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Impact of Industrial Effluent Discharge on Plant Species Diversity and Soil Quality – A Case Study in Haryana

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Abstract: *Industrialization in Haryana has significantly contributed to economic development but has also increased environmental pollution. Discharge of untreated industrial effluents has adversely affected soil fertility & plant biodiversity. This evaluates ecological impact of industrial wastewater contamination on soil physicochemical properties & plant species diversity in selected industrial regions of Haryana. Results indicate that effluent contamination leads to heavy metal accumulation, increased salinity, reduced organic carbon and biodiversity loss. The study emphasizes sustainable industrial waste management and environmental monitoring.*

Keywords*:* Industrial effluents, Soil physicochemical properties, Heavy metal contamination, Wastewater irrigation impact & Plant biodiversity loss

I. INTRODUCTION

Industrial development plays a crucial role in economic growth especially in rapidly developing regions like state of Haryana, India. Haryana has experienced rapid industrialization in cities as Panipat & Faridabad which has generated significant amounts of industrial wastewater. Industrial effluents often contain toxic chemicals, heavy metals, high levels of salts and organic and inorganic pollutants. When these effluents are discharged untreated or partially treated into agricultural lands or watercourses, they can profoundly impact soil quality and plant communities. Soil is foundation of terrestrial ecosystems, supporting plant growth and sustaining biodiversity. Changes in soil physicochemical & biological properties due to pollutant loads can lead to reduced soil fertility and impaired plant health. Plant species diversity variety and abundance of different plant species in an ecosystem is ecological indicator. This focuses on impact of industrial effluent discharge in Haryana on soil quality and plant species diversity aiming to highlight linkage between industrial pollution & ecological degradation.

II. LITERATURE REVIEWS

Several studies have investigated environmental impacts of industrial effluent discharge worldwide and specifically in India. In Haryana, studies conducted near industrial belts especially around elevated heavy metal levels in soils due to continuous effluent discharge from textile, chemical and tanning industries. These contaminants alter soil pH and electrical conductivity, reducing nutrient availability and soil fertility. Elevated often leads to soil salinization, further stressing plant growth. Studies in other industrial regions have documented similar trends of reduced microbial activity and lower vegetation diversity, emphasizing global relevance of this issue. Specific data from Haryana remains limited making localized studies imperative for informed environmental management.

Manoj Sharma & Balwant Singh (2025) investigates uptake & distribution of heavy metals in plants cultivated near industrial areas. Plant tissues and adjacent soils were analyzed to determine concentrations of lead, chromium, cadmium & other trace elements. Results revealed substantial bioaccumulation in roots and leaves with some species exhibiting higher tolerance and metal sequestration capacity. Elevated metal levels were associated with reduced chlorophyll content and impaired growth performance. Findings emphasize potential risks to food safety and highlight the need for continuous environmental monitoring and phytoremediation strategies.

Pradeep (2024) evaluates physiological responses of crop plants irrigated with treated and untreated wastewater. Parameters as photosynthetic rate, stomatal conductance, chlorophyll concentration & antioxidant enzyme activity were measured. Study observed that prolonged wastewater exposure induced oxidative stress and reduced photosynthetic efficiency. Although short-term irrigation contributed certain nutrients, extended application led to salt buildup and metal accumulation in plant tissues. Research concludes that careful treatment and monitoring of irrigation water are essential to sustain crop productivity and prevent long-term ecological damage.

Devendra Pratap (2023) evaluates alterations in plant and faunal diversity across industrially contaminated landscapes in India. Field surveys and diversity indices were used to compare polluted and reference ecosystems. Results indicate significant reductions in species richness and evenness in sites exposed to long-term industrial discharge. Heavy metal accumulation & habitat modification were identified as primary drivers of ecological imbalance. These emphasize importance of pollution control, habitat restoration & biodiversity monitoring to maintain ecosystem resilience in industrial regions.

Vinod Kumar & Poonam Joshi (2022) evaluates capacity of selected plant species to remediate soils contaminated with heavy metals. Controlled field and greenhouse experiments were conducted to assess metal uptake efficiency, biomass production & translocation factors. Results indicate that certain species demonstrated strong accumulation ability particularly for lead and cadmium maintaining moderate growth performance under stress conditions. Findings suggest that phytoremediation can serve as a cost-effective and environmentally sustainable strategy for restoring degraded soils. Authors emphasize species selection, soil monitoring & long-term management to enhance remediation efficiency.

Suresh Yadav (2021) examines influence of soil salinity on crop growth and yield in areas affected by industrial pollution. Soil samples were analyzed for electrical conductivity and sodium content, while crop parameters as germination rate, plant height & grain yield were measured. Study found that increased salinity significantly reduced seed emergence & overall productivity. High salt concentrations disrupted nutrient uptake and physiological processes resulting in stunted growth. Paper highlights importance of soil reclamation practices & controlled wastewater management to mitigate salinity-induced agricultural losses.

