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Spatial Distribution and Contamination Assessment of Heavy Metals in Gomti River Sediments

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Abstract: *Heavy metal contamination in river sediments has become a major environmental concern due to its persistence, toxicity, and bioaccumulation potential. The present study assessed heavy metal contamination in the sediments of the Gomti River along the Lucknow city stretch, Uttar Pradesh, India, using pollution assessment indices such as Enrichment Factor (EF), Contamination Factor (CF), and Pollution Load Index (PLI). Sediment samples were collected from three selected sites: Nishat Ganj Bridge (S1), Gomti Barrage (S2), and Sports Ground Area (S3), representing varying degrees of urban influence. Surface sediment samples (0–10 cm depth) were analysed for Chromium (Cr), Iron (Fe), Cadmium (Cd), and Zinc (Zn) using standard analytical procedures.*

The concentration of heavy metals varied significantly among the sampling sites. Chromium ranged from 145.78 to 227.98 mg/kg, iron from 20640.03 to 21540.07 mg/kg, cadmium from 0.35 to 16.35 mg/kg, and zinc from 91.28 to 417.53 mg/kg. The highest concentrations of cadmium and zinc were recorded at the Sports Ground Area, indicating localized anthropogenic contamination. Enrichment Factor analysis revealed moderate to significant enrichment for Cr (3.92–5.89) and Zn (2.25–10.20), while Cd exhibited extremely high enrichment with a maximum value of 126.57. Contamination Factor values indicated moderate contamination for Cr, low contamination for Fe, and severe contamination for Cd, particularly at S3 (54.52). The Pollution Load Index values of 4.35, 5.09, and 61.28 for S1, S2, and S3 respectively confirmed progressive deterioration of sediment quality across all sites.

The findings indicate substantial heavy metal contamination in the Gomti River sediments, primarily due to urban runoff, sewage discharge, and other anthropogenic activities. The study highlights the urgent need for continuous environmental monitoring, effective wastewater management, and pollution control measures to protect the ecological health of the river system and minimize associated human health risks.

Keywords: Heavy metals, River sediments, Gomti River, Pollution Load Index (PLI), Anthropogenic contamination

I. INTRODUCTION

Heavy metals are naturally occurring elements characterized by relatively high atomic mass and density (Choudhury et al., 2026). They have attracted significant environmental attention due to their toxic nature, long-term persistence, and tendency to accumulate in biological systems. In contrast to organic contaminants, heavy metals are non-degradable, allowing them to remain in environmental compartments for extended periods and thereby posing continuous ecological and health-related risks (He et al., 2025). In recent decades, accelerated industrial growth, rapid urban development, and intensified agricultural activities have collectively contributed to an increased influx of heavy metals into various ecosystems worldwide (Rachna et al., 2025).

At the global level, contamination by metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) has been widely reported in soils, aquatic environments, and urban settings (Chai et al., 2017). These elements originate from both natural processes, including rock weathering and volcanic activity, as well as anthropogenic sources such as mining operations, industrial effluent discharge, vehicular emissions, improper solid waste disposal, and the extensive application of agrochemicals (Pant et al., 2025). Once released into the environment, these metals tend to accumulate in sediments and soils, disturbing ecological equilibrium and entering food webs, where they may undergo biomagnification and ultimately impact higher trophic levels, including humans (Pant et al., 2025).

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In the Indian context, heavy metal pollution has intensified due to rapid urbanization, population growth, industrial expansion, and insufficient wastewater treatment infrastructure (Si et al., 2024). A considerable number of river systems in the country receive untreated or partially treated effluents from domestic and industrial sources, leading to progressive degradation of water and sediment quality. River sediments, in particular, act as both sinks and potential secondary sources of heavy metals, influencing their mobility, bioavailability, and long-term environmental behaviour (Chakma et al., 2025). The Gomti River, an important tributary of the Ganga River system, plays a crucial role in sustaining domestic, agricultural, industrial, and ecological demands in northern India. However, increasing anthropogenic pressure within its basin has raised serious concerns regarding its environmental integrity (Tokatlı et al., 2026).

