Toxic Metals in Indian Waters: A Systematic Assessment of Lead and Cadmium Contamination and Associated Health Hazards

Janaika Mariz Culaway[1], Princess Erika Dolor[2], Gecelene Estorico[3]

[1]Civil and Allied Department, Chemical Technology Department, Technological University of the Philippines – Taguig Metro Manila 1630 Philippines
[2]De La Salle University – Dasmariñas Cavite 1630 Philippines

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Abstract: Water is fundamental to life and essential for India's economic and ecological stability, supporting agriculture, industry, and domestic needs. However, the quality of India's vital water resources, particularly rivers and groundwater, is increasingly threatened by heavy metal contamination. Lead (Pb) and cadmium (Cd) are heavy metals introduced through anthropogenic activities and natural processes that pose significant risks to human health and environmental integrity. This study analyzes the lead and cadmium concentration from Indian waters through recent scientific studies with the use of the PRISMA system, 15 scientific articles were assessed and narrowed down to 10 articles after applying the inclusion and exclusion criteria. The findings highlight lead (Pb) and cadmium (Cd) in Indian water samples, revealing significant variations. Hyderabad showed pre-monsoon Pb up to 1207 µg/L and Cd up to 0.42 µg/L. Uttara Kannada exhibited significant contamination, with pre-monsoon Pb up to 0.29 mg/L and Cd up to 8.99 mg/L, exceeding safe limits (HQ > 1). Singrauli groundwater had Pb up to 317 µg/L and Cd up to 108 µg/L, also with HQ > 1. The scientific studies show that during seasonal sampling, Pb and Cd have high concentrations compared to non-seasonal sampling. These findings highlight the need for targeted monitoring and mitigation and provide background and reference to future research.

Keywords: *Concentration; Heavy Metal; Industrial; Municipal; Season.*

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I. INTRODUCTION

Water is one of the most essential resources on Earth, integral to sustaining all forms of life and playing a critical role in economic and ecological processes. Beyond its indispensable biological functions, water is vital for various sectors such as agriculture, livestock production, industrial operations, and fisheries, which collectively support human livelihoods and national economies.

In India, rivers and groundwater serve as the primary sources of water, meeting approximately 80% of domestic needs and more than 45% of the nation's irrigation requirements (Kumar et al., 2005). These resources are fundamental to the country's agricultural productivity and food security, underscoring their significance in sustaining both rural and urban populations.

However, according to Sharma et al. (2021) the quality of water is increasingly compromised by the presence of heavy metals, which pose serious risks to human health and the environment. Anthropogenic activities, including vehicle emissions and the use of leaded gasoline, are primary sources of the toxic heavy metal lead (Pb) in the environment. A substantial portion (approximately 75%) of the lead present in roadside gasoline emissions (roughly 20% of total emissions) is released directly into the atmosphere, contributing to widespread contamination. Cadmium (Cd), another hazardous heavy metal, enters the environment through both natural phenomena, such as volcanic activity and the weathering of metal-bearing rocks, and human activities, including industrial discharges and mining operations.

Lead (Pb) can cause several health effects to humans, like many heavy metal lead can accumulate in bones and higher intake of Pb may be extremely poisonous and dangerous, chronic lead intoxication is linked to Alzheimer's disease (Gupta et al., 2020). Moreover, long term exposure to cadmium (Cd) induces renal damage and high Cd exposure have reported cases of prostate and lung cancer (Idrees et al., 2018).

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II. METHODOLOGY

This systematic review used Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA system) as a guideline in selecting published literature about the Source, Method, and Human and Environmental Risk Synthesis of Lead (Pb) and Cadmium (Cd) in Indian Waters.

➢ *Data Sources*

The published research articles and studies were gathered across established academic search databases such as Google Scholar, Springer Nature, Science Direct (Elsevier), and Journal Geological Society of India. These sources were carefully reviewed and selected by researchers.

➢ *Literature Search*

The researchers used a set of keywords to collect and gather published literature from the search engines. The set of keywords were used as a strategy to obtain relevant studies. The first set of keywords are the general terms used in the researcher's study, such as "Lead", "Pb", "Cadmium", "Cd", "Indian Water", "water", and "India". The second set of keywords are for the parameters of the study, such as "Risk Assessment", "Risk", "Pb and Cd", "assessment", "health risk", and "Human health risk".

The results of the searches from the search engines were limited to scientific papers and journal articles from 2015-2025. The collected reference studies were narrowed by selecting papers based on their title, publication dates, and content information.

