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ANALYSIS OF HEAVY METAL CONTAMINATION IN INDUSTRIAL WASTEWATER ALONG THE BIRATNAGAR–DUHABI INDUSTRIAL CORRIDOR: THEIR ENVIRONMENTAL IMPACTS

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ABSTRACT

The generation and collection of heavy metals in wastewater are increasing due to rapid overpopulation, urbanization, and industrialization. Thus, it is critical to manage and treat the wastewater released from industries, cities, and agricultural sites, before discharging them into the drainage system. This research paper investigated the contamination of heavy metals in industrial effluent in the Biratnagar-Duhabi corridor of Kosi province, Nepal. Three types of industrial effluents, namely, the iron processing industry (IR), battery industry (BT), and leather processing industry (LT) are chosen. pH, biological oxygen demand (BOD), chemical oxygen demand (COD), and selected heavy metals such as Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium(Cr), Nickel (Ni), and Cobalt (Co) are investigated in the samples of effluents. pH was found in the range of 1.86 to 11.63. BOD and COD data showed that the samples are heavily polluted from organic and other chemical pollutants. One sample from IR has high levels of Zn concentrations. Samples from BT were found to have high levels of Pb concentration.

Keywords: wastewater, heavy metals, water, BOD, COD

INTRODUCTION

Water, which covers more than 70% of the Earth's surface, is a critical resource for human survival and economic activities. However, its usability depends significantly on quality and availability. Clean water is essential for domestic use, agriculture, and industries, but its access is increasingly compromised by pollution. Pollutants such as organic waste, chemicals, pathogens, and heavy metals degrade water quality, making it unsafe for consumption and ecosystem sustainability. Heavy metals, including Cd, Pb, Hg, and As, are particularly hazardous due to their non-biodegradable nature, toxicity, and ability to bioaccumulate in living organisms, posing long-term threats to ecosystems and human health (Ram *et al*., 2021; Agoro *et al*., 2020; Dagne, 2020; Morin-Crini *et al*., 2022; Shelford, 1917).

Pollutants originate from point sources, such as industrial discharges, and dispersed sources, like agricultural runoff. Urbanization and industrialization have exacerbated the issue, with significant volumes of untreated wastewater being discharged daily into water bodies. This effluent, rich in heavy metals and organic pollutants, compromises aquatic ecosystems, vegetation, and human health (Begum *et al*., 2012; Shelford, 1917). The importance of wastewater management cannot be overstated, as it is critical to conserving water resources and mitigating hazardous impacts.

Heavy metals are characterized by their high density and atomic weight. While some, such as Cu, Zn, and Ni, are essential for biological processes in trace amounts, others like Pb, Hg, and Cd are purely toxic. Industrial activities, including metal processing, mining, and battery manufacturing, primarily contribute to heavy metal contamination in wastewater. These metals are non-biodegradable and accumulate in soil, water, and living organisms, causing significant ecological and health challenges (Ahmaruzzaman, 2011; Liu & Wang, 2024).

Agricultural wastewater, characterized by its high biochemical oxygen demand (BOD) and suspended solids, significantly contributes to heavy metal contamination when untreated. Heavy metals like Cd, Ni, Cu, and Hg disrupt soil health and plant physiology. They impede nutrient uptake, reduce photosynthesis efficiency, and affect plant metabolism. Cadmium and nickel are particularly detrimental, lowering seed germination rates, while copper and mercury diminish plants' photosynthetic power, ultimately stunting growth and development (Gardea-Torresdey *et al*., 2005; Hossain & Komatsu, 2013; Kesari *et al*., 2021).

Cadmium is a heavy metal with a high level of toxicity. When absorbed biologically, cadmium can cause serious health problems

(Fronczak *et al.*, 2019). It was reported in 2022 that nickel has both carcinogenic and useful properties (Begum *et al.*, 2022).

Excessive heavy metals in soil lead to chlorosis, enzyme impairment, and physiological disruptions, affecting critical metabolic activities in plants. Prolonged exposure to these metals not only harms plant growth but also transfers these contaminants to crops irrigated with polluted water. These crops, consumed by animals and humans, become vehicles for the bioaccumulation of heavy metals within food chains. This process exacerbates health issues, including organ damage, developmental delays, and long-term ecological consequences (Abd Elnabi *et al*., 2023; Kananke *et al*., 2014; Singh & Rathore, 2020). Efforts to mitigate the release of heavy metals into agricultural systems are crucial for safeguarding plant health, food safety, and overall ecosystem sustainability.