Due to their persistent and non-biodegradable nature, heavy metals pose significant risks to aquatic ecosystems through accumulation in sediments and subsequent uptake by aquatic organisms (Ma et al., 2024). This process facilitates their transfer through the food chain, potentially resulting in biomagnification and adverse health outcomes in humans. Prolonged exposure to elevated levels of heavy metals has been associated with a range of health complications, including neurological impairment, renal dysfunction, hepatic disorders, cardiovascular diseases, and carcinogenic effects (Ma et al., 2024; Siddig et al., 2025). Therefore, continuous monitoring and systematic assessment of heavy metal contamination in riverine sediments are essential components of environmental quality management (Naaz & Pandey, 2024).

In this study, an evaluation of heavy metal contamination in the sediments of the Gomti River is undertaken using widely applied pollution assessment tools, including the Enrichment Factor (EF), Contamination Factor (CF), and Pollution Load Index (PLI). These indices provide a comprehensive understanding of the degree of metal enrichment, contamination intensity, and overall pollution status of the sediment environment. Furthermore, the study aims to identify potential sources of contamination and assess their ecological implications. The findings are expected to contribute valuable insights for environmental monitoring and the development of effective river conservation and management strategies.

II. METHODOLOGY

1. Study Area

The present study is focused on the Gomti River within the Lucknow city stretch, Uttar Pradesh, India (Gondial & Bharti, 2025a). The Gomti River is a major tributary of the Ganga River system and originates from the Madhotanda region in Pilibhit district. It traverses a total length of approximately 900 km before joining the Ganga River at Saidpur, Varanasi district (Bhan et al., 2025). The river plays a crucial role in supporting domestic water supply, agricultural irrigation, industrial activities, and maintaining ecological balance in the densely populated regions of northern India (Bhan et al., 2025; Gondial & Bharti, 2025a).

Within Lucknow, the river flows for an approximate stretch of 12–15 km, dividing the city into trans-Gomti and cis-Gomti regions (A. Singh et al., 2026). This urban stretch is among the most environmentally sensitive sections of the river due to intense anthropogenic pressure (Gondial & Bharti, 2025b). As the river enters and passes through Lucknow, it receives substantial inputs of untreated or partially treated domestic sewage, stormwater runoff, and industrial effluents, significantly altering its natural physicochemical and sediment characteristics (Sevak & Pushkar, 2024).

The Lucknow segment of the Gomti River is characterized by high population density along its banks and rapid urban expansion (Botle et al., 2024). Several residential colonies, commercial zones, and informal settlements are situated close to the river, contributing continuous loads of organic and inorganic pollutants (Gayathri et al., 2021). In addition, multiple drains (nallahs) such as the Kukrail drain and other local sewage channels discharge directly into the river, especially during non-monsoon periods when dilution capacity is limited (Zhao et al., 2018).

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Although large-scale heavy industries are limited within the immediate river corridor in Lucknow, the river is influenced by small-scale industrial units, textile dyeing activities, metal workshops, electroplating units, and tanneries located in the broader catchment area (Gayathri et al., 2021). These activities contribute trace metals such as lead, chromium, cadmium, and nickel to the river system. Furthermore, agricultural runoff from peri-urban areas introduces fertilizers and pesticides, which may indirectly influence heavy metal mobility and accumulation in sediments (Zhao et al., 2018).
Hydrologically, the river in this urban reach exhibits reduced flow velocity during dry seasons, which enhances sediment deposition and facilitates the accumulation of contaminants (Xiao et al., 2021). The riverbanks in several sections are encroached and modified, reducing natural buffering capacity(Li et al., 2023). These conditions make the sediments of the Gomti River in Lucknow particularly susceptible to heavy metal accumulation and long-term pollution storage (Gondial & Bharti, 2025b).

Given these environmental settings, the Lucknow stretch of the Gomti River represents a critical zone for assessing anthropogenic impact and sediment quality deterioration (Gondial & Bharti, 2025b). The present study area thus provides a representative urban riverine system to evaluate heavy metal contamination using standard pollution indices and to understand the spatial influence of urban activities on river sediment quality (A. Singh et al., 2026).

