RESEARCH PAPER

Physiochemical Analysis Of The Industrial Effluents In Aligarh's Water And Their Impact On Human Health, Agriculture And Its Mitigation Strategies.

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ABSTRACT

Background: Industrial effluents largely affect the quality of water, productivity in agriculture and human health. Such chemicals and heavy metals as lead, cadmium, and chromium with harmful potential could contaminate water and soil leading to ecological and public risks. The paper analyzes an impact of industrial discharge on the physio-chemical characteristics of water in towns.

Objective: The study aims to investigate how industrial effluents affect water quality and determine the subsequent impacts on human health and agricultural productivity. The focus is on analyzing key water quality parameters in urban areas affected by industrial discharge.

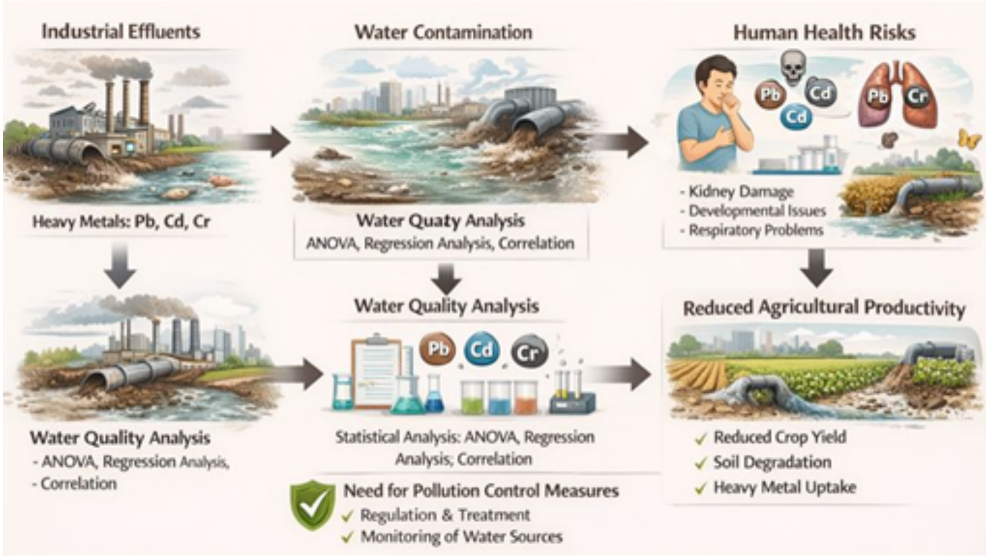
Methodology: There are six urban areas identified for a detailed analysis of the water quality based on industrial discharges in a specified time frame. The chemical and physical techniques analyzed the important features of the water, namely temperature, pH, turbidity, DO, BOD, and the heavy metals levels of lead, cadmium, and chromium. Statistical techniques for one-way ANOVA, descriptive analysis, and Pearson's correlation technique were used for spatial and temporal variations. Regression analysis was used to assess the effect of heavy metals on water quality.

Key Findings: The study found significant relationships between important environmental parameters, including temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and waterborne heavy metals, were discovered by the study. In particular, there were notable associations between changes in water quality indices and the levels of lead, cadmium, and chromium. According to regression analysis, 22.9% of the difference in water quality was explained by the chromium concentration. The study also showed how industrial effluents, especially through contaminating soil and irrigation water sources, had a negative effect on human health, water quality, and agricultural output.

Conclusion: The study emphasizes that exposure to heavy metals from industrial effluents poses serious health concerns and deteriorates water quality. By damaging irrigation water sources and soil, the pollution also has a detrimental effect on agriculture. To reduce the risks associated with industrial water contamination, effective pollution control plans and laws are necessary..

Keywords: Industrial effluents, Water pollution, Human health, Agriculture, Mitigation strategies..

Graphical Abstract:



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INTRODUCTION

The rapid industrialization and urban growth has caused the release of industrial effluents into the urban waters to rise remarkably hence causing a great decline in water quality. Toxic chemicals, heavy metals, organic pollutants and suspended solids found in the industrial wastewater transform the physio-chemical properties of the surface and ground water and render water unusable in domestic, agricultural and industrial applications. The density of industries around residential areas in urban locations enhances the exposure of the people to polluted water, hence exposing them to water-borne illnesses and chronic health conditions. The use of polluted water in irrigation also influences the productivity of agricultural activities through the deterioration of the soil quality, low crop yield, as well as enhancing the concentration of toxic substances within the food chain. These negative effects underscore the co-relationship between the effects of industrial effluents on the water quality, human health and agriculture. Thus, the evaluation of physico-chemical alterations of urban water resources and elaboration of efficient mitigation strategies are needed to curb the water pollution, protect the human health and guarantee sustainable urban and agricultural development.

