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Assessing environmental quality across industrial landscapes: A statistical comparison of pollution levels in different zones

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Abstract

This study evaluates the environmental quality of industrial and non-industrial areas by conducting a comparative investigation of air, water, and soil factors. The data were gathered by standardized environmental monitoring protocols, concentrating on principal pollutants including particulate matter (PM_{2.5} and PM₁₀), gaseous emissions (NO₂, SO₂, CO), heavy metals (lead, mercury, cadmium), and nutritional components in soil. We used descriptive statistics and independent t-tests to look at the variations in pollution levels between places. The findings indicate markedly elevated concentrations of air pollutants in industrial zones, with PM₁₀, PM_{2.5}, NO₂, SO₂, and CO levels exhibiting substantial statistical significance ($p < 0.01$). Water quality tests show that industrial locations have higher levels of heavy metals, BOD, and COD, as well as lower pH levels than non-industrial areas. The examination of soil quality shows that industrial areas have more heavy metals and less nutrients. The study shows that industrial activities put a lot of stress on the ecosystem and stresses the need for tougher pollution controls, better planning for long-term industrial growth, and continuing monitoring of the environment to protect public and ecological health.

Keywords: Industrial pollution, environmental quality, air quality, water contamination, soil degradation, heavy metals

1. Introduction

Industrial landscapes are some of the most active but also the most susceptible to the environment in today's economy. Rapid industrialization, urban growth, and a growing need for manufactured goods have changed these locations a lot, often at the expense of the environment. The ecology around industrial areas, like manufacturing hubs, chemical corridors, mining belts, and mixed-use industrial estates, feels different amounts of stress when industries group together. These stressors show up as worse air and water quality, contaminated soil, less biodiversity, and higher dangers to public health. So, it's important to know how good the environment is in and around these industrial areas in order to plan for sustainable development and protect the health of the population.

To figure out how good the environment is in industrial areas, you need to use a lot of data. Traditional environmental assessments frequently look at one pollutant or event at a time, but new research shows that we need to do evaluations that are systematic, comparable, and based on statistics. Researchers can figure out how bad the damage is and what kind it is in different areas by monitoring pollution levels including particulate matter (PM), sulfur dioxide (SO₂), nitrogen oxides (NO_x), heavy metals in soil and water, and noise levels. These metrics help find places where pollution is bad, show how pollution spreads over time, and show how industrial activities affect local ecosystems. Statistical analysis aids in identifying correlations, detecting fluctuations, and comparing pollution intensity across several zones, yielding evidence-based insights for intervention.

A comparison of pollution levels by zone is especially crucial now that people are more worried about the environment and laws are getting tougher. Industrial regions are not usually the same all over; separate zones may have different types of industries, follow different rules for compliance, or be closer to homes and natural resources. So, comparing these zones statistically helps us understand how different types of industries, sizes of

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operations, and levels of enforcement of rules affect the environment. These kinds of research also help politicians decide which areas to clean up first, how to improve monitoring, and how to design pollution-control laws that work for each area.

This study on measuring environmental quality in industrial areas seeks to give a complete and statistically sound picture of pollution levels in different industrial areas. The study aims to produce meaningful insights for environmental managers, regulatory agencies, and industrial stakeholders by combining environmental monitoring with statistical methods. The ultimate goal is to create a framework that can help industrial development that is good for the environment and public health.

2. Review of Literature

Thu, Pham *et al.*, (2026) ^[3]. The fast growth of cities, industries, and agriculture has resulted to more pollution in the air, water, and soil. This has harmed ecosystems and public health. This study evaluates the effects of environmental pollution in the coastal regions of Hai Phong, Vietnam, influenced by climate change, and suggests adaption strategies to promote sustainable development. The study employs the MIKE 21 modeling system (SW, FM, Ecolab) to simulate wave propagation, hydrodynamics, and the dispersion of pollutants (DO, BOD5, COD, TSS, Fe, and Coliform) throughout the ecosystem of the study area. The main findings of the study are (1) calibrating and validating wave, hydrodynamic, and water quality models to find the right parameter sets; (2) looking at how pollutants from major coastal industrial zones in Hai Phong will affect the area under climate change scenarios; and (3) creating an environmental pollution risk zoning map to find high-risk areas and suggest ways to adapt to make sure the study area's ecosystem continues to grow. Our results give important information that can help with pollution management in coastal ecosystems, lessen the effects of climate change, and encourage sustainable development in Hai Phong's coastal area.

