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Biological health of River Ganga, in the Light of Metal Pollution: A Review

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Abstract: Having immense sacred importance, the longest river of the Indian subcontinent, river Ganges spans around 2,525 kilometres starting from Uttarakhand until Bay of Bengal. The crystal-clear water at the point of origin of this river gets loaded with enormous discharges from the cities as it travels down the plain. Industrial pollution, sewage discharge and other anthropogenic activities have degraded the water quality index over the last few decades. Toxic heavy metals that form the major constituent of this pollution are not readily degradable in nature and enter the environment leading to bioaccumulation in various trophic levels beyond a specific limit. The Aquatic life including microorganisms and fish are the best indicators for pollution, as they are sensitive to micro-environmental conditions. These heavy metals travel through various trophic levels, ultimately reaches to cause health risks to humans. Cancer, neurodegeneration, and gastrointestinal problems are major health effects reported. Although the government has launched several schemes to control the pollution level, still they are unchecked and need local involvement in the immediate future. In this review, we are trying to summarise the present status of the Ganga River concerning heavy metal toxicity. This review aims at finding the potential sources of metal pollution in river Ganga with their possible fate in the river system and their possible impact on the organisms dwelling in the river with a final suggestion to improve water quality through the involvement of different world organizations under collaborative programs.

Keywords: Ganga, Metals, Metalloids, Biochemical, Pollution, Toxicity

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Introduction

The mystical significance of the river Ganga in the Indian subcontinent is known since time immemorial. Its journey from the Gomukh ice cave of the Gangotri glacier system to the Bay of Bengal covers 2525 km after traveling through five Indian states viz. Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal (Singh and Singh, 2007). Although the river is the lifeline for about 400 million inhabitants and possesses several antimicrobial and medicinal properties (Das and Tamminga, 2012; Dwivedi *et al.*, 2018), human civilization has profoundly affected the river's biochemical and biological health over the years. The middle stretch of the river especially from Kannauj to Varanasi is predominantly susceptible to anthropogenic activities viz., agricultural runoff, sewage discharge, and industrial effluents as well as the use of chemicals and pesticides are very common in Gangetic plains, which is the most fertile land of the country. In this sequence, inorganic pollutants such as heavy metals (discharged from major electroplating industries and thermal power plants) play an important role with relatively high density, non-biodegradable that are poisonous even at low concentrations and accumulate slowly and steadily in the atmosphere to such concentrations that affect plant and animal life due to their toxic potential, persistence, and long-lasting availability (Kloke *et al.*, 1984; Dwivedi *et al.*, 2006; Biswas, 2015). Metals and metalloids including Cu, Cd, Cr, Pb, Hg, Mn, Fe, and Al contribute a lot to decreasing the water quality index in polluted cities. For instance, the water quality index reported good at less polluted sites like Haridwar while it was poor in polluted cities like Kanpur due to the contamination of metals (Kumar *et al.*, 2019). Metals may alter biochemical parameters like chemical oxygen demand, biological oxygen demand, and dissolved oxygen in polluted areas. These pollutants are reported to alter the self-purifying and antimicrobial properties of Ganga water by reducing the dissolved oxygen (DO) and light penetration in the river (Tare *et al.*, 2003).

Metal pollutants that reach bottom sediment in substantial amounts regulate the aquatic trophic system, ecological cycling, and detritus food web (Singh *et al.*, 2005). Parallel evaluation of metals in water and bed sediment can give an account for anthropogenic activities and risks caused by effluents' discharge in the river (Pandey *et al.*, 2010). Water dwellers such as fishes, zooplankton, benthic algae, etc. are the toxicological target for heavy metal pollution and possess high variation in accumulation due to their mobility feeding behavior, trophic status, and hydrodynamic determinants (Jaiswal and Pandey, 2019). Overall, it can be said that biomagnifications of organic compounds, pesticides, and heavy metals have the potential to adversely affect the health of Gangetic living organisms and their diversity (Sinha *et al.*, 2007).

Humans residing in the Gangetic basin are also at high health risk, due to toxicants and heavy metal-contaminated fish consumption. The indices developed so far, to assess the risk associated with heavy metals, such as enrichment factor, potential ecological risk index, pollution load index, pollution index, modified pollution index, and accumulation index are used to calculate the sediment and health risk assessments (Brady *et al.*, 2015). Some metals like Pb, Cr, Cd, Cu, Ni, Zn, etc. are reported to cause renal failure, liver damage, genotoxicity, hypertension, and poor reproductive capacity (Leston *et al.*, 2010).

