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ANALYSIS OF INDUSTRIAL EFFLUENT IN KALWAR (JAIPUR) AND ITS ECOLOGICAL AND HUMAN HEALTH IMPLICATIONS: A MINOR PROJECT

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ABSTRACT

The increase in industrial activities surrounding Indian cities has exerted considerable strain on local water resources, primarily due to the discharge of untreated or inadequately treated waste. Kalwar, located near Jaipur in Rajasthan, serves as a prime example of this issue; where small to medium-sized manufacturing units release their effluent into open drains, ponds, and agricultural fields. This research aimed to analyze the chemical and physical characteristics, assess the level of heavy metal contamination, evaluate the ecological effects, and identify potential health risks to humans arising from industrial discharge in Kalwar. Water samples were collected from effluent discharge points and adjacent water bodies, while selected soil samples were examined to measure heavy metal accumulation. The physical and chemical parameters measured included pH, temperature, electrical conductivity, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and nutrient concentrations. Heavy metals, specifically chromium (Cr), lead (Pb), and cadmium (Cd), were quantified using Atomic Absorption Spectroscopy. The results indicated that several water quality parameters exceeded permissible limits. Turbidity (35 NTU), BOD (45 mg/L), and TDS (1200 mg/L) were above the acceptable thresholds established by BIS/WHO standards, while DO (3.2 mg/L) was below the recommended levels, indicating contamination from organic and chemical pollutants. Concentrations of heavy metals were found to be high, with Cr (0.12 mg/L), Pb (0.08 mg/L), and Cd (0.02 mg/L) producing risk quotients (RQ) greater than 1, signifying considerable risks to both the environment and human health. The ecological evaluation revealed a dominance of pollution-tolerant aquatic plants such as water hyacinth and algae, a lack of fish populations, and a moderate presence of macroinvertebrates, indicating a stressed ecosystem and reduced biodiversity. This study highlights the serious implications of industrial effluent on water quality, biodiversity, and human health in the region. Some recommendations consist of establishing facilities for waste treatment, employing techniques that do not produce any liquid waste, routinely monitoring water quality, establishing protected zones, adopting eco-friendly practices in industries, and rehabilitating impaired water sources. These measures are crucial for minimizing pollution, safeguarding aquatic ecosystems, and ensuring the sustainable management of water resources in industrial regions near urban areas.

KEYWORDS: Industrial effluent, Water quality, Heavy metals, Biodiversity, Human health risk.

INTRODUCTION

The industrial growth in peri-urban areas of India has markedly increased the strain on local water resources, especially through the release of untreated or inadequately treated effluents into both natural and artificial water bodies. Kalwar, situated on the outskirts of Jaipur, Rajasthan, exemplifies a rapidly evolving area where small- and medium-sized industrial enterprises discharge wastewater into adjacent drains, ponds, and agricultural lands. These effluents generally contain elevated levels of heavy metals, organic contaminants, suspended solids, and chemical residues, all of which present significant threats to both environmental and human health (CPCB, 2022; UNEP, 2020).

Research conducted in the Jaipur district has shown that peri-urban areas are more susceptible to industrial pollution due to insufficient wastewater treatment facilities and unregulated discharge routes (Sharma & Singh, 2021). Industrial effluents frequently cause changes in water quality indicators such as pH, electrical conductivity, dissolved oxygen, biochemical oxygen demand (BOD), and chemical oxygen demand (COD), which can disrupt aquatic ecosystems and diminish the survival rates of fish, plankton, macro-invertebrates, and other organisms (Kumar et al., 2020). These ecological disruptions can propagate through the food web, ultimately impacting biodiversity and the stability of ecosystems (Gupta & Tare, 2019).

In addition to the ecological impacts, industrial wastewater poses significant public health risks. Contaminants like chromium, lead, nickel, and fluoride, which are frequently found in the industrial zones of Rajasthan, have been linked to gastrointestinal issues, neurological disorders, skin conditions, and long-term cancer risks among communities that depend on contaminated groundwater or surface water sources (WHO, 2017; BIS, 2012). The reliance of Kalwar on both shallow and deep aquifers heightens the risk of pollutant infiltration, particularly during times of groundwater depletion, a well-recognized issue in the Jaipur area (CGWB, 2023).

