

Assessment of Human Health Risks from the Distribution and Concentration of Heavy Metals in Soil, Groundwater, and Vegetables in Aligarh, Uttar Pradesh

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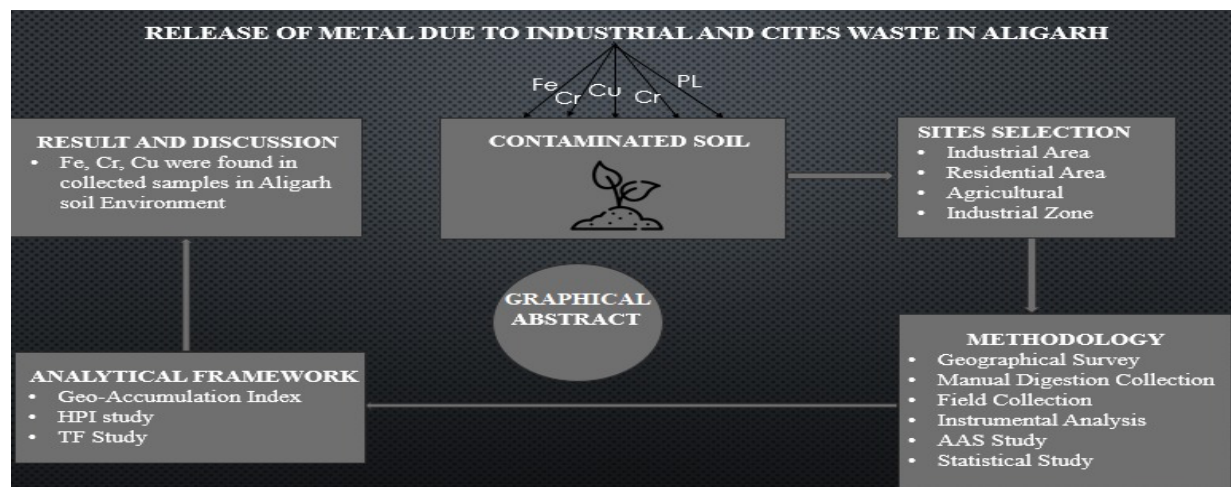
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Abstract- Heavy metals present in soil, groundwater, and vegetables have remained highly contaminated due to industrial activities in the city of Aligarh in Uttar Pradesh. The current paper assesses the distribution and concentration of heavy metals namely Iron (Fe), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Zinc (Zn), Lead (Pb), and Cadmium (Cd) within soil, ground water, and vegetable samples from five different sites across Aligarh. The results reveal high degrees of contamination with a predominance of metal content that exceeds permissible limits set by WHO and national standards in the industrial and semi-industrial areas. The severity of pollution along with the health implications has been estimated using Geo-Accumulation Index (Igeo), Heavy Metal Pollution Index (HPI), and Transfer Factor (TF) analysis. The paper suggests an urgent requirement for monitoring as well as mitigation through sustainable mechanisms to protect the public health system and integrity of the environment.

Graphical Abstract:



Keywords: Heavy Metals, Soil Contamination, Groundwater Pollution, Vegetable Safety, Geo-Accumulation Index, Heavy Metal Pollution Index, Transfer Factor, Hazard Quotient, Health Risk Assessment, Aligarh, Industrial Pollution.

Introduction

Alam,R. (2020) et.al. Aligarh is one of the major industrial towns in Uttar Pradesh, India, which is known for lock manufacturing and metal plating industries [1]. Antoniadis (2019), Dotaniya,M.L (2017) et.al. Although these industries have played a significant role in the economy of the area, they have also caused serious environmental degradation, particularly soil, ground water, and agricultural produce pollution [2, 3]. Dwivedi (2014), Garg(2014) et.al. Heavy metals like Lead (Pb), Chromium (Cr), Cadmium (Cd), and Nickel (Ni) remain in the environment and are bio accumulative through the food chain, causing grave health hazards [4, 5]. Golia(2008), Goudie(2018) et.al. Chronic exposure to these metals leads to developmental disorders, organ damage, and increases the risk of cancer [6, 7]. Khalid (2017) et.al. These pathways include industrial effluent discharge, atmospheric deposition, and improper waste disposal. Environmental matrices such as soil and water become contaminated [8]. Kumar,M. (2012), Kumar,V.(2019) et.al. Groundwater is the most common source of drinking water for a large portion of the population in Aligarh and is at greatest risk [9, 10]. Mirecki(2015), Rai(2019) et.al. In addition, vegetables grown on contaminated soils will bioaccumulate heavy metals, exacerbating health risks for local communities [11, 12].