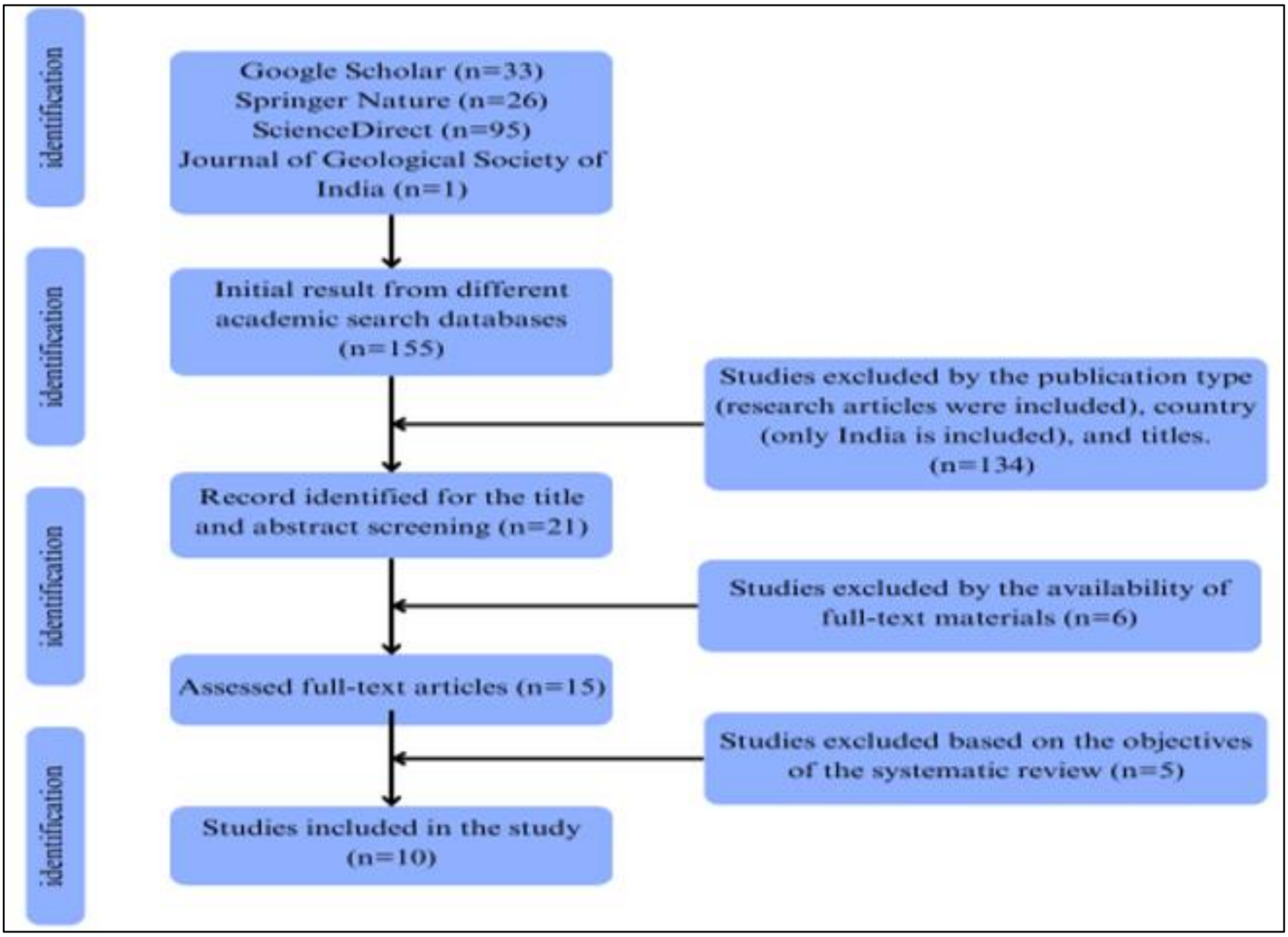

Fig 1 Flow Diagram of the Selection of Studies using the PRISMA Guidelines

➢ *Inclusion and Exclusion*

The studies considered for inclusion in this systematic review were chosen according to specific criteria: (1) Studies that state the source of the contaminants; (2) Studies must contain Pb and Cd contents in water; (3) Studies that include the category of waters being measured; (4) Studies that discuss the method of contaminant determination; (5) Studies that shows the risk quantification of Pb and Cd; (6) Studies published between 2015 - 2025; (7) Quantitative studies; (8) Scientific papers and journal articles; (9)Studies accessible in their complete text form; (10) Studies either originally published in English or translated into English; (11) Studies published from India only.

The exclusion criteria includes: (1) Studies that does not include Lead (Pb) and Cadmium (Cd); (2) Studies that does not provide the following key aspect (source of pollution, determination of pollutant method, risk quantification, and

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human health risk analysis); (3) Commentaries, case reports, or systematic review that lacks original data results; (4) Studies that does not focus on Indian waters (5) Studies published before 2015; (6) Studies published from other countries aside India; (7) Studies not in English language.

➢ *Search Results*

The initial data for search results shows a total of 155: 33 in Google Scholar, 26 in Springer Nature, 95 in Science Direct, and 1 in Journal of Geological Society of India the results are limited to English language research articles published between 2015-2025. The 155 initial results are filtered by the inclusion criteria that narrowed the result to 21 articles. Following an additional review of titles, abstract, and availability of full-text materials, 10 were selected for this study. The selection process and result are shown in the PRISMA system flow diagram (Figure 1).

➢ *Data Extraction*

This study is a systematic overview of concentrations of lead (Pb) and cadmium (Cd) in Indian waters and its risk to humans. The studies included were assessed based on their relevance to the topic. The data extracted from each studies has the following content: (1) author and publication year; (2) type of water being assessed; (3) source of lead and cadmium content in water; (4) studies with seasonal and non-seasonal sampling; and (5) the methods used to identify the Pb and Cd content as well as risk quantification.

➢ *Statistical Analysis*

The selected literature is evaluated in terms of its quantitative characteristics. Each research article and journal indicates Lead (Pb) and Cadmium (Cd) in Indian waters with its source, methods of identification, and risk analysis.

III. RESULTS AND DISCUSSION

➢ *Locations of each sampling area.*

The following table (Table 1) summarizes the geographical scope and sampling characteristics of groundwater heavy metal contamination studies conducted across nine Indian states.

Table 1 Sample Location and Type of Water Sample

Location	**Type Of Water Sample**
Kadapa District, Andhra Pradesh state	Municipal
Ghaziabad district, Uttar Pradesh	Municipal
Singhbhum district, Jharkhand state	Municipal
Solapur district, Maharashtra state	Municipal
Varanasi district, Uttar Pradesh state	Municipal
Virudhunagar district, Tamil Nadu state	Industrial
Bokaro district, Jharkhand State	Industrial
Hyderabad district, Andhra Pradesh state	Industrial
Uttara Kannada district, Karnataka state	Industrial
Singrauli district, Madhya Pradesh	Industrial

Studies on heavy metal contamination in groundwater were conducted in nine Indian states: Andhra Pradesh, Uttar Pradesh, Jharkhand, Maharashtra, Tamil Nadu, Karnataka, and Madhya Pradesh. Specific districts included Kadapa, Ghaziabad, Singhbhum, Solapur, Varanasi, Virudhunagar, Bokaro, Hyderabad, Uttara Kannada, and Singrauli. Each study analyzed fewer than 100 samples, primarily collected from hand pumps and bore-wells.