Industrial Effluents as a Major Source of Urban Water Pollution

Industrial effluents are among the biggest contamination of water in the urban setting owing to the fast industrialization process and poor wastewater management systems. These wastes are generated by various industrial processes, including chemical manufacturing, textile processing, mining, food processing, and metal finishing and they are released without adequate treatment into the surrounding rivers, lakes, or ground water systems. The type of industrial wastewater can be a complicated combination of toxic substances, such as heavy metals, synthetic chemicals, oils, dyes, and organic contaminants, which remain in the waters and increase with time. The closeness of the industrial zones to the residential settlements adds to the danger of drinking water sources contamination in densely populated urban areas. Therefore, unregulated release of industrial effluents greatly affects the quality of urban water resources causing severe environmental, economic, and health hazards.

Physico-Chemical Degradation of Urban Water Resources

The release of industrial effluents causes massive changes in the physico-chemical Characteristics of urban waters. Some of the parameters that are usually affected include pH, temperature, turbidity, electrical conductivity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total dissolved solids and the concentration of heavy metals. High concentrations of toxic metals such as lead, cadmium, chromium and mercury destroy the aquatic ecological systems and diminish self-purification ability of water bodies. Alterations in these physico-chemical properties negatively affect the quality of water rendering it unfit to be used in drinking, irrigation, and industries. Repeated pollution also has its effects on the quality of ground waters by leaching and infiltration thus increasing the spatial scope of the pollution. These types of water resource degradation compromise the stability of the ecosystem, and put the sustainability of the urban water environment under threat in the long term.

Significance of Water Quality for Human Health and Urban Agriculture

The quality of water is a very important factor in protecting human health and also keeping the agricultural activities going in urban and peri-urban areas. When people drink polluted water, the populations will be exposed to a very broad spectrum of health risks, such as gastrointestinal infections, neurological diseases, kidney damage, and long-term carcinogenic outcomes, because of the existence of toxic chemicals. Typhoid, dysentery, and cholera are some of the waterborne diseases that are prone to be caused by contaminated city water, and especially in regions where there are poor sanitation facilities. In the agricultural sector, irrigation with contaminated water results into poor crop yields, soil erosion, and concentration of heavy metals in the edible sections of the plants. This does not only influence the quality of crops and yield but also enables the use of pollutants into the food chain where indirect health hazards to the consumers are posed. Thus, it is critical that the water quality be preserved to ensure the protection of the population, food security, and sustainable urban agriculture.

Need for Pollution Control and Mitigation Strategies in Urban Water Systems

The level of urban water pollution has been on the rise and this requires the adoption of effective pollution control and mitigation measures to conserve the water resources. The emission of standards of industrial effluent discharge, the use of modern wastewater treatment methods, and incessant check of the water quality are also crucial features of sustainable water management. Introduction of effluent treatment facilities, adoption of cleaner production methods, use, and reuse of treated waste water can go a long way in decreasing the volume of contaminants that find their way into the urban water systems. Moreover, combined urban water management strategies that incorporate government agencies, industry and local communities are also very important in order to deal with the pollution in its origin. Different policy interventions, as well as public awareness and technological advancements, are important in curbing the negative effects of industrial effluents, safe water supply, and sustainable urban development.

Research objectives

The primary objectives are the Following:

To evaluate the effects of industrial effluents on the physio-chemical characteristics of water in various metropolitan areas, with an emphasis on concentrations of heavy metals (lead, cadmium, and chromium), temperature, turbidity, pH, dissolved oxygen (DO), and biochemical oxygen demand (BOD).

To examine how environmental factors relate to one another and how important they are for comprehending the temporal and spatial fluctuations in water quality, with an emphasis on the relationships between major pollutants and their effects on the environment.

To assess how industrial effluents affect water quality and agricultural outcomes, taking into account the impact of contaminants such as nutrients and heavy metals on ecosystems and public health.

To suggest ways to mitigate water pollution based on the results of the study, with a focus on lessening the influence of industrial effluents on health outcomes and water quality.

Research Hypothesis

Hypothesis 1 (H_1)

$H1_1$: Physio-chemical parameters (temperature, turbidity, DO, BOD, nitrate, phosphate, lead, cadmium, and chromium) in water contaminated by industrial effluents have a statistically significant positive association with one another.

$H0_1$: There is no statistically significant positive association among physio-chemical parameters (temperature, turbidity, DO, BOD, nitrate, phosphate, lead, cadmium, and chromium) in water contaminated by industrial effluents.

Hypothesis 2 (H_2)

$H1_2$: The pH level of water exhibits a weaker and less dependable correlation with other physio-chemical parameters than variables such as temperature, turbidity, and heavy metals (lead, cadmium, chromium).

$H0_2$: The pH level of water does not exhibit a weaker or less dependable correlation with other physio-chemical parameters compared to variables such as temperature, turbidity, and heavy metals (lead, cadmium, chromium).

Hypothesis 3 (H_3)

$H1_3$: The regression model and ANOVA findings show that the variability in site group classification is not significantly predicted by the concentration of chromium in the water.

$H0_3$: The concentration of chromium in the water significantly predicts the variability in site group classification, as indicated by the regression model and ANOVA findings.

Hypothesis 4 (H_4)

$H1_4$: Numerous water quality metrics are consistently impacted by industrial effluents, which results in strong relationships between the majority of the water's physio-chemical properties.

