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Assessment of Trace Element Pollution in Indian Rivers: Development of a Pollution Index and Implications for Water Quality Management

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Abstract

India faces substantial environmental and human health concerns as a result of water pollution caused by trace elements. This study aims to evaluate the contamination of trace elements in Indian rivers and create a Pollution Index as a means of assessing water quality. The Trace Element Pollution Index (TEPI) is utilized to assess pollution levels and pinpoint regions of concern by analyzing data from many river basins. The TEPI readings indicate extensive pollution, especially in heavily industrialized areas like the Gangetic plains. We analyzed the consequences of these discoveries for the management of water quality and emphasize the significance of initiatives such as the Namami Gange Project in tackling pollution and protecting freshwater resources. The report highlights the immediate requirement for comprehensive actions to reduce trace element pollution and guarantee the sustainable management of India's river systems.

Keywords: Environmental management, Indian rivers, Pollution index, Trace elements, Water quality

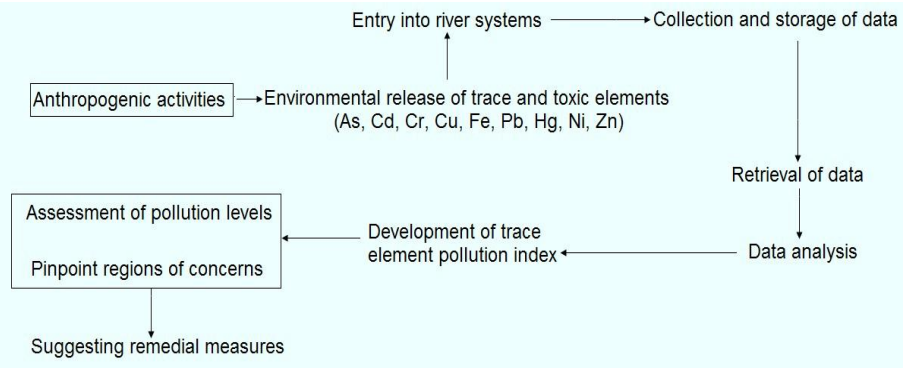

Figure 1: Graphical summary

INTRODUCTION

Rivers serve as vital conduits for civilizations, providing nourishment to ecosystems, supporting livelihoods, and influencing cultural development. Rivers in India hold significance that extends beyond their hydrological value. They are considered sacred and play a crucial role in the spiritual, social, and economic aspects of the country. Nevertheless, Indian rivers are currently encountering unparalleled challenges due to pollution, including contamination caused by trace elements, notwithstanding their cultural value and ecological relevance. The decline in water quality in these rivers presents significant hazards to human health, biodiversity, and ecosystem services, requiring immediate attention and efficient management techniques.

Importance of Indian Rivers*:*

The rivers of India play a crucial role in the country's geography, history, and mythology. Indian rivers such as the Ganga, Yamuna, Brahmaputra, and Godavari have profoundly influenced landscapes, nurtured ancient civilizations, and maintained diverse ecosystems for thousands of years. These rivers serve as both freshwater sources and repository of cultural heritage, religious beliefs, and biodiversity hotspots. Rivers function as channels for the movement of people and goods, as well as for the distribution of water for agricultural purposes and the production of hydroelectric power. This plays a crucial role in the overall progress of the nation's social and economic development (Bassi and Katyaini, 2023).

Escalating Threats to Water Quality:

Indian rivers are facing significant strain as a result of human activities such as industrialization, urbanization, intensified agriculture, and inadequate waste management techniques, despite their great significance. The release of untreated industrial effluents, urban sewage, agricultural runoff, and solid waste into rivers has resulted in the degradation of water quality and the buildup of contaminants, such as toxic and trace elements. Consequently, numerous rivers throughout India are currently facing contamination problems, which provide serious risks to human health, aquatic ecosystems, and biodiversity (Sharma *et al.*, 2020).