➢ *Concentration of Lead (Pb) and Cadmium (Cd)*

The reviewed articles were organized into two distinct categories based on their sampling methodologies. Studies that incorporated seasonal variations, specifically pre- and post-monsoon sampling, were grouped to assess the Time variations in heavy metal concentrations within groundwater. Conversely, studies with non-seasonal data acquisition or relied measurements were categorized separately. This classification allowed for a comparative analysis of studies that considered seasonal influences against those that provided a snapshot of heavy metal levels, thus highlighting the potential impact of monsoon patterns on groundwater contamination.

➢ *Studies with Non-Seasonal Sampling*

Table 2 presents a comparative analysis of lead and cadmium concentrations in groundwater across various municipal and industrial water sources, summarizing studies that did not differentiate between seasonal variations, and highlighting significant disparities in contamination levels.

Table 2 Concentration of Lead and Cadmium from Studies with Non-Seasonal Sampling

District	**Pb** (mg/L)	**Cd** (mg/L)	**Reference**
Singhbhum	0.08 - 0.42	0.01 - 0.08	Singh, U. K., et. al. (2018)
Solapur	<0.01	<0.003	Mawari, G., et. al. (2022)
Varanasi	0.004 - 0.0138	0.0005 - 0.0346	Chaurasia, A. K., et. al. (2018)
Virudhunagar	0.11 - 0.96	0.03 - 0.05	Raja, V., et. al. (2021)
Bokaro	0.00001 - 0.0076	0.00001 - 0.0032	Mahato, M. K., et. al. (2016)
Singrauli	0.4 - 0.317	0.2 - 0.108	Bhardwaj, S., et. al. (2020)

Each of the concentration level are converted: 1mg/L=1000 µg/L ND:Not determined.

Groundwater assessments across various regions of India revealed a spectrum of lead and cadmium contamination, highlighting the influence of local environmental factors and industrial activities. In municipal water sources, East Singhbhum, Jharkhand (Singh, U. K., et. al. 2018), exhibited the highest lead concentrations, ranging from 0.08 to 0.42 mg/L, and cadmium levels between 0.01 and 0.08 mg/L. Solapur district, Maharashtra (Mawari, G., et. al. 2022), presented a contrasting scenario with consistently low concentrations of both metals, below 0.01 mg/L for lead and 0.003 mg/L for cadmium. Varanasi district, Uttar Pradesh (Chaurasia, A. K., et. al., 2018), showed lead levels between 0.004 and 0.0138 mg/L and cadmium between 0.0005 and 0.0346 mg/L. Shifting to industrial water sources, significantly higher contamination levels were observed. Virudhunagar district, Tamil Nadu (Raja, V., et. al., 2021), reported alarming lead concentrations ranging from 0.11 to 0.96 mg/L, and cadmium levels between 0.03 and 0.05 mg/L. The East Bokaro coalfield in Jharkhand (Mahato, M. K., et. al. 2016) showed lead concentrations from 0.00001 - 0.0076 mg/L and cadmium from 0.00001 - 0.0032 mg/L. The Singrauli industrial belt (Bhardwaj, S., 2020) displayed lead concentrations from 0.4 to 0.317 mg/L and cadmium from 0.2 - 0.108 mg/L. Each unit is converted to a common measure, the articles under the industrial water category clearly display the highest levels of contamination of both lead and cadmium. This comparative analysis underscores the significant impact of industrial activities on groundwater quality, demanding stringent monitoring and potential remediation strategies to protect public health.

➢ *Studies with Seasonal Sampling (Pre- and Post-Monsoon)*

Table 3 presents a comparative analysis of lead and cadmium concentrations in groundwater across various municipal and industrial water sources, highlighting seasonal variations and significant disparities in contamination levels.

Table 3 Concentration of Lead and Cadmium from Studies with Seasonal Sampling (Pre-Monsoon and Post-Monsoon)

District	**Pb (mg/L)**		**Cd (mg/L)**		**Reference**
	Pre	**Post**	**Pre**	**Post**	
Kadapa	ND − 0.175	ND − 0.1702	ND − 0.0253	ND − 0.0281	Reddy, Y. S., & Sunitha, V. (2023)
Ghaziabad	0.087 − 0.552	0.047 − 0.254	ND−0.060	ND − 0.012	Chabukdhara, M., et. al. (2017)
Hyderabad	0.00022 - 1.207	0.02530 − 0.8772	0.00008 - 0.00042	0.0005− 0.0062	Krishna, A. K., & Mohan, K. R. (2014)
Uttara Kannada	0.06 - 0.29	0.03 - 0.17	2.99 - 8.99	1.87 - 7.19	Mishra, S., et. al. (2018)

Each of the concentration level are converted: 1 mg/L =1000 µg/L.1 mg/L = 1000 µg/L

Groundwater contamination by lead and cadmium was assessed across several municipal and Industrial water sources, revealing significant variations in metal concentrations. In the municipal type of water sample, the Cuddapah Basin (Reddy, Y. S., & Sunitha, V., 2023) study reported lead concentrations reaching up to 0.175 mg/L for pre-monsoon, while post-monsoon reached 0.1702 mg/L, to which this indicates substantial contamination. Ghaziabad (Chabukdhara, M., et al., 2017) also exhibited high lead levels, ranging from 0.087 to 0.552 mg/L pre-monsoon and 0.047 to 0.254 mg/L post-monsoon. Cadmium levels in Ghaziabad reached up to 0.06 mg/L pre-monsoon.