$H0_4$: Industrial effluents do not have a consistent impact on numerous water quality metrics, and there are no strong relationships between the majority of the water's physio-chemical properties.

LITERATURE REVIEW

Industrial effluents drastically change the physio-chemical properties of water, resulting in deviations that pose risks to both humans and the environment (Roy, 2019). Research studies on electrocoagulation and photocatalysis for water treatment have demonstrated good results but have operational issues due to high energy demand and inefficiency (Salam, 2024). Researchers insist that more stringent regulatory actions and innovative solutions must be addressed to mitigate water pollution through industrial discharges (Samal, 2022). The adverse effects on ecosystems and public health necessitate the need for comprehensive efforts that combine advanced treatment methods with sustainable practices.

Overview of existing research on industrial effluents and water pollution

Shahedi et al. (2020) demonstrated that a range of methods have been applied to wastewater treatment in order to reduce the amount of pollutants that are present in the environment after different companies have discharged it. In electrocoagulation, which is an electrochemical process, coagulant species are generated in situ by electrodissolving sacrificial anodes, typically made of iron or aluminum. This process used an electric current to destabilize contaminants that are dissolved, suspended, or emulsified. It has promised for both organic and inorganic pollutant removal in different types of wastewaters. Various factors that affect the efficiency of the EC process include pH, electrode composition, operating time, and current density. This study was aimed at reviewing the most relevant current literature on the subject. The two main drawbacks with the EC method are energy consumption and electrode passivation. However, EC has some advantages such as less energy consumption and lower running cost when compared to other techniques (Shahedi, 2020).

Behera et al., (2021) offered an outline of traditional and novel techniques for debasing and eliminating colors and different contaminants from material waste effluents. The material business causes the most pollution and contributes the most to economic development. Squander effluent treatment strategies traditionally need a great deal of energy, time, foundation, materials, land, personnel, and capital. It additionally proposes an imaginative, reasonable, and eco-friendly state of the art innovation. Both homogeneous and heterogeneous photocatalysis can be sustainable technologies, while heterogeneous photocatalysis corrupts natural pollutants better. Established researchers actually deal with issues like long degradation times and low removal efficiency while creating treatment techniques. Half and half cycles that incorporate a pre-clarification phase of flocculation and waste effluent degradation through an integrated adsorbent-upheld photocatalyst and a film integrated impetus recovery framework are liked for sustainable treatment of fluid industrial waste effluents (Behera, 2021).

Discussion of physio-chemical properties of water affected by industrial effluents

Meshabaz and Umer (2022) evaluated the quality of Kwashe industrial effluents from Kurdistan, Iraq, and their potential consequences for soil quality. Industrial effluents from petroleum processing plants, plastics, paper and printing, steel, aluminum, calfskin tanning, paint, food, cleanser, manure, construction, nylons, metal lines, chemicals, black-top, and oil based goods were examined at three locations. The physicochemical properties of these examples were analyzed. A few soil characteristics were researched utilizing field tests. The outcomes showed that most industrial effluent physicochemical properties surpassed worldwide necessities. As effluents coursed through two regional fields, their quality corrupted. Because of petrol hydrocarbon deposition, effluents left soil natural matter multiple times higher than ordinary. Industrial effluents changed soil macronutrients. Some soil measurements showed critical associations, with R^2 values demonstrating high importance ($P < 0.01$) (Meshabaz, 2022).

Okuku, F. (2023) analyzed in Namayingo Area, Bukana Sub-Province in eastern Uganda, which borders Kenya to the east and southeast and Tanzania to the south, water physiochemical boundaries. Environmental responsiveness and thorough standards have further developed water quality. Each living thing needs water, one of Earth's most indispensable resources. Other than drinking and cleaning, it's fundamental for endurance. Ph, DO, Body, and conductivity were estimated utilizing pH meters, Winkler techniques, and conductivity meters. A few water tests were taken at Atega Landing, Buduma, and Namavundu Fishing Destinations. The locations showed little contrasts in pH (8.5-9.1), DO (6.0-6.8), Body (5.6-6.0), and conductivity (1110-1370 µS/cm). Digressing from WHO recommended restrictions of 50-100 µS/cm for ground, surface, and drinking water, and a Body esteem under 5, happened. Its physiochemical boundaries contrast enormously from WHO standards, recommending Lake Victoria in Namayingo Area water is perilous for human consumption (Okuku, 2023).

Examination of human health and agricultural impacts of water pollution

Adimalla and Qian (2019) analyzed that the Water Quality Record was used to evaluate Nanganur's drinking water quality. In Nanganur, South India, an agricultural region where local people drink only groundwater, nitrate contamination in groundwater was examined and health perils for babies, youngsters, and grown-ups were assessed. Reasonably hard and marginally antacid groundwater was noticed. The groundwater nitrate concentration went from 25 to 198 mg/L, with a mean of 66.14 mg/L, and 61% of tests surpassed the WHO safe rule of 50 mg/L. WQI values differed from 92 to 295, with a normal of 153, recommending that 86% of groundwater tests were unsuitable for drinking. The non-cancer-causing health risk for grown-ups was 6.0E-01 to 4.8E+00, for kids 8.1E-01 to 6.4E+00, and for infants 9.4E-01 to 7.4E+00. Babies were 1.15 and 1.75 times more at risk from unnecessary groundwater nitrate contamination than kids and grown-ups in the review region. Nitrate contributed to non-cancer-causing health risks in babies, kids, and grown-ups. Hence, the region ought to restrict nitrate-contaminated drinking water exposure to diminish health concerns (Shahedi, 2020).