Understanding Trace Element Pollution:

Trace elements, commonly referred to as heavy metals, are elements that occur naturally and have high atomic weights and densities. Although trace elements are necessary nutrients for organisms in small quantities, high levels of specific heavy metals like arsenic, cadmium, lead, mercury, and chromium can be harmful to both human health and the environment. Industrial discharges, mining activities, agricultural runoff, atmospheric deposition, and municipal waste disposal are all sources of trace element pollution in rivers. After being released into the environment, these pollutants can remain for extended periods, build up in sediments, accumulate in aquatic creatures, and increase in concentration down the food chain. This poses threats to both human health and the overall balance of the ecosystem (Manoj *et al.*, 2015).

Impacts of Trace Element Pollution:

The presence of trace elements in river water has significant consequences for human health, aquatic organisms, and the functioning of ecosystems. Prolonged exposure to high levels of heavy metals through the ingestion of contaminated drinking water, consumption of fish and shellfish that have been contaminated, and the consumption of agricultural produce that has been irrigated with polluted water can result in various health issues. These health problems may include neurological diseases, developmental abnormalities, organ damage, and the development of cancer. Furthermore, the presence of trace element pollution can negatively impact the ability of aquatic organisms to reproduce, disturb the intricate network of food chains, and deteriorate the overall quality of their habitat. This can result in a reduction in biodiversity and a drop in the services provided by the ecosystem (CWC, 2014).

Need for Assessment and Management:

Due to the widespread occurrence and possible health hazards linked to trace element contamination in Indian rivers, there is an immediate requirement for systematic evaluation, surveillance, and implementation of control measures. Monitoring programs and pollution indices are essential for assessing water quality, identifying areas with high pollution levels, and directing efforts to address the issue. An Indian river-specific Pollution Index can offer policymakers, academics, and stakeholders a complete instrument to evaluate and control trace element pollution. Indices that quantify pollution levels, identify pollution sources, and estimate ecological risks can provide valuable information for evidence-based decision-making and help prioritize resource allocation for pollution management strategies (Manoj *et al.*, 2015).

Objectives of the Study:

This study seeks to evaluate the pollution of trace elements in Indian rivers and create a pollution Index to accurately determine the quality of water. Through the examination of data from specific river basins in India, our objective is to measure the degree of contamination caused by trace elements, determine the origins of pollution, and evaluate the potential consequences for both the environment and human well-being. Moreover, our objective is to emphasize the significance of efficient water

quality management measures in reducing trace element contamination and protecting the integrity of Indian River ecosystems. This project aims to enhance the scientific comprehension of trace element contamination in Indian rivers and offer significant insights for policymakers, researchers, and stakeholders involved in water resource management and environmental conservation endeavors.

To summarize, evaluating the presence of small amounts of harmful substances in Indian rivers and creating a Pollution Index are important measures to tackle the increasing risks to water quality and public health. Policymakers and stakeholders can develop evidence-based plans for sustainable water management and environmental protection by comprehending the origins, dispersion, and consequences of trace element pollution. A graphical summary of the investigation is presented in Figure 1.

Materials and Methods

Environmental data of trace elements in the rivers of India was obtained from the report "*Status of trace and toxic metals in Indian rivers*", published by the Central Water Commission, Ministry of Water Resources, Government of India (CWC, 2014). The Trace Element Pollution Index was determined using the formula –

$$TEPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

Where,

W = Unit weightage and is inversely proportional to S.

The Qi value was calculated as:

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} x100$$

Where,

S = Highest permissible values for trace elements in the drinking water.

M = Observed value of the ith parameter.

I = Maximum desirable value of the ith parameter.

The TEPI was computed following the notes of Manoj *et al.* (2015) and for more information the readers are referred to follow the same.

Results and Discussion

The high concentration of trace elements in water bodies, especially rivers, is a major global environmental issue, including in India. This study aimed to examine the presence of trace element pollution in rivers in India and to create a Pollution Index for assessing the quality of water. The findings of our investigation offer unique

perspectives on the magnitude of contamination, pinpoint areas of concentrated pollution, and underscore the consequences for both the ecosystem and human well-being.