A case study was conducted on the impact of open dumping and burning on the surrounding soil, air, and river water at the Biratnagar metropolitan city dumping site (Gautam *et al*., 2014). In a recent study, the sources of groundwater contamination around Nepal were examined along with the extent of arsenic pollution (Rasaili *et al*., 2024).In Nepal, wastewater management is inadequate, leading to severe pollution of rivers, lakes, and groundwater. The study by Shah *et al.* (2024) examined the concentration of Fe, Zn, Cr, Ni, Pb, and As in wastewater at the Biratnagar-Rangeli corridor of Morang district of Nepal.

Shrestha *et al.* (2017) analyzed wastewater samples collected from five different industrial sites across four districts of Nepal. Among the sites, two were wastewater treatment plants that processed effluents from a variety of sources. Industries accounted for the other three sites involved in wire and cable manufacturing, paint production, and plastic cutting. Key physicochemical parameters assessed included pH, conductivity, temperature, turbidity, and concentrations of Cu and Cr. On-site measurements were conducted utilizing handheld, portable electronics, while additional parameters were analyzed in the laboratory. A comparison was made between the observed parameters and the national industrial effluent standards of Nepal. In cases where specific standards for industrial effluents were unavailable, relevant international standards were used for comparison. The results indicated that most parameters were within permissible limits, except for deviations in pH and Cr levels at some sites.

Koju *et al.* (2022) assessed the physico-chemical parameters and heavy metal concentrations in industrial effluents from Kathmandu. Parameters such as pH, turbidity, and hardness were analyzed, with total suspended solids, calcium hardness, and nitrate exceeding permissible limits. Heavy metals were observed in the order Fe > As > Zn > Mn > Pb > Cu > Ni > Cd, with Fe, Pb, Zn, and As surpassing national and international standards. Significant correlations between metals indicated effluents as a potential threat to water sources and human health. The study recommends establishing wastewater treatment plants and enforcing strict environmental laws to mitigate risks (Koju *et al*., 2022).

Similarly, Karki *et al*., (2024) analyzed heavy metal (HM) risks in 23 rivers and two lakes spread over Nepal's five provinces, assessing their impact on humans and ecosystems using indexes like Cancer Index (CI), Hazard Index (HI), and Hazard Quotient (HQ). Female children are most vulnerable, with Co, Pb, Cd, As, Cr, and Cu posing high non-carcinogenic risks (HI > 1) for all age groups, while Mn and Ni risks are confined to children. Carcinogenic risks from Cr, Ni, As, Cd and Pb (CI > 1.00E-3) are significant in some rivers. Ecologically, Cu, Cd, and Pb show the highest risks (Karki *et al*., 2024).

These studies highlight the need for region-specific assessments to develop effective management strategies. However, existing research often lacks a comprehensive analysis of multiple contamination pathways, the impact on ecosystems, and mitigation measures tailored to local contexts.

The maximum contamination level (MCL) values of major heavy metals like Pb, Cr, Cd, Zn, Mn, and Ni are 0.015, 0.10, 0.005, 5.000, 0.050, 0.070 mgL^{-1} respectively in drinking water are reported in the US Environment Protection Agency (USEPA) which can be used to compare with our study.

Among various heavy metals found in wastewater, six heavy metals (Zn, Pb, Cd, Cr, Ni, and Co) are selected for the study in this work. Some of the heavy metals selected are poisonous (Cr, Cd, Pb, and As) and some are biologically important (Mn, Zn, Fe, and Ni). The selection was made aiming to know the concentrations of heavy metals in wastewater discharged from metal processing industries and their toxicity to plants, animals, agriculture, the ecosystem, and humans around. Table 1 shows the guidelines for drinking water by the National Drinking Water Quality Standards and the World Health Organization.

Table 1

Guideline in drinking water by the National Drinking Water Quality Standards, 2005 and World Health Organization (WHO, 2019).

S.N.	Heavy metals	Maximum acceptable concentration (WHO)	Maximum acceptable concentration (NDWQS)
1.	Zn	5.000 mg/l	3.000 mg/l
2.	Cd	0.003 mg/l	0.003 mg/l
3.	Pb	0.010 mg/l	0.010 mg/l
4.	Hg	0.001 mg/l	0.001 mg/l
5.	Mn	0.100 mg/l	0.200 mg/l

This study seeks to bridge research gaps by analyzing physicochemical properties and key heavy metals (Zn, Pb, Cd, Cr, Ni, and Co) in wastewater from industrial effluents of Biratnagar-Duhabi corridor, identifying contamination levels, and evaluating their ecological, environmental and health impacts with the help of pH, BOD, and COD.

