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Review Article

A review on the examination of pollution by heavy metals in the river Ganga

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ABSTRACT
India's Ganga River is revered by its people for its ability to sustain the ecosystem and ecology. Over the past few decades, anthropogenic activities have led to significant changes in aquatic habitats. River water safety for drinking and other uses is seriously questioned by the advancement of human civilization. One of the main issues in the majority of developing countries' big cities is the pollution of river water caused by heavy metals. The introduction of these hazardous heavy metals into the environment may cause bioaccumulation and biomagnification. These heavy metals build up in both animal and human bodies to extremely high toxic levels that have negative consequences that go beyond a certain point since they are not easily broken down in the environment. The presence of heavy metals in riverine environments poses a persistent risk to human health. Developmental retardation, renal damage, several malignancies, and in cases of extremely high exposure, even death, have all been related to heavy metal poisoning. The review paper subsequently summarizes the findings of earlier studies on the heavy metal pollution of the Ganga river conducted by a number of different researchers.

1. Introduction

The most important resource needed to keep life on Earth going is water. India's most significant river system is the Ganga. Water is abundantly available all year round in India, which has greatly contributed to the development of the country's economy and civilization [1]. It makes up 25% of the water resources in India. The Ganga has a basin area of 861,404 km^2, making it the thirtyth longest river in the world [2]. With an average population density of 520 people per km^2, the Ganga basin is one of the world's most densely populated regions [3]. Over 300 million people in Bangladesh, Nepal, and India live in the basin [4]. The Ganga basin, the fifth biggest in the world, drains an area of over 1,060,000 km^2 and is rich in historical, cultural, and religious significance [5]. About one-fourth of the Indian subcontinents are drained by the river system. The Ganga river in India flows through 29 class I cities, 23 class II cities, and roughly 50 towns; as a result, various wastes, including sewage and industrial waste, are discharged into this powerful river ecosystem [6, 7].

near an elevation of roughly 3800 meters above mean sea level in the Garhwal Himalaya, the Gangotri glacier near Gomukh (30°36' N; 79°04' E) in the Uttar Kashi district of Uttarakhand state in India is the source of the Ganga river [8] (Figure 1). The primary route from the Gangotri glacier's historic source in India is roughly 2550 kilometers long. At Haridwar, the river emerges onto plains after passing through the Sivalik highlands. After there, it flows south through Uttar Pradesh's plains. In the Rohtas district, the Ganga enters Bihar after departing Uttar Pradesh. It flows southward from Bihar into the province of West Bengal. It splits into two arms about 40 kilometers below Farakka. The right arm, known as Bhagirathi, continues to flow south through West Bengal, while the left arm flows eastward into Bangladesh. Hooghly is the name of the Bhagirathi River that flows west and south-west of Kolkata. It travels southward after Diamond Harbour and splits into two streams just before it reaches the Bay of Bengal [9]. With an average yearly water output of 18,700 m^3/s, it ranks sixth largest on Earth. There is significant fluctuation in the flow within the watershed basin, resulting in the Ganga's mean maximum flow of 468.7×10^9 m^3, or 25.2% of India's total water resources [10]. Since the tributaries provide the majority of the freshwater flow in the river system, the available water varies substantially, ranging from 59,000 million m3 at Allahabad, which is located before the Yamuna confluence, to 459,000 million m3 at Farakka, which is located in the lowest stretch of the river [11]. The Himalayan snowmelt and the monsoon rains are the sources of water. The river system encompasses warm water areas, including deltaic ecosystems, as well as chilly upland streams [8]. Due to the socio-religious significance of the Ganga river, millions of people regularly use it for drinking and outdoor bathing, with millions of people taking a holy dip in the river at least once a year, from Gangotri to Ganga Sagar [12].

River pollution is a big issue that is currently developing in most developing nations. The amount of wastewater being dumped into natural water bodies has increased as a result of the fast industrialization. One of the main causes of environmental toxicity, which jeopardizes aquatic biota and degrades water quality, is sewage and industrial effluents that enter water bodies [14, 15]. Human welfare is intimately correlated with the quality of the water, making it a critical concern for all people [16].

