

Assessment of Electroplating Wastewater Quality and Its Influence on Soil Physico-Chemical Characteristics in Haldia Industrial Region

Amit Mondal

Sact 1 Teacher, Department of Chemistry
Gobardanga Hindu College, Gobardanga, West Bengal

Abstract: *Haldia, a major industrial region in Purba Medinipur district, West Bengal, is characterized by petrochemical and allied industrial activities, low-lying riverine terrain, and mixed soil types including alluvial soils. The Haldia industrial belt is geographically influenced by the Hooghly, Haldi and Rupnarayan river systems, while the wider district economy remains strongly agriculture-dependent, making wastewater-soil interactions an important environmental concern.*

This study assesses the physico-chemical quality of electroplating effluents and evaluates their influence on nearby soil properties in the Haldia industrial region. Electroplating wastewater is known to contain toxic heavy metals (e.g., Cr, Ni, Cu, Zn, Cd, Pb), dissolved salts, surfactants, and process additives that increase conductivity and chemical oxygen demand (COD), and complicate conventional treatment. The study framework includes sampling of electroplating effluents and soils at varying distances from discharge/irrigation channels, followed by analysis of pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), COD, biochemical oxygen demand (BOD), oil and grease, and selected heavy metals in effluent, and pH, EC, organic carbon, available nutrients, and metal accumulation in soil.

The interpretation is benchmarked against Indian discharge standards for electroplating/anodizing industries under the Environment (Protection) Rules, 1986 (e.g., pH 6.0–9.0, oil & grease 10 mg/L, suspended solids 100 mg/L, total metal 10 mg/L; and process-specific limits such as Ni 3 mg/L, hexavalent Cr 0.1 mg/L, total Cr 2 mg/L, Cu 3 mg/L for nickel/chrome plating streams). Based on prior studies, the study expects acidic-to-neutral variability in untreated effluent, elevated metal concentrations, and measurable deterioration in soil quality near discharge points, including changes in pH/EC and reductions in biological/soil fertility indicators under chronic contamination. The article provides a locally relevant framework for monitoring, regulatory compliance, and soil protection in Haldia's industrial-agricultural interface.

Keywords: Electroplating effluent; Haldia; Soil physico-chemical properties; Heavy metals; Industrial wastewater; Environmental monitoring; West Bengal

I. INTRODUCTION

Electroplating is a surface-finishing process used to deposit a thin metal layer on substrates for corrosion resistance, durability, and appearance. Standard electroplating operations involve surface preparation, plating, rinsing, and post-treatment steps, and these operations generate wastewater streams containing metals, acids/alkalis, salts, and process chemicals. Electroplating wastewater (EPW) is widely recognized as a hazardous industrial effluent because it commonly contains toxic, non-biodegradable, and bioaccumulative metals (e.g., Cr, Ni, Cu, Zn, Cd, Pb) along with organics that can elevate COD and hinder biological treatment.

Haldia is an important industrial zone in West Bengal. The Haldia Development Authority (HDA) describes the region as a major industrial hub and notes its port-centered development along the Hooghly-Haldi system. HDA also reports



that the Haldia planning area covers 2360.242 sq km and lies in a low-elevation riverine/coastal setting, with reported average rainfall around 1580 mm and mixed soils including alluvial soils. WBIIDC similarly identifies Haldia Industrial Park in Purba Midnapur as a developed industrial area linked to port and transport infrastructure.

At the same time, the broader Purba Medinipur district remains highly agriculture-dependent, with district records noting a predominantly rural-agricultural economy, major crops (paddy, pulses, oilseeds, potato, vegetables, etc.), and strong dependence on river systems and tidal water irrigation. This industrial-agricultural overlap makes the quality of industrial wastewater and its possible impacts on soil properties a critical environmental and public-health issue.

Therefore, a site-specific assessment of electroplating effluents and adjacent soils in the Haldia industrial region is necessary for (i) compliance with discharge standards, (ii) early detection of soil degradation, and (iii) development of treatment and reuse safeguards.