EXPERIMENTAL METHODS

Study Area

The study area was selected from Biratnagar Metropolitan City to Duhabi Municipality industrial corridor as shown in Figure 1. For this study, total of 10 sampling sites were selected from different types of industries (Table 2) to assess the impact of industrial effluent on water quality. Seven samples were collected from the steel and iron industry, two samples were obtained from a leather procession facility and one sample was collected from the battery industry. The samples were taken from the direct discharge point where the effluents were released into the stream channel running alongside the roadside. The sampling sites were positioned to capture the immediate effects of effluent discharge as they entered the waterway.

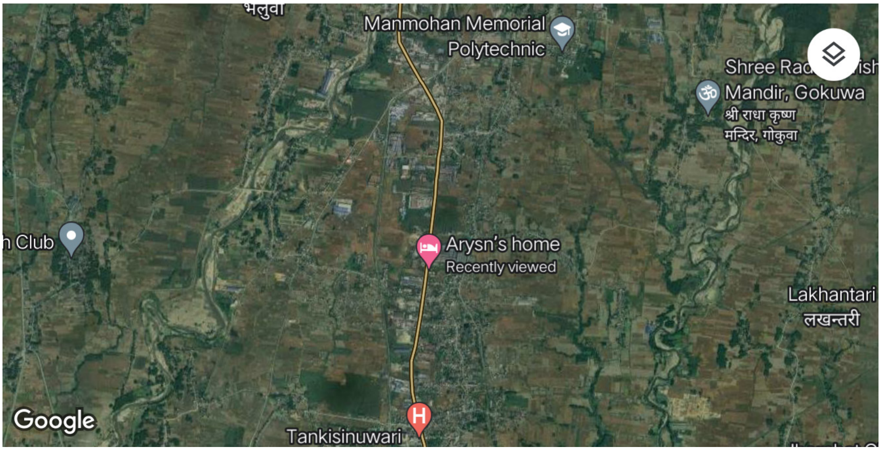
Table 2

Types of industries and their abbreviations

S N	Types of industry	Abbreviations
1	Steel and iron industry	IR
2	Batteries industry	BT
3	Leather industry	LT

Figure 1

Circled areas of sample collection in the map (Biratnagar-Duhabi Industrial Corridor)



Sampling Method

The method of sampling was adopted from method number APHA – 1060 B (Rice *et al*., 2017). Samples were collected from effluents of three different industries.

Experimentation

The pH of the sample solutions was measured by pH meter of research quality (Hanna, HI5521 Italy) at room temperature. The calibration of the pH meter was done using buffer pH standards of 4.0, 7.0, and 10.0 as described in the literature (Madhav *et al*., 2020; Singh & Rathore, 2020).

Using the Winkler Titration Method, the samples' BOD was tested, and using by potassium dichromate method, the COD of the samples was measured as described in method numbers APHA 5210B and APHA 5220B respectively (Rice *et al*., 2017).

For heavy metals analysis, the sample was transferred into beaker and mixed with 5 ml of concentrated nitric acid then heated over a hot plate until 10–20 milliliters of liquid remained. In the cleaned and dry volumetric flask, after cooling, the content was diluted to 100 milliliters. By using the direct air-acetylene flame method (APHA 2111B), heavy metals were analyzed. Concentrations of heavy metals were determined using Atomic Absorption Spectrophotometer (AAS) (Thermo Fischer, ice3000 series, Thermo Fischer, USA). Heavy metal analysis was performed in Nepal

Batawaraniya Sewa Kendra (formerly called SEAM-N Laboratory, Funded by the Finish Government), Biratnagar, Nepal. All measurements were done in triplicates.

RESULTS AND DISCUSSION

Obtained results of pH, BOD, COD, and heavy metals (Zn, Pb, Cd, Cr, Ni, and Co) are presented in Table 3 with error analysis.