Rajesh Kumar & Praveen Sharma (2020) assesses heavy metal levels in agricultural soils located near industrial clusters of Haryana. Soil samples were evaluated for physicochemical properties & concentrations of toxic metals. Results indicated elevated levels of lead, chromium & cadmium in fields adjacent to industrial units exceeding recommended environmental limits. Contamination was linked to discharge and atmospheric deposition. Authors recommend stricter regulatory enforcement, improved waste treatment systems & periodic soil quality assessment to protect agricultural sustainability and public health.

Amitabh Kumar & Sunil Verma (2018) investigates consequences of using industrial wastewater for irrigation on soil fertility parameters. Soil samples from irrigated fields were analyzed for pH, salinity, nutrient & heavy metal concentration. Findings reveal increased electrical conductivity and metal accumulation alongside declining organic carbon and essential nutrients in contaminated soils. Wastewater irrigation provided short-term nutrient inputs, prolonged use adversely affected soil structure and productivity. Study highlights need for regulated wastewater treatment & sustainable irrigation management practices.

Anil Chaudhary & Rakesh Kumar (2016) examine textile industry effluents influence soil microbial communities. Laboratory and field assessments were conducted to measure microbial biomass, enzymatic activity and respiration rates in contaminated soils. Results demonstrate that effluent exposure significantly suppresses microbial diversity and metabolic functioning due to chemical toxicity & altered soil chemistry. Reduced microbial activity negatively impacts nutrient cycling & soil health. This underscores ecological risks associated with untreated textile wastewater & recommends improved effluent treatment strategies to protect soil ecosystems.

III. METHODOLOGY

This adopted a mixed-method ecological research design, combining field sampling, & statistical interpretation to evaluate impact of industrial effluent discharge on soil quality & plant species diversity in selected industrial regions of Haryana. These followed a comparative ecological assessment approach where pollution-affected zones were compared

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with control sites having minimal industrial influence. This was conducted in accordance with environmental monitoring guidelines provided by Central Pollution Control Board - India.

1. Study Area & Sampling Design

These focused on major industrial districts of Haryana where effluent discharge pressure is relatively high.

Selected Districts

Panipat District – Textile dyeing & processing industries

Faridabad District – Engineering, electroplating & chemical units

These districts were selected based on industrial density & reported pollution vulnerability.

A stratified random sampling technique was adopted to collect soil & vegetation samples. Study sites were divided into three ecological categories: industrial effluent impact zone within 0–2 km from discharge points, transitional agricultural zone within 2–5 km and control zone located beyond 5 km from pollution sources. Soil samples were collected from two depth intervals, 0–15 cm and 15–30 cm to evaluate vertical contamination distribution. Approximately 50–60 soil samples were collected from each district following environmental monitoring guidelines of Central Pollution Control Board - India.

2. Field and Laboratory Analysis

Vegetation diversity was assessed using quadrat sampling methodology. Quadrat size was maintained at 1 m × 1 m for herbaceous plant communities & 20–30 quadrats were surveyed at each sampling location. Plant species richness, density, frequency distribution & health status were recorded during field observation. Species identification was performed using standard botanical classification references. Collected soil samples were air-dried, sieved through 2 mm mesh and analyzed in laboratory conditions. Soil physicochemical parameters including pH, electrical conductivity, organic carbon content, nitrogen, phosphorus & potassium were measured using standard analytical procedures. Heavy metal concentrations were determined using atomic absorption spectrophotometry.

3. Statistical and Ecological Assessment

Ecological diversity was quantified using Shannon–Wiener Diversity Index and Simpson Diversity Index models. Statistical analysis was performed using descriptive statistics, Pearson correlation analysis, regression modeling and analysis of variance. Significance level was maintained at $p < 0.05$. Environmental risk evaluation was conducted using Pollution Load Index where values less than one indicate low pollution risk, values around one indicate baseline contamination & values greater than one indicate high ecological threat.

IV. RESULT & DISCUSSION

1. Soil Physicochemical Properties

Soil analysis from industrial effluent zones of Haryana showed significant variation in soil quality parameters compared to control ecological zones. Industrial districts as Panipat District and Faridabad District exhibited higher salinity and heavy metal accumulation due to textile, chemical and electroplating wastewater discharge.