In this review, we will explore the sources of metal pollution as well as biochemical and biological parameters affected due to heavy metal pollution in river Ganga at different stretches of the river and try to establish some possible strategies to revive and increase the water quality index of the river.

The bibliographic search was performed on Scopus, PubMed, and Web of Science databases for compilation. Search keywords including 'Metals' OR 'Metalloids' OR 'Lead' OR 'Manganese' OR 'Cadmium' OR 'Aluminum' OR 'Zinc' OR 'Ganga' OR 'Pollution' OR 'Biochemical' OR 'Trace Elements' AND 'Microorganisms 'in all fields. Identified studies were screened by their respective title, followed by abstracts, and full text. A reference list of the identified articles was also included in the present study to increase the variety and sensitivity of the literature. A separate investigation of all the articles was carried out excluding the non-relevant articles and the inclusion index criteria was done. Searching for the last 20 years of articles from 2000-2020, 72 relevant articles were selected including all the above-mentioned search engines.

Physicochemical Properties of Ganga water in current state:

The major source of contaminants in rivers, specifically the Ganga, is sewage and household wastewater due to increasing urbanization in the surrounding areas. While there is no uniform data available for all parameters, there is a clear trend among different states and time periods. The pH of river water is an important measure to detect the solubility and toxicity of chemicals. An increase or decrease in pH is harmful to aquatic life and it varies from place to place in Ganga water. The pH level of the Ganga is slightly more alkaline in states other than Uttarakhand, and in recent decades, there has been a slight increase in pH in Uttarakhand. Although the mean pH level fell within the WHO's recommended bathing limit of 6.5-8.5, the pH range exceeded permissible limits of 5.9-9. Dissolved oxygen (DO) levels were highest in Uttarakhand, followed by Bihar and Uttar Pradesh, and lowest in West Bengal (NMCGNEERI, 2018).

The level of DO was highest in Uttarakhand followed by Bihar and Uttar Pradesh and minimum in West Bengal. In Uttarakhand, the level of DO has increased in the last decades as reported by the National Ganga River Basin Authority (Kumar *et al.*, 2010).

In Uttarakhand, BOD values exceeded 5.2 ppm (recorded at Haridwar) (CPCB, 2009) indicating severe pollution due to sewage drains during 20112-2016. Algal blooms are responsible factors for higher BOD, as reported by Bhatnagar *et al*. (2013) in the Kanpur region of Uttar Pradesh (Siegel, 2002). BOD also varies with temperature and solvent dilution. Varanasi witnessed higher BOD in summer and lower in the rainy season, due to the dilution of water (Bhatnagar *et al.*, 2013). Again, in the lower stretch of the Ganga, BOD values increased to 6.0 ppm in West Bengal, indicating poor water quality for human consumption and aquatic life (Rai *et al.*, 2010).

National Ganga River Basin Authority has shown an increasing trend in the level of DO and BOD in recent years in many states. The level of various ions viz., nitrate, nitrite, sulfate, phosphate, and the alkalinity and hardness were highest in Uttar Pradesh followed by Bihar and Uttarakhand, except for nitrate which was higher in West Bengal after Uttar Pradesh (CPCB, 2018; Mariya *et al.*, 2019;). The microbial count (faecal and total coliform) time-wise analysis of physicochemical data and microbial contamination showed that Ganga water in West Bengal (lower stretch) and Uttar Pradesh (middle stretch) has always been most contaminated which is directly correlated with the amount of wastewater discharged in these stretches of Ganga (CPCB, 2018). The summer months are chosen for water sampling to avoid the dilution effect observed during rainy and post-rainy periods. Metals are correlated with the concentration of organic pollutants. In a study, heavy metals show a negative correlation with DO and pH which indicates that the more organic load in the water bodies, the more will be the concentration of heavy metals. This is because organic matter provides a surface for the lechation of metals in acidic conditions (Kansal *et al.*, 2013). On the other hand, metals showed a positive correlation with electrical conductivity (EC). A higher concentration of EC may be the result of rock–bed interaction with flowing water (Yadav and Chakrapani, 2006). Heavy metal toxicity depends on physicochemical parameters, especially the pH and DO for fish culture (Akbora *et al.*, 2020). The narrow ranges of pH values (7.5 To 8.5) indicated low solubility of metals in the water column especially Pb and the heavy metal concentrations in all seasons were lower than the international standard for fisheries set by Food and Agricultural Organization (Svobodova *et al.*, 1993). As Ganga starts its journey from the Himalayas, the mineral and oxygen content is high until it detaches from nature and comes in contact with anthropogenic activities. According to National Environmental Engineering Research Institute (NIREE) (NMCGNEERI, 2018), the river was divided into three stretches, and BOD, DO, total hardness (Ca and Mg), and total coliform were calculated at various sites, which is illustrated in Table 1.