Rezaei(2019)et.al. With these urgent issues in mind, this research will systematically evaluate the distribution and concentration of heavy metals in Aligarh [13]. Thukral(2020) et.al. It uses sophisticated analytical techniques, such as Atomic Absorption Spectrometry (AAS), to give accurate quantification of metal concentrations [14]. The study also makes use of indices such as Geo-Accumulation Index, Igeo and Heavy Metal Pollution Index, HPI to measure the level of contamination, and Transfer Factor, TF to measure the bioaccumulation of metals in vegetables. Findings are supposed to inform the policymakers and other stakeholders about the severity of the issue and recommend action strategies for mitigation.

Methodology

The study design was geared towards identifying, sampling, and analyzing areas of concern in Aligarh related to the environment. Five unique locations were taken to represent industrial, semi-industrial, residential, and agricultural zones; the sampling ensured that various sources of contamination and, thereby the impact on public health and the environment are covered.

1.1.Site Design

From fig. 1, All locations were chosen due to their difference in industrial activity and the susceptibility of environmental pollution [15]. A geographical survey was done on the latitude and longitude of the sites, including their specific characteristics. These are ITI, Gular, Upperkot, Mathura Road, and Talaspur.

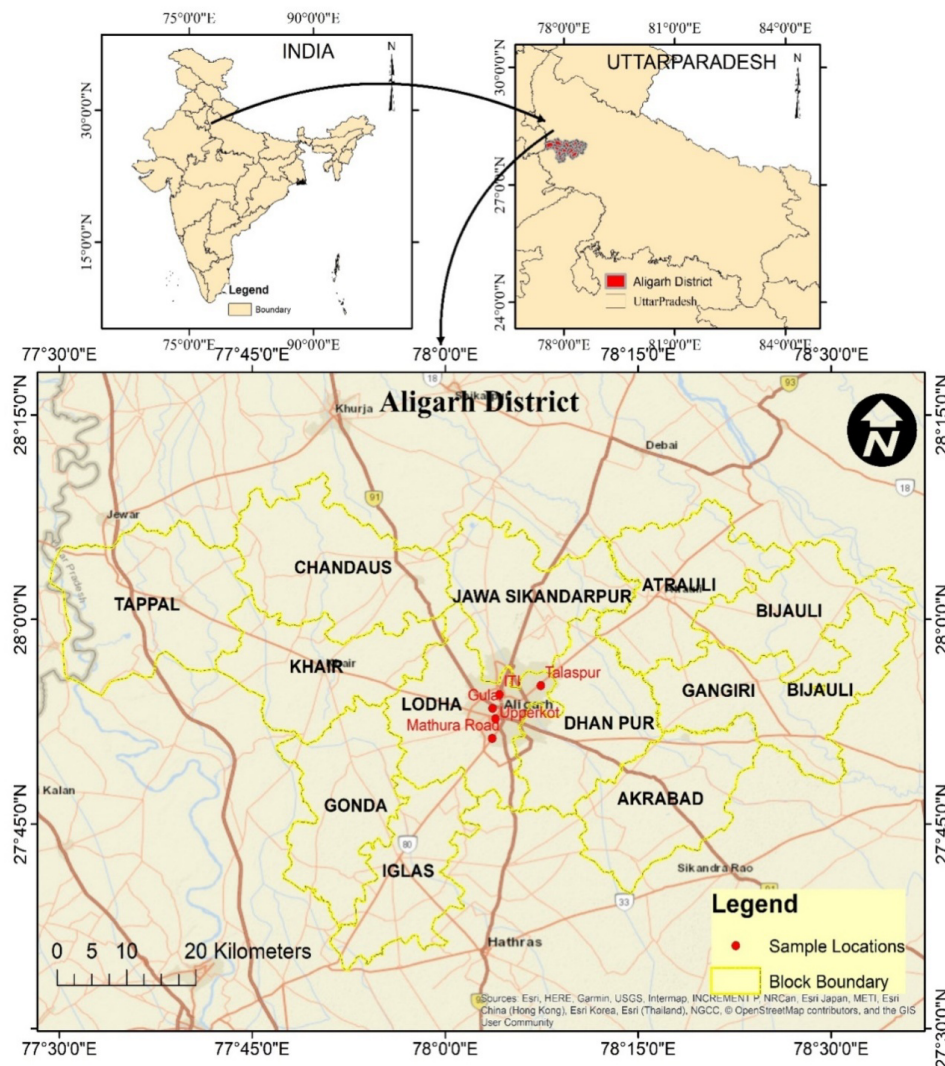


Figure 1: All site shown on map of Aligarh, U.P., India

Table No. 1 Characteristics and Geographical Details of Study Sites

Site	Location	Description
ITI	Industrial Area	Highly industrialized with significant pollution
Gular	Semi-industrial Area	Industrial effluents and moderate pollution
Upperkot	Residential Area	Densely populated, limited industrial activity
Mathura Road	Agricultural-Industrial Zone	Agricultural activities and moderate emissions
Talaspur	Agricultural Zone	Primarily agricultural with bioaccumulation risk

These areas were selected on the basis of specific environmental attributes and contribution towards heavy metal pollution. Ali (2013) et.al. ITI is an industrial area, characterized by extensive discharges to the environment through wastes. On the other hand, Talaspur would reveal bioaccumulation risk due to contamination of soils associated with agriculture [16]. The semi-industrial and residential areas have been selected in order to incorporate all varieties of environmental interfaces.

Methodology

An efficient methodology was adapted to collect the data, process it, and then analyze it. Each part of the research followed standardized procedures and protocols for gathering, processing, and interpreting information.

