper Tracer	3.49	22	186

D= Dispersion Coefficient, $t_{0.16}$ and $t_{0.84}$ are the times required for the concentration.

The comparison values between experimental and calculated values are represented for the Inside PIA and Outside PIA, respectively. Figures represent the break-through curves for C_e/C_0 vs time for 20cm depth. It is seen that the concentration field increases in the beginning and reaches a steady state value for a fixed depth. The composition of the theory and experiment breaks through curves. Figures 8(a, b, c & d) and 9 (a, b, c & d) compare calculated values with the experimental ones and are found to align well for both Inside and Outside PIA, respectively. Both the curves Mathematica and BTC are close to each other. Hence, it is possible to use the models based on the observed physical conditions to predict a dimensional flow pattern when experimentations can be avoided altogether [17].

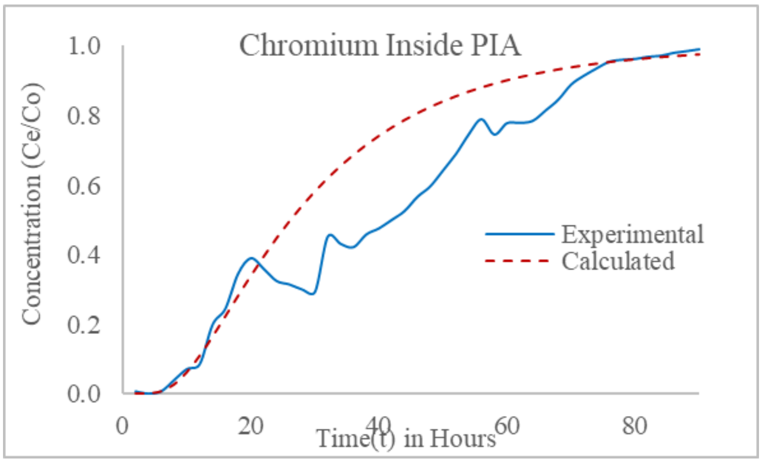

Figure 8a: Breakthrough Curve of Experimental Vs Calculated Chromium Inside Peenya Industrial Area (PIA)

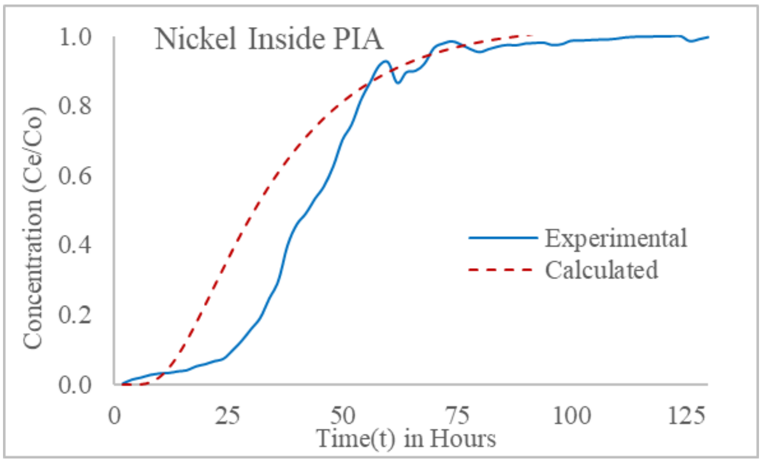

Figure 8b: Breakthrough Curve of Experimental Vs Calculated Nickel Inside Peenya Industrial Area (PIA)

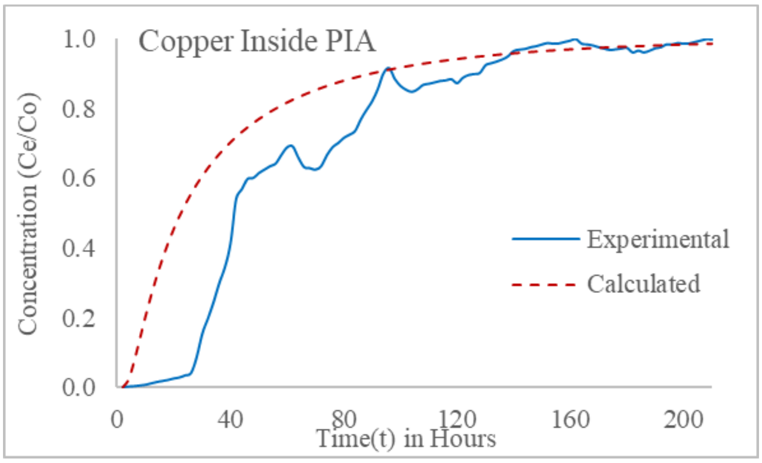

Figure 8c: Breakthrough Curve of Experimental Vs Calculated Copper Inside Peenya Industrial Area (PIA)