Table 1: Biochemical parameters at three different stretches of river Ganga

Parameters	Stretch I Gomukh to Haridwar	Stretch II Bijnor to Farakka	Stretch III Farakka to Kolkata
Dissolved Oxygen (DO)	7-9.5 mg/l	6-9 mg/l	6-9 mg/l
COD	10-200 mg/l	20 – 70 mg/l	
Total hardness (Ca and Mg)	40-70 mg/l	120 mg/l	138 mg/l
Total coliform	200 cfu/100 ml	350 cfu/100 ml	190 cfu/100 ml
Biological Oxygen Demand (BOD)	<2 mg/l	2-7 mg/l	2-4 mg/l
Aluminium	<50 µg/l	50-250 µg/l Outlier: Varanasi 1060	Approx. 400 µg/l

Snehlata *et al*. (2018) did a seasonal physicochemical study in Ganga water at Haridwar and concluded that the maximum (12.34±0.49) value of DO has recorded in January while the minimum (8.40±0.33) in July (Lata *et al.*, 2018). Similarly, another seasonal physico-chemical study at Allahabad by Tripathi B *et al.* (2014) revealed that the BOD value was higher in summer at 5.53±0.25 mg/l and lower in the monsoon at 5.13±0.45 mg/l and biological oxygen demand shows a high significant positive relationship with DO. Higher COD was observed in summer and lower in monsoon whereas an intermediate value was observed in the summer season (Tripathi *et al.*, 2014). Hamner *et al*. (2007) in their river system volume have widely studied the sewage pollution in river Ganga from the last 30 years and concluded that the water quality was of Class B type according to the Government of India's Central Pollution Control.

Prominence of the microbial community in river Ganga:

For centuries, people have used water from the Ganga for medicinal purposes to combat various diseases. Ancient beliefs held that bathing in the Ganga could cure illnesses and infections. The antibacterial properties of Ganga water were recognized as far back as 1896 by Ernest Hankin (Hankin, 1896), a British bacteriologist who discovered its ability to combat Vibrio cholera. Mukherjee *et al.* (1993) stated that the Ganga water possesses an exceptional capacity for retaining oxygen, which allows it to remain fresh even after being stored for a long time (Mukherjee *et al.*, 1993). Additionally, Bhargava (1981) discovered that the Ganga water has a BOD rate constant and a reaction rate constant value that is ten times higher than those of other rivers (Bhargava, 1981). Moreover, coliform levels were found to decrease significantly within a short period of time. The Ganga water possesses unique antimicrobial properties, which confirms its extraordinary ability to self-purify. However, despite these impressive self-cleaning abilities, various types of pollution have significantly impacted the water quality of the Ganga. Due to reduced levels of dissolved oxygen and light penetration, the Ganga water has lost its ability to self-purify, especially in the middle and lower sections of the river. Despite its exceptional qualities, the Ganga water is still subjected to stressors such as heavy metals, which can affect microbial extracellular enzymes (EE) in the sediment on the riverbed. This can result in a negative impact on the microbial community, its structure, and function, (Jaiswal and Pandey, 2017). These stressors can have an impact even at small ecological changes and are likely to cause experimental responses. When the self-purifying ability of the Ganga water is compromised, it leads to the proliferation of pathogenic bacteria. Fecal coliform (FC) bacteria, such as *E. coli*, are commonly found in human excreta that contaminate water due to untreated sewage. The