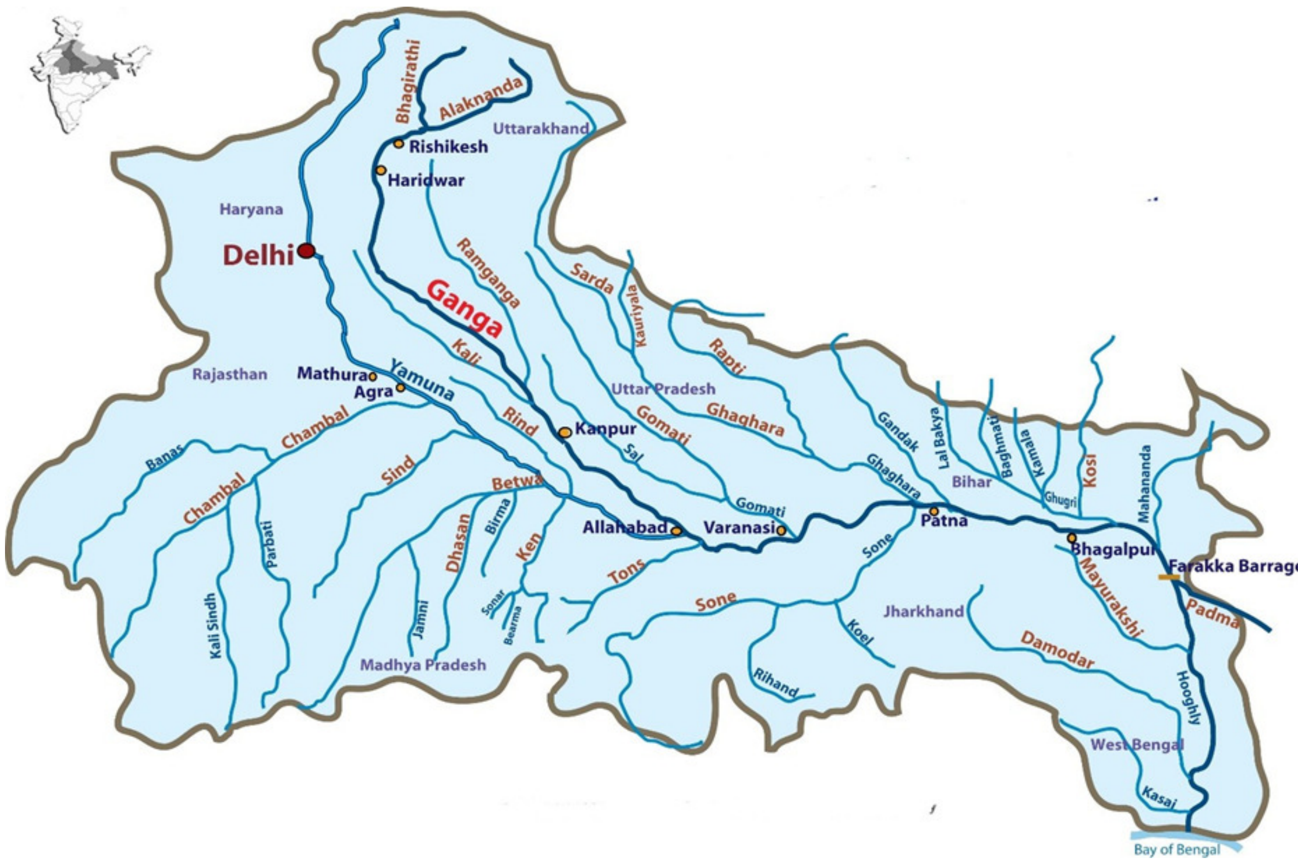

Figure 1: Map of the river Ganga

Water is contaminated by a variety of major substances, such as suspended particles, plant nutrients, harmful metals, microbial diseases, parasites, and volatile, biodegradable, and resistant organic chemicals [17–19]. Toxic metals are one type of pollution that should be taken very seriously since they build up via the food chain and can harm the environment [20, 21]. Elevated levels of heavy metals can combine to create dangerous complex compounds that have a major impact on various biological processes [22]. Heavy metal contamination of industrial effluent poses a concern to humans, animals, and aquatic ecosystems. Any ecosystem's ecology and biota are frequently seriously threatened by high concentrations of heavy metals [23]. Because heavy metals are not broken down by natural processes and remain in soil and sediment, where they eventually seep into water bodies, heavy metal pollution can be a far more catastrophic issue [24]. The results of previous study on the heavy metal pollution of the Ganga River by different researchers are presented in the review article that follows.

2. Sources of heavy metal

The set of metals and metalloids with an atomic density greater than 4 g/cm^3, or five times greater than that of water, are collectively referred to as "heavy metals" [25]. The problem of heavy-metal contamination predates industrialization and originated with the processing of ores by humans [26, 27]. Since then, there has been a significant growth in the usage of metals and their effects on the environment, particularly in the 19th and 20th centuries [28]. The majority of heavy metals typically enter rivers through a variety of causes, including anthropogenic sources like weathering and erosion or natural sources like erosion [29–31] (Table 1). Natural heavy metal sources from rock weathering and leaching are often not very significant given the high level of human activities [32–34]. Because the carbonates, hydroxides, and sulfides of heavy metals precipitate and become incorporated into sediments, sediments contain these metals.