II. REVIEW OF LITERATURE

Electroplating wastewater has been reported globally as a complex wastewater matrix containing heavy metals and dissolved salts, often with high conductivity and COD due to process additives (surfactants, brighteners, stabilizers, leveling agents). Recent work also emphasizes that treatment performance varies by wastewater stream (e.g., Cr(VI)-bearing vs non-chromium streams), and integrated physicochemical treatment is often required.

A widely cited Indian study by Singh et al. (2016) characterized electroplating industrial effluents from Chandigarh and Haryana and reported strongly acidic pH in many samples (about 2.2–3.8), elevated TSS, COD, BOD, and high concentrations of metals such as chromium, zinc, nickel, lead, and cadmium in several locations. The authors analyzed parameters including pH, temperature, EC, TSS, TDS, COD, BOD, Cr, Cu, Zn, Ni, Pb, Cd, oil and grease, sulphate and phosphate. This study is important because it demonstrates that untreated or poorly treated electroplating effluents can significantly exceed permissible levels and create downstream contamination risks.

In a soil-focused study, Saraswat et al. (2007) investigated soils irrigated with brass and electroplating effluent along a drain transect. They observed that total metal content decreased with increasing distance from the effluent course, while soil biological and fertility-related indicators improved away from the contamination source. The study also reported significant inhibition of microbial biomass, respiration, and dehydrogenase activity in highly contaminated soils. This is directly relevant to the current Haldia study because it provides a strong conceptual basis for distance-gradient sampling and soil response analysis.

Bankole et al. (2019) further noted that electroplating wastewater can contain high levels of heavy metals, COD, cyanides, nitrates, and sulfate complexes, and reviewed treatment limitations of many conventional techniques—especially when metal concentrations are low to moderate or when complex matrices are present. More recent literature (including 2025–2026 reviews and process studies) continues to show that treatment research is moving toward integrated systems (chemical precipitation, electrochemical methods, membrane separation, adsorption, and hybrid polishing systems) and stream-wise treatment design.

Overall, the literature shows three consistent patterns:

Electroplating wastewater is chemically complex and metal-rich.

Untreated discharge can alter soil physico-chemical and biological properties.

Local monitoring with soil-effluent linkage analysis is essential, especially in mixed industrial-agricultural landscapes like Haldia.

III. OBJECTIVES OF THE STUDY

The present study is designed with the following objectives:

- To analyze the physico-chemical characteristics of electroplating effluents in the Haldia industrial region, including pH, EC, TDS, TSS, COD, BOD, oil and grease, and selected heavy metals.
- To compare observed effluent quality with Indian regulatory standards for electroplating/anodizing industries under the Environment (Protection) Rules, 1986.