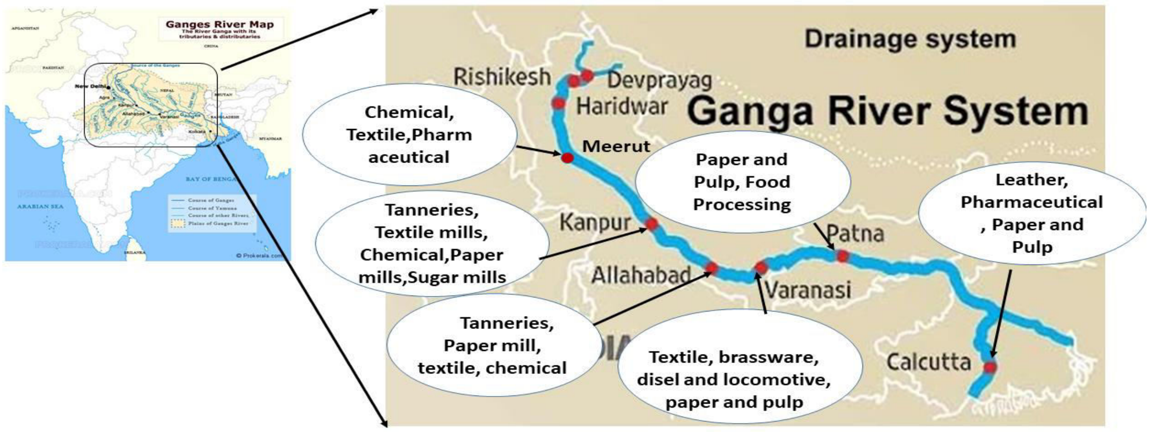

Fig. 1: Showing various industries in different districts through which the river Ganga travels.

greater the concentration of FC bacteria, the greater the presence of disease-causing pathogens in the water. The acceptable limit for FC is 2,500 MPN (Most probable number) per 100 ml, while the preferable level is 500 MPN per 100 ml (NMCGNEERI, 2018). In the whole stretch of river Ganga, the microbial count (Faecal and total coliform) was measured maximum at Khagra in Berhampore in West Bengal (30,000 MPN/ml), followed by Uttar Pradesh. This level is 12 times greater than the acceptable limit and 60 times greater than the preferred limit. Uttar Pradesh had the second-highest levels, with Kanpur and Varanasi measuring 93,000 and 50,000 MPN/100 ml of faecal coliform, respectively. As per the data provided by CPCB, faecal coliform levels were within the acceptable limit at only two locations, Sultanpur in Uttarakhand and Bijnor in Uttar Pradesh (CPCB, 2018). While the growth phase of bacteria helps to reduce BOD and turbidity in Ganga, the presence of metal pollution has been found to reduce the growth rate of these microorganisms. As a result, the self-purifying ability of the river is negatively impacted.

Sources of Metal pollution in river Ganga:

- *Industrial pollution*:

During the journey of five states, Ganga crosses major ancient Indian cities like Meerut, Kanpur, Allahabad, Varanasi, Patna, and Kolkata, where most of the industries are situated as shown in Figure 1.

Industrial units including textiles, electroplating, power plants, sugar mills, distilleries, paper and pulp, and several others directly discharge their wastes into the river, because the water treatment plants are less than the required numbers. Industries at Ajamu, Kanpur are situated in a cluster along the southern bank of the Ganga and discharge 5.8 to 8.8 MLD of wastewater. Metals are the major constituent of these discharges. In the Jajmau area as high as 52.12 ± 15.52 mg L^{-1} Cr has been reported in Ganga water (Katiyar, 2011). Tannery effluent contains a significant number of heavy metals, such as As, Zn, Mn, Cu, Pb, and Cr (Bhuiyan *et al.*, 2011). Besides the tanneries, other small and big industries containing untreated or partially treated effluents also significantly increase toxic elements in the Ganga water. Figure 2 gives an account for the amount of city discharge in various Indian cities at the bank of the river Ganga according to CPCB,2014 (CPCB, 2013).