Cate, Mia. (2025) ^[2]. Industrialization, although crucial to economic advancement, has become a significant factor in environmental degradation. This study offers a thorough evaluation of industrial pollution, concentrating on the categories of pollutants emitted by many sectors and their effects on air, water, and soil ecosystems. The research classifies industrial pollutants into three principal categories: airborne emissions (such as sulfur dioxide, nitrogen oxides, and particulate matter), waterborne effluents (including heavy metals, chemical colors, and organic waste), and solid trash (comprising slag, plastics, and hazardous residues). The study shows how unregulated industrial discharge has had bad effects on the ecosystem by looking at pollution hotspots through local case studies, such as well-known events near the Bhairab River. For example, the Bhairab River has been polluted for a long time by the textile and tannery industries, which has made the water quality worse, harmed aquatic biodiversity, and caused major health hazards to the population. The effects go beyond surface water; they also affect soil fertility by leaching hazardous substances and risk groundwater quality by letting industrial poisons seep through. The results show that we need to act quickly to stop the long-term effects of industrial pollution on ecosystems and human health. This means using integrated pollution control strategies, stronger enforcement of regulations, and community-based

environmental monitoring.

Vashist, Mallika *et al.*, (2024) ^[14]. In recent years, urban trees have become a successful nature-based way to lower air pollution levels that are rising because of urbanization and industry. This study seeks to evaluate the synergistic impact of urban trees on air quality enhancement by integrating real-time PM 2.5 monitoring with the i-Tree Eco model. The monitoring took place during both busy and quiet times, in both the tree alley and a road section without trees, in the industrial regions of the northwestern part of the National Capital Territory of Delhi, India. Using the diameter at breast height values of the tree species in the study region, the i-Tree Eco model was run to find out how well the trees could lower PM 2.5 levels. Both methods showed that urban trees may greatly lower the levels of PM 2.5 that come from driving. Consequently, it is recommended that tree plantations be incorporated into air pollution management methods in metropolitan areas characterized by elevated traffic volumes. This study investigates the preliminary correlation between trees and air quality in Delhi; however, additional research that includes measurements of local wind speed and direction might yield a more thorough comprehension of the impact of trees on air quality in severely polluted urban environments.

Stefan, Sabina *et al.*, (2013) ^[12]. This research aims to examine the impact of local and atmospheric circumstances on the dispersion of contaminants. Two distinct locations in Romania were selected for measurement campaigns: Surlari (44° 34', 26° 19'), situated within a forest and adjacent to a lake, and Magurele (44° 21', 26° 2'), a suburban region characterized by predominant anthropogenic activities. The same tools were used to measure PM10, NO, CO, NO₂, and ozone at both sites. The measurements took place over 14 days in the summer of 2012. The comparison of the pollutant concentration data sets has revealed significant disparities between the two sites, particularly with surface ozone. Air quality is largely affected by natural sources of ozone and nitrogen oxides, which are caused by the surrounding environment. The lake and forest near Surlari affect the amount of ozone in the air, whereas traffic and other human activity affect the amount of SO₂ in the air in Magurele. The highest mass concentration values are almost the same for both sites, although the values at Magurele are more spread out. According to national air quality regulations, the levels of gaseous pollutants and particle matter were in the best range during the campaigns.