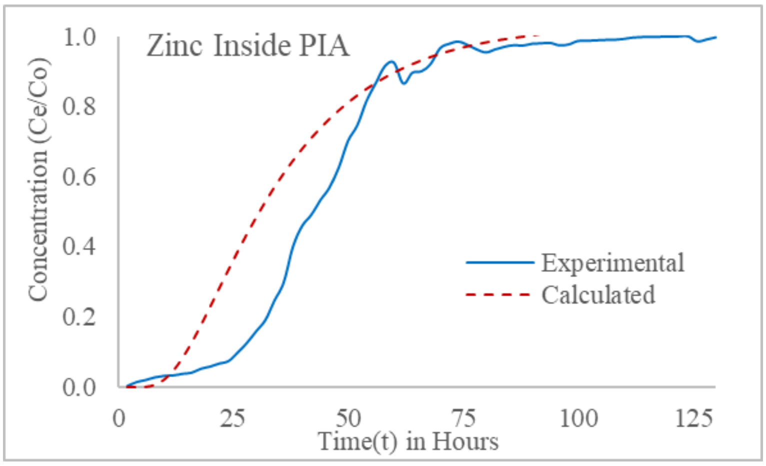

Figure 8d: Breakthrough Curve of Experimental Vs Calculated Zinc Inside Peenya Industrial Area (PIA)

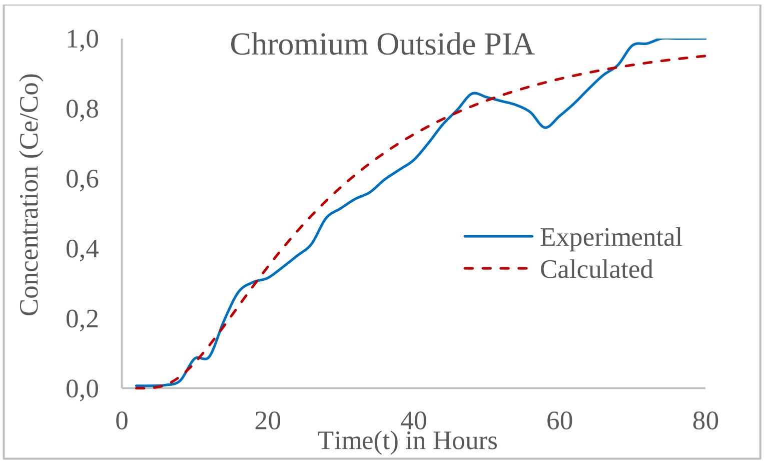

Figure 9a: Breakthrough Curve of Experimental Vs Calculated Chromium Outside Peenya Industrial Area (PIA)

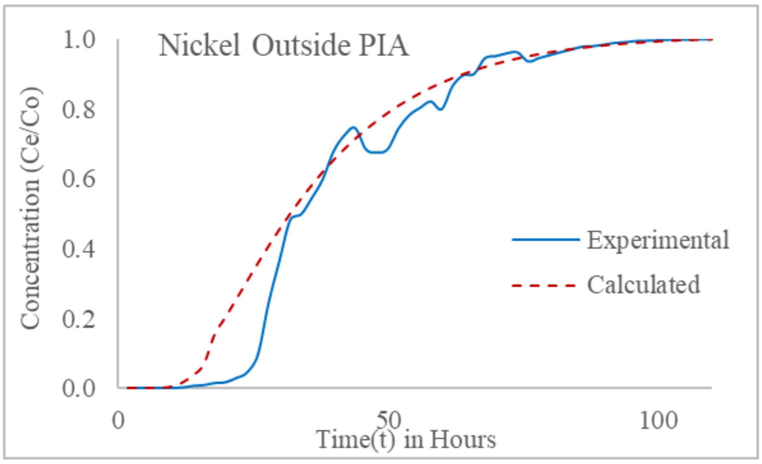

Figure 9b: Breakthrough Curve of Experimental Vs Calculated Nickel Outside Peenya Industrial Area (PIA)

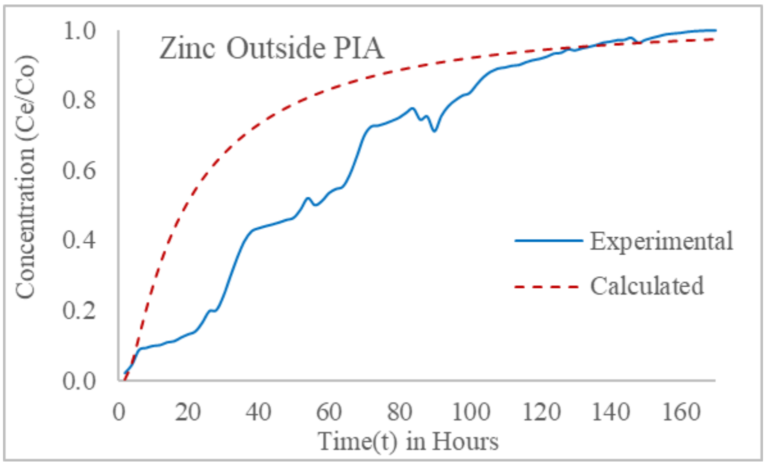

Figure 9c: Breakthrough Curve of Experimental Vs Calculated Zinc Outside Peenya Industrial Area (PIA)