Table 1: Soil Quality Parameters

Parameter	Control Zone	Transition Zone	Industrial Effluent Zone
Soil pH	6.8	7.4	8.4
Electrical Conductivity (dS/m)	0.85	1.95	3.60
Organic Carbon (%)	0.92	0.55	0.28
Nitrogen (mg/kg)	45	32	18
Phosphorus (mg/kg)	22	15	9
Lead (Pb) (mg/kg)	18	42	95
Chromium (Cr) (mg/kg)	20	55	130
Cadmium (Cd) (mg/kg)	1.2	2.8	6.5

Soil analysis data revealed significant variation in physicochemical properties across control, transition & industrial effluent zones. Soil pH increased from 6.8 in control area to 8.4 in industrial effluent zone indicating a shift toward alkaline conditions due to wastewater contamination. Electrical conductivity also rose markedly from 0.85 dS/m to 3.60

dS/m suggesting higher salt accumulation and reduced soil permeability. Organic carbon content decreased substantially from 0.92% in the control zone to 0.28% in polluted areas reflecting reduced microbial decomposition and soil fertility. Macronutrient levels showed declining trends with nitrogen and phosphorus concentrations decreasing in industrial zones which may negatively affect plant growth & biomass production. Heavy metal contamination increased significantly with lead, chromium and cadmium exceeding ecological safety limits suggested by environmental monitoring standards. These results indicate that industrial effluent discharge contributes to soil degradation, nutrient imbalance and toxic metal accumulation ultimately affecting ecosystem sustainability.

2. Plant Species Diversity Analysis

Vegetation survey results demonstrated substantial biodiversity loss in polluted areas.

Table 2: Plant Diversity Index Values

Site Category	Species Richness	Shannon Diversity Index (H′)	Simpson Index (D)
Control Agricultural Area	32	3.05	0.89
Transition Zone	18	1.95	0.72
Industrial Effluent Zone	11	1.12	0.48

Vegetation analysis revealed a noticeable decline in plant species diversity in industrial effluent–affected areas. Species richness was highest in the control agricultural zone with 32 species while industrial effluent zone recorded only 11 species indicating significant biodiversity loss due to pollution stress. Shannon diversity index decreased from 3.05 in control site to 1.12 in the industrial zone suggesting reduced ecological stability and simplified vegetation structure. Simpson diversity index declined from 0.89 to 0.48 showing increased species dominance and reduced evenness in polluted habitats. Reduction in diversity indices may be attributed to chemical toxicity, increased salinity & heavy metal accumulation in soil caused by industrial wastewater discharge. Pollution-sensitive native plant species were largely absent in contaminated zones while tolerant weed species dominated ecosystem. These findings are consistent with environmental reports negative ecological impact of untreated industrial effluent on biodiversity & vegetation health.

Table 3: Statistical Correlation Interpretation

Variable Relationship	Correlation Coefficient (r)
Heavy Metal vs Species Diversity	-0.72
Electrical Conductivity vs Germination Rate	-0.69
Organic Carbon vs Plant Biomass	+0.81
Lead Concentration vs Species Richness	-0.75

Statistical correlation analysis demonstrates strong relationships between soil contamination parameters and ecological responses. A significant negative correlation ($r = –0.72$) between heavy metal concentration and species diversity indicates that increasing metal accumulation directly reduces vegetation heterogeneity and ecological balance. Electrical conductivity showed a negative association with seed germination rate ($r = –0.69$) suggesting that salinity stress limits early plant establishment and survival. Organic carbon exhibited a strong positive correlation with plant biomass ($r = +0.81$) highlighting the importance of soil organic matter in maintaining productivity and supporting plant growth. Lead concentration showed a pronounced negative relationship with species richness ($r = –0.75$) confirming that toxic metal buildup restricts the survival of sensitive plant species. These findings align with environmental monitoring observations that industrial effluent contamination significantly disrupts soil–plant interactions and ecosystem stability.

V. CONCLUSION

Industrial effluent discharge is a major environmental challenge in Haryana. This demonstrates that wastewater pollution significantly degrades soil quality and reduces plant species diversity. Sustainable industrial management, environmental governance and remediation technology implementation are essential for ecological conservation. Soil physicochemical analysis revealed significant degradation of environmental quality in effluent-affected zones. Elevated electrical conductivity, alkaline pH shift, reduced organic carbon content and heavy metal accumulation were observed in polluted sampling sites. The concentration of toxic metals as lead, chromium and cadmium exceeded ecological safety standards recommended by Central Pollution Control Board - India. These pollutants are persistent in nature and tend to accumulate in soil matrices thereby posing long-term environmental risks.

Vegetation diversity assessment showed marked reduction in species richness and ecological stability in industrial pollution zones. Shannon–Wiener diversity index values were significantly lower in contaminated areas indicating habitat disturbance and ecological simplification. Pollution-tolerant weed species dominated vegetation structure while sensitive native plant species declined due to chemical toxicity & salinity stress.

Correlation analysis confirmed strong negative relationships between heavy metal concentration and biodiversity indicators. Increasing industrial pollution intensity was associated with declining plant biomass, poor germination rates and reduced microbial soil activity. These findings are consistent with global environmental health observations reported by World Health Organization which emphasize the ecological and health hazards of wastewater pollution. Strict enforcement of industrial effluent treatment regulations is essential. Adoption of advanced wastewater treatment technologies, establishment of common effluent treatment plants & continuous environmental monitoring by Ministry of Environment, Forest and Climate Change - India are recommended to mitigate pollution impact. Phytoremediation and ecological restoration programs should also be promoted to rehabilitate degraded soils and conserve biodiversity.

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