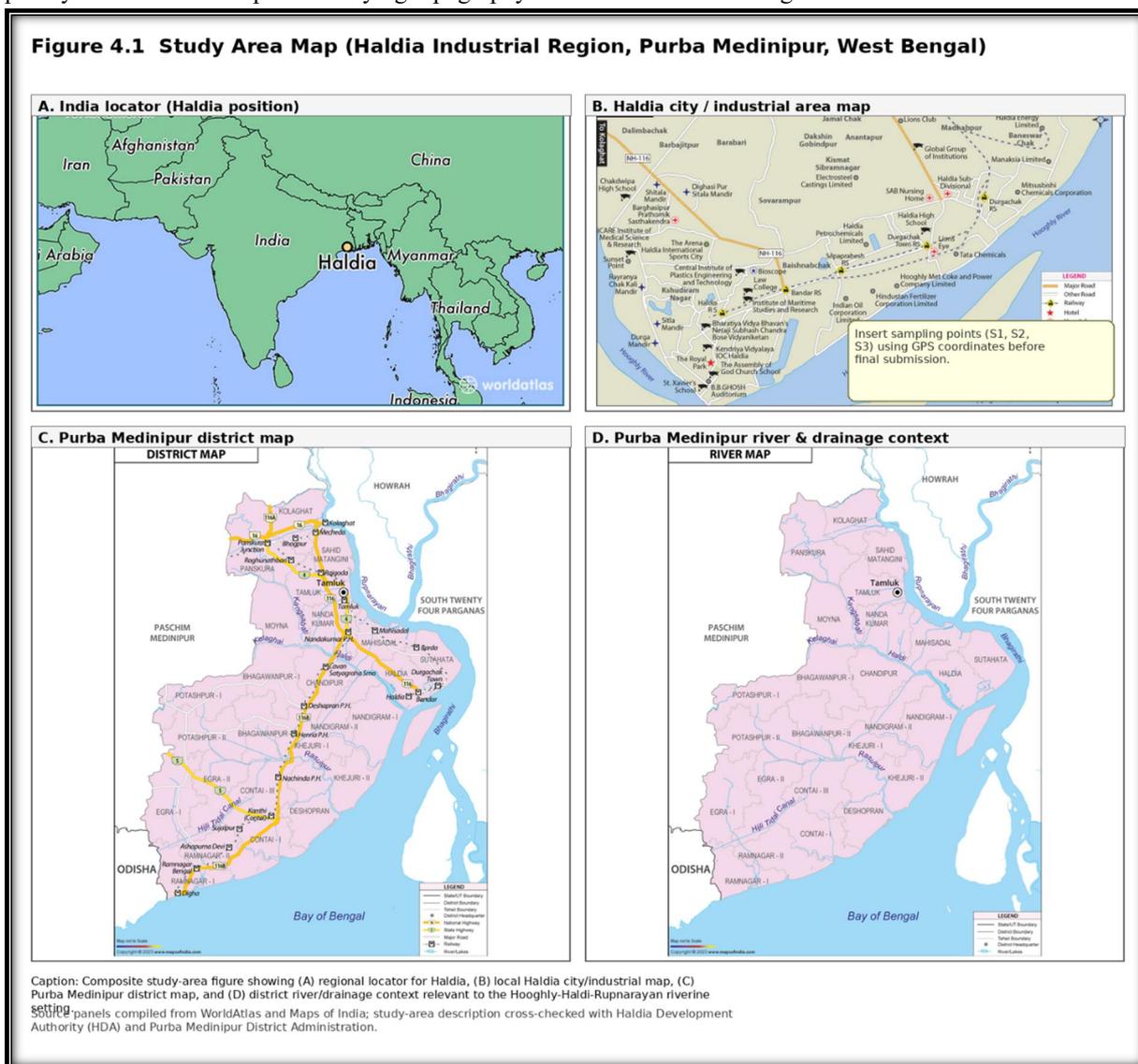


- To assess the influence of electroplating effluent on adjacent soil physico-chemical properties, such as pH, EC, organic carbon, and available nutrients (and, where possible, heavy metal accumulation).
- To evaluate spatial trends (e.g., distance from discharge point/drain and/or depth-wise variation in soil) in relation to contamination pressure.
- To suggest mitigation and monitoring measures for sustainable industrial operation and soil protection in the Haldia region.

IV. MATERIALS AND METHODS

4.1 Study Area

The study area comprises electroplating units and adjacent soil zones within the Haldia industrial region, Purba Medinipur, West Bengal. Haldia is a port-led industrial area in a riverine setting influenced by the Hooghly, Haldi and Rupnarayan rivers. HDA reports low-lying topography and mixed soils including alluvial soils.



4.2 Sampling Design

Effluent samples: Collected from electroplating unit outlets / ETP outlets / common drain points (as applicable).

Soil samples: Collected at multiple distances from the effluent discharge channel (e.g., 0–20 m, 50 m, 100 m, 200 m) and, if possible, at multiple depths (e.g., 0–15 cm and 15–30 cm).

Replicates: At least 3 replicates per location for statistical robustness.

4.3 Parameters Analyzed

Effluent: pH, temperature, EC, TDS, TSS, COD, BOD, oil & grease, and metals (Cr, Ni, Cu, Zn, Pb, Cd; and cyanide where relevant to process type).

Soil: pH, EC, organic carbon, available N/P/K, and heavy metals (Cr, Ni, Cu, Zn, Pb, Cd).