In light of these issues, conducting a thorough analysis of industrial effluent in Kalwar is crucial to comprehend its chemical makeup, assess its ecological effects, and evaluate the related human health risks. This evaluation can offer vital information for local authorities, policymakers, and environmental managers to develop effective pollution control measures, enhance regulatory frameworks, and encourage sustainable development practices.

OBJECTIVES

1. To investigate the physicochemical properties of industrial effluent in Kalwar. This involves evaluating essential water-quality indicators such as pH, temperature, electrical conductivity, turbidity, TDS, DO, BOD, COD, hardness, and nutrient concentrations.
2. To ascertain the levels of heavy metals and hazardous pollutants found in the industrial effluent. Elements like chromium, lead, cadmium, nickel, arsenic, and fluoride will be analyzed due to their recognized ecological and health hazards.
3. To assess the effects of industrial effluent on the quality of adjacent soil and surface water/groundwater. The aim is to comprehend how the discharge of effluent affects pathways of environmental contamination.
4. To investigate the ecological consequences of industrial effluent on local biodiversity. This encompasses evaluating alterations in aquatic life (fish, plankton, macroinvertebrates) and terrestrial organisms in proximity to the discharge location.
5. To evaluate the potential health risks to humans associated with exposure to contaminated water sources. This objective seeks to identify dangers for communities utilizing polluted water for drinking, irrigation, bathing, or livestock.
6. To compare the detected pollutant concentrations with national and international regulations. The standards referenced include WHO (2017), BIS IS 10500:2012, and CPCB effluent discharge guidelines to assess compliance.

7. To offer recommendations for pollution reduction and sustainable effluent management practices in Kalwar. These suggestions will assist local authorities, industries, and policymakers in minimizing environmental and health repercussions.

METHODOLOGY

1. Study Area: The research was carried out in Kalwar, a peri-urban region situated on the outskirts of Jaipur, Rajasthan. The primary focus of the investigation was a specific site of industrial effluent discharge, such as a drain or outfall point, which serves as the main source of wastewater entering the local ecosystem. The surrounding environment encompasses nearby water bodies, soil, and residential or agricultural lands that may be adversely affected by the effluent. Analyzing this site facilitates an evaluation of the impact of industrial discharges on water quality, soil contamination, and the health of local ecosystems, as well as the potential consequences for human populations residing in close proximity to the discharge site.

2. Sample Collection: In this study, water samples were gathered from the industrial effluent discharge point in Kalwar, along with samples from adjacent water bodies that could be affected. A total of 5–6 samples were collected, either in a single instance or repeated 2–3 times to ensure reliability and representativeness. The water samples were obtained using clean, sterilized polyethylene bottles from both the surface and mid-depth (~0.5 m) of the water column. Each sample was meticulously labeled with the date, time, and location of collection and stored in a cool box to preserve sample integrity until laboratory analysis. In addition, soil samples were optionally collected from areas where the industrial effluent was discharged or had accumulated. These samples were taken from the 0–15 cm surface layer of soil to evaluate potential heavy metal accumulation resulting from effluent contamination.

3. Water Quality Analysis

The water samples that were collected underwent analysis to ascertain their physicochemical properties and heavy metal content. The physicochemical parameters that were measured included pH, which was determined with a portable pH meter, and temperature, which was recorded on-site using a thermometer. Electrical conductivity (EC) and total dissolved solids (TDS) were assessed with a conductivity meter, while dissolved oxygen (DO) was evaluated using either the Winkler method or a digital DO meter. Organic pollution was measured through biochemical oxygen demand (BOD) via a 5-day BOD test, and chemical oxygen demand (COD) was determined using the standard dichromate method. Turbidity was gauged with a nephelometric turbidity meter, and nutrient concentrations, including nitrate and phosphate, were analyzed through colorimetric methods.

Furthermore, the heavy metal content of the effluent was examined for metals such as chromium (Cr), lead (Pb), cadmium (Cd), nickel (Ni), arsenic (As), and uranium (U) utilizing Atomic Absorption Spectroscopy (AAS). These analyses were performed to evaluate the potential ecological and human health impacts of the industrial effluent on the surrounding environment.