Shifting to Industrial water sources, the Hyderabad KIDA (Krishna, A. K., & Mohan, K. R., 2014) site showed alarmingly high lead concentrations, ranging from 0.00022 to 1.207 mg/L pre-monsoon and 0.0253 to 0.8772 mg/L post-monsoon. Cadmium levels in Hyderabad were lower but increased post-monsoon, ranging from 0.08 to 0.42 µg/L pre-monsoon and 0.50 to 6.20 µg/L post-monsoon. However, the Uttara Kannada district (Mishra, S., 2018) presented the most extreme cadmium contamination, with levels ranging from 2.99 to 8.99 mg/L pre-monsoon and 1.87 to 7.19 mg/L post-monsoon. Lead concentrations in Uttara Kannada ranged from 0.06 to 0.29 mg/L pre-monsoon and 0.03 to 0.17 mg/L post-monsoon.

Comparing the sites, the Hyderabad industrial site exhibited the highest lead concentrations, while Uttara Kannada displayed extremely high cadmium levels, several orders of magnitude greater than other sites. The Cuddapah Basin and Ghaziabad municipal sites showed considerable lead contamination. This analysis clearly indicates that Industrial water sources, particularly Uttara Kannada, exhibit significantly higher heavy metal contamination compared to municipal areas.

➢ *Method of Heavy Metal Analysis*

Table 4 summarizes the distribution of analytical techniques used in heavy metal concentration analysis of water samples, showcasing the list of four types of analysis which are ICP-OES, Standard Methods (APHA, 1998), AAS, and ICP-MS.

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Table 4 List of The Articles and Their Respective Methods to Determine the Concentration of Lead and Cadmium.

District	Method of HM Analysis	Type of water sample	Reference
Kadapa	ICP-OES	Municipal	Reddy, Y. S., & Sunitha, V. (2023)
Ghaziabad	Standard Methods (APHA, 1998)	Municipal	Chabukdhara, M., et. al. (2017)
Singhbhum	AAS	Municipal	Singh, U. K., et. al. (2018)
Solapur	ICP-MS	Municipal	Mawari, G., et. al. (2022)
Varanasi	AAS	Municipal	Chaurasia, A. K., et. al. (2018)
Virudhunagar	AAS	Industrial	Raja, V., et. al. (2021)
Bokaro	ICP-MS	Industrial	Mahato, M. K., et. al. (2016)
Hyderabad	ICP-MS	Industrial	Krishna, A. K., & Mohan, K. R. (2014)
Uttara Kannada	AAS	Industrial	Mishra, S., et. al. (2018)
Singrauli	ICP-MS	Industrial	Bhardwaj, S., et. al. (2020)

The analysis of heavy metal concentrations in both municipal and industrial water sources employed a range of analytical techniques. Notably, Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) were each utilized in 40% of the studies, indicating their widespread acceptance and reliability in heavy metal analysis. Additionally, Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and Standard Methods (APHA, 1998) were each used in 10% of the studies. This distribution highlights the prevalence of AAS and ICP-MS as preferred methods for determining heavy metal presence and levels in groundwater and surface water samples, while also acknowledging the use of other established techniques.