Table 3

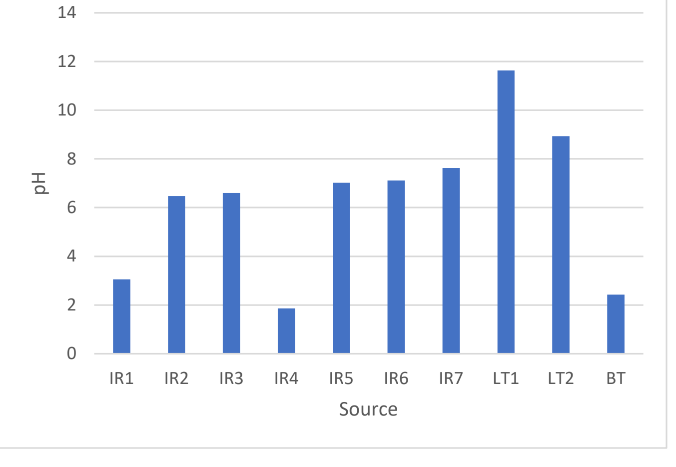
Observed values of pH, BOD, COD, and heavy metals

	pH	BOD mg/L	COD mg/L	Zn mg/L	Pb mg/L	Cd mg/L	Cr mg/L	Ni mg/L	Co mg/L
IR1	3.05	1070.29	2000	8.31	0.11	<0.003	0.27	0.07	<0.05
IR2	6.48	293.93	580	0.22	0.11	<0.003	<0.05	<0.05	<0.05
IR3	6.60	210.86	420	0.16	0.14	<0.003	<0.05	<0.05	<0.05
IR4	1.86	2507.99	5000	12.02	0.15	<0.003	0.07	0.09	<0.05
IR5	7.02	153.35	300	0.71	0.15	<0.003	<0.05	<0.05	<0.05
IR6	7.11	204.47	400	15.09	0.18	<0.003	<0.05	<0.05	<0.05
IR7	7.63	54.31	100	1.50	0.16	0.003	0.18	<0.05	<0.05
LT1	11.63	792.33	1500	0.20	0.18	0.004	2.15	0.06	<0.05
LT2	8.93	1517.57	3000	0.34	0.25	0.020	1.72	0.12	<0.05
BT	2.43	100.32	200	0.31	29.86	<0.003	<0.05	<0.05	<0.05

[a] *Errors in pH, BOD, COD, Zn, Pb, Cd, Cr, Ni, and Co are within ±2, ±5, ±6, ±2, ±3, ±3, ±3, ±3, ±3 % respectively.*

Figure 2

Comparison of pH values of different samples.



The data shows that wastewater discharged from LT1 (pH =11.63) is the most alkaline and that from IR4 (pH =1.86) is the most acidic (Figure 2 and Table 3).

The effluents from the leather industries are found to be most alkaline. This may be due to the reason that leather industries use lime (Calcium hydroxide) in the stage to remove hair and flesh. Moreover, these industries also use various alkaline substances such as proteolytic enzymes, ammonia-based chemicals, chromium salts, etc during different stages of leather processing.

The wastewater from the majority of Iron and steel industries is found to possess pH within the acid-base borderline. However, two samples i.e. IR1 (pH =3.05) and IR4 (pH =1.86) are recorded as acidic. This may arise because of acid pickling and descaling processes employed to remove rust, scale, and other contaminants from metal surfaces. Additionally, the Acid Bessemer process for steel manufacture uses acidic substances.

Battery manufacturing industries involve the use of acidic electrolytes such as sulphuric acid and acidic solutions for cleaning metal components. Besides these, battery recycling and leaching processes may result in acidic wastewater.

Both acidic and alkaline wastewater are harmful. The alkaline wastewater from industries namely LT1 and LT2 and acidic wastewater from industries namely IR4, BT, and IR2 are responsible for various negative impacts in the nearby areas. Acidic wastewater, often containing heavy metals and toxic substances, can leach into soil and water sources, leading to soil degradation, erosion, and contamination of groundwater and surface water bodies. This contamination poses serious risks to aquatic ecosystems, causing harm to aquatic organisms and disrupting food chains. Additionally, acidic wastewater can corrode infrastructure, such as pipes and sewage systems, leading to costly repairs and potential breaches that further exacerbate environmental contamination. On the other hand, alkaline wastewater, with its high pH levels, can disrupt the natural balance of aquatic ecosystems by altering the pH of water bodies. This can lead to the death of fish and other aquatic organisms, as well as the destruction of habitats like coral reefs. Moreover, alkaline wastewater can also contribute to nutrient imbalances in water bodies, leading to algal blooms and eutrophication (Zhou *et al*., 2018), which depletes oxygen levels and further harms aquatic life. Overall, the discharge of acidic and alkaline wastewater from industries underscores the urgent need for stringent regulations and effective wastewater treatment processes to minimize environmental degradation and protect human health.