2. Site Selection

For the present study, three sampling sites were selected along the Gomti River within Lucknow city to assess the level and distribution of heavy metal contamination in sediments under different urban influences (Botle et al., 2024). The selected sites represent areas exposed to varying degrees of anthropogenic activities, sewage discharge, traffic density, and hydrological conditions (Gayathri et al., 2021).
The Nishat Ganj Bridge (S1), is situated in a densely populated and highly urbanized area of Lucknow. This region experiences heavy vehicular traffic, domestic wastewater discharge, and commercial activities, which contribute significantly to pollutant input into the river (A. Singh et al., 2026). The site was selected to evaluate the impact of urban runoff and municipal waste on sediment quality (Gondial & Bharti, 2025b).
The Gomti Barrage Bridge (S2), is an important hydraulic control point where water flow is regulated through the barrage system (ŞIMŞEK et al., 2021). Reduced flow velocity in this section promotes sediment deposition and accumulation of contaminants. The area is also influenced by nearby residential settlements and recreational activities, making it suitable for studying heavy metal enrichment in sediments (Yi et al., 2011).
The Sports Ground area (S3), represents a comparatively less congested section of the river with moderate anthropogenic influence (V. K. Singh et al., 2005). This site was selected to provide comparative information on sediment contamination under relatively lower urban pressure along the Gomti River stretch (Kumar et al., 2020).

3. Sample Collection

Sediment samples were collected from three selected sites along the Gomti River within Lucknow city, namely the 1st site (Nishat Ganj Bridge), 2nd site (Gomti Barrage Bridge), and 3rd site (Sports Ground area) (V. K. Singh et al., 2005). The sampling was carried out to evaluate the concentration and distribution of heavy metals in river sediments under varying urban and anthropogenic influences (V. Singh et al., 2023).
At each site, surface sediment samples were collected from the riverbed using a clean stainless-steel scoop to avoid contamination during sampling (Pujari & Kapoor, 2021). The upper layer of sediment (0–10 cm depth) was carefully collected, as this layer is considered most active in terms of pollutant accumulation and interaction with the aquatic environment (Sharma & Nagpal, 2020). Multiple sub-samples were collected from nearby points at each location and mixed thoroughly to obtain a representative composite sample (Nkwunonwo et al., 2020).
The collected samples were transferred into pre-cleaned polyethylene bags, properly labelled, and transported to the laboratory for further analysis (Zaynab et al., 2022). In the laboratory, the samples were air-dried at room temperature,

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followed by the removal of pebbles, plant residues, and other unwanted materials (Arisekar et al., 2020). The dried samples were then ground gently using a mortar and pestle and sieved through a fine mesh sieve to obtain uniform particle size suitable for physicochemical and heavy metal analysis (Duncan et al., 2018).

Proper precautions were maintained throughout the sampling and handling procedures to minimize external contamination and ensure reliability of analytical results (Sanaei et al., 2021).

4. Quality Assurance and Quality Control (QA/QC)

Quality assurance and quality control (QA/QC) procedures were strictly followed throughout the sampling, preparation, and analytical processes to ensure the accuracy, precision, and reliability of the results obtained in the present study. All sampling equipment and laboratory glassware were thoroughly cleaned and rinsed with distilled water prior to use in order to minimize contamination (USEPA, 2024).

Sediment samples were collected in pre-cleaned polyethylene bags and properly labelled to avoid sample misidentification (Dong et al., 2020; USEPA, 2024). During sample preparation, precautions were taken to prevent cross-contamination between samples. The samples were air-dried under controlled laboratory conditions, and non-sediment materials such as stones, plant debris, and other impurities were carefully removed before analysis (Yi et al., 2011).

Analytical measurements were carried out using standard laboratory procedures and calibrated instruments (Kumar et al., 2020). Reagent blanks and duplicate samples were analysed periodically to check the precision and consistency of the analytical results. Standard reference materials and certified chemicals were used wherever applicable for instrument calibration and validation of analytical accuracy (Sharma & Nagpal, 2020).

All chemicals and reagents used in the study were of analytical grade, and distilled or deionized water was used throughout the experimental work. The obtained data were carefully verified and statistically examined to ensure reliability and reproducibility (Munir et al., 2021; Pujari & Kapoor, 2021). These QA/QC measures helped maintain the overall quality and credibility of the analytical findings related to heavy metal contamination in the Gomti River sediments (Nkwunonwo et al., 2020).