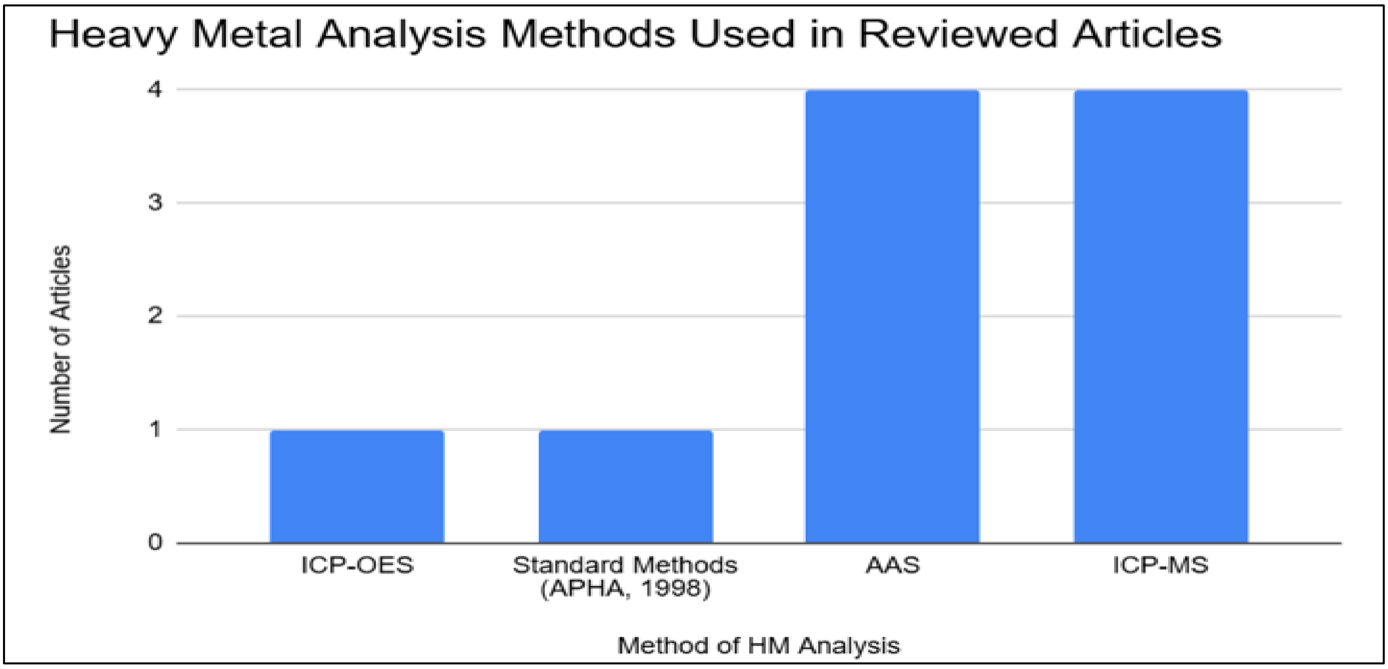

Fig 2 Graphical Chart of Heavy Metal Analysis Methods Used in Reviewed Articles

- *Risk Quantification using Hazard Quotient*

For the assessment of health risks associated with heavy metal exposure, specifically lead and cadmium, this review categorized the selected studies based on their sampling methodologies. Articles were divided into two groups: those employing seasonal sampling (pre- and post-monsoon) and those utilizing non-seasonal. This categorization allowed for a comparative analysis of how seasonal variations impact the Hazard Quotient (HQ). The HQ, a measure of potential non-carcinogenic health risks, was determined in several studies by manually dividing the estimated exposure to lead and cadmium by the reference dose, representing the level at which no adverse effects are anticipated. While many studies calculated Chronic Daily Intake (CDI) as part of their risk assessment, this review focused solely on the reported Hazard Quotients for lead and cadmium to provide a targeted analysis of the potential risks associated with these specific heavy metals across various sampling periods.

- *Studies with Non-Seasonal Sampling.*

Table 5 summarizes the Hazard Quotient (HQ) analysis of lead and cadmium across various municipal and industrial water sources from studies with non-seasonal sampling, highlighting regions with significant health risks and disparities.

Table 5 Risk Quantification Lead and Cadmium Using Hazard Quotient from Studies with Non-Seasonal Sampling.

District	Lead (Pb)	Cadmium (Cd)	HQ_{Pb}	HQ_{Cd}	Type of water	Reference
Singhbhum Adults	0.0145	0.242	<1	<1	Municipal	Singh, U. K., et. al. (2018)
Children	0.00675	1.13	<1	>1		
Solapur	<0.01	<0.003	<1	<1	Municipal	Mawari, G., et. al. (2022)
Varanasi	0.826	3.053	<1	>1	Municipal	Chaurasia, A. K., et. al. (2018)
Virudhunagar	3.8	0.51	>1	<1	Industrial	Raja, V., et. al. (2021)
Bokaro	0.025	0.066	<1	<1	Industrial	Mahato, M. K., et. al. (2016)
Singrauli	7.916	3.44	>1	>1	Industrial	Bhardwaj, S., et. al. (2020)

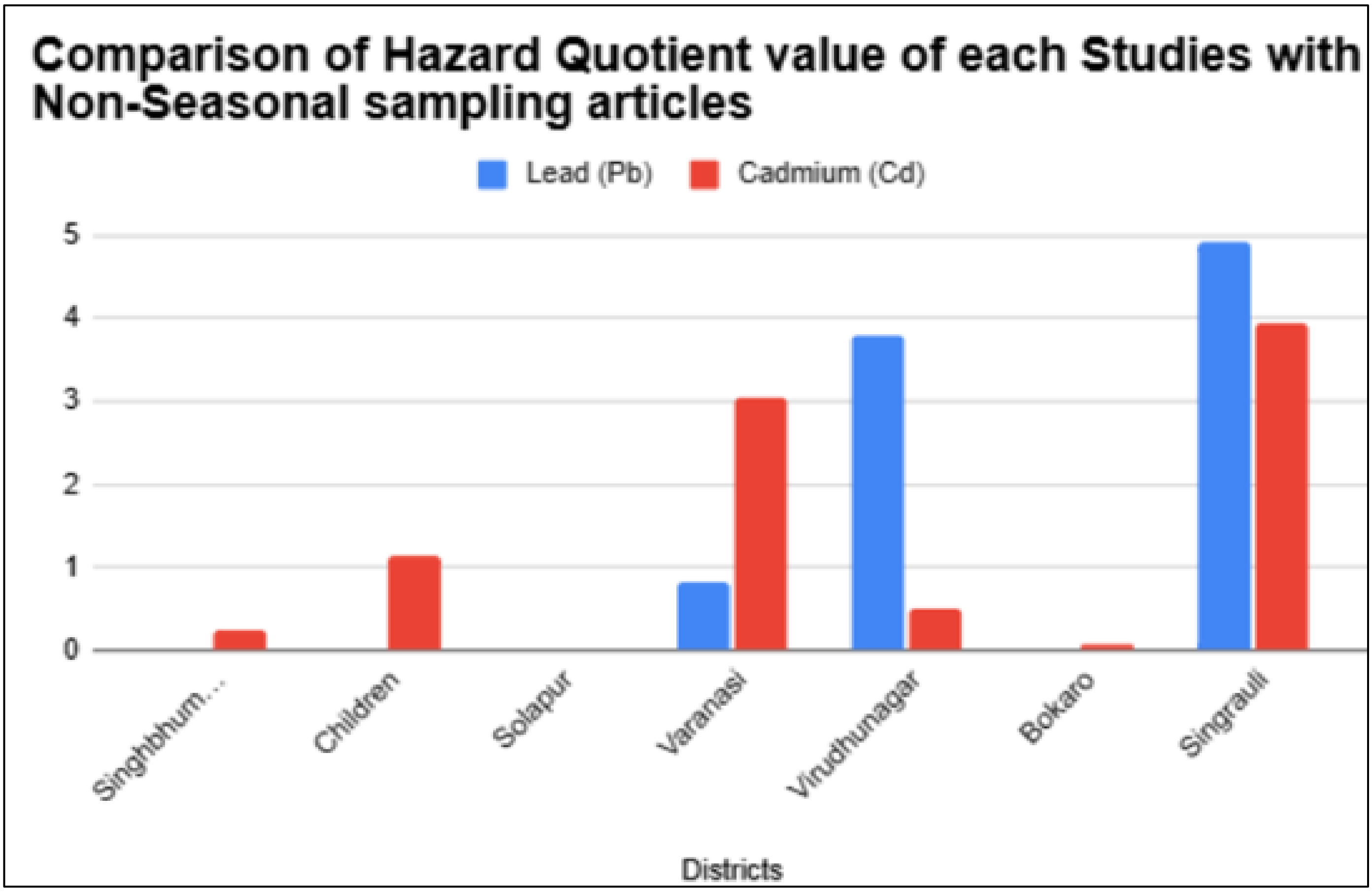

Fig 3 Graphical Representation of the Comparison Between Each Hazard Quotient from Different District That Has No Seasonal Sampling

The assessment of potential health risks through Hazard Quotient (HQ) analysis revealed varying levels of concern across both municipal and industrial water sources. In municipal areas, East Singhbhum, Jharkhand, reported low HQ values for lead and cadmium in adults, but children faced a significant dermal cadmium exposure risk, with HQ exceeding 1. Solapur district, Maharashtra, showed consistently low HQ values for both lead and cadmium, which indicates minimal health risk. In Varanasi district, Uttar Pradesh, lead posed a low risk (HQ < 1), while cadmium showed a significant health risk (HQ > 1).