- *Agriculture runoff*:

A lot of organophosphates and organometallic compounds enter the river from agricultural runoff in one of the most fruitful regions in the

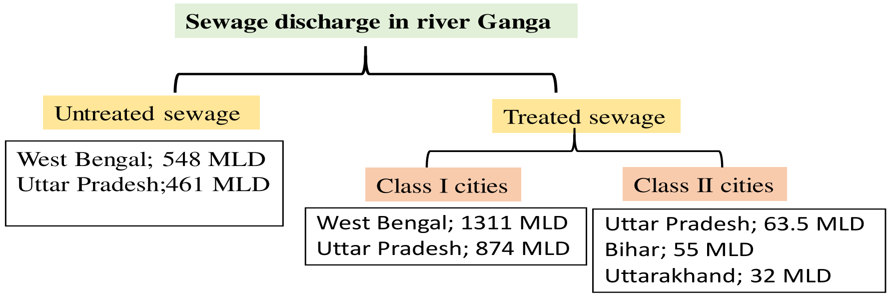

Fig. 2: City discharge in various Indian states at the bank of river Ganga.

nation. Through runoff streams and tributaries, pesticides employed in agriculture are able to find their way into rivers with ease. About 60,000 megatonnes (MT) of pesticides are used in India each year, with the Ganga basin alone accounting for the majority of usage (Kumar *et al.*, 2013). India ranks fourth in the world for pesticide production, behind China, Japan, and the US, producing about 85,000 MT of pesticide annually Organophosphorus pesticides (OPPs) and organochlorine pesticides (OCPs) are widely used in India in agriculture, with OCPs being considered as persistent organic pollutants. Although the use of certain pesticides like DDT, aldrin, and HCH is prohibited by law, they are still being used in agriculture, leading to severe pollution of rivers.

- *Religious activities*:

Being part of Indian tradition, the river Ganga is treated as a goddess, therefore religious and ritual offerings in addition to body cremation and idol immersion contribute a lot to water pollution. As, Cd, Cr, Hg, and Pb are proven carcinogens that are used in the paints to colour these idols (WHO, 2008). Plaster of Paris, which is commonly utilized for making idols, contains various components such as gypsum, sulfur, phosphorus, and magnesium. Due to the increase in acidity and the concentration of heavy metals, the immersion of these idols taints the water. In West Bengal, Sarkar *et al.* (2012) reported that the immersion of idols during the Durga Pooja has sufficient impact to raise the temperature, pH, conductivity, BOD, COD, total alkalinity, chloride, total hardness, and phosphate of the Ganga River (Sarkar, 2013).

Influence of Metal accumulation in river Ganga:

Due to the recurrent low or high flows, the dynamicity, and variability of the river cause temporary alterations in its water quality characteristics. This can result in unexpected environmental conditions at a particular location and time, which may differ from the norm. Metal accumulation in the water and sediment is one of the factors for such change. Several authors have documented the accumulation of heavy metals in different locations along the Ganges River. Goswami and Sanjay (2014) conducted a study using differential pulse anodic stripping voltametry to measure the levels of heavy metals, including cadmium, copper, lead, and zinc ions from Rishikesh to Allahabad. The purpose of the study was to analyze the concentration of these metals at different matrices of the river and concluded that the pollution levels of water and sediment at Narora Barrage and Jajmau Kanpur are alarming (Goswami and Sanjay, 2014). The pollutants are believed to have gathered as a result of the discharge of point sources from tannery industries. Another study (Gupta *et al.*, 2009), in the Allahabad district of UP, reported the order of heavy metal concentration in river Ganga as Zn > Pb > Cu > Cr > Cd. In the midstream of Ganga, nine heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb) were studied in the Varanasi district, from Samne Ghat to Varuna-Ganga confluence. The results showed that Cd and Pb had the highest Geo-accumulation index (Igeo) and

Table 2: Pollution level classification of heavy metals in sediment

Igeo	Level	Pollution Level
< 0	0	Unpolluted
> 0 to 1	1	Unpolluted to Moderately polluted
> 1 to 2	2	Moderately polluted
> 2 to 3	3	Moderately to heavily polluted
> 3 to 4	4	Heavily polluted
> 4 to 5	5	Heavily to extremely polluted
> 5	6	Extremely polluted

risk assessment code, indicating greater concern for their potential impact on the environment. On the other hand, Mn, Fe, and Ni showed negative accumulation indexes at all the sampling stations, indicating their levels were decreasing rather than accumulating over time (Pandey *et al.*, 2014).