Biological Oxygen Demand (BOD)

BOD measurements (5 days) of the samples were determined by the Azide modification method (Winkler Titration method). Standardized laboratory techniques are employed to ascertain the relative oxygen requirements of effluents, wastewater, and polluted waterways. After incubation, dissolving oxygen (DO) was measured and the difference between initial and final DOs was used to calculate BOD. BOD of 5 days at 20°C is the total amount of oxygen (in milligrams) consumed by microorganisms while decomposing waste. The value of BOD is expressed in ppm (mg/L) and used as a measure of the degree of water pollution. Clean water has a BOD of less than 5 ppm.

In the Winkle method, Mn^{2+} (form Manganous sulfate) reacts with DO under alkaline conditions (the alkali-azide-iodide solution) to produce a brown (manganic hydroxide).

$$2Mn^{2+}+O_2+4OH^- \rightarrow 2MnO(OH)_2$$

Under acidic conditions, iodine is released when the oxidized manganic hydroxide is reduced back to the divalent state.

$$2Mn^{2+}+O_2+4OH^- \rightarrow 2MnO(OH)_2$$

The amount of iodine generated is proportional to the initial concentration of DO in the solution. By titrating with standard sodium thiosulphate amount of iodine release corresponding to DO is quantified. Starch is added before titration to detect the endpoint.

$$2Mn^{2+}+O_2+4OH^- \rightarrow 2MnO(OH)_2$$

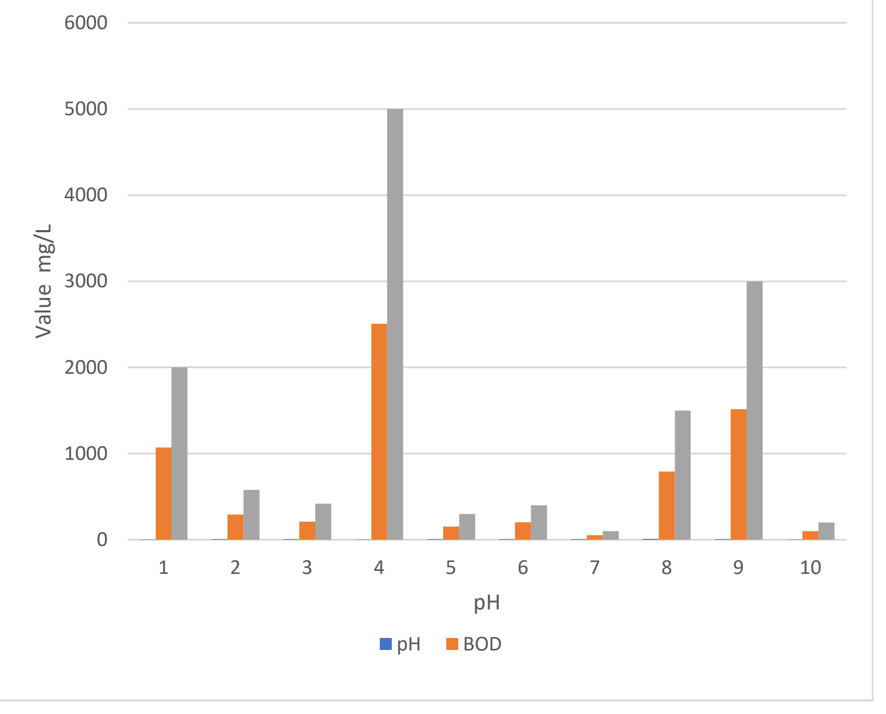
Chemical Oxygen Demand (COD)

COD is the amount of oxygen that is needed by organic matter in a sample of water to be oxidized by a strong oxidizing agent, such as $K_2Cr_2O_7$ in an acidic media, for two hours. COD is a measurement of the amount of organic compounds in water that can be oxidized by a powerful chemical oxidizing agent.

Correlation of pH with BOD and COD

Figure 3

Correlation among pH, BOD, and COD of different samples of effluents.