Among industrial water sources, Virudhunagar district, Tamil Nadu, reported a substantial health risk from lead, with an HQ of 3.8, exceeding the safe limit. Conversely, cadmium in this region showed low risk (HQ < 1). The East Bokaro coalfield in Jharkhand showed low HQ values for both lead and cadmium, which indicates minimal risk. However, the Singrauli industrial belt area exhibited significantly high risks from both lead and cadmium, with HQ values of 7.916 and 3.44, respectively, both exceeding 1.

➢ *Studies with Seasonal Sampling (Pre- and Post-Monsoon)*

The following table summarizes the Hazard Quotient (HQ) analysis of lead and cadmium across municipal and industrial water sources from studies with seasonal sampling (pre-monsoon and post-monsoon), highlighting areas with significant health risks and seasonal variations.

Table 6 Risk Quantification Lead and Cadmium Using Hazard Quotient from Studies with Seasonal Sampling (Pre-Monsoon and Post-Monsoon)

District	Lead (Pb)		Cadmium(Cd)		HQ Result				Type of water	Reference
					Pre		Post			
	Pre	Post	Pre	Post	HQ_{Pb}	HQ_{Cd}	HQ_{Pb}	HQ_{Cd}		
Kadapa	2.046	0.088	0	0	>1	<1	<1	<1	Municipal	Reddy, Y. S., & Sunitha, V. (2023)
Ghaziabad	2.4	1.23	2.1	<1	>1	>1	>1	<1	Municipal	Chabukdhara, M., et. al. (2017)
Hyderabad	0.063	0.002	0.001	0	<1	<1	<1	<1	Industrial	Krishna, A. K., & Mohan, K. R. (2014)
Uttara Kannada	1.4	0.9	620	456	>1	>1	<1	>1	Industrial	Mishra, S., et. al. (2018)

The assessment of potential health risks through Hazard Quotient (HQ) analysis revealed varying degrees of concern across municipal and industrial water sources. In the municipal type of water samples (Table 5), Ghaziabad showed a substantial health risk from both lead and cadmium during the pre-monsoon season, with HQ values exceeding 1. Post-monsoon, lead still posed a significant risk (HQ > 1), while cadmium risk decreased (HQ < 1). In East Singhbhum, Jharkhand, adults showed low HQ values for both lead and cadmium, and children showed low HQ for lead. However, children faced a significant dermal cadmium exposure risk, with HQ exceeding 1.

Moving to industrial water sources (Table 6), the Hyderabad KIDA site, despite high lead and cadmium concentrations, reported low HQ values for both metals in both seasons, based on average exposure. However, it was still emphasized that the high lead levels are a serious concern. In contrast, the Uttara Kannada district revealed a potential health risk from lead during the pre-monsoon season (HQ=1.4). More alarmingly, cadmium posed extremely high health risks, with HQ values of 620 and 456 during pre- and post-monsoon seasons, respectively, significantly exceeding the safe limit of 1.