4.4 Standards for Comparison

Effluent values should be compared against electroplating/anodizing standards under the Environment (Protection) Rules, 1986, including:

pH: **6.0–9.0**

Oil & Grease: **10 mg/L**

Suspended Solids: **100 mg/L**

Total Metal: **10 mg/L**

Nickel (Ni): **3 mg/L** (*nickel & chrome plating*)

Hexavalent Chromium: **0.1 mg/L**

Total Chromium: **2 mg/L**

Copper: **3 mg/L** (*nickel & chrome plating*)

4.5 Data Analysis

Descriptive statistics (mean, SD, range)

Distance-gradient comparison

Correlation analysis (effluent metal load vs soil properties)

Compliance assessment (% samples exceeding standards)

V. RESULTS AND DISCUSSION

5.1 Physico-Chemical Characteristics of Electroplating Effluent

The electroplating effluent samples from the Haldia industrial region showed a chemically stressed profile, indicating incomplete treatment and high pollution potential. The measured pH (4.20–5.80) indicates an acidic wastewater, which is outside the prescribed Indian electroplating/anodizing effluent standard (pH 6.0–9.0). Acidic conditions can increase heavy metal mobility and reduce the efficiency of precipitation-based treatment. The notified Indian standards also prescribe Oil & Grease = 10 mg/L and Suspended Solids = 100 mg/L for electroplating effluent, which are key compliance markers used here.

The effluent also showed high EC (8.42 mS/cm) and high TDS (5260 mg/L), which is consistent with electroplating wastewater chemistry (dissolved salts, metal ions, acids/alkalis, and process additives). Recent electroplating wastewater treatment literature confirms that electroplating wastewater is typically a complex, metal-rich matrix with high conductivity and mixed organic/inorganic contaminants, often requiring physicochemical rather than purely biological treatment.

The observed COD (780 mg/L) and BOD (165 mg/L) indicate a substantial organic load, likely from surfactants, brighteners, and degreasing residues. The BOD/COD ratio (0.21) suggests low biodegradability, supporting the use of physicochemical treatment. Similar parameter sets (pH, EC, TDS, TSS, COD, BOD, oil & grease, and metals) have been reported in Indian electroplating effluent characterization studies.



Table 5.1. Physico-Chemical Characteristics of Electroplating Effluent and Compliance Status (Sample Values)

Parameter	Observed Value	Standard Limit*	Exceedance Factor (EF)	Compliance Status	Interpretation
pH	4.20–5.80	6.0–9.0	—	Non-compliant	Acidic effluent; increases metal mobility and lowers precipitation efficiency
Electrical Conductivity (EC)	8.42 mS/cm	—	—	Not assessed (no process-specific limit applied here)	High ionic/salt load
Total Dissolved Solids (TDS)	5260 mg/L	—	—	Not assessed (contextual parameter)	Strong salinity potential; risk to soil EC
Chemical Oxygen Demand (COD)	780 mg/L	—	—	Not assessed (contextual parameter)	High oxidizable chemical load
Biochemical Oxygen Demand (BOD)	165 mg/L	—	—	Not assessed (contextual parameter)	Biodegradable organic fraction present
BOD/COD Ratio	0.21	—	—	Not a compliance parameter	Low biodegradability; biological treatment alone may be insufficient
Oil & Grease	18.40 mg/L	10 mg/L	1.84×	Non-compliant	Poor skimming/separation; degreasing waste contribution
Total Suspended Solids (TSS)	186 mg/L	100 mg/L	1.86×	Non-compliant	Incomplete settling/clarification; sludge carryover

*Standards used from notified Indian electroplating/anodizing effluent rules (Environment (Protection) Rules amendment).

The sample effluent is non-compliant for pH, oil & grease, and TSS, and shows high salinity (EC/TDS) and mixed organic load (COD/BOD), indicating a chemically complex wastewater stream with strong potential to degrade nearby soils if discharged untreated or partially treated.

5.2 Heavy Metal Profile of Effluent and Compliance Assessment

Heavy metal contamination is the most critical dimension of electroplating effluent assessment because metals are persistent, non-biodegradable, and directly linked to long-term soil contamination through discharge, seepage, and sludge transport. Electroplating wastewater typically contains chromium, nickel, copper, zinc, lead, and cadmium, and this pattern is widely reported in the literature.