III. POLLUTION ASSESSMENT

1. The Enrichment Factor (EF)

CF Value	Contamination Level
CF < 1	Low contamination
1 – 3	Moderate contamination
3 – 6	Considerable contamination
CF > 6	Very high contamination

The Enrichment Factor (EF) is used to evaluate the degree of anthropogenic influence on heavy metal accumulation in sediments by comparing metal concentrations with background values (Arisekar et al., 2020). Iron (Fe) is commonly used as the reference element due to its natural abundance and stability (Duncan et al., 2018).

$$EF = \frac{\left(\frac{C_M}{C_{Fe}}\right)_{sample}}{\left(\frac{C_{M(bg)}}{C_{Fe}}\right)_{background}}$$

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Where, C_M = measured concentration of the heavy metal (Arisekar et al., 2020; Duncan et al., 2018) CM(bg) = concentration of the iron (Fe) metal in the sediment (Kumar et al., 2020; V. K. Singh et al., 2005) C_{Fe} = background concentration of the heavy metal(ŞIMŞEK et al., 2021).

Table 1. Standard Classification of Enrichment Factor (EF) (Kumar et al., 2020; V. Singh et al., 2023)

EF Value	Degree of Enrichment
EF < 2	Deficiency to minimal enrichment
2 – 5	Moderate enrichment
5 – 20	Significant enrichment
20 – 40	Very high enrichment
EF > 40	Extremely high enrichment

2. Contamination Factor (CF)

The Contamination Factor (CF) is used to determine the level of heavy metal contamination in sediments by comparing the measured concentration of a metal with its background concentration (Arisekar et al., 2020).

Where, Csample represents the concentration of the metal in the sediment sample, (Duncan et al., 2018) Cbackground

$$CF = \frac{C_{sample}}{C_{background}}$$

is the background concentration of the respective metal.

Table 2. Contamination Level Classification Using CF Values(Arisekar et al., 2020; Duncan et al., 2018)

CF Value	Contamination Level
CF < 1	Low contamination
1 – 3	Moderate contamination
3 – 6	Considerable contamination
CF > 6	Very high contamination

3. Pollution Load Index (PLI)

The Pollution Load Index (PLI) is used to evaluate the overall level of heavy metal pollution in sediments at a particular site. It provides a combined assessment of contamination by different metals (Sanaei et al., 2021).

$$\mathrm{PLI} = \sqrt[n]{(\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times \cdots \times \mathrm{CF}_n)}$$

Where:

CF represents the contamination factor of each metal and n is the number of metals analysed (Tchounwou et al., 2012).

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Table 3. Classification of Pollution Load Index (PLI) Values and Pollution Status(Sall et al., 2020)

PLI Value	Pollution Status
PLI < 1	No pollution
PLI = 1	Baseline level of pollution
PLI > 1	Progressive deterioration of sediment quality

IV. RESULTS AND DISCUSSION

1. Heavy Metal Concentration in Sediments

The concentrations of heavy metals in sediment samples collected from the Gomti River showed considerable variation among the selected sampling sites. Chromium (Cr) concentrations ranged from 145.781 to 227.980 mg/kg, with the highest concentration observed at the Gomti Barrage site (S2), indicating a greater influence of urban and anthropogenic activities in this region. Iron (Fe) was found in the highest concentration among all analysed metals, varying between 20640.038 and 21540.076 mg/kg, which reflects its natural abundance in sediments.

Table 4. Concentration and Statistical Analysis of Heavy Metals in Sediments of the Gomti River

Heavy Metals	Nishat Ganj Bridge (S1)	Gomti Barrage (S2)	Sports Ground Area (S3)	Min	Max	Mean	SD	CV (%)
Cr	145.78	227.98	174.25	145.78	227.98	182.67	41.74	22.85
Fe	20640.03	21496.83	21540.07	20640.03	21540.07	21225.64	507.61	2.39
Cd	0.40	0.35	16.35	0.35	16.35	5.70	9.22	161.71
Zn	91.28	92.05	417.53	91.28	417.53	200.28	188.13	93.93

Cadmium (Cd) concentrations showed significant variation, ranging from 0.350 to 16.358 mg/kg. The highest Cd concentration was recorded at the Sports Ground area (S3), suggesting possible localized contamination from urban runoff and human activities. Zinc (Zn) concentrations varied from 91.288 to 417.530 mg/kg, with the maximum concentration also observed at the Mini Stadium site.

The statistical analysis indicated relatively low variation for Fe (CV = 2.392%), whereas Cd (CV = 161.715%) and Zn (CV = 93.932%) exhibited high variability, reflecting uneven distribution and strong anthropogenic influence. Overall, the results demonstrate the accumulation of heavy metals in the Gomti River sediments and indicate varying pollution intensity across the selected sites.