Moving towards the down plains, Howrah and Rajghat have witnessed a high concentration of Cd, due to high traffic density and industrial release (Singh and Pandey, 2014). In West Bengal, Kolkata-Howrah represents one of the largest urban agglomerations in India with the highest number of vehicles per hour. The increased traffic volume and industrial emissions appeared to be connected with the elevated levels of Cd at the Howrah and Rajghat. Diamond Harbour witnessed the highest concentration of Cu. Boat ramps appeared to be an additional source of Cu at this location (Mummullage and Wasanthi, 2015). The river completes its journey at the Ganga Sagar site, located downstream of the Hooghly estuary, and also receives pollutants from a variety of urban industrial sources.

However, we can say that anthropogenic activities are the prime cause of metal pollution in the River Ganga. When such human activities cause environmental stress, metals can become unstable in forms like oxides, hydroxides, carbonates, and sulfides, and can mix with water (Pandey *et al.*, 2015a). Study shows that Cd and Pb have been deposited for a long time in their unstable and accessible forms in the river Ganga (Pandey *et al.*, 2015b). Extended metal deposition can result in changes to the composition of the bed sediment which can help more accurately to understand the response relationships and magnitude of ecological degradation (Turley *et al.*, 2016). River sediment provides important cues for the assessment of pollution sources, river health, and ecological risks (Pandey *et al.*, 2016). Calculation of the geo-accumulation index is a common criterion to evaluate the heavy metal pollution in sediments as suggested by Muller (1979).

The geo- accumulation index (Igeo) scale consists of seven grades (0 - 6) ranging from unpolluted to highly polluted, given in Table 2.

In a study at Allahabad, concentrations of Chromium (Cr) and Copper (Cu) in the sediment samples exceed the guidelines set by the Environmental Protection Agency (EPA) for heavily polluted sediment. On the other hand, the concentrations of Zinc (Zn) and Lead (Pb) in the sediment samples fall within the criteria for moderately polluted and not polluted sediment respectively. Siddique *et al*. (2019) studied 9 sites from Devprayag to Ganga Sagar and the highest I_{geo} was found for Cd, whereas the highest degree of contamination was recorded for Cr at Kannauj. Soil texture and pH are also effectively regulated by heavy metal enrichment in the given site. For instance, clay soil with alkaline pH and reductive dissolution of Fe and Mn oxy-hydroxides is regulated by heavy metal distribution. Hakanson's empirical relationship is used to assess ecological risk and potential ecological risk. The potential ecological risk index (PERI) is used to address the combined effects of all factors at a site. In Kanpur Cd contamination had the highest potential ecological risk. The reason for the high ecological risk associated with Cd may be due to its significantly higher toxicity response factor compared to Zn, which is 30 times higher (Ansari *et al.*, 1999).

The prosperous ecological diversity of river bed sediment determines the trophic status and detritus food web in the aquatic ecosystem ((Singh *et al.*, 2005).

Bioaccumulation of heavy metals in fish species of river Ganga:

Ganga serves as the habitat for more than 140 fish species, including many exotic species (Sarkar *et al.*, 2011). However, the river's water is contaminated with pesticides and herbicides from agricultural runoff, which accumulate in the organs and tissues of fish, causing reproductive and metabolic dysfunction. This pollution also leads to a decrease in fish growth, size, and survival, and some species, such as river dolphins, may become extinct (Khanna *et al.*, 2007). Basically, there are two means of toxicant accumulation; first, through contaminated water. Gills are the main site of toxicant uptake, which readily gets absorbed in the blood of secondary lamellae. Second, through contaminated food, such as phytoplankton which accumulates a high number of heavy metals (Dwivedi *et al.*, 2006). Fish health and diversity are adversely affected by organic and inorganic pollution and a decrease in the water volume of the river. A significant decline in various commercially valuable fish species has been observed, while forage fishes have increased in Ganga from 1959 to 2004 (Sarkar *et al.*, 2012). The liver, kidney, gills, muscles, skin, and brain are the target organs for metal deposition and may alter various metabolic parameters (Vaseem and Banerjee, 2013). Metal accumulation in different organs is calculated as the Bioaccumulation Factor (BAF) which is the concentration of a pollutant (heavy metal) accumulated in the tissue of an organism with respect to the concentration of that pollutant (heavy metal) in the water body (Authman and Abbas, 2007).

Species-specific variation is widely observed in metal accumulation (Zn, Cu, Pb, and Cd) in the muscles of some commercially important fishes of the river Ganga. The level of toxic metals particularly Pb and Cd were higher than WHO permissible limits in *Channa striata*, (a bottom feeder) *Labeo rohita*, (column feeder), and *Catla catla* (surface feeder) in Jajmau, Kanpur. (Kumar *et al.*, 2020).