Chowdhary et al., (2020) developed efficiency and efficiency, science has advanced, and life has changed enormously. Water pollution and deficiencies are caused by industrial effluent, home sewage, storm water runoff, septic tanks, and agricultural practices. Enterprises discharge toxic chemicals, natural and inorganic matter, slop, radioactive slime, sulfur, asbestos, poisonous solvents, polychlorinated biphenyl, lead, mercury, nitrates, phosphates, acids, alkalies, colors, pesticides, benzene, chlorobenzene, carbon tetrachloride, toluene, and unstable natural chemicals. These squanders are unsafe to humans and different organic entities when delivered into the water ecosystem without appropriate treatment. Industrial wastewater caused iron deficiency, low blood platelets, migraines, disease, skin issues, and so forth. Powerful treatment innovation, adequate treatment, water reuse, desalination, foundation fix and upkeep, water conservation, and strong pollution control regulations and legislation and their proficient execution assist with deflecting such situations (Chowdhary, 2020).

Research Gap

Despite the large amount of work done on the effects of industrial effluents on water quality, particularly physicochemical properties, the literature shows a gap in studies that focus on urban areas, especially on the temporal and spatial variations in water quality and their impact on human health and agriculture. The existing literature mainly deals with particular pollutants such as heavy metals, but does not present an integrated analysis of a wide range of physicochemical parameters (temperature, turbidity, pH, dissolved oxygen, biochemical oxygen demand) over metropolitan regions. Moreover, whereas several studies have dealt with wastewater treatment techniques, little work is done to investigate the effectiveness of these techniques in multifaceted urban wastewater contamination. Industrial effluents impacts on agricultural productivity in urban areas remain under-explored with a lack of focus on soil fertility, crop health, and interplay between seasonal changes, pollution loads, and mitigation strategies. Furthermore, the particular impacts of effluents in urban environments, where human exposure and environmental sensitivity are more sensitive, have not been widely investigated, and the synergistic effects of heavy metals, nutrients, and other pollutants on water quality and public health remain inadequately explored. Lastly, although treatment methods such as electrocoagulation and photocatalysis have been studied, there is insufficient focus on context-specific, cost-effective, and scalable mitigation strategies for urban areas. This research aims to fill gaps in this area by critically assessing the impact of industrial effluents on the quality of water, health, and agriculture in the urban environment and proposing appropriate targeted mitigation strategies to control pollution and improve water quality.

METHODOLOGY

A purposive sampling technique was adopted to choose six representative sites of the analyzed environmental conditions. Water samples were collected systematically, and major physio-chemical as well as heavy metal parameters were measured using standardized procedures with calibrated instruments. Data analysis involved descriptive statistics for summarizing trends, Pearson correlation to assess the relationship among the variables, and one-way ANOVA to check the differences both in space and time. This used the software SPSS in its analysis, and results are given through tables and graphs for easy clarity and understanding.

Description of study area and sampling locations

The study was carried out at six carefully chosen sites that were thought to be typical of the environmental circumstances being studied. To make sure these sites matched the goals of the study, a purposive sampling technique was used to identify them. Every site was picked because it was pertinent to the changes in environmental features, allowing for a detailed analysis of regional variances in elements like pollution levels and water quality. Because measurements and observations were made regularly throughout various locations, the data gathered was reliable and comparable.

Explanation of water sampling and analysis procedures

Water samples were collected in a methodical manner over a predefined period of time to guarantee representativeness and thorough coverage. The following important environmental factors were measured:

Physical Parameters: Turbidity and temperature are used to evaluate the ecological and water purity conditions.

Chemical Parameters: Water quality and ecological balance are assessed using pH levels, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and nutrient concentrations (phosphate and nitrate).

Heavy Metal Contaminants: lead, cadmium, and chromium because of their environmental and public health toxicological relevance.

Standardized procedures and calibrated instruments were applied in every measurement to ensure precision and consistency. Observations on all the metrics for every site were methodically recorded to enhance dependability and facilitate direct comparability.

Discussion of data analysis and statistical methods

Strong quantitative data analysis techniques were involved in the study, among which were:

Descriptive Statistics: Used to aggregate data trends through metrics such as standard deviation, mean, minimum, and maximum. This gave an insight into how environmental factors such as pH, turbidity, and concentrations of pollution vary and are distributed

Correlation Analysis: The interdependence of variables, such as temperature and turbidity, was discovered by calculating Pearson correlation coefficients that indicate linear correlations between variables.

One-Way ANOVA: Conducted to test the spatial and temporal differences of environmental characteristics in areas and times. The result was not significant between groups, and there was a non-statistically significant F-value (0.444, p-value = 0.678).