The BOD and COD values across different samples exhibit significant variability, indicating varying levels of pollution in the samples. It is noted that wastewater from IR4 (pH=1.86) has the highest BOD and COD values, which are 2507.99 and 5000 respectively (Figure 3). Similarly, the wastewater from IR7 (pH=7.63) possesses the lowest BOD and COD values, which are 54.31 and 100 respectively. BOD values suggest that the wastewater from the majority of industries contains a high amount of organic waste and is highly polluted. Many studies consider wastewater with BOD values above 100 as highly polluted. Thus, the wastewater from IR1, IR2, IR3, IR4, IR5, IR6, LT1, LT2, and BT should immediately and extensively be treated before discharge. Otherwise, such wastewater severely harms aquatic animals, livestock, agriculture, and humans directly or indirectly. Similarly, the wastewater from all industries exhibits COD values beyond 100. These indicate the high amount of chemical pollutants in it.

Elevated BOD levels can result in hypoxic (low oxygen) or anoxic (no oxygen) conditions, leading to the death of aquatic organisms such as fish and other aquatic life (Waddington *et al*., 2023).This disruption of the aquatic ecosystem can have cascading effects on biodiversity and ecosystem function. Similarly, oxygen depletion may result from elevated COD levels in receiving water bodies through chemical reactions, exacerbating the negative impacts on aquatic ecosystems. Additionally, the degradation of organic pollutants through chemical oxidation processes can produce harmful by-products such as toxic compounds and heavy metals, further contaminating water bodies and posing risks to human health and the environment (Igbinosa & Okoh, 2009).

Furthermore, the presence of high BOD and COD levels in industrial wastewater can also impair the aesthetic quality of water bodies, leading to unpleasant odors, discoloration, and the formation of foam and scum. Disinfection is the principal approach for inactivating harmful organisms, preventing the spread of waterborne diseases to downstream consumers and the environment (Disinfection, 1999). The quality of water conductivity can be checked as mentioned in the literature (Yadav *et al*., 2024).

Heavy Metals

Madhav *et al.,* (2020) discussed different sources of water pollutants, and their impacts on the environment and human health. Several traditional water pollutants were discussed in this study, including nutrients (NO3 and PO4), organic pollutants (POPs, EDS, and pesticides), halogens (Cl, Br, and F), microbial pollutants, and heavy metals (Mn, Fe, Cu, Al, Zn, Pb, Cr, Ni, Cd, and Hg).

Cadmium is highly poisonous to humans even in very low concentrations. Exposure to Cd may cause renal malfunction, pneumonitis, bone defects, high blood pressure, etc (Duruibe *et al*., 2007). Similarly, Cd may cause kidney damage, lung cancer, proteinuria, etc. Its sources are the pipe industry, paints industry, waste batteries, and metal refineries. Although its emission is under controlled scale in developed countries, it is reported that Cd is responsible for various health hazards, especially to workers in developing countries (Sethi & Khandelwal, 2006). Cd released in wastewater may persist in water and soils for decades and transfer to other organisms via food chains. Other sources are food and smoking. Cd is found to harm the liver and kidneys. It also harms some species of fish (Bernard & Lauwerys, 1986). For most locations, the concentration of Cadmium is below the detection limit (<0.003 mg/L), except for three instances: IR7 (0.003 mg/L), LT2 (0.020 mg/L), and LT1 (0.004 mg/L). Similarly, the concentration of Cobalt is found below the detection limit (<0.05 mg/L) for all samples.

Nickel is one of the primary nutrients and plays a very important role in various microbial cellular processes. However, a high concentration of Ni is toxic to bacteria. Certain bacteria, such as E. coli and H. pylori, have developed techniques to modulate intracellular Ni levels to address the toxicity problem (Mulrooney & Hausinger, 2003). Continuous exposure to Ni may cause chronic bronchitis, cancer, and lung dysfunctions. The accumulation of Ni in water is mainly due to air pollution caused by power plants and waste incinerators which settles into the soil and is carried to the water bodies through the surface runoff. It may also mix with the water bodies via the poorly treated Nickel-containing wastewater. Pure Ni in a limited amount is useful, however, its high consumption plays an adverse role in the lungs, kidneys, skin, etc (Vilvanathan & Shanthakumar, 2017). The concentration of Nickel was below the detection limit in the samples from IR2, IR3, IR5, IR6, IR7, and BT. However, four samples were detected with Nickel, which in descending order of concentration are 0.12 (LT2), 0.09 (IR4), 0.07 (IR1), and 0.06 (LT1) mg/L respectively. The concentration remains relatively low across all locations, with no values exceeding 0.12 mg/L.