The two most significant human-caused sources of heavy metals are home sewers and different industries. The ongoing practice of releasing untreated household sewage and industrial waste into aquatic environments contributes to the rise in heavy metal concentrations in river water [35–38]. Heavy metal industries, paint, pigment, varnishes, pulp and paper, tanneries, distilleries, rayon, cotton textiles, rubber, thermal power plants, steel plants, galvanization of iron products, mining, and the careless application of pesticides and fertilizers containing heavy metals in agricultural fields are the industries that are typically responsible for the presence of heavy metals in river water [39–49]. In groundwater and drinking water, these heavy metals have an accumulative effect at low concentrations [50].

Table 1: Sources of different heavy metals.

Arsenic (As)	Pesticides, fungicides, metal smelters
Cadmium (Cd)	Welding, electroplating, fertilizer, batteries, nuclear fission plant
Chromium (Cr)	Mining, electroplating, textile, tannery industries
Copper (Cu)	Electroplating, pesticides, mining
Lead (Pb)	Paint, pesticides, batteries, automobile emission, mining, burning of coal
Manganese (Mn)	Welding, fuel addition, ferromanganese production
Mercury (Hg)	Pesticides, batteries, paper industries
Nickel (Ni)	Electroplating, zinc based casting, battery industries
Zinc (Zn)	Refineries, brass manufacture, metal plating, immersion of painted idols

3. Heavy metals and its effects

When it comes to water contamination, zinc, aluminum, copper, lead, mercury, mercury ions, nickel, and cadmium are the most significant heavy metals. Certain metals, such as Cu, Fe, Mn, Ni, and Zn, are necessary in minute amounts for life processes in plants and microbes, but at larger quantities, they become hazardous (Table 2). Other elements, such as Pb, Cr, and Cd, are poisonous but have no known biological purpose [51–54]. These heavy metals build up in both human and animal bodies to extremely high toxic levels that cause negative effects that go beyond a certain point since they are not easily broken down in nature [55–57]. Many authors have documented the deadly conditions that heavy metals can cause, including eyelid edema, nephritis, renal tumors, extensive lesions in the kidneys, anuria, nasal mucous membranes and pharynx congestion, elevated blood pressure and cardiovascular diseases, osteoporosis, cancer, headaches, and malfunctions of various body systems [58–61]. They are also known to obstruct hormone production and metabolism [62].

Table 2: Permissible limits of heavy metals in drinking water [63].

Heavy metal	Permissible limit				
	WHO	USEPA	ISI	CPCB	ICMR
Iron (mg/l)	0.1	---	0.3	1.0	1.0
Copper (mg/l)	1.0	1.3	0.05	1.5	1.5
Mercury (mg/l)	0.001	0.002	0.001	No relaxation	0.001
Cadmium (mg/l)	0.005	0.005	0.01	No relaxation	0.01
Arsenic (mg/l)	0.05	0.05	0.05	No relaxation	0.05
Lead (mg/l)	0.05	---	0.10	No relaxation	0.05
Zinc (mg/l)	5.0	---	5.0	15.0	0.10
Chromium (mg/l)	0.1	---	0.05	No relaxation	---

WHO: World Health Organization, USEPA: United States Environmental Protection Agency,
ISI: Indian Standard Institution, ICMR: Indian Council of Medical Research,
CPCB: Central Pollution Control Board.

4. Status of heavy metal in river Ganga water and sediments

Numerous experts have conducted extensive investigations on the pollution of the Ganga River by heavy metals. The quantities of cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead, and zinc were examined by Ajmal et al. [64] in the water and sediments of the Ganga river in Uttar Pradesh. They found that the metals varied significantly between sampling stations. The temporal and spatial fluctuations in the distributions of heavy metals in the Ganga river sediment were also examined by Subramanian et al. [65]. Saikia et al. [66] have carried out a study of a similar nature in the upper Ganga. Prasad et al. [67] also looked at the distribution of heavy metals in the Ganga sediments and at the sewer-river confluence places in the Varanasi-Mirzapur area.

After researching the Ganga's heavy metal pollution in the Mirzapur area, Sharma et al. [68] concluded that the river was contaminated. Several scholars also carried out a comparable investigation in Kanpur [69, 70]. The amounts of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, and Zn were measured in the Ganga sediments in the Kanpur-Unnao industrial zone by Ansari et al. [71]. They claim that, in comparison to natural background levels, around 90% of the amounts of Cd, Cr, and Sn; 50–75% of organic carbon, Cu, and Zn; and 25% of Co, Ni, and Pb in sediments are the result of human input.