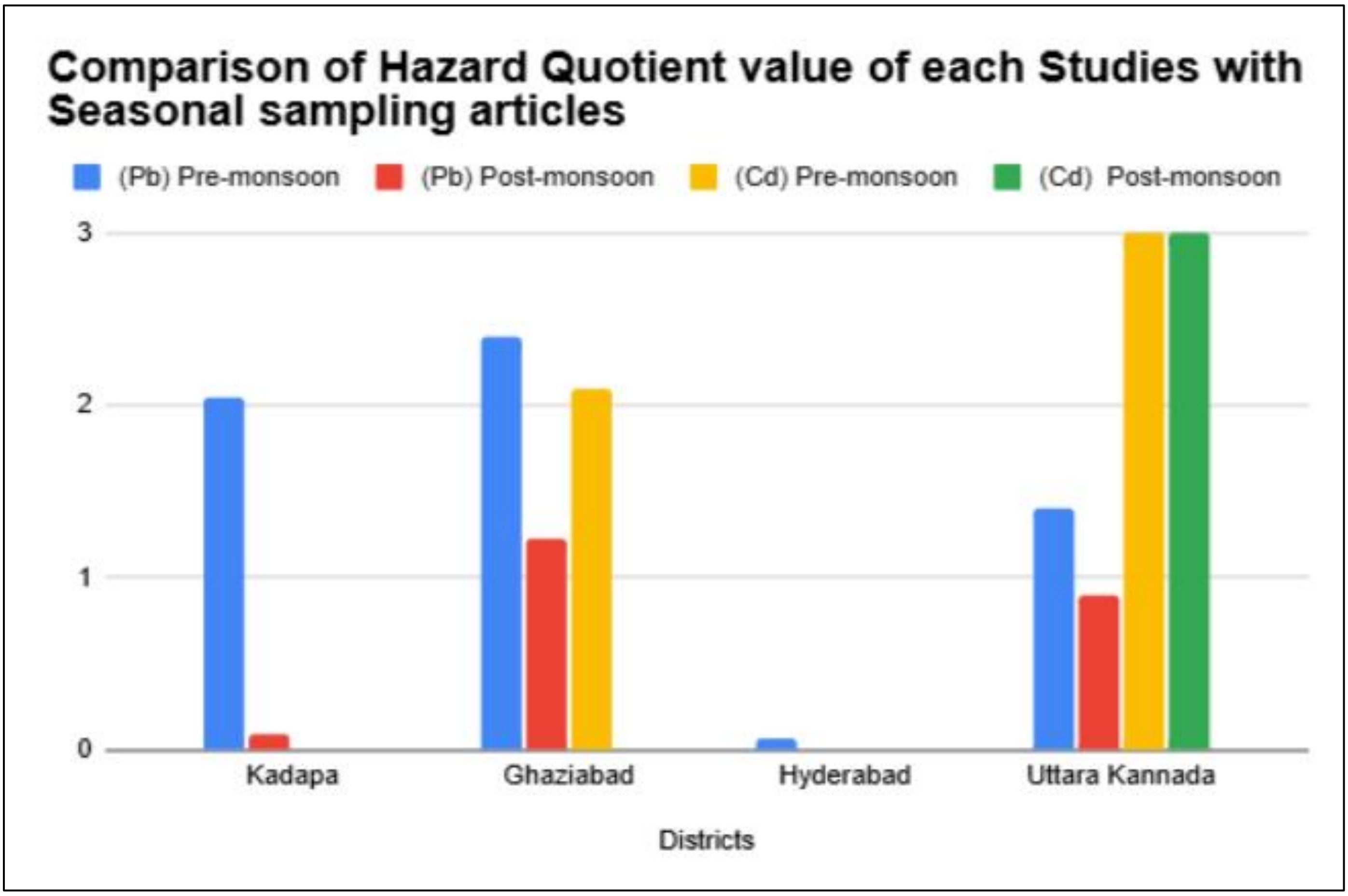

Fig 4 Graphical representation of the Comparison between each Hazard Quotient from different District that has seasonal sampling

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➢ *Comparative Analysis*

The seasonal variability of Hazard Quotient (HQ) values across the studied districts reveals a critical dependency of human health risk on temporal factors, particularly monsoon patterns. In Ghaziabad, a marked reduction in cadmium-related health risk post-monsoon suggests that dilution or altered contaminant mobilization during the rainy season can significantly influence exposure. Conversely, Uttara Kannada demonstrated persistently extreme cadmium risks (Fig. 4), albeit with a slight decrease post-monsoon, underscoring the severity of contamination regardless of seasonal shifts. This highlights that while monsoon events can modulate heavy metal concentrations, certain sites retain alarmingly high risk levels. The observed fluctuations emphasize the limitation of single-point-in-time assessments and reinforce the necessity for longitudinal seasonal sampling to accurately characterize and mitigate potential health hazards arising from heavy metal contamination in water sources.

The data indicates that relying on non-seasonal sampling, as seen in the studies of East Singhbhum, Solapur, Varanasi, Virudhunagar, Bokaro, and Singrauli, provides only a snapshot of contamination levels. These single-point measurements fail to capture the potential fluctuations driven by seasonal changes, potentially underestimating or overestimating the actual risk. For instance, if a sample is taken during a period of low rainfall, it might not reflect the elevated metal concentrations that occur during heavy monsoon periods.

The significance of seasonal sampling lies in its ability to provide a more holistic understanding of groundwater contamination. It allows for the identification of critical periods of high risk, such as pre-monsoon phases with concentrated contaminants, and helps in formulating effective mitigation strategies. By contrast, single-point sampling can lead to misleading conclusions, potentially overlooking the dynamic nature of contaminant behavior.

Table 7 Compilation of Raw Data from Municipal Water Source Articles: Location, Heavy Metal Concentration, Methodology, and Risk Quantification

<table>
<tr><th colspan="7">Source: Municipal water</th></tr>
<tr><th rowspan="2">#</th><th rowspan="2">Location and type of water sample</th><th colspan="2">Concentration</th><th rowspan="2">Method of HM Analysis</th><th rowspan="2">Risk Quantification</th><th rowspan="2">Reference</th></tr>
<tr><th>Lead (Pb):</th><th>Cadmium (Cd):</th></tr>
<tr><td>1</td><td>Kadapa District, Andhra Pradesh state, India</td><td>Pre-monsoon: ND–175.6 µg/L
Post-monsoon: ND–170.2 µg/L</td><td>Pre-monsoon: ND–25.3 µg/L
Post-monsoon: ND–28.1 µg/L</td><td>ICP-OES instrument (Agilent 725 series)</td><td>Hazard Quotient<table><tr><th>HQ</th><th>Pb</th><th>Cd</th><th>HQ Limit</th></tr><tr><td>Pre-monsoon:</td><td>2.046</td><td>0</td><td><1</td></tr><tr><td>Post-monsoon:</td><td>0.088</td><td>0</td><td><1</td></tr></table>Pre-monsoon: Pb = >1, Cd = <1
Post-monsoon: Pb and Cd = <1
Both are from exposed adults</td><td>Reddy, Y. S., & Sunitha, V. (2023)</td></tr>
<tr><td>2</td><td>Ghaziabad district, Uttar Pradesh, India.</td><td>Pre-monsoon: 87–552 µg/L
Post-monsoon: 47–254 µg/L</td><td>Pre-monsoon: ND–60 µg/L
Post-monsoon: ND–12 µg/L</td><td>Standard Methods (APHA, 1998)</td><td>Hazard Quotient<table><tr><th>Children</th><th>Pb</th><th>Cd</th><th>HQ Limit</th></tr><tr><td>Pre-monsoon:</td><td>2.4</td><td>2.1</td><td><1</td></tr><tr><td>Post-monsoon:</td><td>1.23</td><td><1</td><td><1</td></tr></table>Pre-monsoon: Pb and Cd = > 1
Post-monsoon: Pb = > 1, Cd = <1</td><td>Chabukdhara, M., et. al. (2017)</td></tr>
<tr><td>3</td><td>Singhbhum district, Jharkhand state, India</td><td>0.08-0.42 mg/L</td><td>0.01-0.08 mg/L</td><td>Atomic Absorption Spectrophotometer (AAS) using Micro Mist nebulizer (Model GBC-902)</td><td>Hazard Quotient<table><tr><th></th><th>Parameters</th><th>Pb</th><th>Cd</th></tr><tr><td>C</td><td>HQ: Dermal</td><td>6.75E-02</td><td>1.13E+00</td></tr><tr><td>A</td><td>HQ: Dermal</td><td>1.45E-02</td><td>2.42E-01</td></tr></table>Adults: Pb and Cd = <1
Children: Pb = <1, Cd = > 1</td><td>Singh, U. K., et. al. (2018)</td></tr>
<tr><td>4</td><td>Solapur district, Maharashtra state, India</td><td><0.01 mg/L</td><td><0.003 mg/L</td><td>Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Agilent 7500.</td><td>Hazard Quotient<table><tr><th>Heavy metal</th><th>Pb</th><th>Cd</th><th>HQ Limit</th></tr><tr><td>HQ</td><td><0.01</td><td><0.003</td><td><1</td></tr></table>Pb and Cd = <1</td><td>Mawari, G., et. al. (2022)</td></tr>
<tr><td>5</td><td>Varanasi district, Uttar Pradesh state, India</td><td>0.004-0.0138 mg/l</td><td>0.0005-0.0346 mg/l</td><td>Atomic Absorption Spectrophotometer (AAS) Thermo Scientific M series</td><td>Hazard Quotient<table><tr><th></th><th>Pb</th><th>Cd</th><th>HQ Limit</th></tr><tr><td>Hazard quotient (HQ)</td><td>0.826</td><td>3.053</td><td><1</td></tr></table>Pb = <1, Cd = >1</td><td>Chaurasia, A. K., et. al. (2018)</td></tr>
</table>