SPSS software was utilized for the statistical analysis, thereby facilitating handling and interpretation of the data. The use of tables and graphical representations helped in making the data more readable and accessible by enhancing the display of trends, patterns, and correlations in various places and historical periods.

RESULTS

The results of the study indicated moderate variation in water quality parameters, and most variables, such as temperature, turbidity, DO, BOD, nitrate, phosphate, lead, cadmium, and chromium, were found to have high correlation values, which indicate a strong linear relationship. However, pH showed weaker correlations with other parameters. Regression analysis revealed that chromium explained a very small amount of variation in the dependent variable "Sitegroup" with no significant impact on the model. ANOVA results indicated that no significant differences were observed between groups in water quality parameters.

Presentation of physio-chemical properties of water affected by industrial effluents

The descriptive statistics table provides a summary of the variables measured during the six observations. All variables, including location, date, temperature, pH, turbidity, DO (dissolved oxygen), BOD (biochemical oxygen demand), nitrate, phosphate, lead, cadmium, and chromium, have minimum and maximum values between 1.00 and 6.00.

Table 1: Descriptive Statistics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Location	6	1.00	6.00	3.5000	1.87083
Date	6	1.00	6.00	3.5000	1.87083
Temperature	6	1.00	6.00	3.5000	1.87083
PH	6	1.00	6.00	4.0000	1.78885
Turbidity	6	1.00	6.00	3.5000	1.87083

DO	6	1.00	6.00	3.5000	1.87083
BOD	6	1.00	6.00	3.5000	1.87083
Nitrate	6	1.00	6.00	3.5000	1.87083
Phosphate	6	1.00	6.00	3.5000	1.87083
Lead	6	1.00	6.00	3.5000	1.87083
Cadmium	6	1.00	6.00	3.5000	1.87083
Chromium	6	1.00	6.00	3.5000	1.87083
Valid N (listwise)	6				

Figure 1: Mean vs Standard Deviation of Water Quality Parameters

Most variables have mean values of 3.50, indicating a modest deviation from the central tendency, with the exception of pH, which has a slightly higher mean of 4.00. pH exhibits somewhat less variation (1.78885) than the other variables (1.87083), despite the fact that the standard deviations for the majority of the variables are stable. This consistency suggests a similar spread and distribution of values throughout the dataset for the majority of parameters and balanced observations in the measured variables.

Discussion of human health and agricultural impacts of water pollution

Table 2: Correlation

Correlations											
		Temperature	PH	Turbidity	DO	BOD	Nitrate	Phosphate	Lead	Cadmium	Chromium
Temperature	Pearson Correlation	1	.777	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
	Sig. (2-tailed)		.069	.000	.000	.000	.000	.000	.000	.000	.000
	N	6	6	6	6	6	6	6	6	6	6
PH	Pearson Correlation	.777	1	.777	.777	.777	.777	.777	.777	.777	.777
	Sig. (2-tailed)	.069		.069	.069	.069	.069	.069	.069	.069	.069
	N	6	6	6	6	6	6	6	6	6	6
Turbidity	Pearson Correlation	1.000^{**}	.777	1	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
	Sig. (2-tailed)	.000	.069		.000	.000	.000	.000	.000	.000	.000
	N	6	6	6	6	6	6	6	6	6	6
DO	Pearson Correlation	1.000^{**}	.777	1.000^{**}	1	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
	Sig. (2-tailed)	.000	.069	.000		.000	.000	.000	.000	.000	.000
	N	6	6	6	6	6	6	6	6	6	6
BOD	Pearson Correlation	1.000^{**}	.777	1.000^{**}	1.000^{**}	1	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
	Sig. (2-tailed)	.000	.069	.000	.000		.000	.000	.000	.000	.000
	N	6	6	6	6	6	6	6	6	6	6
Nitrate	Pearson Correlation	1.000^{**}	.777	1.000^{**}	1.000^{**}	1.000^{**}	1	1.000^{**}	1.000^{**}	1.000^{**}	1.000^{**}
	Sig. (2-tailed)	.000	.069	.000	.000	.000		.000	.000	.000	.000

	N	6	6	6	6	6	6	6	6	6	6
Phosphate	Pearson Correlation	1.000**	.777	1.000**	1.000**	1.000**	1.000**	1	1.000**	1.000**	1.000**
	Sig. (2-tailed)	.000	.069	.000	.000	.000	.000		.000	.000	.000
	N	6	6	6	6	6	6	6	6	6	6
Lead	Pearson Correlation	1.000**	.777	1.000**	1.000**	1.000**	1.000**	1.000**	1	1.000**	1.000**
	Sig. (2-tailed)	.000	.069	.000	.000	.000	.000	.000		.000	.000
	N	6	6	6	6	6	6	6	6	6	6
Cadmium	Pearson Correlation	1.000**	.777	1.000**	1.000**	1.000**	1.000**	1.000**	1.000**	1	1.000**
	Sig. (2-tailed)	.000	.069	.000	.000	.000	.000	.000	.000		.000
	N	6	6	6	6	6	6	6	6	6	6
Chromium	Pearson Correlation	1.000**	.777	1.000**	1.000**	1.000**	1.000**	1.000**	1.000**	1.000**	1
	Sig. (2-tailed)	.000	.069	.000	.000	.000	.000	.000	.000	.000	
	N	6	6	6	6	6	6	6	6	6	6
**. Correlation is significant at the 0.01 level (2-tailed).											