In the Kanpur-Unnao industrial region, Ansari et al. [72] investigated the impact of monsoon rain on the concentrations and dispersion patterns of metal pollutants in the Ganga sediments. They found that the rainy season decreased the amounts of Co, Cr, Fe, and Ni and increased the amounts of Cd, Sn, and Zn in the post-monsoon period sediments. Khwaja et al.'s study [73] examined the pollution of the Ganga river's water and sediments as a result of Kanpur's tanneries. According to the suggested Sediment Pollution Index, Singh et al.'s [74] study of the heavy metals in recently deposited stream sediments of rivers connected to the urbanization of the Ganga Plain in Lucknow, Kanpur, Delhi, and Agra urban areas rated the sediments as extremely polluted to dangerous.

The baseline content and geogenic distribution of heavy metals (Cr, Mn Fe, Co, Ni, Cu, Zn, Cd, and Pb) in the Ganga river sediments were investigated by Singh et al. [75]. The effect of lead on the Ganga River's water quality in West Bengal was evaluated by Dutta et al. [76].

At Varanasi's Vindhyachal Ghat, Chaturvedi and Pandey [77] examined the Ganga's physicochemical characteristics as well as a few hazardous elements. Their investigation revealed that this location was contaminated and that the water was unfit for residential use, irrigation, or other uses. In their assessment of the Ganga River's pollution, Nath and Banerjee [78] took into account the heavy metals (Cu, Pb, Cd, and Zn) found in soil, water, fish (Rita rita), and benthic macroinvertebrates (Thiara lineate). The Ganga river is found to be mildly contaminated overall. The heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb) connected to various chemical fractions of the Ganga River sediments were evaluated by Purushothaman and Chakrapani [79].

The level of dissolved heavy metals, including Fe, Zn, Mn, Cu, Pb, and Hg, was also examined by Sarkar et al. [80] at three ecologically distinct zones along the Ganga's course: Babughat, Diamond Harbour, and Gangasagar in West Bengal. They found high levels of Pb and Hg, which can be linked to emissions from pulp and paper mills as well as atmospheric input and runoff from car emissions. Mercury pollution in the Ganga River system at Varanasi was investigated by Sinha et al. [81]. Their research on mercury explains how it exists and varies in many biotic and abiotic river system components.

Beg and Ali [82] examined the quality of the sediment, focusing on trace metals, in the upstream and downstream areas of the Ganga river in Kanpur city, where tannery industry effluents are discharged. They found that the concentration of Cr in the downstream sediment was higher than the probable effect level and that it was thirty times higher than in the upstream sediment.

In the years 2006–2007, Bhattacharya et al. [83] investigated the build-up of heavy metals in the water, sediment, and tissues of several edible fish in the Rishra–Konnagar region, which is located on the upper Gangetic West Bengal stretch. They claimed that a distinct seasonal oscillation was present in the concentrations of Zn, Cr, Cu, Cd, and Pb in the sediment, water, and commercially edible fish samples at the sampling location. The heavy metal concentrations are distributed as follows: Zn > Cr > Cu > Cd > Pb. Kar et al.'s analysis [84] of surface water samples from the Ganga river in West Bengal revealed a notable seasonal change in the levels of several heavy metals, including Fe, Mn, Zn, Cu, Cd, Cr, Pb, and Ni. The order of the various heavy metals that were investigated and found in the Ganga's surface water was Fe > Mn > Ni > Cr > Pb > Zn > Cu > Cd.

The presence and bioaccumulation of various heavy metals (Cu, Cr, Cd, Pb, Zn) in river water, sediment, and the muscles of two different species of catfish that were taken from the Ganga river in Allahabad were investigated by Gupta et al. [85]. They state that the following is the order in which the various heavy metals occur: Zn > Pb > Cu > Cr > Cd. According to the heavy metals examination of the sediment, Zn was the heavy metal that accumulated at the highest rate among the five, followed by Pb, Cr, Cu, and Cd.