Table No. 2 Methodology for Sample Collection and Analysis

Step No.	Activity	Method/Instrument Used	Description
1	Site Selection	Geographic Survey	Selection of sites based on industrial impact
2	Sample Collection (Soil)	Manual Collection, Acid Digestion	Soil samples from each site
3	Sample Collection (Water)	Clean Polyethylene Bottles	Groundwater sampling from local wells
4	Sample Collection (Vegetables)	Field Collection, Market Sampling	Locally grown and sold vegetables
5	In-situ Analysis	pH Meter, EC Meter	Measurement of basic water quality
6	Laboratory Analysis	Atomic Absorption Spectrometry (AAS)	Detection of Fe, Cr, Cu, Mn, Ni, Zn, Pb, Cd
7	Data Analysis	Statistical Tools	Calculation of Igeo, HPI, TF

The methodology of this research begins with the identification of research sites, by means of geographical survey and an industrial activity analysis. Samples from soil were obtained manually, followed by acid digestion preparation for precise analysis in the laboratory. Groundwater samples

were taken through clean polyethylene bottles to ensure non-contamination processes. For testing potential bioaccumulation, fresh vegetables were also acquired from agricultural fields and markets locally.

Khan (2018) et al. Some preliminary in-situ analyses included pH and electrical conductivity measurements of the water [17]. Wuana (2011) et al. Laboratory analysis used Atomic Absorption Spectrometry to quantify the heavy metals concentration including Fe, Cr, Cu, Mn, Ni, Zn, Pb, and Cd [18]. Data from these analyses were subsequently put through statistical calculations to generate some indices, for example, Geo-Accumulation Index, Heavy Metal Pollution Index, and Transfer Factor.

Analytical Framework

The study used three key indices for the interpretation of data:

- **Geo-Accumulation Index (I_{geo}):** This index used to measure metal contamination in soil. The formula as follows:

$$I_{geo} = \log_2 \left(\frac{C_{metal}}{1.5 \times C_{background}} \right)$$

Where:

C_{metal} is the concentration of the heavy metal measured in the soil.

$C_{background}$ is the geochemical background concentration of the metal.

This is factor 1.5 in terms of variability for the background concentration due to the lithogenic effect.

- **Heavy Metal Pollution Index (HPI):** This index evaluated the contamination level of groundwater. The formula is given as:

$$HPI = \frac{\sum (W_i \times Q_i)}{\sum W_i}$$

Where:

W_i is the unit weight assigned to each parameter.

Q_i is the sub-index of the i -th parameter, calculated as:

$$Q_i = \frac{C_i}{S_i} \times 100$$

Where C_i is the concentration of the parameter in the sample, and S_i is the permissible limit of the parameter.