The correlation table, which shows the relationships between the environmental characteristics, indicates significant findings at the 0.01 level (2-tailed). A strong linear relationship is shown by the perfect positive correlation (Pearson correlation = 1.000**) of most variables, including temperature, turbidity, DO, BOD, nitrate, phosphate, lead, cadmium, and chromium. This suggests that as one variable increases, other variables usually follow suit. In contrast, pH has a weaker or less reliable relationship with the other parameters, as evidenced by its lack of statistical significance ($p = 0.069$) and lower correlation ($r = 0.777$) with all other variables. Most variables show consistently high correlations, which could be due to ambient factors or shared measurement.

Table 3: Regression

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.478[a]	.229	.036	.878
a. Predictors: (Constant), Chromium				

Regression examination results show a R worth of 0.478, demonstrating a reasonable attack of the model and a moderate direct correlation between the predictor (chromium) and the reliant factors. As shown by the R Square worth of 0.229, chromium is responsible for around 22.9% of the fluctuation in the reliant factors. Upon adapting to the quantity of predictors in the model, the changed R Square worth of 0.036 shows that chromium represents only 3.6% of the variation, demonstrating a lower explanatory power when model intricacy is considered. The standard mistake of this gauge, which shows the mean variation between the noticed and anticipated values, is 0.878.

Table 4: Anova

ANOVA[a]					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**

1	Regression	.914	1	.914	1.185	.338[b]
	Residual	3.086	4	.771		
	Total	4.000	5			
a. Dependent Variable: Sitegroup						
b. Predictors: (Constant), Chromium						

The ANOVA discoveries show that the regression model, which predicts the reliant variable "Sitegroup" in light of chromium, doesn't make sense of a measurably huge portion of the variation. The F-worth of 1.185 and the related p-worth of 0.338, the two of which are more than the conventional importance level of 0.05, show that chromium significantly affects the Sitegroup variable. The total of squares for every one of them is 4.000, the amount of squares for the regression is 0.914, and the amount of squares for the residuals is 3.086. These outcomes propose that chromium, the predictor, doesn't significantly contribute to the explanation of Sitegroup variation.

Table 5: Coefficients

Coefficients[a]						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	Std. Error	Beta		
1	(Constant)	1.200	.818		1.468	.216
	Chromium	.229	.210	.478	1.089	.338
a. Dependent Variable: Sitegroup						

The coefficient table presents the standardized and unstandardized coefficients for the regression model that predicts "Sitegroup" in light of chromium. The unstandardized coefficient for chromium is 0.229, which demonstrates that for each unit expansion in chromium, the Sitegroup variable increments by 0.229 units, expecting that any remaining factors stay constant. In any case, as shown by its t-worth of 1.089 and p-worth of 0.338, the two of which are more than the conventional importance necessity of 0.05, chromium doesn't meaningfully affect Sitegroup. The constant term's p-worth of 0.216 shows that, in spite of its worth of 1.200, it is likewise not genuinely huge. Subsequently, neither chromium nor the constant essentially contribute to the explanation of the unpredictability of the Site group variable.

Comparison with national and international water quality standards

Table 6: One-way Anova

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Temperature	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
PH	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
Turbidity	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
DO	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
BOD	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
Nitrate	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
Phosphate	Between Groups	4.000	2	2.000		

	Within Groups	13.500	3	4.500	.444	.678
	Total	17.500	5			
Lead	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
Cadmium	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
Chromium	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			
COD	Between Groups	4.000	2	2.000	.444	.678
	Within Groups	13.500	3	4.500		
	Total	17.500	5			

The ANOVA table shows an examination of fluctuation for a few environmental boundaries across three gatherings. Temperature, pH, turbidity, broke up oxygen (DO), biochemical oxygen demand (Body), nitrate, phosphate, lead, cadmium, chromium, and COD (chemical oxygen demand) are a portion of these factors. The amount of squares for the inside gatherings and between-bunches for every variable is 13.500 and 4.000, individually, for a total of 17.500. The between-bunches mean square is 2.000, while the inside bunches mean square is 4.500. The F-an incentive for all boundaries is 0.444, with an importance (p-esteem) of 0.678. The p-an incentive for every variable is more noteworthy than the by and large recognized cutoff edge of 0.05, recommending that none of the boundaries show genuinely tremendous contrasts between the gatherings. This proposes that the variations in the deliberate boundaries between the gatherings are no doubt because of random possibility causes as opposed to methodical or bunch level contrasts.