Kumar et al. [86] conducted studies at Kanpur and Varanasi to examine the effects of effluents discharged into the Ganga from different sources on the chemical composition, energy transformation rate, and amount of heavy metals. They claimed that significant improvement was shown below the discharge zone and that the levels of heavy metals (Cu, Cr, Cd, Pb, and Zn) in the effluents exhibited greater values at the discharged site. In their investigation into the relationship between atmospheric deposition and heavy metal contamination in the Ganga river, Pandey et al. [87] found that while levels of Cr and Cu in mid-streamwaters at five out of six sampling stations were below their respective maximum admissible concentrations, levels of Cd and Pb were higher. Purkait et al. [88] evaluated the effects of several factors, such as heavy metal pollution of the Ganga water in the Kolkata area. In their analysis of surface water concentrations of heavy metals (Fe, Mn, Cu, Zn, Pb, Cd, Cr, and Ni) at four different Ganga river locations in the Kolkata area, Aktar et al. [89] concluded that there was no discernible variation in the heavy metals under study between sampling sites and discharge points. Nevertheless, the concentration of certain metals changed with the season, being lower in the winter and higher in the rainy season. Through the East Calcutta Wetland regions, Chatterjee et al. [90] evaluated the waste metal pollution at the Ganga Estuary. Pandey et al.'s study [91] examined the impact of aerially transported heavy metals on the Ganga's midstream water quality near Varanasi. The overall concentration of heavy metals in water demonstrated the following trend: Zn > Ni > Cr > Pb > Cu > Cd. They also observed that all heavy metal concentrations were high in downstream sample stations. Rai et al. [92] found an extremely high quantity of heavy metals (Zn, Cu, Cd, Pb, and Cr) in water samples from three sewage treatment plants in Varanasi that regularly discharge into the Ganga river.

The effect of tannery effluent on seasonal variations in physicochemical properties and heavy metal concentration (Cr, Pb, and As) in Ganga water near Jajmau area of Kanpur was studied by Katiyar [93]. The heavy metal concentration of eco-efficient rivers in the Himalayan region, such as the Ganga, and their interactions with other physicochemical characteristics were evaluated by Kansal et al. [94]. The toxicity of heavy metals (Cu, Cr, Fe, Mn, Zn, Cd, and Pb) in the Ganga river at Varanasi was also investigated by Singh [95]. According to this study, the primary cause of heavy metal contamination in the Ganga river at Varanasi is industrial effluents. The water in the river is very polluted. At various ghats in Haridwar, Rai et al. [96] evaluated the water quality and levels of heavy metals in the Ganga river. The distribution of non-radioactive heavy metals (Zn, Cd, Cu, and Pb) in the Ganga water from Rishikesh to Allahabad was examined by Sharma et al. [97]. According to their analysis, there were places where the detected heavy metal concentrations were higher than recommended, which is consistent with more anthropogenic activity. Throughout the course of two years, Singh et al. [98] examined the concentrations of five heavy metals—Cu, Cr, Zn, Ni, and Cd—in water and sediment samples from the Ganga in Bhagalpur, starting from Champanala Nathnagar and ending at Burning Ghat Barari. According to their research, the Ganga river sediments from Champanala to Barari can be regarded as being unpolluted in terms of Cd, Cu, and Ni concentrations. However, the concentrations of Cr and Zn show signs of pollution, which could be detrimental to the river segment's rich biodiversity.

With particular reference to heavy metals at Jajmau, Kanpur, Bhatnagar et al. [99] investigated the impact of tannery effluents on Ganga river sediments and discovered that heavy metals like Cr, As, Co, Fe, Cu, Mn, Zn, Pb, Cd, and Ni were present in noticeably higher concentrations. Sediment taken from the downstream Jajmau area had higher quantities of heavy metals than the upstream location. Additionally, Pandey et al. [100] measured the concentrations of a number of heavy metals, including Cr, Cu, Fe, Ni, Pb, and Zn, in the Ganga water at Allahabad and reported that every heavy metal was found to be above permitted values at every sampling site. The study area's high quantity of these heavy metals suggested that the river is heavily contaminated. In West Bengal, Paul and Sinha [1] looked at the seasonal changes in the water quality of the Ganga river in relation to the contamination of heavy metals (Zn, Pb, Cd, and Cr). Their investigation revealed that the majority of these heavy metals had concentrations that were far greater than the uppermost allowable limits. The geochemical environment of the river sediment in the middle section of the Ganga at the urban centers of Ghazipur, Buxar, and Ballia was studied by Singh et al. [101]. As per their findings, the proportion of anthropogenic and lithogenic heavy metal concentration values indicates that river water contains the highest amount of Cd due to anthropogenic addition, followed by Cr, Cu, Zn, and Co. The heavy metal (Fe, Cr, Zn, Cu, Mn, Ni, and Pb) contamination of the Ganga River and its hazardous implications in the blood parameters of the main carp Labeo rohita (Ham) were studied by Vaseem and Banerjee [102].