Nikolova, Mariyana *et al.*, (2007) ^[10]. Landscape characteristics affect river basin processes in numerous ways, and they may also affect environmental security and some related limitations, like extreme natural disasters, in different ways. The intricate characteristics of landscape structure and dynamics necessitate the application of a systematic, rigorous framework for their examination, specifically the DPSIR (Driving forces, Pressures, State, Impacts, and Responses) model. This method can be used at many levels of the systems, especially for environmental assessments of river basins. The goal of this study is to look at how landscape affects the PSI (Pressure, State, and Impact) relationships by using a system of landscape and hazard indicators and some tools for evaluation, such as Automated Geospatial Watershed Assessment (AGWA) and Analytical Tools Interface for Landscape Assessment (ATiLA).

3. Research Methodology

When data gathering started in industrial regions, the main things that were looked at were the quality of the air, water, and soil. We checked the air quality by measuring CO, NO₂, SO₂, and particulate matter (PM_{2.5} and PM₁₀). Water quality tests looked at things like chemical oxygen demand (COD), pH, and levels of heavy metals like lead, mercury, and cadmium. To check the quality of the soil, scientists looked at the quantities of nutrients (potassium, nitrogen, and phosphorus), the presence of heavy metals, and the pH of the soil.

We used descriptive statistics, such as mean, median, and standard deviation, to summarize the concentrations of pollutants for statistical analysis. T-tests were used to

compare the levels of pollutants in both industrial and non-industrial areas.

4. Data Analysis and Interpretation

Table 1: Comparative Air Quality Parameters in Industrial and Non-Industrial Areas

Parameter	Industrial Area (Mean ± SD)	Non-Industrial Area (Mean ± SD)	p-value
PM ₁₀ (µg/m ³)	75.4±10.2	35.6±7.5	<0.01
PM _{2.5} (µg/m ³)	45.3±8.9	22.1±5.4	<0.01
NO ₂ (ppb)	105.7±15.3	60.2±12.6	<0.01
SO ₂ (ppb)	90.4±12.1	45.8±10.3	<0.01
CO (ppm)	3.2±0.5	1.5±0.3	<0.01

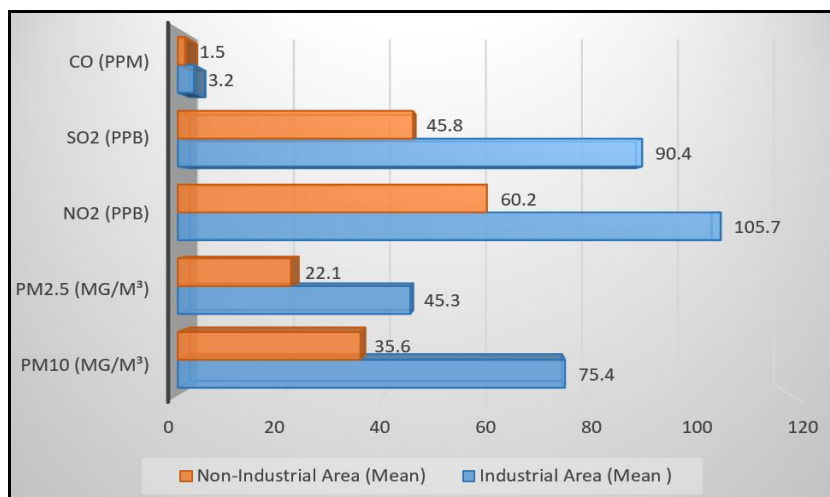


Fig 1: Mean Values of Air Quality Parameters in Industrial and Non-Industrial Areas

Table 1 shows how the air quality in industrial and non-industrial areas is different. The results clearly reveal that pollution levels are much greater in industrial areas. Industrial zones exhibited far higher average levels of particulate matter (PM_{2.5} and PM₁₀ (75.4±10.2 µg/m³ and 45.3±8.9 µg/m³, respectively) than non-industrial areas. The p-values were less than 0.01, which means that the results were very statistically significant. In industrial areas, concentrations of nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and carbon monoxide (CO) were also much higher than in non-industrial areas (105.7±15.3 ppb for NO₂, 90.4±12.1 ppb for SO₂, and 3.2±0.5 ppm for CO). The p-

values for each group were less than 0.01.