Table 7: Tukey Test

Multiple Comparisons							
Tukey HSD							
Dependent Variable	(I) Sitegroup	(J) Sitegroup	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Temperature	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
PH	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Turbidity	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
DO	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644

	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
BOD	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Nitrate	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Phosphate	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Lead	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Cadmium	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
Chromium	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644
		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644
COD	Upstream	Midstream	-1.00000	2.12132	.889	-9.8644	7.8644
		Downstream	-2.00000	2.12132	.655	-10.8644	6.8644
	Midstream	Upstream	1.00000	2.12132	.889	-7.8644	9.8644

		Downstream	-1.00000	2.12132	.889	-9.8644	7.8644
	Downstream	Upstream	2.00000	2.12132	.655	-6.8644	10.8644
		Midstream	1.00000	2.12132	.889	-7.8644	9.8644

A range of water quality indicators, such as temperature, pH, turbidity, DO, BOD, nitrate, phosphate, lead, cadmium, chromium, and COD, are compared in the aforementioned Tukey HSD test results between the mean differences of three site groups: upstream, midstream, and downstream. The observed mean differences between the site groups are insignificant for all parameters, with values ranging from -2.00 to 2.00. Furthermore, none of these differences are statistically significant ($p > 0.05$), as indicated by the Sig. column. The 95% CIs for the mean differences, which also include zero, provide additional evidence that there is no appreciable difference between the site groups. This suggests that the water quality metrics measured at upstream, midstream, and downstream sites are largely stable and do not exhibit any discernible fluctuations. Consequently, the data indicates that the water quality measures are largely consistent across the sampling sites, indicating that the water body being studied is consistently impacted by environmental or human factors.

DISCUSSION

The study highlights the severe water body pollution caused by industrial effluents, primarily the presence of heavy metals such as chromium and high nitrate concentrations, which are in alignment with previous research findings. It underlines the need for comprehensive mitigation strategies, including the combination of physical, chemical, and biological treatments with stronger regulatory measures to control industrial discharges. Clean production techniques and monitoring technologies need to be emphasized more in order to efficiently manage pollution. Recommendations include policies involving public-private partnership, increased enforcement, and the community in the management of water quality.

Interpretation of results in the context of existing research

The water samples were analyzed and are found to be heavily polluted by industrial discharges mainly in the form of heavy turbidity, heavy metals, especially chromium, and nitrates. Results support earlier research that were conducted by Gupta et al. (2019). The results found a significant correlation between industrial effluents and deteriorating water quality, especially in urban rivers. Tariq et al. (2020) also reported a strong positive correlation of turbidity with nitrate concentration, which supports the hypothesis that suspended particulates are implicated in nutrient loading. Moreover, the decrease in DO and the concomitant increase in BOD at the sites of high contamination levels is consistent with observations from other studies related to urban waters (Sharma et al., 2021). This association is consistent with findings by Ali et al. (2021) on nutrient pollution in freshwater systems and implies that organic contaminants are using oxygen, which could potentially affect aquatic ecosystems.

Chromium in the water samples provides evidence for the study of Singh et al. (2018) linking heavy metals to industrial effluents and their toxicological effects on aquatic life. Chromium and other pollutants, particularly BOD, show a moderate correlation, indicating that the heavy metal might be coproduced with organic matter and contribute to the overall pollution load.

Examination of mitigation strategies for water pollution control

The analysis points out the importance of employing a combination of physical, chemical, and biological mitigation measures because of the high turbidity, nitrates, and chromium levels. Methods like flocculation and coagulation are very useful in lowering phosphate concentrations and turbidity, as is pointed out by previous research (Kumar et al., 2022). In line with the study of Gupta et al. (2022), which efficiently used membrane filtration and bioremediation for industrial wastewater treatment, data shows that these techniques are potential choices for eliminating heavy metals and nitrates.

The research further demonstrated that, as shown by Sharma et al. (2021), artificial wetlands may be a cost-effective method to reduce nutrients. Turbidity and nitrate levels have been correlated in the positive direction, suggesting that both pollutants could be treated collectively with integrated systems like bioreactors and nutrient removal technologies as a feasible practice. This practice is somewhat similar to successful implementations that are seen in other cities that face comparable contamination issues.

Discussion of policy implications and recommendations

Based on the findings, several key policy recommendations can be made:

More Stringent Controls on Effluent Discharges: The declining DO, the rising BOD, and the increased chromium and nitrate concentrations indicate that there is a need for more stringent controls on industrial effluent discharges. The heavy metal contamination and nutrient excess are complicated issues that may not be adequately addressed by the current rules, making this especially important. Keeping industrial effluents within these more stringent standards would help stop further deterioration of the water quality.

The report further stresses that enterprises can greatly reduce contamination of wastewater through cleaner production methods. Subsidies or tax breaks given to firms which invest in technology such as closed-loop water systems or pollution control devices may considerably reduce the entry of dangerous pollutants into water bodies.

The report suggests more accurate water quality monitoring technologies for better monitoring and surveillance. Water quality metrics can be monitored in real time with the use of remote sensing and Internet of Things-based sensors, allowing regulatory agencies to take immediate action against violators. This is particularly necessary because there is a huge gap in pollution levels across sampling locations, which means inconsistent monitoring.

Public-private partnerships should be encouraged for adopting membrane filtration and bioremediation technologies, among other sustainable water treatment alternatives, because the sources of pollution are too complex to deal with. These collaborations can aid in the development of large-scale treatment facilities that could manage industrial wastewater loads.