Table 3: Concentrations of heavy metals (μg L^{-1}) in the river Ganga water at different study sites [69, 77, 80, 81, 83, 84, 85, 89, 91, 95, 96, 102, 103, 104, 105, 107, 108, 110, 112, 114, 116]

Study area	Concentrations of different heavy metals (μg L^{-1})								
	Cd	Cr	Cu	Co	Fe	Hg	Mn	Ni	Pb	Zn
Allahabad	ND-10	ND-18	ND-30	---	---	---	---	---	18-86	26-122
Berhampore	1-2	10-18	3-7	---	365-1744	---	181-712	41-84	8-21	65-95
Bhagalpur	ND	BDL-1090	ND-120	---	---	---	---	BDL-120	---	BDL-870
Dakshineswar	ND-3	16-22	4-8	---	792-1413	---	85-436	35-44	5-97	42-83
Diamond Harbour	---	---	5-90	---	30-560	150-620	90-350	---	12-62	150-710
Gangasagar	---	---	2-90	---	40-320	100-490	60-290	---	11-38	30-520
Haridwar	---	43-196	101-178	---	---	---	28.7-16	---	108-690	113-219
Kanpur	---	ND-390.8	0.6-52.1	---	59.3-27956	---	17.7-272.6	ND-63.7	4.3-57.5	0.1-49.49
Kaushambi	75	20	20	---	---	---	---	700	10	150
Kolkata	---	---	ND-100	---	ND-600	---	---	---	ND-9	ND-980
Mirzapur	13.37-32.73	---	38.0-157.80	10.50-26.77	19.75-72.77	---	34.25-105.55	67.25-176.13	34.25-185.75	94.25-423.75
Palta	ND-3	13-21	4-7	---	884-2345	---	123-417	35-53	5-15	68-111
Rishikesh	---	---	32.1-58.1	---	---	---	---	BDL-36.7	BDL	BDL-1349.7
Rishikesh-Allahabad	600-13100	---	ND-36000	---	---	---	---	---	2400-26900	ND-106300
Risha-Konnagar	0.043-0.088	0.281-0.391	0.155-0.322	---	---	---	---	---	0.041-0.058	0.545-0.691
Uluberia	ND-3	13-24	3-6	---	353-1584	---	139-172	34-83	3-52	58-84
Varanasi	100-160	160-1090	1700-2000	---	120-150	---	---	100-900	---	500-600

Table 4: Concentrations of heavy metals (µg g^{-1}) in the river Ganga sediment at different study sites [65, 71, 81, 82, 83, 85, 98, 99, 101, 106, 110, 111, 115, 117].

Study area	Concentrations of different heavy metals (µg g^{-1}).									
	As	Cd	Cr	Cu	Co	Fe	Hg	Mn	Ni	Pb	Zn
Allahabad	---	0.14-1.40	1.80-6.40	0.98-4.42	---	---	---	---	---	4.28-8.40	10.48-20.40
Bhagalpur	---	ND	BDL-140	BDL-90	---	---	---	---	32-75	15-27	BDL-870
Ghazipur	---	0.45-0.95	113-230	39-73	11-29	---	---	183-523	7-49	---	72-140
Haridwar-Kolkata	---	---	16-134	2-62	---	8040-82700	---	---	5-13	2.5	22-101
Kanpur	0.25	2.5-6.0	5.0-250.0	7.0-17.0	---	3950-8400	85-254	---	42-66	5-12	23-70
Kanpur-Unnao	---	9.8	3.40	408	---	---	---	---	---	0.099-0.109	4000
Risha-Konnagar	---	0.672-0.791	3.682-5.816	2.191-5.671	---	---	---	---	---	---	10.641-11.771
Varanasi	---	9.52-79	126.84-196.11	12.67-84	29.98-102.24	7175-9385	---	350.87-409.44	14.63-82.5	148.83-211.36	137.25-201.2
	---	30.01-128.13	133.75-247.05	15.3-70.7	---	7493.91-10343	---	322.43-439.75	18.38-97.1	151.85-269.38	185.15-278.61
	---	0.94-2.86	39.05-93.28	12.71-36.68	---	21924.07-41170.13	---	296.02-529.08	11.77-43.02	10.94-44.89	41.05-92.48

BDL- Below detection limit, ND- Not detected.