Table 8 Compilation of Raw Data from Industrial Water Source Articles: Location, Heavy Metal Concentration, Methodology, and Risk Quantification

Source: Industrial water						
#	Location and type of water sample	Concentration		Method of HM Analysis	Risk Quantification	Reference
		Lead (Pb):	Cadmium (Cd):			
6	Virudhunagar district, Tamil Nadu state. India	0.11-0.96 mg/L	0.03-0.05 mg/L	Atomic Absorption Spectrophotometer (AAS) Make-Shimadzu; Model No.AA-6300	Hazard Quotient — / Pb / Cd / HQ Limit Hazard quotient (HQ) / 3.8 / 0.51 / <1 Pb = >1, Cd = <1	Raja, V., et. al. (2021)
7	Bokaro district, Jharkhand State. India	0.01-7.6 µg/l	0.01-3.2 µg/l	Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Perkin Elmer Elan DRC-e	Hazard Quotient — / Pb / Cd / HQ Limit Hazard quotient (HQ) / 0.025 / 0.066 / <1 Pb and Cd = <1	Mahato, M. K., et. al. (2016)
8	Hyderabad district, Andhra Pradesh state, India	**Pre-monsoon:** 0.22-1,207µg/L **Post-monsoon:** 25.30–877.2 µg/L	**Pre-monsoon:** 0.08-0.42 µg/L **Post-monsoon:** 0.50–6.20 µg/L	Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)	Hazard Quotient HQ / Pb / Cd / HQ Limit **Pre-monsoon:** / 0.063 / 0.001 / <1 **Post-monsoon:** / 0.002 / 0 / <1 Pb and Cd = <1	Krishna, A. K., & Mohan, K. R. (2014)
9	Uttara Kannada district, Karnataka state, India.	**Pre-monsoon:** 0.06 - 0.29 mg/l **Post-monsoon:** 0.03 - 0.17 mg/l	**Pre-monsoon:** 2.99 - 8.99 mg/l **Post-monsoon:** 1.87 - 7.19 mg/l	Atomic Absorption Spectrophotometer (AAS) GCB-Avanta	Hazard Quotient HQ / Pb / Cd / HQ Limit **Pre-monsoon:** / 1.4 / 620 / <1 **Post-monsoon:** / 0.9 / 456 / <1 Pre-monsoon: Pb and Cd = >1 Post-monsoon: Pb = <1, Cd = >1	Mishra, S., et. al. (2018)
10	Singrauli district, Madhya Pradesh, India	**Groundwater:** 4-317 µg/L	**Groundwater:** 2-108 µg/L	Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)	Hazard Quotient — / Pb / Cd / HQ Limit HQ / 7.916 / 3.44 / <1 Pb and Cd = >1	Bhardwaj, S., et. al. (2020)

IV. CONCLUSION

This systematic review analyzed ten scientific articles to assess lead (Pb) and cadmium (Cd) contamination in Indian aquatic environments. The review specifically examined: (1) the types of water matrices studied (e.g., groundwater, surface water), (2) the seasonal and non-seasonal concentrations of Pb and Cd, (3) the identified sources of contamination, and (4) the analytical methods employed for Pb and Cd quantification, as well as the methodologies used for risk assessment in children and adults. Lead and cadmium, known for their toxicity, particularly Cd even at low concentrations, were primarily quantified using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectrophotometry (AAS). The highest measured concentrations of Pb and Cd were: 0.96 mg/L and 0.108 mg/L during non-seasonal periods; 1.207 mg/L and 8.99 mg/L during the pre-monsoon season; and 0.8773 mg/L and 7.19 mg/L during the post-monsoon season. Notably, hazard quotient (HQ) calculations for Cd consistently yielded values exceeding 1 for all age groups and seasons, signifying substantial health risks and emphasizing the urgent need for mitigation measures to reduce Cd release into Indian waters.

This review provides a comprehensive overview of Pb and Cd contamination levels and associated risks in Indian aquatic ecosystems, serving as a valuable resource for future research and informing targeted interventions for water quality management.

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