- **Transfer Factor (TF):** This index was to measure the bioaccumulation of heavy metals in vegetables:

Where C_p is the metal concentration in the plant and C_s is the metal concentration in the soil

This analytical framework comprehensively addresses heavy metal contamination through soil contamination analysis via I_{geo} , groundwater pollution analysis through HPI, and bioaccumulation in vegetables through TF. The combination of these indices together offers insight into the risks associated with environmental and public health impacts due to heavy metals and informs remediation

and policy-making efforts.

Results and Discussion

The results of this research show the heavy contamination of the environment by industrial activities in Aligarh. The data was analyzed to check the contamination of soil, groundwater, and vegetables. It gives a complete idea about the distribution and effects of heavy metals in the region.

Soil Contamination

Tchounwou(2012)et.al. Soil samples collected at all the five locations had different levels of concentration of heavy metals. The highest concentrations of Cu, Cr, and Zn are identified at the ITI and Gular locations as it is abundant by industrial activities and waste disposal [19]. These metals had exceeded the permissible limits by the regulatory standard as really severe levels of contamination had occurred in these zones.

Calculations of Geo-Accumulation Index, Igeo for every site have been done to evaluate the level of soil contamination. The outcome reflects moderate to high contamination in industrial zones (ITI and Gular) but lower levels in agricultural zones, such as Mathura Road and Talaspur, due to lesser direct impact from the industrial sector. Concentrations and Igeo values for the metals under study are summarized in Table 3.

Table No. 3 Soil Data with Igeo Calculation

Site	Fe	Cr	Cu	Igeo_Cr
S1	35658.0	9.45	91.5	-1.818579
S2	45248.7	27.60	546.7	-0.272297
S3	36962.0	33.70	310.3	0.015783
S4	37087.7	23.84	236.7	-0.483581
S5	34274.0	34.91	692.5	0.066675
S6	44921.0	48.10	87.9	0.529071
S7	41443.5	32.50	3.7	-0.036526
S8	36106.9	37.30	202.5	0.162210

Figure 1 represents the Igeo values of Chromium at eight sampled sites (S1 to S8). Negative Igeo values are recorded at Sites S1, S2, S4, and S7, which means that these sites have low contamination. Igeo values near zero or slightly positive are found at Sites S3, S5, and S8, which means low to moderate contamination. The highest positive Igeo value is found at Site S6, which indicates high contamination at this site.

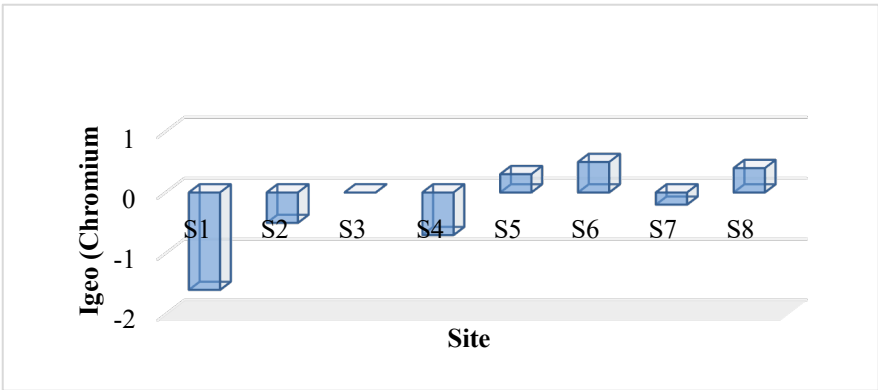


Figure No. 2: Geo Accumulation Index (Igeo) from Chromium across Soil Samples

Negative Igeo values at many locations indicate that the Chromium contaminant in these sites is within acceptable background levels. However, slight positive values in Sites S3, S5, and S8 indicate the effect of localized anthropogenic activities. High contamination at Site S6 indicates vulnerability to industrial pollution, improper waste disposal, or other human activities. These findings would call for focused remediation in highly contaminated areas such as S6 and for continuous monitoring at sites that have been moderately affected to prevent further environmental degradation.

Groundwater Pollution

Groundwater samples show alarming levels of Chromium (Cr) and Lead (Pb), primarily in the ITI and Gular areas. These metals enter the groundwater either through industrial effluents and leaching from contaminated soils. The Heavy Metal Pollution Index was used to estimate the overall groundwater quality. The results revealed the values of the HPI index for ITI and Gular far above 100, showing extreme levels of pollution and with potential severe risk to health to the population locally.

