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Physicochemical and Heavy meatal Analysis in Industrial Wastewater: Impact on Biodiversity in Morang District, Koshi Province, Nepal

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Abstract

This study investigates the concentration of heavy metal ions in wastewater samples collected from various industrial facilities located in the Biratnagar-Rangeli corridor of Morang district. The physical and chemical parameters, such as pH, electrical conductivity (EC), biological oxygen demand (BOD), and chemical oxygen demand (COD) were measured, and the presence of heavy metals, including iron (Fe), Zinc (Zn), Chromium (Cr), Nickel (Ni), Lead (Pb), and Arsenic (As), was assessed. Atomic Absorption Spectrophotometer (AAS) (Thermo Scientific, ice3000 series, Thermo Fischer, USA) was used to measure heavy metals. The findings reveal elevated levels of these pollutants, particularly Iron (Fe) and Zinc (Zn), which exceed acceptable safety limits. The study also identifies potential impacts on biodiversity, human health, and the local ecosystem, with significant risks associated with long-term exposure.

Keywords: wastewater, heavy metals, electrical conductivity, biological oxygen demand, chemical oxygen demand

INTRODUCTION

In industrial regions, wastewater is generated from various processes and operations. These wastewater sources vary depending on the type of industry, the materials used, and the manufacturing processes. Many industries use water as part of their manufacturing processes. This water becomes contaminated with chemicals, oils, and other substances during production (Morin-Crini et al., 2022). A common example includes in chemical manufacturing industries where water is used in chemical reactions and becomes contaminated with solvents, acids, and other hazardous chemicals. Food and beverage processing industries release wastewater from cleaning, cooking, and equipment sanitation, often containing organic matter and fats. Wastewater from textile industries contains dyes, chemicals, and detergents used in fabric treatment and washing. Metal processing industries release wastewater during processes such as cooling, plating, and surface cleaning containing heavy metals like Pb, Cd, and Zn (Obasi et al., 2024; Wei et al., 2009).

Industries such as power plants, steel mills, and refineries use large quantities of water for cooling machinery and processes. Although this water is not in direct contact with raw materials, it can pick up heat and chemical residues from corrosion inhibitors and anti-scaling agents, creating thermal pollution when discharged into water bodies. In many factories, water is used to clean floors, equipment, and workspaces. This water can become contaminated with grease and oils from machinery, chemicals used in the

cleaning process, dirt, and solids that accumulate in production areas. During rainstorms, water can flow over industrial sites and pick up contaminants like oil, chemicals, and heavy metals from outdoor storage areas, vehicle parking lots, and loading docks. This contaminated stormwater is often discharged directly into water bodies without treatment, contributing to surface water pollution (Beh et al., 2012).
Boilers are used in many industries to generate steam for power or heating purposes (Tong et al., 2023). The water used in boilers tends to accumulate dissolved salts and chemicals over time. To maintain efficiency, some of the water is periodically discharged, known as boiler blowdown. This wastewater contains high concentrations of salts, corrosion inhibitors, and antiscaling agents. Accidental spills and leaks of chemicals, oils, or other hazardous substances during production, storage, or transportation can contribute to wastewater pollution. In industrial areas, spills often mix with water used for cleaning process operations, increasing the level of contaminants in the effluent.

The term ‘heavy metals’ lacks a universally accepted definition, with varying interpretations contributing to ambiguity. Definitions often rely on physical properties like density, relative atomic masses, or atomic number. Traditionally, heavy metals are described as elements with high density generally above 5 g/cc, but these criteria vary among sources. Interestingly, Selenium (Se), a non-metal, and Arsenic (As), a metalloid, are frequently categorized as heavy metals, especially in contexts related to environmental pollution and toxicity. One heavy metal with a significant potential for toxicity is cadmium. Cadmium absorbed biologically can result in serious illness (Fronczak et al., 2019). Many scientific publications use ‘heavy metals’ to collectively describe metals and metalloids linked to pollution and ecological harm. A more precise definition was proposed by Ali et al. and Khan et al., who separated non-metals like Se and metalloids like As from the category of "heavy metals" by classifying them as naturally occurring metals with an atomic number over 20 and a density larger than 5 g/cc (Ali et al., 2018; Khan et al., 2018).

When industrial wastewater is discharged untreated, the heavy metals within it interact with air, rain, soil, and water, leading to widespread environmental contamination. In polluted soils, plants absorb these metals, introducing them into the food chain (Singh & Rathore, 2020). Bioaccumulation occurs when animals consume contaminated plants or drink polluted water, leading to higher concentrations of heavy metals in their tissues. Similarly, aquatic animals in polluted waters are directly exposed to metal contaminants, which they absorb and accumulate over time. This process ultimately impacts humans, who consume these contaminated plants and animals, resulting in heavy metals exposure. Beyond humans, all organisms in contaminated ecosystems face varying degrees of heavy metal poisoning through food chains (Abd Elnabi et al., 2023). In 2022, an article was written about nickel's dual properties as a carcinogen and a useful element (Begum et al., 2022). There was a study provides an overview of arsenic pollution in several locations around Nepal and examines the sources of groundwater contamination (Rasaili et al., 2024). Table 1 lists the selected heavy metals together with the highest degree of contamination that has been reported in the literature (Ahmad et al., 2021).