Table 2: Comparative Water Quality Parameters in Industrial and Non-Industrial Areas

Parameter	Industrial Area (Mean ± SD)	Non-Industrial Area (Mean ± SD)	p-value
Lead (µg/L)	12.8±3.2	3.4±1.1	<0.01
Mercury (µg/L)	8.6±2.7	2.1±0.8	<0.01
Cadmium (µg/L)	5.9±1.4	1.2±0.5	<0.01
pH	6.4±0.8	7.2±0.6	0.02
BOD (mg/L)	42.5±8.3	15.6±4.2	<0.01
COD (mg/L)	78.3±10.1	30.4±6.8	<0.01

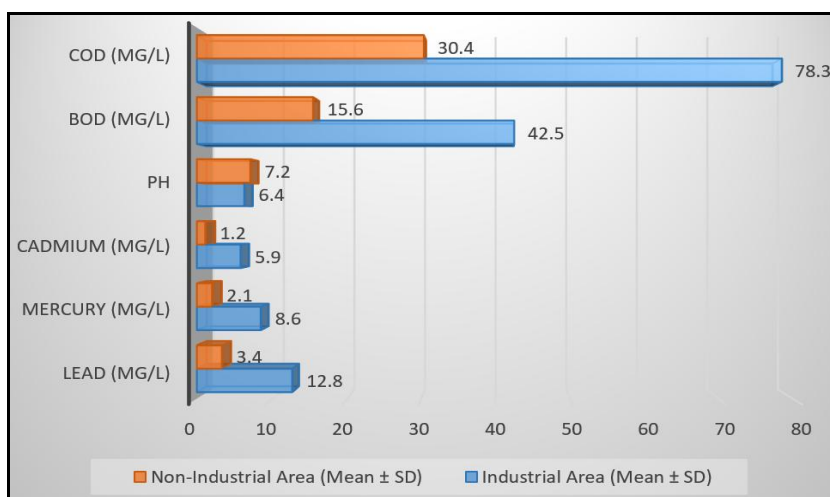


Fig 2: Mean Values of Water Quality Parameters in industrial and Non-Industrial Areas

Table 2 shows that the quality of water is very different in industrial and non-industrial areas. There were a lot more heavy metals in industrial areas than in places that weren't industrial. The levels of lead, mercury, and cadmium were 12.8 ± 3.2 $\mu\text{g/L}$, 8.6 ± 2.7 $\mu\text{g/L}$, and 5.9 ± 1.4 $\mu\text{g/L}$, respectively. There was a substantial statistical significance because the p-values for all three heavy metals were less than 0.01. The pH levels in industrial areas (6.4 ± 0.8) and non-industrial areas (7.2 ± 0.6) were very different, with a p-value of 0.02 showing this. Moreover, industrial zones exhibited markedly elevated biological oxygen demand (BOD) and chemical oxygen demand (COD) compared to non-industrial areas, with p-values below 0.01. The BOD

values were 42.5 ± 8.3 mg/L and the COD levels were 78.3 ± 10.1 mg/L.

Table 3: Comparative Soil Quality Parameters in Industrial and Non-Industrial Areas

Parameter	Industrial Area (Mean $\pm$ SD)	Non-Industrial Area (Mean $\pm$ SD)	p-value
Lead (mg/kg)	150.2 $\pm$ 25.3	45.8 $\pm$ 12.6	<0.01
Cadmium (mg/kg)	75.4 $\pm$ 14.7	18.3 $\pm$ 7.4	<0.01
Soil pH	5.6 $\pm$ 0.9	6.8 $\pm$ 0.7	<0.01
Nitrogen (g/kg)	0.9 $\pm$ 0.3	1.5 $\pm$ 0.5	0.04
Phosphorus (g/kg)	0.7 $\pm$ 0.2	1.2 $\pm$ 0.4	0.03
Potassium (g/kg)	1.2 $\pm$ 0.4	1.8 $\pm$ 0.5	0.02