In this dataset (sample values inserted for writing), the following concentrations were used:

Total Chromium (Cr): 4.82 mg/L

Hexavalent Chromium [Cr(VI)]: 0.36 mg/L

Nickel (Ni): 7.45 mg/L

Copper (Cu): 3.91 mg/L

Zinc (Zn): 12.60 mg/L

Lead (Pb): 0.82 mg/L

Cadmium (Cd): 0.14 mg/L



These were compared with notified Indian electroplating/anodizing standards, including Total Metal = 10 mg/L, and process-specific values such as Ni = 3 mg/L, Cr(VI) = 0.1 mg/L, Total Cr = 2 mg/L, Cu = 3 mg/L, Zn = 5 mg/L, Pb = 0.1 mg/L, and Cd = 2 mg/L (depending on plating stream category). The standard also explicitly defines “Total Metal” as the combined concentration of Zn + Cu + Ni + Al + Fe + Cr + Cd + Pb + Sn + Ag.

Table 5.2. Heavy Metal Profile and Compliance Assessment of Electroplating Effluent (Sample Values)

Metal / Parameter	Observed Value (mg/L)	Standard Limit (mg/L)*	Exceedance Factor (EF)	Compliance Status	Interpretation
Total Chromium (Cr)	4.82	2.0	2.41×	Non-compliant	Inadequate chromium treatment/precipitation
Hexavalent Chromium [Cr(VI)]	0.36	0.1	3.60×	Non-compliant	Incomplete Cr(VI) reduction to Cr(III) likely
Nickel (Ni)	7.45	3.0	2.48×	Non-compliant	Poor Ni precipitation / pH control
Copper (Cu)	3.91	3.0	1.30×	Non-compliant	Mild exceedance but contributes to cumulative toxicity
Zinc (Zn)	12.60	5.0	2.52×	Non-compliant	Major contributor to total metal load
Lead (Pb)	0.82	0.1	8.20×	Non-compliant	Severe exceedance; high toxicological concern
Cadmium (Cd)	0.14	2.0	0.07×	Within limit	Within process-specific limit, but ecologically relevant
Total Metal (Cr+Ni+Cu+Zn+Pb+Cd)	29.74	10.0	2.97×	Non-compliant	Combined heavy metal burden is nearly 3× the limit

*Process-specific limits apply according to the plating stream; Total Metal is a compulsory parameter. Cr(VI) is not added separately into Total Metal to avoid double counting, because it is part of total chromium.

The sample is non-compliant for Total Cr, Cr(VI), Ni, Cu, Zn, and Pb. Although Cd is within the cited process-specific limit, the combined Total Metal (29.74 mg/L) exceeds the permissible limit by 2.97×, confirming that the effluent is unsuitable for direct discharge. This pattern is consistent with Indian electroplating effluent studies that report elevated heavy metals and mixed pollutant loads.

5.3 Influence on Soil Physico-Chemical Properties

Soils located closer to the effluent drain/discharge channel (S1) are expected to show stronger contamination signatures than intermediate (S2) and far-field/control-like sites (S3). This spatial trend is well established in electroplating-effluent-affected soils. Saraswat et al. (2007) reported a clear **S1–S3 transect pattern** in which total metal content decreased with distance from the effluent course, while physico-chemical properties (pH, EC, organic carbon, available N, etc.) improved away from the contaminated drain.

This is especially relevant in Purba Medinipur, where agriculture is dominant (>80% rural population dependent on agriculture) and flooding is common in river-influenced areas (including the Haldi and Rupnarayan systems), which can aid contaminant spread in soils and drains.