Table 1. Selected heavy metals and their maximum contamination level (Ahmad et al., 2021).

S.N.	Heavy metals	Maximum Contamination Level (mgL^{-1})
1.	Lead (Pb)	0.015
2.	Chromium (Cr)	0.010
3.	Cadmium (Cd)	0.005
4.	Zinc (Zn)	5.000
5.	Manganese (Mn)	0.050
6.	Nickel (Ni)	0.070
7.	Iron (Fe)	0.300
8.	Arsenic (As)	0.010

The study finds that the main sources of wastewater in the Biratnagar-Rangeli industrial zone are metal processing, food processing, leather tanning, and oil refineries. These sources of industrial wastewater contribute to the contamination of nearby water bodies with pollutants, including heavy metals and organic compounds, leading to significant environmental treatment and management practices to minimize their impact on ecosystems and human health.

In Nepal, and particularly in the Morang District, industrial growth has outpaced the implementation of effective wastewater management practices. Factories such as oil refineries, leather tanneries, metal processing, and food processing plants discharge large volumes of wastewater into local water sources without adequate treatment. This leads to the contamination of water with heavy metals and other pollutants, which not only degrades the quality of water but also endangers the surrounding ecosystem and human communities.

This study is essential for addressing the growing issue of water pollution caused by industrial activities in the Morang District of Nepal. By assessing the concentration of heavy metal ions in wastewater, identifying their sources, and exploring potential remediation strategies, the researcher will contribute to safeguarding public health, preserving local biodiversity, and promoting sustainable industrial practices.

MATERIALS AND METHODS

Study area

Biratnagar – Rangeli corridor (Figure 1) was selected for the collection of industrial wastewater covering the oil industry (OI), leather industry (LI), and food processing industry (FP).

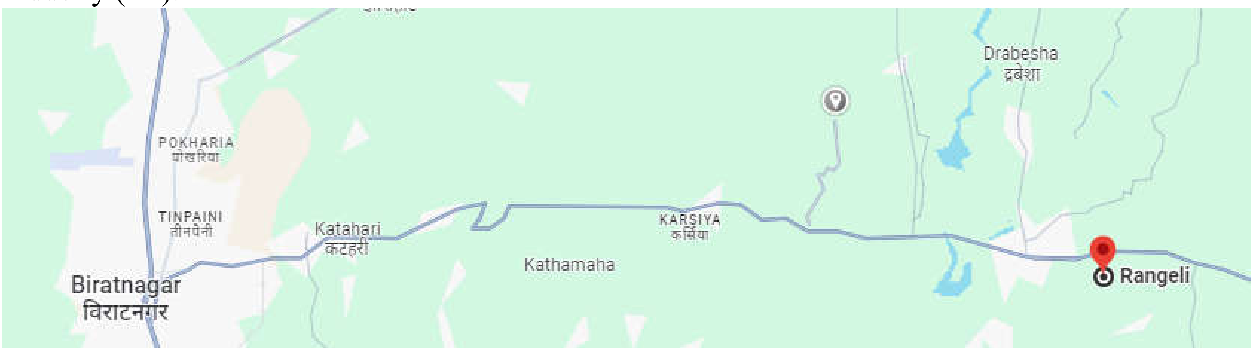

Figure 1. Study area

Sampling method

The sampling method was followed as described in the method of the American Public Health Association (APHA). Three samples from each industrial wastewater were collected and preserved as per the methods described in APHA (Rice E. W. et al., 2017).

Experimentation

A research grade pH/EC meter (Hanna, HI5521, Hanna Instruments, Italy) was used to measure pH and the electrical conductivity of the sample solutions at ambient temperature. The pH meter was calibrated before use by buffer standards of pH values 4.0, 7.0, and 10.0. As stated in the literature (Yadav et al., 2024), the calibrated electrical conductivity meter was used. BOD of the samples was measured using the Winkler Titration Method and COD was measured using by potassium dichromate method.

Heavy metals analysis: 100 ml of the sample was poured into a clean beaker and 5 ml of conc. Nitric acid was mixed and heated over the hot plate until the volume was reduced to 10 – 20 ml. Then the content was cooled and diluted to 100 ml in the clean and dry volumetric flask. The prepared sample was used for heavy metal analysis by direct air–acetylene flame method (APHA 2111B) (Rice E. W. et al., 2017). Atomic Absorption Spectrophotometer (AAS) (Thermo Scientific, ice3000 series, Thermo Fischer, USA) was used to measure the concentration of heavy metals.

RESULTS AND DISCUSSION

The physical and chemical parameters observed in wastewater samples from different industries in the Biratnagar-Rangeli corridor are summarized in Table 2.