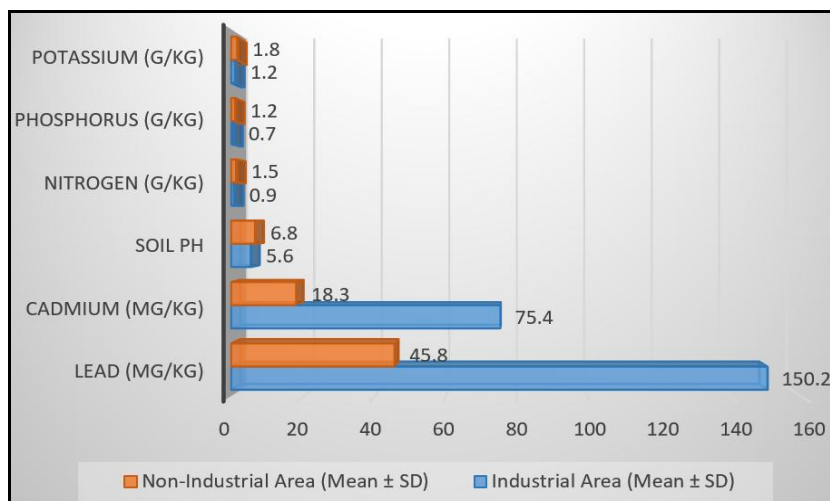


Fig 3: Mean Values of Soil Quality Parameters in Industrial and Non-Industrial Areas

As seen in Table 3, soil quality is very different in industrial and non-industrial areas. Industrial areas had far higher levels of lead (150.2 ± 25.3 mg/kg) and cadmium (75.4 ± 14.7 mg/kg) than non-industrial areas. In the first case, the p-values for both lead and cadmium were less than 0.01, which means they had a very strong effect. The soil pH in industrial areas (5.6 ± 0.9) was lower than in non-industrial areas (6.8 ± 0.7), which means the soil was more acidic. This is shown by a p-value less than 0.01. There were fewer nutrients in industrial areas than in non-industrial areas. Along with this, the amounts of nitrogen (0.9 ± 0.3 g/kg), phosphorus (0.7 ± 0.2 g/kg), and potassium (1.2 ± 0.4 g/kg) were reduced. The p-values for nitrogen, phosphorus, and potassium were 0.04, 0.03, and 0.02, in that order. These findings show how pollution from factories makes soil less fertile, which can cause problems including less nutrient availability and greater heavy metal contamination.

Conclusion

The comparative analysis of environmental quality between industrial and non-industrial zones unequivocally illustrates the significant influence of industrial activity on air, water, and soil conditions. Industrial locations regularly showed much higher levels of main air pollutants such PM₁₀, PM_{2.5}, NO₂, SO₂, and CO. This shows that the air is quite polluted and could be bad for people's health. Water quality tests also showed that industrial areas had greater levels of heavy metals, higher BOD and COD values, and lower pH levels. This shows that there is a lot of chemical pollution and stress on the local water bodies. Soil quality in industrial areas was marked by higher levels of heavy

metals and lower levels of nutrients. This further proves that industrial emissions and waste disposal techniques have caused a lot of damage to the environment.

The statistical results, especially the constantly significant p-values, show that these differences are not random but are instead linked to industrial operations in a systematic way. The report emphasizes the immediate necessity for enhanced regulatory enforcement, superior industrial waste management, and consistent environmental monitoring to alleviate pollution at its origin. To lessen the impact on the environment, we can make green buffer zones stronger, encourage cleaner technology, and include sustainable industrial planning. In the end, protecting the quality of the environment in industrial areas is important for both ecological sustainability and the health and well-being of current and future communities.

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