Assessment of Trace Element Pollution:

The study conducted an analysis of data from certain river basins in India in order to measure the extent of pollution caused by trace elements. The Trace Element Pollution Index (TEPI) was calculated for each location using measured values of trace elements in relation to acceptable and preferable thresholds. The TEPI exhibited a wide range of values, spanning from 2.79 to 74.82 across different river locations, signifying diverse levels of pollution. The Ganga and its tributaries exhibited elevated TEPI readings, indicating significant pollution, especially in areas with industrial activity. Conversely, rivers in western and northeast India displayed lower TEPI values, indicating comparatively lower pollution levels (Table 1-5).

Factors Contributing to Pollution:

The elevated amounts of trace element pollution reported in specific river basins can be ascribed to several reasons, such as industrial discharges, mining activities, agricultural runoff, and urban sewage. Industrial waste including toxic heavy metals like arsenic, cadmium, and lead significantly contribute to river pollution, particularly in heavily industrialized areas. Furthermore, the inadequate disposal of solid wastes containing perilous metal salts and the utilization of mercury-based pesticides in agriculture boost contamination levels (Bassi and Katyaini, 2023).

Regional Disparities in Pollution Levels:

The investigation we conducted uncovered variations in pollution levels among different regions of Indian rivers. Rivers in the Gangetic plains demonstrated elevated TEPI values, indicating significant pollution, whereas rivers in western and northeast India displayed comparatively lower TEPI values, suggesting a reduced degree of contamination. The geographical variations can be ascribed to disparities in industrialization, urbanization, agricultural techniques, and geological variables. The Ganga basin experiences high pollution levels due to the presence of major industries and urban centers, while areas with less industrial activity have lower pollution levels (Table 1-5).

Implications for Water Quality Management:

The results of our study have important ramifications for the management of water quality and the preservation of the environment in India. Efficient strategies are necessary to reduce trace element contamination and revive the well-being of polluted waterways. To reduce pollution levels, it is crucial to enforce strict pollution control rules, promote cleaner production technologies, embrace sustainable agriculture practices, and expand wastewater treatment facilities. Furthermore, it is imperative to emphasize public awareness initiatives, active community involvement, and meaningful interaction with stakeholders in order to cultivate a mindset of environmental responsibility and advocate for conscientious water consumption (Bassi and Katyaini, 2023).

Policy Interventions and Future Directions:

Effectively addressing trace element pollution in Indian rivers requires a comprehensive strategy that includes legislative interventions, technological advancements, and cooperative initiatives among governments, businesses, academia, and civil society. The government's dedication to eliminating river pollution is exemplified by initiatives like the Namami Gange Project, which focuses on cleaning up the Ganga and its tributaries. Nevertheless, it is imperative to take coordinated measures at both the national and regional levels in order to successfully address the intricate issues presented by trace element pollution. Additionally, it is crucial to conduct ongoing research, monitoring, and evaluation in order to track pollution trends, evaluate the effectiveness of actions taken to reduce pollution, and provide information for decision-making based on evidence (Manoj *et al.*, 2015).

Table 1: TEPI of selected river sites – I

Site Name	River Basin	TEPI	Site Name	River Basin	TEPI
Champasarai	Teesta	32.4	Diana	Diana	17.81
Dhubri	Brahmaputra	15.44	Ghish	Teesta	17.53
Majhitar	Teesta	28.04	Hasimara	Teesta	13.83
Sonapurhat	Damodar	18.26	Coronation	Teesta	15.7
Mathanguri	Manas	30.36	Panbari	Brahmaputra	26.54
Manas NH Crossing	Manas	11.04	Chepan	Ganga	11.8
Mathabhanga	Ichamoti (Ganga)	12.53	Barobisha	Mahananda	11.27
Rangpo	Teesta	14.62	Teesta Bazar	Teesta	15.51
Nagrakata	Jaldhaka	11.74	Mekhliganj	Teesta	16.76
Delhi Railway Bridge	Yamuna	64.62	Neora	Neora	13.97
Jaldhaka NH-31	Brahmaputra	25.21	Tufanganj	Raidak	7.79
Matigara	Damodar	14.88	Tuini	Ganga	9.8
Ghugumari	Torsa	12.19	Paonta	Yamuna	-
Sevoke	Teesta	12.66	Kalanaur	Yamuna	24.64
Palla	Palar	19.95	Mawi	Ganga	8.13
Beki Road Bridge	Beki	21.13	Galeta	Hindon	48.14
Chel	Chel	22.03	Mohana Mohana	Mohana	60.06
Golokganj	Gangadhar	9.62	Gokul Barrage (Mathura)	Yamuna	74.82
SinglaBazar	Barak	13.7	Agra (P.G.)	Yamuna	60.84
Kokrajhar	Brahmaputra	14.21	Auraiya	Ganga	30.86
Sankosh LRP	Brahmaputra	13.38	Etawah	Yamuna	35.44
Murti	Jaldhaka	11.43	Hamirpur	Yamuna	17.72