Cobalt causes several adverse effects on health. Its major health issues include asthma, heart damage, thyroid gland damage, and liver damage. The removal of cobalt from wastewater can be carried out by various chemical, biological, and physical methods. The amount of cobalt in drinking water that is acceptable is 2μg/L. Similarly, the permissible limits for livestock and irrigation water are 1 mg/L and 0.05 mg/L, respectively (Kulkarni, 2016).

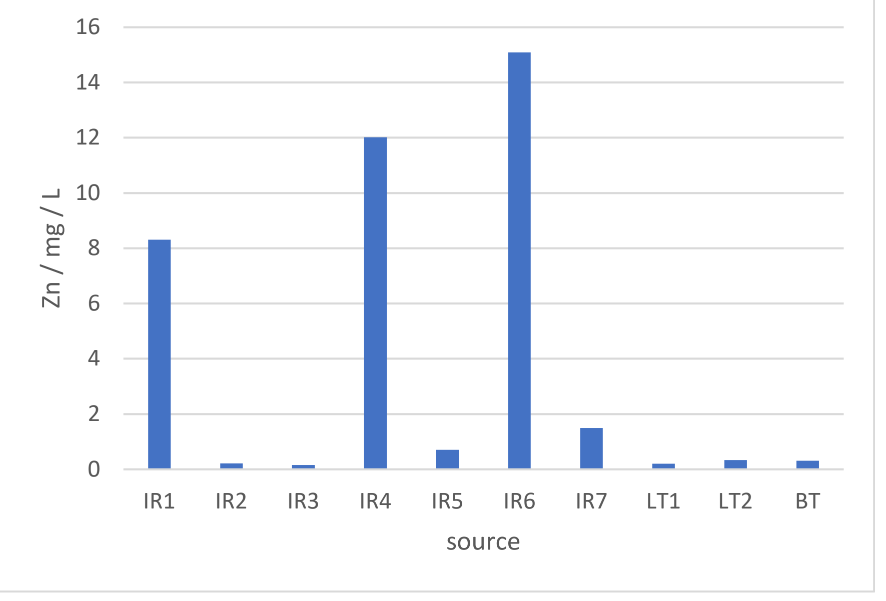
Chromium (Cr) can have a number of negative effects on the environment, including soil and water pollution, plant growth, aquatic life, human health and so on. A serious threat to the environment, chromium pollution has a negative effect on our natural resources, particularly soil and water. Higher levels of accumulation in human and animal tissues due to excessive exposure may result in harmful and harmful health effects (Prasad *et al*., 2024). The maximum concentration of Chromium is observed at LT1 with a value of 2.15 mg/L. The samples collected from LT2, IR1, IR7, and IR4 contained 1.72, 0.27, 0.18, and 0.07 mg/L of Chromium respectively. In the remaining locations, the concentration is below the detection limit (<0.05 mg/L).

Zn is also widely utilized to manufacture paints, synthetic rubber, and cosmetics (Johnson *et al*., 2007). Due to the high use of Zn in industries, large amounts of Zn may be present in soils and water bodies if the wastewater is not treated properly. On the other hand, Zn particles in the air released from industries may settle down to the soils and hence mix with groundwater sources. Zn plays an important role in balancing Cu level in our body, wound healing, growth & development of cells, immunity system, and male reproductive system. It also prevents skin aging. However, its high level causes kidney problems, bloody urine, vomiting, anemia, etc. The high concentration of Zn in the human body leads to system dysfunctions and ultimately slows down growth and development. The major symptoms of Zn poisoning are diarrhea, vomiting, and kidney & liver disorders (Nolan, 1983; Duruibe *et al*., 2007).

One extremely hazardous heavy metal is lead. It is found naturally at a low level in the Earth's crust. Its major sources of exposure are mining, smelting, refining processes, leaded gasoline, and industries of battery, paints, ceramics, glass, etc (Obasi *et al*., 2024). It has been reported that Pb greatly harms children and pregnant women. Its long-term exposure causes miscarriage, stillbirth, and premature birth. Additionally, it may also cause gastrointestinal disorders, hepatic & renal damage, high blood pressure, and neurological disorders. Similarly, in children, it badly harms the development of the nervous system. Intake of or exposure to lead is also responsible for anemia, lethargy, paralysis, and tremors. Its inhalation causes low hemoglobin synthesis, kidney & joint malfunctioning, cardiovascular disorders, acute & chronic damage to the central nervous system, bloody urine, brain damage, etc (Prüss-üstün *et al*., 2003).Data from Table 3 shows a significant amount of Zn and Pd in the effluent samples. Zinc content was lower in the battery (BT) industry sample than lead content.