4. Ecological Assessment

In order to assess the ecological impact of the industrial effluent, the aquatic biodiversity in and around the discharge site was evaluated. Observations were conducted to document the presence or absence of fish, macroinvertebrates such as insects and mollusks, and plankton. Additionally, a vegetation survey was carried out to identify any aquatic or riparian plants that were affected by the effluent discharge, noting any changes in species composition, abundance, or health. Optional observations were also made regarding birds and amphibians frequenting nearby water bodies, as these organisms can act as significant indicators of ecological health. This assessment offers insights into the effects of industrial effluent on both aquatic ecosystems and the adjacent terrestrial environment.

5. Data Analysis

The gathered data regarding physicochemical parameters and concentrations of heavy metals were compared against the standards set by WHO (2017) to identify any deviations from safe limits. Parameters that exceeded permissible thresholds were emphasized to evaluate potential ecological and human health risks. The observed alterations in aquatic biodiversity were subsequently correlated with water-quality parameters, including dissolved oxygen, BOD, heavy metals, and nutrient levels, to comprehend how pollution affects species abundance and diversity. Fundamental statistical analyses, such as mean and standard deviation, were conducted to summarize the findings and present the data in a clear manner. This methodology facilitates both a quantitative and qualitative evaluation of the environmental impact of industrial effluent in Kalwar.

6. Health Risk Assessment (Basic)

The potential health risks to humans associated with industrial effluent in Kalwar were assessed based on possible exposure pathways, which include the consumption of contaminated water, irrigation of crops with polluted water, and the use of this water by livestock. Levels of pollutants that surpassed permissible limits for parameters such as heavy metals (Cr, Pb, Cd) and elevated BOD/TDS were utilized to determine the risk level. For the purposes of this minor project, the assessment is qualitative, categorizing risks as high, medium, or low based on the severity of contamination and the likelihood of human exposure. This offers an initial insight into how industrial discharges may affect local communities and underscores areas that require attention or further investigation.

RESULTS

Physicochemical Parameters

The analysis of water samples from the industrial effluent site in Kalwar revealed several deviations from standard water-quality parameters. The pH of the effluent was 8.2, which is slightly alkaline but still within the permissible limit of 6.5–8.5, indicating minimal risk from acidity or alkalinity. The temperature was recorded as 28°C, which is typical for the region and considered normal. The electrical conductivity (EC) measured 1450 µS/cm**,** within the BIS/WHO recommended limit of <2000 µS/cm, suggesting moderate ionic content.

However, certain parameters exceeded safe limits. The turbidity was notably high at 35 NTU, well above the permissible limit of 5 NTU, indicating a significant presence of suspended particles that can reduce light penetration and affect aquatic life. Dissolved oxygen (DO) was measured at 3.2 mg/L, below the recommended level of >5 mg/L, suggesting oxygen depletion in the water, likely due to organic pollution. The biochemical oxygen demand (BOD) was 45 mg/L**,** exceeding the limit of 30 mg/L, which reflects a high load of biodegradable organic matter; it was calculated as BOD = DOi – DOf = 8.2 – 3.2 = 5 mg/L*.

The chemical oxygen demand (COD) was found to be 120 mg/L**,** within the permissible limit of 250 mg/L, though the calculated COD value from titration methods indicated 3680 mg/L, highlighting substantial chemical pollution from industrial effluents. The total dissolved solids (TDS) were 1200 mg/L, exceeding the standard limit of 500 mg/L, suggesting high salinity and dissolved pollutant content, which can affect aquatic organisms and water usability for human purposes.

Overall, the results indicate that the industrial effluent from Kalwar significantly impacts water quality, particularly in terms of turbidity, oxygen depletion, organic pollution, and dissolved solids, which can have adverse effects on aquatic life and may pose potential risks to human health if the water is used for consumption or irrigation.

Heavy Metals

The analysis of industrial effluent from Kalwar revealed the presence of several heavy metals at concentrations exceeding safe limits. Chromium (Cr) was measured at 0.12 mg/L**,** which is higher than the BIS/WHO permissible limit of 0.05 mg/L. The risk quotient (RQ) for chromium was calculated as 2.4, indicating a high potential ecological and human health risk**.** Lead (Pb) was found at 0.08 mg/L, substantially above the standard limit of 0.01 mg/L, with an RQ of 8.0, marking it as a major contaminant of concern. Prolonged exposure to lead can lead to serious health effects, including neurological and developmental disorders.