Table 2: TEPI of selected river sites – II

Site Name	River Basin	TEPI	Site Name	River Basin	TEPI
Ashramam	Tamsa	16.81	Jagibhakatgaon	Brahmaputra	15.93
Kuttyadi	Kuttiyadi	14.46	Bhomoraguri	Brahmaputra	14.84
Tezu	Lohit	18.4	Tezpur	Brahmaputra	20.63
Dholabazar	Brahmaputra	13.06	Seppa	Kameng	16.95
Namsai	Brahmaputra	15.45	Bhalukpong	Brahmaputra	16.13
Margherita	Brahmaputra	14.33	Jiabharali NT Road Xing	Brahmaputra	24.04
Naharkatia	Brahmaputra	13.94	Bihubar	Brahmaputra	19.58
Chenimari	Beki	11	Dibrugarh	Brahmaputra	7.84

Dillighat	Yamuna	13.36	Golaghat	Dhansiri	17.51
Desangpani	Brahmaputra	21.28	Miao	Nao-Dihing	6
Nanglamoraghat	Brahmaputra	16.65	Neamtighat	Brahmaputra	20.68
Sivasagar	Brahmaputra	19.63	Udaypur	Banas	5.01
Bokajan	Brahmaputra	15.39	Tuting	Brahmaputra	11.5
Numaligarh	Brahmaputra	18.24	Passighat	Brahmaputra	20.86
Chouldhowaghat	Ganga	11.57	Puthimari DRF	Brahmaputra	20.88
Badatighat	Narmada	18.22	Pancharatna	Brahmaputra	17.63
Ranganadi NT Road Xing	Brahmaputra	13.04	Suklai	Brahmaputra	25.2
Kheronighat	Kopili	10.02	Dudhnai	Brahmaputra	23.87
Kanpur	Ganga	16.33	Pandu	Ganga	15.15

Table 3: TEPI of selected river sites – III

Site Name	**River Basin**	**TEPI**	**Site Name**	**River Basin**	**TEPI**
Maharo	Mayurakshi	8.63	Champua	Baitarani	17.4
Nutanhat	Ajay	25.88	Govindapur	Barakar	20.13
Talcher	Mahanadi	18.28	Purushottampur	Rushikulya	21.58
Jenapur	Brahmani	15.77	Srikakulam	Nagavali	18.17
Anandpur	Sutlej	21.6	Kashinagar	Kosi	21.49
Tikarpara	Mahanadi	29.75	Fatehgarh	Ganga	42.33
Panposh	Brahmani	18.35	Bareilly	Ganga	46.49
Gomlai	Brahmani	24.86	Dabri Kanpur	Ganga	32.63 43.43
Muri	Subarnarekha	14.95	Ankinghat	Ganga	37.4
Jamshedpur	Subarnarekha	32.45	Bhitaura	Ganga	37.88
Adityapur	Kharkai	20.09	Hathidah		16.92
Ghatsila	Subarnarekha	29.87	Azmabad	Ganga	20.13
Tilga	Mahanadi	15.2	Japla	Son	20.06
Jaraikela	Brahmani	13.99	Bamnidih	Ganga	26.15
Farakka / H/R	Ganga	11.09	Kumhari	Karun	15.68
English Bazar	Ganga	28.07	Pauni	Wainganga	30.93
Labha	Fulahar	17.67	Ashti	Ashti	32.7
Berhampore	Ganga	14.98	Hivra	Hivra	24.64
Katwa	Ganga	12.85	Bamini	Agniyar	38.33
Nandgaon	Sakambari	37.84	Satrapur	Kanhan	19.2
P. G. Bridge	Brahmaputra	32.8	Ambarampalayam	Aliyar	17.13
Bhatpalli	Peddavagu	21.01	Gummanur	Ponnaiyar	12.37
Tekra	Godavari	24.34	Theni	Periyar	7.55
Rajrgaon	Wainganga	27.98	Musiri	Krishna	10.22
Durvesh	Vaitarna	25.55	Koelwar	Sone	54.52
Garudeshwar	Narmada	9.37	Gaya	Ganga	39.38
Chanwada	Barakar	-	Lakhisarai	Kiul(Ganag)	12.02
Pingalwada	Dhadher	21.19	Sripalpur	Punpun	17.14
Motinaroli	Kim	17.99	Lalganj	Narayani	15.04
Vapi	Daman Ganga	21.75	Tribeni	Ganga	14.09
Hendegir	Damodar	15.29	Sikandarpur	Ghaghra	11.53
Ramgarh	Ganga	7.07	Hayaghat	Bagmati	25.01
Jamtara	Ganga	2.79	Dheng Bridge	Bagmati	11.47