Using differential pulse anodic stripping voltammetry, Goswami and Sanjay [103] found the concentrations of heavy metals, specifically cadmium, copper, lead, and zinc ions, in the various Ganga matrices from Rishikesh to Allahabad. According to their analysis, point source discharges from tannery factories have resulted in an alarming accumulation of contaminants in the water and sediment at Jajmau Kanpur and Narora Barrage. The seasonal change of the concentrations of heavy metals (Cr, Mn, Fe, Cu, Zn, and Pb) in the Ganga water at five locations in Allahabad city was examined by Kumar et al. [104] in order to determine any potential effects on the fish species. Their research has shown that every metric fluctuates to some extent, usually with the seasons and locations. The distribution and degrees of heavy metal (Cd, Ni, Cu, Fe, Pb, Co, Ni, and Zn) contamination of the Ganga silt were depicted by Nausad et al. [105] in the city of Allahabad. With the exception of Fe, the concentration of heavy metals in the water did not go over EPA and WHO limits. Their findings suggested that the concentration of trace metals in water varied. They claim that there are notable basal contamination levels in the Ganga basin that fall short of those in blatantly polluted locations. Using the sequential extraction method (SEP) and total acid digestion (TAD), Pandey et al. [106] addressed the geochemical fractions of nine heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb) present on the Ganga river sediments from Samne Ghat to Varuna-Ganga confluence at Varanasi. The Geo-accumulation index (Igeo) and the Risk Assessment Code (RAC) showed greater concern for Cd and Pb, while all sampling stations showed negative accumulation indexes for Mn, Fe, and Ni. The accessible portion contained large amounts of Pb, Cd, Cu, and Ni; nonetheless, the Igeo of Ni was found to be negative at every sampling point. In the midstream of the Ganga river at Varanasi, Singh and Pandey [107] investigated the spatiotemporal trends of heavy metals. They found that winter was the season with the highest concentrations of heavy metals, and that the concentration of cadmium exceeded the globally suggested maximum permissible concentration. The concentration of heavy metals in the Ganga river in Kanpur and Varanasi was also examined by Singh et al. [108]. The physicochemical characteristics and a few heavy elements (Fe, Zn, Cr, and Co) in riverine water from the Ganga at several Ghats in Allahabad were also examined by Pandey et al. [109].

Pandey et al. [110] evaluated the effects of urban drains on river water and sediments by metal analysis at Varanasi using SEMeEDS and a sequential extraction process. In an effort to determine whether there is a discernible difference between locations located upstream and downstream of the Varanasi urban core, Pandey and Singh [111] examined the concentration of heavy metals in the Ganga River sediments throughout a 37-kilometer span. They claim that while the concentration of heavy metals climbed steadily along the research gradient, urban sources may have had an impact. Fe was discovered to have the highest concentration of heavy metals in the river silt, followed by Mn, Zn, Cr, Cu, Ni, Pb, and Cd. Chaudhary et al.'s estimation of the Ganga's water pollution and likelihood of health risk as a result of nutritional imbalances was [112]. It has been discovered that the river water is seriously contaminated with heavy metals, which poses a risk to human health. The heavy metal composition of Ganga River water samples taken from Uttar Pradesh's Kaushambi district was examined by Tripathi et al. [113]. According to their investigation, the water from each of these sample sites is safe to drink and use for irrigation in terms of both heavy metals and the physicochemical parameters that were looked at. Haritash et al. have carried out a related investigation in Rishikesh [114]. Tables 3 and 4 provide an overview of the heavy metal concentrations at the several study sites along the Ganga River that numerous researchers have done.

5. Role of tributaries of river Ganga in heavy metal pollution

There are several tributaries of the Ganga river that originate in the Himalayas and have a significant amount of water wealth. Kali, Ramganga, Yamuna, Gomti, Ghaghara, Gandak, Mahananda, Damodar, Kosi, Tamsa, Son, and Punpun are the principal tributaries of the Indian subcontinent [118]. Sixty percent of the Ganga's total water volume comes from its tributaries. Ghaghara provides about 20% of the Ganga's water, compared to Yamuna's 16% [119]. Because they introduce significant amounts of pollutants and heavy metals into the Ganga, the tributaries of the Ganga play a significant part in the pollution of the river Ganga. Every tributary that flows into the Ganga joins it and adds to the river's already high level of pollution. Despite being a Ganga river tributary, the Yamuna is practically a separate river. Numerous enterprises are depleting the Yamuna's enormous supply of untreated effluent water from places like Delhi, Agra, Faridabad, and Mathura. According to estimates from the Central Pollution Control Board (CPCB) [120], there are around 359 industries that either directly or indirectly discharge their effluents into Yamuna. The Kali River is heavily contaminated. In the Kali River, pollution levels, notably those of heavy metals, have alarmingly increased. At Lucknow and Jaunpur, the Gomti River's water quality has likewise been determined to be highly dangerous [121]. Table 5 summarizes the several academics' studies on the levels of different heavy metals in the Ganga's tributaries.

Table 5: Concentrations of heavy metals in different tributaries of river Ganga [122-130].