Cadmium (Cd) was detected at 0.02 mg/L, exceeding the safe limit of 0.01 mg/L, with an RQ of 2.0. Cadmium is highly toxic and can accumulate in the body, affecting kidneys and liver function over time.

Overall, the results indicate that the industrial effluent is a significant source of heavy metal contamination, posing high ecological and human health risks, especially to communities relying on nearby water bodies for drinking, irrigation, or livestock.

Ecological Observations

The ecological assessment near the industrial effluent site in Kalwar indicated notable changes in aquatic biodiversity. Among aquatic plants, species such as water hyacinth and algae were found to be dominant**,** reflecting eutrophication likely caused by nutrient enrichment from the effluent.

In terms of fish populations, only a few minor fish species were observed, indicating low abundance, which may result from decreased dissolved oxygen levels and poor water quality. Macroinvertebrates, including snails and various aquatic insects, were present in moderate numbers**,** suggesting that some species are able to tolerate the pollution, while sensitive species may have declined or disappeared.

Overall, these observations highlight that the industrial effluent has a direct impact on aquatic ecosystems, favoring tolerant species like algae and water hyacinth while reducing the abundance of more sensitive organisms such as fish. This shift in biodiversity reflects ecological stress and a decline in the health and stability of the affected water body.

DISCUSSION

The examination of water samples from the industrial effluent site in Kalwar indicates notable discrepancies from standard water-quality metrics, underscoring the environmental repercussions of industrial discharges.

The pH level of 8.2, while slightly alkaline, remains within the acceptable BIS/WHO range of 6.5–8.5, suggesting that the effluent does not present immediate concerns regarding acidity or alkalinity. Likewise, the recorded temperature of 28°C is typical for the area and falls within acceptable parameters, implying that thermal stress on aquatic organisms is minimal. Electrical conductivity (EC) was recorded at 1450 µS/cm, which is below the threshold of 2000 µS/cm, indicating a moderate ionic concentration that does not surpass safe limits. Conversely, several critical parameters exceeded normal or safe thresholds. Turbidity was measured at 35 NTU, significantly above the WHO/BIS limit of 5 NTU, indicating a high level of suspended solids. Elevated turbidity diminishes light penetration, disrupting photosynthesis in aquatic vegetation and contributing to eutrophication, as evidenced by the prevalence of water hyacinth and algae.

Dissolved oxygen (DO) was found to be 3.2 mg/L, considerably below the standard of >5 mg/L. Low DO levels indicate oxygen depletion due to a high organic load, which restricts the survival of sensitive aquatic species such as fish, which were noted to be in low numbers. Biochemical oxygen demand (BOD) was recorded at 45 mg/L, surpassing the permissible limit of 30 mg/L, reflecting significant levels of biodegradable organic pollution. Chemical oxygen demand (COD) was measured at 120 mg/L, which is within the standard limit of 250 mg/L; however, the calculated titration value of 3680 mg/L suggests the presence of additional chemical pollutants not captured in routine COD assessments. Total dissolved solids (TDS) were found to be 1200 mg/L, more than double the BIS limit of 500 mg/L, indicating increased salinity and dissolved contaminants that could impact both aquatic life and potential human utilization. Heavy metal analysis indicated that chromium (0.12 mg/L), lead (0.08 mg/L), and cadmium (0.02 mg/L) surpassed the permissible limits of 0.05, 0.01, and 0.01 mg/L, respectively. Risk quotients (RQ >1) suggest significant ecological and human health hazards. These metals are recognized for their ability to bioaccumulate and exhibit toxicity even at minimal concentrations, which may account for the decline of sensitive fish species and the potential long-term effects on human populations that depend on water for drinking or irrigation. Ecological observations further support the findings regarding water quality. The prevalence of tolerant species such as algae and water hyacinth, along with a low abundance of fish and moderate populations of macroinvertebrates, indicates ecological stress. This trend aligns with eutrophication and chemical pollution, underscoring the detrimental effects of industrial discharges on local biodiversity. In conclusion, the discussion illustrates that while certain parameters like pH and temperature remain within safe limits, excessive turbidity, low dissolved oxygen (DO), high biochemical oxygen demand (BOD), elevated total dissolved solids (TDS), and heavy metal contamination signify severe pollution. The changes observed in aquatic biodiversity are directly related to these altered water quality parameters, highlighting the interconnected impacts of industrial effluents on ecosystem health and human safety.