Table 4: TEPI of selected river sites – IV

Site Name	River Basin	TEPI	Site Name	River Basin	TEPI
Elunuthimangalam	Ponnaiyar	30.89	Sawki	Dawki	20.62
Kudlur	Kudumbur	12.21	Badar Pur Ghat (B.P. Ghat)	Barak	17.95
Pratappur	Yamuna	44.33	Sibbari	Barak	18.78
Seondha	Sindh	41.19	Matijuri	Brahmaputra	21.15
Rajghat	Betwa	30.07	Fulertal	Barak	18.93
Shahijina	Betwa	24.03	Fakirabazar	Barak	23.11
Garrauli	Ghaghara	50.64	Gumrabazar	Ganga	21.78
Kora	Panjkora	72.62	Sankalan	Brahmaputra/Tista	13.66
Banda	Bhadar	49.32	Behalpur	Indus	11.64
Dholpur	Chambal	37.22	Gajaldoba	Teesta	23.56
Kogaon	Bhima	12.87	Kulsi	Brahmaputra	14.23
Ayilam	Vamanapuram	15.36	Aie NH Crossing	Manas	14.11
Sonapur	Brahmaputra	15.17	Domohani	Brahmaputra	19.89
Matunga	Mithi	18.57	Jammu Tawi	Chenab	7.2
Pagladiya; N. T. Road; Xing	Brahmaputra	16.19	Akhnoor	Chenab	12.94
A.P. Ghat	Krishna	17.66	Tandi	Chandrabhaga	52
Therriaghat	Teesta	23.53	Udaipur	Ahar(Yamuna)	17.01
Dholai	Barak	28.04	Sangam	Ganga	7.61
Dimapara	Brahmaputra	23.09	Ram Munshi Bagh	Jhelum	11.13
Kharkhana	Krishna	26.42	Dhamkund	Chenab	8.19
Prem Nagar	Ganga	24.99	Rangeli	Rangpo	21.14
Safapora	Sind	11.46	Paderdibadi	Mahi	57.07
Tehri	Bhagirathi	14.31	Khanputr	Haro	16.48
Rishikesh	Ganga	19.31	Burhanpur	Tapti	24.13
Uttarkashi	Ganga	16.94	Gopalkheda	Meshwo	16.68
Deoprayag	Ganga	22.81	Gadat	Ambika	12.25
Rudraprayag	Ganga	25.57	Mahuwa	Baya Nadi (Ganga)	18.53
Mataji	Tawi	14.92			