Table 5.3. Soil Physico-Chemical Properties Along Distance Gradient from Effluent Drain (Sample Values)

Parameter	S1 (Near Drain)	S2 (Intermediate)	S3 (Far Field / Control)	Observed Trend (S1→S3)	Interpretation
Soil pH	5.45	6.12	6.78	Increasing	Soil is more acidic near the drain, likely due to acidic effluent influence
Soil EC (dS/m)	2.84	1.63	0.82	Decreasing	Higher salt accumulation near effluent discharge zone
Organic Carbon (%)	0.46	0.62	0.79	Increasing	Lower OC near contaminated site indicates soil stress and reduced organic matter stability
Available N (kg/ha)	182	228	271	Increasing	Nutrient depletion near drain due to disturbed microbial activity and soil quality decline
Available P (kg/ha)	18.4	22.6	28.1	Increasing	Lower P near contamination zone; influenced by pH and metal interactions
Available K (kg/ha)	132	158	189	Increasing	Reduced K near discharge point; likely related to ionic imbalance/salinity stress
Total Cr in soil (mg/kg)	128.4	82.7	39.5	Decreasing	Strong chromium enrichment near effluent source
Total Ni in soil (mg/kg)	74.2	46.8	21.3	Decreasing	Nickel accumulation highest near drain
Total Cu in soil (mg/kg)	66.5	41.2	24.1	Decreasing	Copper shows source-linked metal deposition
Total Zn in soil (mg/kg)	214.6	139.8	72.4	Decreasing	Zinc is a major accumulated metal in near-field soil
Total Pb in soil (mg/kg)	32.8	19.6	8.9	Decreasing	Lead enrichment near drain indicates toxic metal transfer
Total Cd in soil (mg/kg)	1.24	0.71	0.28	Decreasing	Cadmium is lower in concentration but clearly source-linked

The soil data indicate a clear distance-dependent contamination gradient. The near-drain site (S1) shows lower pH, higher EC, lower organic carbon, lower available nutrients, and much higher heavy metal concentrations than S3. This strongly supports source-linked contamination from electroplating effluent discharge and matches the transect-based trends reported by Saraswat et al. (2007).

5.4 Soil Quality Deterioration and Functional Implications

Beyond chemical contamination, electroplating effluent can degrade **soil function** by affecting microbial biomass, respiration, enzyme activity, and nutrient cycling. Saraswat et al. (2007) documented significant inhibition of microbial biomass C and N, respiration, and dehydrogenase activity in heavy-metal-contaminated soils, along with shifts in microbial metabolic indicators.

If biological parameters were not measured in the present study, the following table can be retained as a literature-grounded functional interpretation table linked to the observed metal gradient.



Table 5.4. Soil Functional Deterioration Indicators Under Electroplating Effluent Stress (Interpretive Table)

Indicator	S1 (Near Drain)	S2 (Intermediate)	S3 (Far Field)	Expected Trend (S1→S3)	Functional Implication
Microbial Biomass Carbon (MBC)	Low	Moderate	High	Increasing	Heavy metals suppress microbial biomass near drain
Microbial Biomass Nitrogen (MBN)	Low	Moderate	High	Increasing	Reduced microbial N turnover in contaminated soil
Soil Respiration	Low / disturbed	Moderate	Higher / stable	Increasing	Lower decomposition and carbon cycling near S1
Dehydrogenase Activity	Low	Moderate	High	Increasing	Reduced microbial metabolic activity under metal stress
Cmic/Corg Ratio	Lower	Intermediate	Higher	Increasing	Lower microbial efficiency in polluted soils
Metabolic Quotient (qCO ₂)	Higher	Intermediate	Lower	Decreasing	Indicates stress-driven microbial maintenance cost near S1
Nutrient Transformation Potential	Reduced	Moderate	Better	Increasing	Slower nutrient mineralization in contaminated soils
Overall Soil Fertility Resilience	Weak	Moderate	Stronger	Increasing	Soil recovers function away from contamination source

The heavy metal gradient observed in Table 5.3 is expected to translate into a functional gradient in soil biological health. Soils closer to the effluent drain typically show suppressed microbial and enzymatic activity, reduced nutrient turnover, and lower resilience. This is consistent with published evidence from electroplating/brass effluent-affected soils.

5.5 Treatment and Management Implications for Haldia

The combined results from effluent quality and soil response indicate that electroplating wastewater management in Haldia should be process-specific, compliance-driven, and soil-protective. The Indian notified standards clearly define both compulsory and process-specific parameters for electroplating/anodizing units, and the results here indicate the need for stronger implementation at unit level.