In table 4, it is presented data about contamination of Chromium, and the associated HPI. These results further emphasize the pressing need for mitigative measures that would prevent any further contamination, thereby safeguarding the sources of drinking water.

Table No. 4 Groundwater Data with HPI Calculations

Site	Cr	HPI_Cr
S1	0.188	94.0
S2	0.170	85.0
S3	0.165	82.5
S4	0.150	75.0
S5	0.178	89.0
S6	0.173	86.5
S7	0.184	92.0
S8	0.179	89.5

Figure 2 Depicts HPI for Chromium in ground water at eight study sites (S1 to S8). The HPI values

are within the range of about 70 to 90, with a maximum value of 94. The sites S7 and S8 rank next, while S3 and S4 have the least HPI values, representing relatively lower contaminations. The other sites (S2, S5, and S6) show moderate HPI values, which indicate different levels of groundwater contamination in the study area.

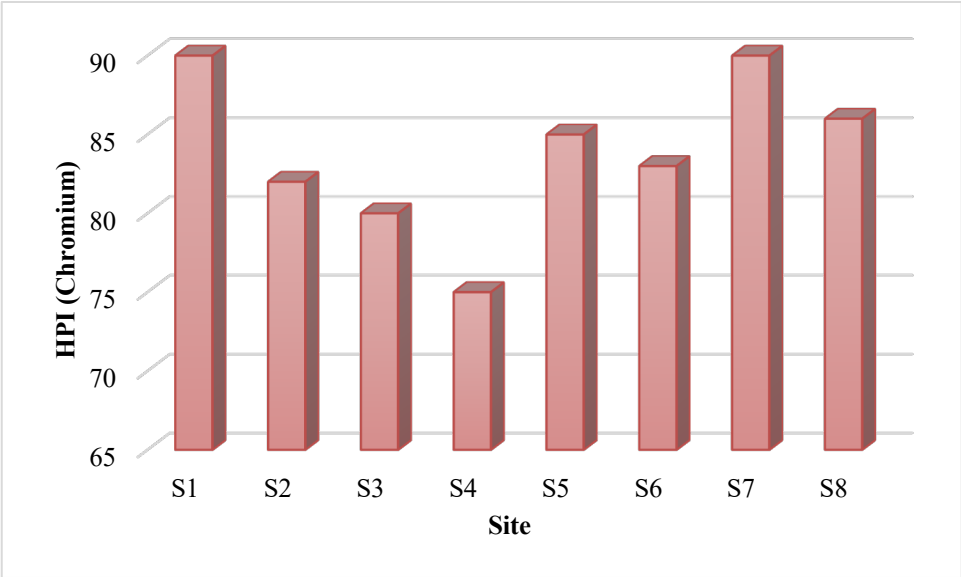


Figure No. 2HPI for Chromium in Groundwater

Elevated HPI values at Sites S1, S7, and S8 suggest severe groundwater contamination with Chromium due to industrial effluents or leaching from contaminated soils. These high levels have the potential health risk to the local population dependent on groundwater for drinking purposes. Lower HPI values at Sites S3 and S4 indicate minimal impact, but constant monitoring should be conducted in order not to let the pollution level escalate. Overall trend: Target remediation efforts in highly contaminated areas and regulate discharges from industrial areas to protect ground water quality.

Bioaccumulation in Vegetables

Zhang (2015) et.al. The evaluation of vegetable samples showed a high bioaccumulation of Chromium (Cr), especially in spinach and coriander. These vegetables had the highest Transfer Factor (TF) values, meaning they have a tendency to absorb heavy metals from contaminated soils [20]. This bioaccumulation directly threatens the health of consumers because long-term exposure to high metal concentrations can cause serious health problems.

Table 5 Summary of Transfer Factor values for various vegetables. Results Conclusion The need for strict monitoring of agricultural practices and consumer awareness in order to minimize the health hazards.