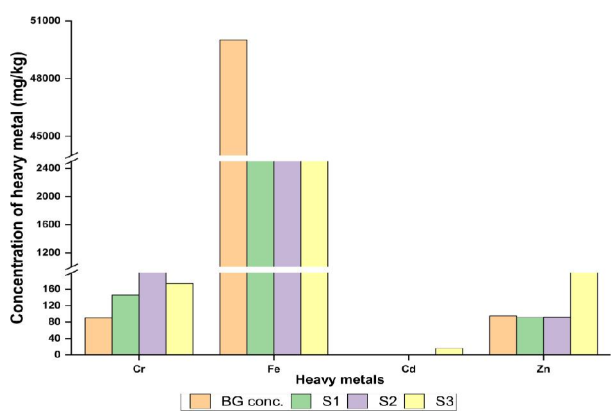

Fig 2. Comparison of Background and Observed Heavy Metal Concentrations in Sediment Samples

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2. Enrichment Factor (EF)

The Enrichment Factor (EF) analysis indicated varying degrees of heavy metal enrichment in the sediment samples collected from the Gomti River. Chromium (Cr) showed moderate to significant enrichment, with EF values ranging from 3.92 to 5.89, suggesting the influence of anthropogenic activities such as urban runoff and wastewater discharge.

Iron (Fe), used as the reference element, exhibited an EF value of 1 at all sampling sites, indicating its natural crustal origin and negligible anthropogenic contribution.

Table 5. Enrichment Factor Analysis of Heavy Metals in Sediment Samples from the Gomti River

Heavy Metals	EF1	EF2	EF3	Min	Max	Mean	SD
Cr	3.92	5.89	4.49	3.92	5.89	4.77	1.00
Fe	1.00	1. 00	1.00	1.00	1.00	1.00	0.00
Cd	3.28	2.71	126.57	2.71	126.57	44.19	71.81
Zn	2.32	2.27	10.20	2.25	10.20	4.92	4.55

Cadmium (Cd) showed the highest enrichment among all analysed metals, with EF values ranging from 2.71 to 126.57. The extremely high EF value observed at the Sports Ground area indicates severe anthropogenic contamination and substantial metal accumulation in sediments. Zinc (Zn) displayed moderate enrichment at Nishat Ganj Bridge and Gomti Barrage, while significant enrichment was observed at the Sports Ground area.

The statistical analysis revealed high standard deviation values for Cd and Zn, indicating considerable spatial variation in contamination levels among the sampling sites. Overall, the EF results suggest that anthropogenic activities play a major role in heavy metal accumulation in the Gomti River sediments, particularly for Cd and Zn.

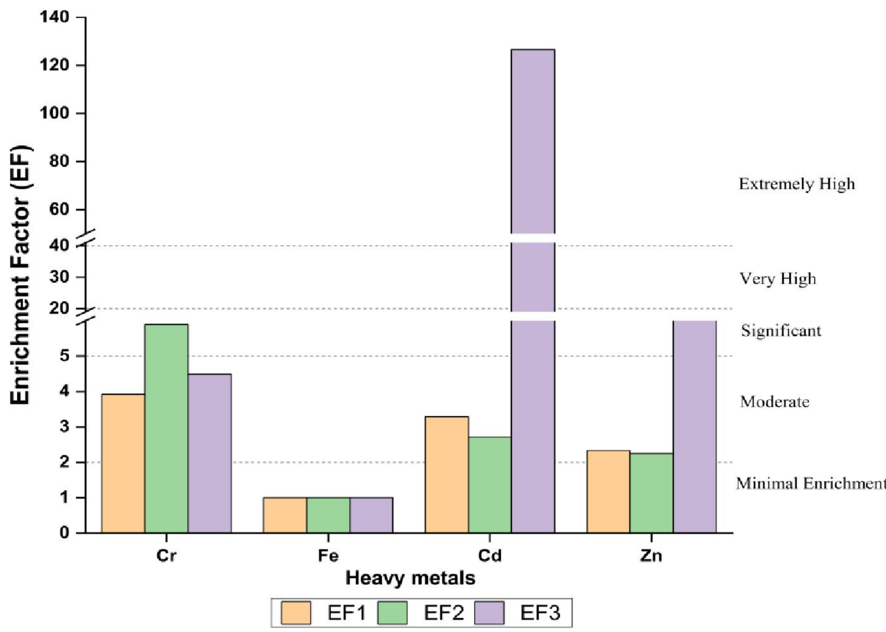

Fig 3. Enrichment Classification of Heavy Metals in Sediment Samples from the Gomti River

3. Contamination Factor (CF)

The Contamination Factor (CF) analysis revealed different levels of heavy metal contamination in the sediment samples collected from the Gomti River. Chromium (Cr) showed CF values ranging from 1.61 to 2.53, indicating moderate contamination at all sampling sites. The highest Cr contamination was observed at Gomti Barrage, suggesting greater anthropogenic influence in this region.