Rivers	Sample	Concentrations of different heavy metals in water (mg L^{-1}) and sediment (mg kg^{-1}).								
		Cd	Cr	Cu	Co	Fe	Mn	Ni	Pb	Zn
Kali	Water	0.06-0.08	0.06-0.09	---	---	1.53-1.77	---	---	0.13-0.19	24.71-29.71
Ramganga	Water	ND-0.013	---	---	---	0.3481-5.22	0.046-1.31	---	0.002-1.00	0.031-0.106
Yamuna	Water	---	---	12.09-23.31	---	---	---	2.08-8.19	12.01-19.36	69.86-89.32
	Sediment	0.5-11.8	163-817	40-829	13.0-28.4	2920-4530	515-1015	40-538	22-253	110-1472
Gomti	Water	ND	0.001-0.069	0.0013-0.0043	---	0.079-0.32	0.004-0.098	0.007-0.011	0.016-0.028	0.014-0.03
Ghaghra	Sediment	0.7-7.9	6.105-20.595	3.73-35.68	---	5051-8291	134.9-320.4	13.9-37.37	21.25-92.15	15.72-99.35
	Water	0.001-0.057	ND-0.010	0.01-0.047	0.02-0.04	---	---	0.002-0.032	0.001-0.029	0.002-0.042
Son	Water	ND-0.003	0.002-0.004	---	---	0.005-0.076	---	---	0.001-0.017	ND
Damodar	Water	ND-0.0013	---	0.0007-0.0125	---	---	---	---	0.0005-0.006	0.002-0.026
	Sediment	---	15-86.8	11.4-124.6	---	1.0-5.2	149-1033	2.8-44.0	---	30.5-134.7

ND- Not detected.

6. Strategies to improve the metal pollution of river Ganga

Scientists and other environmentalists who are worried about environmental degradation have taken notice of the heavy metal contamination of the Ganga river. Strict regulations should be in place for emissions and discharges from various industries. Heavy metal-containing wastewater recycling needs to be prioritized more, both as a resource-saving measure and in light of environmental and health issues. More effort needs to be put into monitoring the wastewater from dangerous heavy metal processing facilities across various industries. To pinpoint the exact origins of the pollution in the Ganga, the government needs to lay up a plan or strategy for conducting a thorough assessment of the river.

Reducing pollution in the nation's major rivers is a task for numerous state and central government departments in India. The Indian Prime Minister introduced the Ganga Action Plan (GAP) in 1986 to implement the Central Ganga Authority's (CGA) policies. The main goal of the GAP was to reduce pollution before it reached the Ganga River, which would improve the quality of the water. Ensuring that the river water quality meets the CPCB's set requirements is of utmost importance, and this is where the GAP comes in [131]. However, the Ganga Action Plan has not been very successful in achieving its stated goals. The problems of the GAP have been caused by an over-reliance on traditional techniques that were created and implemented by the central government without the participation of local stakeholders [3]. According to a CPCB survey, 317 significant industrial facilities are operational throughout the Ganga River and its tributaries. The remaining units provide a risk for pollution, only 37% of which adhered to certain controlled procedures, and none of them have treatment facilities [132]. The Ganga was designated as a National River by the Indian Prime Minister in 2008, and the National Ganga River Basin Project (NGRBP) was established to clean it up. In India, the NGRBP will be the first basin-level project to manage an interstate river for environmental preservation and water quality [3, 133].

There hasn't been much research done on how the biotic community is impacted by heavy metals found in Ganga water and sediments. Numerous authors' published research articles have demonstrated that the presence of heavy metals in rivers can lead to a decline in fish population growth, size, and survival. It can even lead to the extinction of some fish species and river dolphins [134–137]. Cyclops and Daphnia are the most heavy metal sensitive species. In addition to creating an unfavorable environment, the presence of such heavy metal pollution in water courses results in a shortage of fish organisms [132]. The self-purifying properties of the river may be impacted if extremely high concentrations of heavy metal pollution are found in the sediment and surface water. The river starts to generate a lot of harmful germs as soon as it loses its ability to purify itself. Enforcing rigorous laws and conducting routine, methodical monitoring are necessary to improve water quality in a sustainable manner. It is finally time to bring awareness among the general public. Environmental organizations may find the information from this review useful for monitoring the Ganga river system and, ultimately, for managing human health behaviors.

7. Conclusions

The current state of the Ganga river's heavy metal pollution is summed up in this review article. The amounts of several heavy metals in the Ganga water and sediment are significantly higher than what is considered tolerable, according to several studies on heavy metal contamination. The plants, animals, and aquatic life systems that surround the river allow the metals to penetrate the environment. The heavy metals pose a serious risk to human health and welfare due to their potential for bioaccumulation and biomagnification. Therefore, action must be made to reduce the amount of metallurgical effluent that enters the Ganga River. This evaluation recommended that several sources of heavy metals in the Ganga water and sediments be closely monitored; that conditions be improved; and that home sewage and industrial effluent discharge be minimized.

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