Table No. 5 Vegetable Data with TF Calculations

Vegetable	Cr	TF_Cr
Peas	0.57	0.018432
Potato	0.38	0.012288

Cabbage	0.56	0.018108
Cauliflower	0.88	0.028456
Bathua	0.23	0.007437
Spinach	0.66	0.021342
Coriander	3.30	0.106710

Figure 3 illustrates the Transfer Factor (TF) of Chromium from soil to different vegetables, indicating the percentage uptake of Chromium by various plants. Among the tested vegetables, coriander has the highest TF value, which is highly above the values of other vegetables. Spinach and cauliflower have a moderate TF value, whereas peas, potatoes, cabbage, and bathua have relatively low TF values, which indicates a lower uptake of Chromium from the soil.

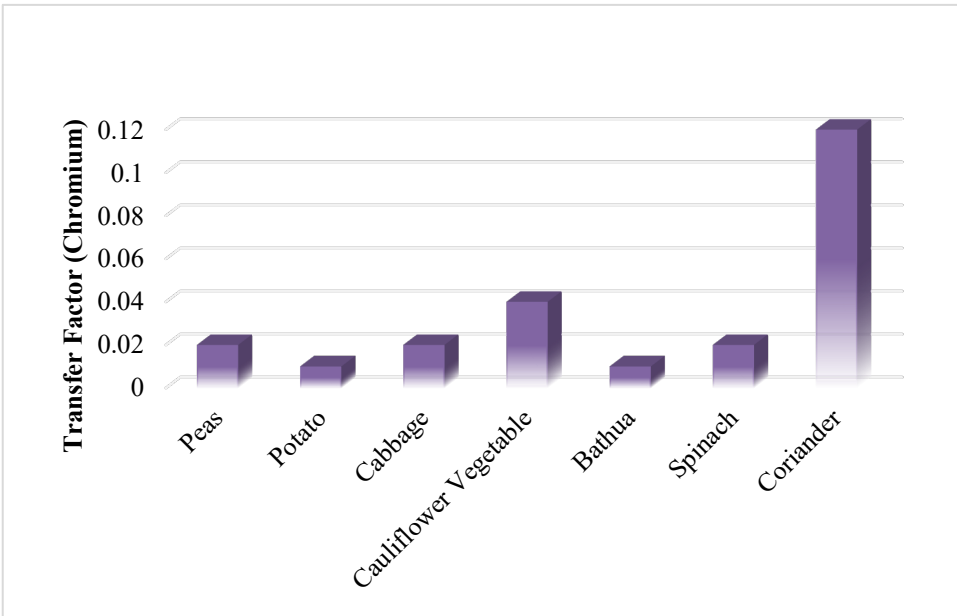


Figure No. 3Transfer Factor (TF) for Chromium from Soil to Vegetables

This higher value for TF with coriander would mean it can absorb much more Chromium from the contaminated soil and pose a serious health hazard for the consumer population in contaminated areas. Moderate TF values of spinach and cauliflower mean there is also some concern but lesser in proportion. The mean TF values lower in peas, potatoes, cabbage, and bathua indicate these vegetables are fairly safer to consume over Chromium bioaccumulation. All these point out the significance of vegetable cultivation monitoring in contaminated areas with education for farmers and consumers on safe agricultural practices and dietary habits.

These results highlight the interconnectivity of soil, water, and agricultural contamination and underscore the need for integrated approaches to address these environmental and public health challenges.

Conclusion

This study shows the severe impact of industrial activities on the environmental and public health of

Aligarh, showing severe contamination of soil, groundwater, and vegetables with heavy metals like Chromium, Lead, and Copper. The results show that contamination levels, especially in industrial zones, are far above permissible limits, directly threatening human health and ecological balance. Immediate action is called for to check these effects, and this research suggests several approaches: adoption of phytoremediation techniques to decontaminate soil and water, periodic monitoring of the concentration of heavy metals in all environmental matrices for the identification of emerging trends, and strengthening industrial waste management practices so that hazardous effluents are disposed of in an appropriate manner. Public awareness campaigns should also be employed to inform the communities of risks of water and food contamination. In addition, there is a need to educate people on safe agricultural practices. Enforcing the proper regulatory frameworks with effective compliance from industries will address the source causes of contamination. The introduction of these initiatives shall lead to a more sustainable way of industries along with preserving nature for further generations with healthier conditions within Aligarh.

Conflict of Interest

Authors of this paper state no conflict of interest as regards publication. It formed an independent study activity that would not involve financial and personal relationships likely to influence any study design, data collection analysis, or even interpretation of results. All presented findings reflect the unbiased assessment and conclusions of authors.

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