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Iron (Fe) exhibited CF values below 1 at all sites, indicating low contamination and confirming its predominantly natural origin in the river sediments. Cadmium (Cd) showed the highest contamination among all analysed metals. CF values for Cd ranged from 1.16 to 54.52, with extremely high contamination recorded at the Sports Ground area. This indicates severe anthropogenic input and significant accumulation of Cd in the sediments.

Zinc (Zn) showed low contamination at Nishat Ganj Bridge and Gomti Barrage, while considerable contamination was observed at the Sports Ground area with a CF value of 4.39. The high standard deviation values for Cd and Zn indicate substantial spatial variation in contamination levels among the selected sites.

Overall, the CF analysis suggests that anthropogenic activities significantly influence heavy metal accumulation in the Gomti River sediments, particularly for Cd and Zn contamination.

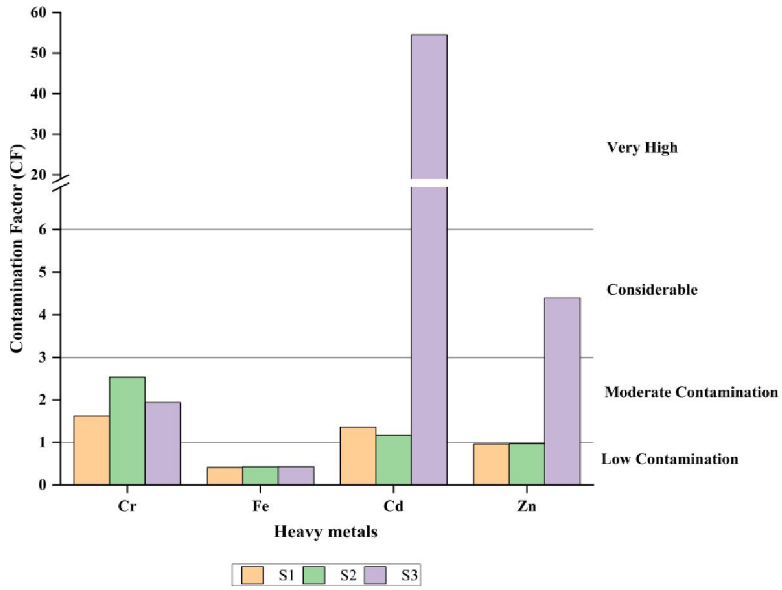

Fig 4. Distribution of Contamination Factor (CF) Values for Heavy Metals Along the Gomti River

4. Pollution Load Index (PLI)

The Pollution Load Index (PLI) was used to evaluate the overall level of heavy metal pollution in the sediment samples collected from the Gomti River. The calculated PLI values for Nishat Ganj Bridge, Gomti Barrage, and Sports Ground area were 4.35, 5.09, and 61.28, respectively. Since all PLI values were greater than 1, the sediments at all sampling sites were considered polluted, indicating progressive deterioration of sediment quality due to heavy metal accumulation.

Table 6. Statistical Summary of Contamination Factor (CF) and Pollution Load Index (PLI) of Heavy Metals in Gomti River Sediments

Heavy Metals	CF1	CF2	CF3	Min	Max	Mean	SD
Cr	1.61	2.53	1.93	1.61	2.53	2.02	0.46
Fe	0.412	0.42	0.43	0.41	0.43	0.42	0.01
Cd	1.35	1.16	54.52	1.16	54.52	19.01	30.89
Zn	0.96	0.96	4.39	0.96	4.39	2.10	1.97
PLI	4.35	5.09	61.28	4.35	61.28	23.57	32.55

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Among the selected sites, the highest PLI value was observed at the Sports Ground area, suggesting severe overall contamination and strong anthropogenic influence. The elevated PLI at this location may be associated with urban runoff, wastewater discharge, and accumulation of pollutants in river sediments. Gomti Barrage also showed a relatively high PLI value, which may be related to reduced water flow and enhanced sediment deposition near the barrage region.