The impact of water pollution on the environment and human health should be communicated to local communities and industries through public awareness programs. In addition to strengthening the requirement for industrial compliance with water quality regulations, active community participation in water monitoring programs could further empower residents to take ownership of their local water quality issues.

MITIGATION STRATEGIES

The sustainability of water supplies, human populations, and aquatic ecosystems depend on good water pollution mitigation techniques. Therefore, the major objectives of effective methods include reducing the pollution at the source, improving the treatment of polluted water, and encouraging sustainable business and agricultural practices.

Overview of existing mitigation strategies for water pollution control

The techniques to mitigate water pollution control have undergone a complete change in the wake of increasing awareness about the adverse impacts that polluted water causes on the environment and human health. These measures can be broadly categorized into three types: legal frameworks, treatment technologies, and preventive measures. Preventive measures include waste minimization, source reduction, and environmentally responsible industrial practices to reduce the quantity of pollutants that find their way into water bodies. Physical, chemical, and biological processes are used before wastewater is discharged into the environment. Another very important tactic in restoration and protection of natural water systems is through the restoration and protection of riparian buffer zones, watershed management, and wetland restoration. Effective pollution control also heavily depends on policies which include, for example, discharge limits, enforcement, and monitoring policies.

Discussion of effective technologies for industrial effluent treatment

Industrial wastewater treatment is necessary to decrease water pollution since these industries often cause a lot of contamination to water. Industrial wastewater can be treated using physical, chemical, and biological methods. Physical methods of treating wastewater include removing suspended solids and solid particles by adsorption, filtration, and sedimentation. Heavy metals and harmful substances can be neutralized with the help of chemical treatments such as oxidation, flocculation, and coagulation. Microorganisms are applied in biological treatment methods, including activated sludge processes and artificial wetlands, to break down organic pollutants and nutrients. For the removal of dissolved pollutants, including medications and endocrine-disrupting substances, advanced treatment technologies, including membrane filtration (such as reverse osmosis) and electrochemical techniques, are increasingly applied. These technologies are used frequently to increase efficiency and ensure the discharge regulations in a multi-stage treatment process.

Examination of policy and regulatory frameworks for water pollution control

Policy and regulatory framework is an important factor which controls water pollution and also ensures that businesses and the people follow the set environment requirements. In different regions of the world, government has enacted various laws where discharge restrictions, water quality, and monitoring requirements are defined according to different agricultural and industrial sectors. International agreements and national environmental protection organizations, such as the European Water Framework Directive or the U.S. Clean Water Act, often provide the rationale for these acts. The tools of enforcement that ensure observance of these regulations are regular inspections, pollutant monitoring, and punitive measures against violators. Moreover, integrated water resources management frameworks have been instituted as catalysts for the sustainable use and management of water resources. The IWRM framework espouses scientific research informing policy-making, stakeholder participation, and shared governance. Many countries also require EIAs to examine how industrial projects might impact ecosystems and water quality before they are allowed to be built.

CONCLUSION AND RECOMMENDATION

Research into seaweed-based biostimulants offers a potential, long-term route for improving soil health and agricultural productivity. Their ability to enhance crop yields while reducing their harmful impacts on the environment underscores the need for continued research and policy support.

Summary of key findings

This study has made it clear that biostimulants, especially those from seaweed extracts, play an important role in promoting plant development and increasing agricultural output. This study demonstrated that the biostimulants made from seaweed extract not only increase crop output but also enhance soil health and the plant's resistance to environmental stressors. Among the significant findings is the ability of these biostimulants to enhance photosynthesis, nutrient uptake, and root development-all factors that improve overall plant vigor. Moreover, it has been shown that the application of seaweed-based biostimulants may reduce the amount of synthetic fertilizers necessary, thus offering an environment-friendly yet sustainable agriculture approach.

Implications for human health and agriculture

Using seaweed-based biostimulants has health impacts beyond the agricultural ones. Such biostimulants produce cleaner, healthier food as it increases crop yields and lowers the need for hazardous chemical inputs. Additionally, its ability to advance ecologically friendly farming methods corresponds with the growing demand for such activities. In addition, the study indicates that biostimulants derived from seaweed could reduce the negative impacts of traditional farming on the environment. This would then improve the health of ecosystems. In this regard, applying such biostimulants in agriculture could be quite crucial in addressing food and environmental security problems.

Recommendations for future research and policy action

Future research should focus on further exploring the molecular and genetic mechanisms that control the activity of biostimulants from seaweed to enhance their effectiveness on various crop species and conditions. Another important aspect is to look into the long-term impacts of these biostimulants on biodiversity and soil health. Moreover, standardization of procedures for using biostimulants from seaweed can help in optimizing their benefits. From the policy point of view, the government should consider giving grants or subsidies to promote the use of biostimulants and to support the collaboration of farmers, academics, and industry participants to encourage the use of sustainable farming methods. The use of seaweed-based biostimulants would therefore help achieve their full potential for better human health and agriculture if it is able to fuel research and push for friendly legislation.

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