Table 5: TEPI of selected river sites – V

Site Name	River Basin	TEPI	Site Name	River Basin	TEPI
Jhanjharpur	Kamala	15.3	Polavaram	Godavari	20.62
Jai Nagar	Kamala	13.49	Konta	Godavari	12.77
Ekmighat	Adhwara	30.8	Bhadrachalam	Godavari	17.91
Baltara	SaptKosi(Ganga)	32.36	Perur	Noyyal	9.6
Dindori	Narmada	22	Pathagudem	Indravati	8.6
Manot	Narmada	20.32	Jagdalpur	Indravati	21.01
Mohgaon	Narmada	14.64	Mancherial	Godavari	12.34
Patan	Saraswati	14.3	Paleru Bridge	Krishna	13.81
Belkhedi	Pench	13.01	Bawapuram	Bhima	18.91
Bamanghat	Piyali (Ganga)	12.25	Damarcherla	Musi	17.65
Gadarwara	Narmada	14.71	Halia	Krishna	21.74
Sandia	Narmada	15.54	Keesara	Krishna	-
Hoshangabad	Narmada	13.59	Malkhed	Bhima	-
Chhidgaon	Betwa	13.63	Badalapur	Barvi	13.77
Handia	Narmada	11.02	Mandleshwar	Narmada	30.29

Importance of Addressing Trace Element Pollution:

This study's findings emphasize the substantial environmental and public health hazards linked to trace element pollution in Indian rivers. Prolonged exposure to high levels of heavy metals and other pollutants presents significant health risks to both humans and aquatic ecosystems. Hence, it is crucial to tackle the issue of trace element contamination in order to preserve environmental integrity, guarantee the availability of safe drinking water, and safeguard human health.

Need for Multi-Faceted Interventions:

To address trace element contamination, a comprehensive strategy is needed that combines policy interventions, technical advancements, and community engagement efforts. Government agencies, industries, academic institutions, and civil society organizations should cooperate to create and execute efficient pollution control policies. This includes the implementation of rigorous laws, the encouragement of more environmentally friendly production methods, and the enhancement of wastewater treatment facilities.

Role of Stakeholder Collaboration:

Efficient water quality management requires the active involvement of all stakeholders, such as government entities, industries, local communities, and non-governmental organizations. Stakeholder engagement is crucial for creating awareness, mobilizing resources, and promoting collective action to tackle environmental concerns. Through the active involvement of stakeholders in decision-making processes and the promotion of transparency and accountability, it is possible to design and implement sustainable solutions.

Policy Implications and Future Directions:

The results of this study have significant policy implications for the management of water resources in India. Policymakers should give top priority to safeguarding and rejuvenating river ecosystems through the implementation of strong pollution control measures and the allocation of resources towards sustainable water management techniques. Furthermore, it is imperative to prioritize the reinforcement of regulatory frameworks, the improvement of monitoring and enforcement procedures, and the promotion of environmentally sustainable technologies.

Research and Monitoring:

Ongoing investigation and surveillance are crucial for monitoring pollution patterns, evaluating the efficiency of actions to reduce its impact, and detecting newly recognized harmful substances. It is necessary to construct long-term monitoring programs in order to get dependable data on water quality metrics and trace element concentrations in rivers across various locations. This will enhance the process of making decisions based on evidence and enable the use of adaptive management strategies.

Public Awareness and Education:

Public awareness and education initiatives are essential in cultivating a culture of environmental stewardship and advocating proper water usage practices. It is necessary to make efforts to increase awareness regarding the negative effects of trace element pollution, enable communities to take action, and enhance the ability to manage water resources in a sustainable manner. Education initiatives should focus on reaching a wide range of people, such as legislators, industry stakeholders, and the general public.

Ultimately, the evaluation of the presence of harmful substances in Indian rivers and the creation of a Pollution Index offer significant understanding of the condition of water purity and the difficulties caused by pollution. India can alleviate the negative effects of trace element contamination on its river ecosystems and water resources by implementing specific interventions, encouraging collaboration among stakeholders, and promoting sustainable behaviors.

Conclusions

An evaluation of the presence of trace elements in Indian rivers, using a Pollution Index, provides important information on the condition of water quality and the level of contamination in various river basins. This study has yielded a thorough comprehension of the variables that contribute to pollution, the consequences for the environment and human well-being, and the variations in pollution levels across different regions. The results emphasize the immediate necessity for aggressive actions to tackle trace element pollution and improve practices for managing water quality in India.

Conflict of Interest

The authors declare no conflict of interest among them.

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