The comparatively lower PLI value at Nishat Ganj Bridge still indicated significant pollution status. Overall, the PLI results demonstrate considerable heavy metal contamination in the Gomti River sediments and highlight the impact of urban and human activities on sediment quality within the Lucknow city stretch.

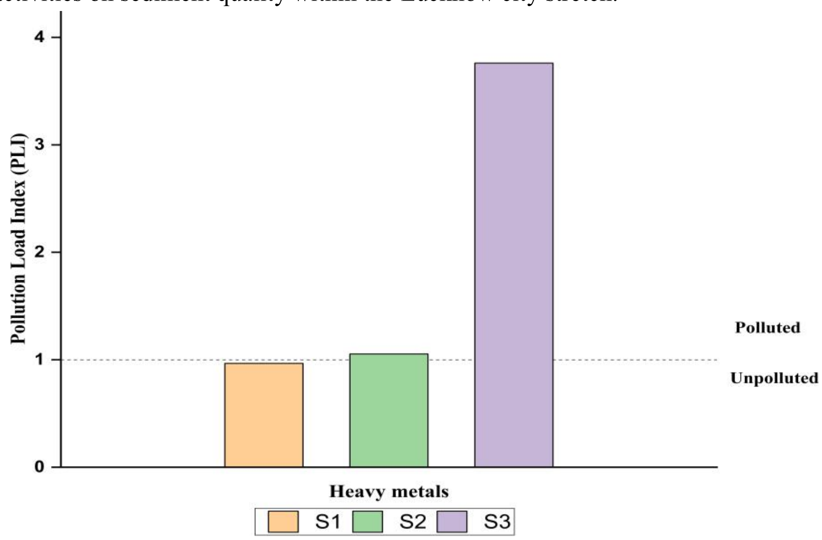

Fig 5. Comparative Pollution Load Index (PLI) at Selected Sampling Sites of the Gomti River

V. CONCLUSION

The present study evaluated heavy metal contamination in the sediments of the Gomti River along the Lucknow city stretch using concentration analysis and pollution assessment indices including Enrichment Factor (EF), Contamination Factor (CF), and Pollution Load Index (PLI). The results clearly indicated that the river sediments are considerably influenced by anthropogenic activities such as urban runoff, sewage discharge, traffic emissions, and other municipal inputs.

Among the analysed heavy metals, iron (Fe) showed the highest concentration at all sampling sites, ranging from 20640.038 to 21540.076 mg/kg, reflecting its natural abundance in sediments. Chromium (Cr) concentrations varied between 145.781 and 227.980 mg/kg, with the maximum concentration observed at Gomti Barrage, indicating moderate contamination due to urban and wastewater inputs. Zinc (Zn) concentrations ranged from 91.288 to 417.530 mg/kg, while cadmium (Cd) showed extremely high variation, ranging from 0.350 to 16.358 mg/kg. The highest Cd and Zn concentrations were recorded at the Sports Ground area, suggesting strong localized anthropogenic influence and pollutant accumulation.

The EF analysis revealed moderate to significant enrichment of Cr (3.92–5.89) and Zn (2.25–10.20), whereas Cd exhibited extremely high enrichment with a maximum EF value of 126.57 at the Sports Ground area. Iron maintained an EF value of 1 at all sites, confirming its natural origin. Similarly, CF values indicated moderate contamination for Cr and extremely high contamination for Cd, particularly at the Sports Ground area where the CF value reached 54.52. Zinc showed considerable contamination at the same site, while Fe remained within low contamination levels.

The Pollution Load Index values for Nishat Ganj Bridge, Gomti Barrage, and Sports Ground area were 4.35, 5.09, and 61.28, respectively. Since all PLI values were greater than 1, the sediments were classified as polluted. The exceptionally high PLI value at the Sports Ground area indicates severe deterioration of sediment quality and substantial heavy metal accumulation.

Overall, the study demonstrates that the Gomti River sediments within Lucknow city are significantly contaminated by heavy metals, particularly cadmium and zinc. The findings highlight the urgent need for continuous environmental monitoring, effective wastewater treatment, and implementation of pollution control measures to minimize further degradation of the river ecosystem and protect aquatic as well as human health.

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