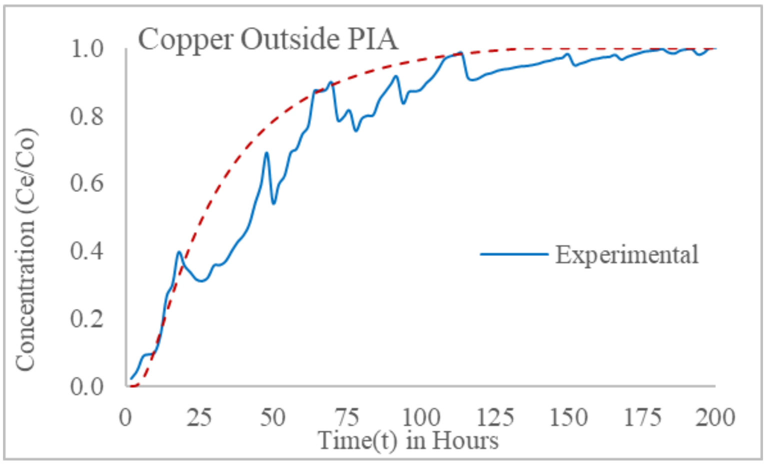

Figure 9d: Breakthrough Curve of Experimental Vs Calculated Copper Outside Peenya Industrial Area (PIA)

Conclusions

1. The soil column experiment apparatus are used to study the migration and attenuation of heavy metals (HMs) through an undisturbed soil column closer to field conditions. Soil column studies are pivotal in understanding heavy metals' behaviour and movement in soils. According to the soil column experiment, the lowest mobility is observed in clay soil (inside the PIA) rather than in sandy loam soil (outside the PIA). The overall study found that the mobility of Cr heavy metal in the soil column was higher than that of other metals in the soil column in both soils (inside and outside the PIA).

2. The current investigation found the dispersion coefficient in four undistributed soils outside the PIA and four undistributed soils inside the PIA. The hydrodynamic dispersion co-efficient 'D' when Cr, Ni, Zn and Cu solution was passed through 20cm soil column outside industrial area was 3.57 m^2/year, 1.99 m^2/year, 10.84 m^2/year, and 3.49 m^2/year and the solution was passed through 20cm soil column inside industrial area 5.22 m^2/year, 2.2 m^2/year, 8.08 m^2/year, and 6.57 m^2/year.

3. The present investigation describes the experimental Vs Calculated Values considerations and presents the Mathematica software tool for analysing solute conditions during infiltration from a source. The curves plotted by Mathematica and BTC are close to each other. Hence, it is possible to use the models based on the observed physical conditions to predict a dimensional flow pattern when experimentations can be avoided altogether. The mathematical models used in the present research help to predict the future effects of heavy metal pollution in the study region.

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Studie o disperzivitě těžkých kovů v nenarušených půdních sloupcích v průmyslové oblasti Peenya a kolem ní, Bengaluru, Indie

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Abstrakt

Tento článek analyzuje vliv indikátorů těžkých kovů na jednorozměrný transport polutantů přes nedistribuované sloupce půdy prováděný v laboratoři a experimentální data jsou porovnána s analytickými daty. V této studii se pomocí „Mathematica“ analyticky používá rovnice advekce-disperze k vyhodnocení transportu znečišťujících látek. Hodnotí kontaminaci těžkými kovy tím, že bere v úvahu vstupní koncentrace znečišťujících látek, a to, jak se mění s časem a hloubkou. Byly analyzovány výsledky experimentálního testu týkající se průlomových křivek, které odhalily základní vzorce migrace těžkých kovů.

Současný výzkum má najít rozptylový koeficient v průmyslové oblasti a kolem ní pro čtyři těžké kovy, tj. čtyři nenarušené sloupce půdy na stanici 1 (uvnitř) a čtyři nenarušené sloupce půdy na stanici 2 (venku). Koeficient hydrodynamické disperze „D“, když roztok chrómu (Cr), niklu (Ni), zinku (Zn) a mědi (Cu) prošel 20cm půdním sloupcem (každý kov na sloupec), byl mimo průmyslovou oblast 3,57 m^2/rok, 1,99 m^2/rok, 10,84 m^2/rok a 3,49 m^2/rok a 5,22 m^2/rok, 2,2 m^2/rok, 8,08 m^2/rok a 6,57 m^2/rok v průmyslové oblasti. Podle experimentu s půdním sloupcem je nejnižší mobilita pozorována v jílovité půdě (uvnitř průmyslové oblasti Peenya), spíše než v písčitohlinité půdě (mimo průmyslovou oblast Peenya). Tato zjištění zlepšují naše chápání znečištění těžkými kovy a poskytují základ pro předpovídání a řízení takového znečištění v průmyslových oblastech. „Mathematica“ použitá v tomto výzkumu pomáhá předpovídat budoucí účinky znečištění těžkými kovy ve studovaném regionu, a tím nás vybavuje znalostmi, abychom mohli přijímat proaktivní opatření.

Klíčová slova: *těžké kovy, mobilita, křivky průlomu (BTC), půdní sloupce, průmyslová oblast Peenya (PIA), kontaminace podzemních vod, hydrodynamická disperze.*