Recent treatment studies on real electroplating wastewater show that integrated physicochemical treatment — especially coagulation + activated carbon filtration — can significantly improve removal of Cr, Ni, Zn, and Cu, often achieving high overall removal efficiencies (above 90% in hybrid systems). This is directly relevant for the Haldia context, where high metal loads and low biodegradability were observed in the profile.

Table 5.5. Treatment and Management Action Plan for Haldia Electroplating Units

Action Point	Why It Is Needed (Based on Findings)	Recommended Practice	Expected Outcome
1. Strict compliance monitoring	pH, O&G, TSS, and multiple metals exceed standards; Total Metal non-compliant	Routine monitoring of pH, TSS, O&G, Total Metal, and process-specific metals (Ni, Cr, Cu, Zn, Pb, Cd)	Early detection of non-compliance; improved enforcement



2. Segregation of chromium-bearing and non-chromium streams	Cr and Cr(VI) exceedance indicates chromium-line treatment weakness	Separate Cr-bearing rinse/drag-out streams before common treatment	Better Cr(VI) reduction and more efficient treatment chemistry
3. Physicochemical treatment optimization	High metals + low biodegradability make biological treatment insufficient	Equalization → Cr(VI) reduction → pH adjustment → precipitation/coagulation → settling → polishing (adsorption/filtration)	Higher metal removal and improved compliance reliability
4. Sludge handling and safe disposal	High Zn/Cr/Ni/Pb loads imply hazardous sludge generation	Sludge dewatering, secure storage, authorized disposal/recovery	Prevents secondary contamination of soil and drains
5. Routine soil monitoring (S1–S3 transect)	Soil contamination gradient indicates ongoing transfer from drain to land	Periodic soil testing for pH, EC, OC, NPK, and metals	Tracks long-term degradation and recovery trends
6. Controlled reuse protocol (if reuse is practiced)	Clear-looking effluent may still contain salts/metals	Reuse only after periodic salinity and metal checks	Reduces hidden soil and crop contamination risks
7. Stormwater–effluent separation	Mixed drainage increases pollutant spread	Maintain separate stormwater and industrial wastewater channels	Reduces off-site transport during rainfall/flood events

The treatment strategy for Haldia should move beyond basic neutralization and focus on stream segregation, precipitation chemistry control, and polishing treatment, supported by regular compliance and soil monitoring. This approach aligns with both the Indian electroplating standards and recent electroplating wastewater treatment evidence.

The Results and Discussion collectively show a coherent pollution pattern: the electroplating effluent (sample values used here for ing) is chemically stressed and non-compliant, with strong heavy metal exceedance and a high combined metal burden. The corresponding soil profile shows a clear distance-based contamination gradient (worse near the drain, better farther away), which is consistent with published transect-based findings from electroplating/brass effluent-affected soils. In an agriculturally dominant and flood-prone district such as Purba Medinipur, unmanaged or partially treated electroplating effluent can create a direct pathway from industrial discharge to soil degradation and possible crop exposure risk.

VI. CONCLUSION

This study framework demonstrates that assessment of electroplating effluent quality and associated soil impacts is highly relevant for the Haldia industrial region due to its riverine setting, industrial concentration, and proximity to agricultural landscapes. Haldia’s planning area characteristics (industrial development, river-bound geography, low-lying terrain, and alluvial soils) increase the importance of localized wastewater-soil monitoring.

Electroplating effluents are expected to contain significant concentrations of heavy metals and dissolved contaminants, and must be evaluated against the specific Indian discharge standards notified for electroplating/anodizing industries under the Environment (Protection) Rules, 1986. Literature strongly indicates that persistent exposure of soils to electroplating wastewater can alter pH, EC, nutrient status, and microbial activity, with the most severe effects near discharge channels.

For Haldia, a robust environmental management strategy should combine:

- source segregation,
- improved effluent treatment,
- compliance auditing,
- and periodic soil quality surveillance.



This Research article can be finalized into a full publishable paper by inserting your actual lab values into the Results section and adding statistical outputs (ANOVA/correlation/regression) from your dataset.

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