Figure 4

Comparison of Zn content in effluent samples of different industries.



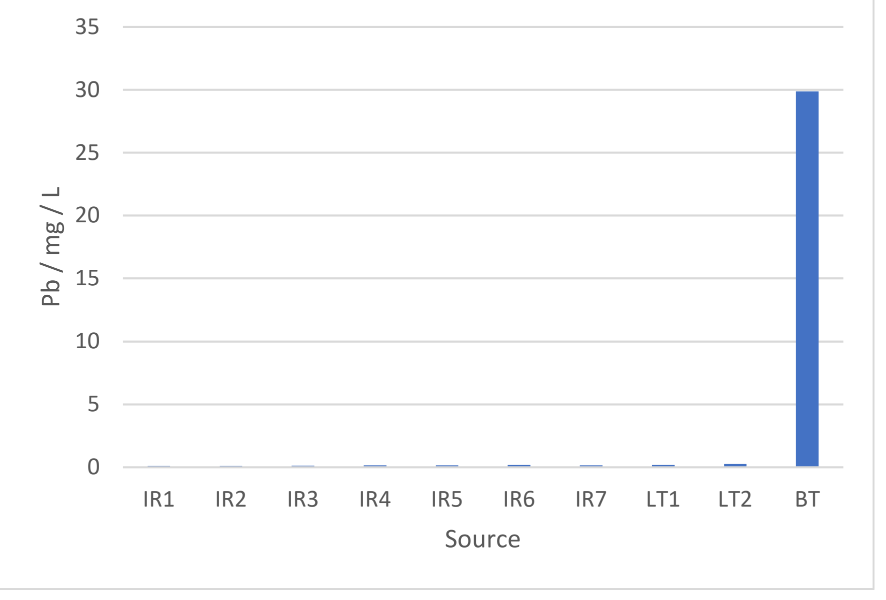
The concentration varies significantly across different locations, ranging from 0.16 mg/L to 15.09 mg/L. The highest concentration is found at IR6 with a value of 15.09 mg/L (Figure 4). The lowest concentration is at IR3 with a value of 0.20 mg/L. Locations IR1, IR4, and IR7 are also found to discharge remarkable Zinc effluents.

As compared to WHO guidelines for drinking water, USEPA (2009) and National Drinking Water Quality Standards (2005), wastewater from IR1, IR4, and IR6 possess very high levels of zinc which are 8.31, 12.02, and 15.09 mg/L respectively. The high amount of zinc from iron industries is because of the galvanization process.

There's a notable spike in concentration at BT, reaching 29.86 mg/L (Figure 5), which is substantially higher compared to other locations. The lowest concentration is at IR1 and IR2 with a value of 0.11 mg/L. Being a very toxic metal, the permissible limit for Lead in drinking water is very low i.e. 0.01 mg/L, as per WHO guidelines and National Drinking Water Quality Standards, 2005. Interestingly, all samples are detected with Lead contents beyond permissible limits. However, the battery industry discharges a very high level (29.86 mg/L) of Lead in wastewater. The reason behind this is that Lead-acid batteries use different lead compounds in them.

Figure 5

Comparison of Pb content in effluent samples of different industries.



CONCLUSION

The following conclusions have been drawn from the results and discussion. The pH values of the samples varied widely, with the most basic sample (LT1) having a pH of 11.63 and the most acidic (IR4) having a pH of 1.86. Several samples showed borderline pH levels, while others were strongly acidic or slightly basic. The BOD and COD values confirmed that all wastewater samples were polluted, with IR4 being the most polluted (BOD = 2507.99 mg/L, COD = 5000 mg/L). The wastewater from IR4, LT2, and IR1 requires immediate treatment. Hazardous heavy metals were detected, with the battery industry (BT) showing high Pb levels (29.86 mg/L) and IR6 containing the highest Zn levels (15.09 mg/L). Cr concentrations were highest in LT1 (2.15 mg/L), followed by LT2 (1.72 mg/L). Other metals like Ni, Co, and Cd were present in small amounts. The findings indicate that most industries are not implementing proper chemical treatment, posing risks to health, agriculture, and the environment. Immediate treatment of industrial wastewater is crucial.

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