Table 2. Observed values of pH, EC, BOD, and COD

	pH	EC mS/cm	BOD mg/L	COD mg/L
Sample 1	6.71	0.598	51.12	100.0
Sample 2	6.67	0.468	255.59	400.0
Sample 3	4.30	1.560	3186.9	7000.0

These parameters include pH, electrical conductivity (EC), biological oxygen demand (BOD), and chemical oxygen demand (COD). The samples have acidic pH ranging from 4.3 to 6.71, indicating that the wastewater could contribute to pH imbalance in receiving water bodies. Sample 3 shows the highest EC value suggesting that higher ionic content compared to other samples. The BOD values vary significantly, with sample 3 showing an extremely high BOD of 3186.9 mg/L, indicating a heavy load of organic matter that could lead to oxygen depletion in aquatic systems. COD values are also highest in sample 3 at 7000 mg/L, reinforcing the evidence of substantial organic pollution, potentially from the process involving organic solvents of residues.

The concentrations of heavy metals in the wastewater samples, measured using Atomic Absorption Spectrophotometer (AAS), are shown in Table 3.

Table 3. Observed values of heavy metals

	Fe mg/L	Zn mg/L	Pb mg/L	Cd mg/L	Cr mg/L	Ni mg/L	Mn mg/L	As mg/L
Sample 1	2.54	0.14	0.22	<0.003	0.11	<0.05	0.32	<0.005
Sample 2	6.50	0.005	0.13	<0.003	0.07	<0.05	0.60	<0.005
Sample 3	21.50	0.87	20.28	<0.003	0.16	0.17	0.70	<0.005

Iron (Fe) concentrations are significantly elevated in Sample 3 at 21.5 mg/L, far exceeding the WHO guideline limit (0.3 mg/L for drinking water), suggesting potential industrial processes with high iron usage. The Pb level in Sample 3 reaches 20.28 mg/L, indicating potential sources from battery industries. Zn concentration was also found to increase in Sample 3 at 0.87 mg/L, which, although lower than other heavy metals, still poses a risk due to its potential to bioaccumulate in aquatic life (Sonone et al., 2021). Other heavy metals, Cd, and As, were below the detectable levels, while Cr and Ni were present in low amounts. Sample 3 showed the highest levels of Mn (0.70 mg/L), which may indicate contamination sources such as the metal processing industry (Hossain & Komatsu, 2013).

Environmental Impact and Biodiversity Risks:
The high BOD and COD levels, especially in Sample 3, indicate a substantial organic load, likely resulting in oxygen depletion when discharged into natural water bodies. Elevated BOD and COD can lead to hypoxic conditions, severely affecting aquatic life by limiting the available dissolved oxygen. This can lead to the death of sensitive species and a reduction in biodiversity (Aguilar-Torrejón et al., 2023).
The acidic pH levels in all samples suggest a potential alteration in the local water chemistry. If discharged without neutralization, the slightly acidic wastewater can further disrupt the aquatic ecosystem, impacting species sensitive to pH fluctuations.

Health and ecological risk of heavy metals:
Iron (Fe) and Lead (Pb) are present in exceptionally high concentrations, with Sample 3 showing particularly hazardous levels. Long-term exposure to such pollutants can lead to bioaccumulation in aquatic organisms, subsequently entering the food chain and posing a risk to higher tropic levels, including humans (Ahmad et al., 2021; Ghosh et al., 2007; Sonone et al., 2021). Zinc (Zn) and Manganese (Mn) while essentially at trace levels, the elevated concentrations observed in these samples pose the risk of metal toxicity, which can impair biological functions in fish and other aquatic organisms. High Zn levels can damage gills, while excess Mn can disrupt enzyme functions.

Human health implications:
The heavy metals contamination in wastewater poses a considerable risk to human health, especially in communities that rely on these water bodies for drinking, agriculture, and other domestic uses (Ahmad et al., 2021; Duruibe et al., 2007; Madhav et al., 2020). These high concentrations of lead and iron are particularly worrisome. Pb found at 20.28 mg/L in Sample 3, is highly toxic to humans, even at low exposure levels. Pb exposure can cause severe health effects, including neurotoxicity, development delays in children, and kidney and liver damage in adults. In 2019, there was research on the pathways of exposure and the health impacts of heavy metals on children (Al osman et al., 2003). Chronic exposure to lead-contaminated water may also increase the risk of cardiovascular disease and anemia (Prüss-üstün et al., 2003).

CONCLUSION

This study highlights the significant impact of heavy metals present in industrial wastewater on both environmental and human health. Heavy metals such as lead, iron, zinc, and chromium, identified in wastewater samples from industries in the Biratnagar–Rangeli corridor, were found at levels that exceed safe limits, posing risks to biodiversity and local communities. High BOD and COD values reflect substantial organic pollution, which can lead to oxygen depletion in water bodies, endangering aquatic life. When discharged untreated, industrial wastewater contaminates soil, water, and plant life, initiating a cycle of bioaccumulation and biomagnification. As these pollutants move up the food chain, they reach toxic levels in animals and humans, increasing the risk of serious health issues, including neurotoxicity, organ damage, and developmental delays. The findings emphasize the urgent need for improved wastewater treatment technologies and stricter regulatory measures to minimize the release of heavy metals and organic pollutants into the environment.

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