Table 1: Water Quality Parameters of Industrial Effluent (Kalwar, Jaipur)

Parameter	**Observed Value**	**BIS/WHO Standard**	**Status**
pH	8.2	6.5–8.5	Within Limit
Temperature (°C)	28	–	Normal
Electrical Conductivity (µS/cm)	1450	<2000	Within Limit
Turbidity (NTU)	35	<5	Exceeds Limit
Dissolved Oxygen (mg/L)	3.2	>5	Low
BOD (mg/L)	45	<30	High
COD (mg/L)	120	<250	Within Limit
TDS (mg/L)	1200	<500	High

Table 2: Heavy Metal Concentration and Risk Quotient

Metal	**Observed Concentration (mg/L)**	**BIS/WHO Limit (mg/L)**	**RQ = Observed / Limit**	**Status**
Chromium (Cr)	0.12	0.05	2.4	High / Risk
Lead (Pb)	0.08	0.01	8.0	High / Risk
Cadmium (Cd)	0.02	0.01	2.0	High / Risk

Interpretation: RQ > 1 indicates potential human health risk and ecological toxicity.

Table 3: Biodiversity Assessment near Effluent Site

Organism Type	Species Observed	Abundance / Status
Aquatic Plants	Water hyacinth, algae	Dominant (Eutrophication)
Fish	Minor fish species	Low abundance
Macroinvertebrates	Snails, aquatic insects	Moderate

CONCLUSION

The study concludes that industrial effluent in Kalwar, Jaipur, significantly degrades water quality, threatens aquatic biodiversity, and poses potential human health risks. Key findings include:

1. Water quality deterioration: High turbidity, low dissolved oxygen, elevated BOD, and excessive TDS indicate organic and chemical pollution.
2. Heavy metal contamination: Chromium, lead, and cadmium exceed permissible limits, posing high ecological and health risks.
3. Biodiversity impacts: Dominance of tolerant species and low abundance of sensitive organisms reflect ecological stress and ecosystem imbalance.

These results underscore the need for proper effluent treatment, regular monitoring, and sustainable wastewater management. Protecting water quality and aquatic ecosystems is essential to safeguard public health and maintain ecological balance in peri-urban areas like Kalwar.

RECOMMENDATIONS FOR MITIGATION AND SUSTAINABLE EFFLUENT MANAGEMENT

1. Installation of Effluent Treatment Plants (ETPs): Industries in Kalwar should be required to install and maintain advanced ETPs to treat wastewater prior to discharge. This process encompasses physical, chemical, and biological treatments aimed at eliminating suspended solids, heavy metals, and organic contaminants.
2. Adoption of Zero-Liquid Discharge (ZLD) Techniques: Encourage industries to adopt ZLD systems, which facilitate the recycling of wastewater within the facility, thereby reducing external effluent discharge and conserving water resources.
3. Regular Water Quality Monitoring: Establish a comprehensive monitoring system for effluent and adjacent water bodies, incorporating parameters such as pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand

(COD), total dissolved solids (TDS), and heavy metals. Real-time monitoring technologies can offer early alerts regarding pollution surges.

4. Eco-Friendly Industrial Practices: Encourage the implementation of environmentally friendly technologies, including the use of less toxic chemicals, energy-efficient processes, and the recycling of raw materials, to diminish pollutant output at the source.
5. Buffer Zones and Green Belts: Create buffer zones with vegetation surrounding effluent discharge areas to absorb nutrients, capture sediments, and mitigate the flow of pollutants into natural water bodies.
6. Community Awareness and Participation: Inform local residents and workers about the health and environmental hazards associated with untreated effluent. Engaging the community in monitoring and reporting pollution can enhance compliance.
7. Policy Enforcement and Incentives: Regulatory bodies should rigorously enforce BIS/WHO discharge standards and offer incentives to industries that implement sustainable wastewater management practices.
8. Ecological Restoration: Initiate remediation initiatives for impacted water bodies, which may include the removal of invasive plant species, restocking of native fish populations, and the rehabilitation of riparian zones to restore ecosystem vitality.
9. Research and Innovation: Promote research on pollution mitigation technologies, bio-remediation of heavy metals, and the long-term effects of industrial effluents on human and ecological health in the Kalwar area.

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