Fish species including bottom feeders have been found to contain high concentrations of various metals including Ni, Pb, Fe, Cu, Zn, Cd, Cr, and Co in their liver, kidney, muscles, and gill tissues. Even delicate organs such as fish scales are affected by pollution in the river Ganga (Khanna *et al.*, 2007). Annulus formation in golden mahseer, Torputitora (Hamilton) is due to the maximum deposition of Ca and a minimum of Fe. High Al deposition leads to brittleness in the margin of scales in fishes (Tandon *et al.*, 1993). Vaseem *et al.* (2013) studied the accumulation of zinc (Zn), iron (Fe), copper (Cu), chromium (Cr), nickel (Ni), manganese (Mn), and lead (Pb) in different tissues (skin, muscles, liver, gills, kidney, and brain of rohu (*Labeo rohita*) collected from the River Ganga in Varanasi, India. They concluded that the concentrations of all metals were higher in River Ganga fish when compared with those from the Banaras Hindu University fish farm. Except for Zn in skin, muscle, and brain tissue, the studied metals were bioaccumulated in all tissues. Kumar *et al.* (2020) investigated the seasonal variation of heavy metals (Cr, Mn, Fe, Cu, Zn, and Pb) concentration in the water of river Ganga at five sites of Allahabad city and its possible effect on fish fauna. All parameters showed fluctuations with seasonal variation in fish species. In the Indian subcontinent, there is no safe level of heavy metals in fish tissue (pollution control authority or any other regulatory body), although fishes contribute a major food protein source in the Indian population, with a weekly average consumption of 1,050 g and an annual rate of 55 kg per person. It has been widely reported in the literature (Kumar *et al.*, 2014, Muchuweti *et al.*, 2006) that humans might be affected significantly by the consumption of heavy metals contaminated fish species. Although, in one study, the concentration of selected heavy metals zinc (Zn), copper (Cu), lead (Pb), and cadmium (Cd) in the muscle tissue of five common finfish species, *Polynemus paradiseus*, *Tenualosa ilisha*, *Liza parsia*, *Liza tade* and *Stolephorus commersonii* in western and central sectors of Indian Sundarbans were found to be lower than the recommended maximum level (except Zn in *Liza parsia* in one station) allowed in food for human consumption as prescribed by food and agricultural Organisation (Das *et al.*, 2014).

Human health risk assessment due to metal pollution:

The environmental chemicals get biomagnified as they travel through different trophic levels, thus impacting largely health risks in humans (Voutsa and Samara, 1996). The human body is exposed to heavy metals in two ways. Either by ingestion of contaminated water and contaminated aquatic organisms, such as fishes, and second by dermal absorption. The human health risk is assessed by calculating THQ (Total Health Quotient) and HI (Hazard Index) (Usepa, 1996). The health quotient is stipulated by Palmer *et al*. (2019) given in Table 3.

Table 3: Health quotient qualifications (Palmer *et al.*, 2019)

Health Quotient (HQ)	Qualifications
<0.01	Negligible
0.01-0.1	Low
0.1-1	Moderate
1-10	High
>10	Very High

Heavy metals have become a serious health risk globally, as they contaminate soil, water, and vegetables via the environment and are consumed by humans. The physicochemical and microbiological studies have shown that at various stretches, particularly in the middle plain of Ganga the water is not even suitable for bathing humans and cattle and for other domestic uses because of the high load of pathogenic bacteria (Mishra and Mohapatra, 2009; CPCB ENVIS, 2007-2014). Regarding heavy metals, their non-bio-degradability and long persistent nature have risked serious health implications in recent years in the Ganga basin, as they have a tendency to bioaccumulate in vital organs such as the kidneys, bones, liver in humans and are involved in numerous serious health disorders, including, gastrointestinal issues, neurodegenerative diseases and carcinogenesis induced tumor promotion (Duruibe *et al.*, 2007; Jain *et al.*, 2012)). In a survey study in Varanasi, UP, people living on the bank of river Ganga, showed high incidents of water-borne/enteric diseases including acute gastrointestinal disease, cholera, dysentery, hepatitis-A, and typhoid (Duruibe *et al.*, 2007). Health risk from exposure to Hg (mercury) contamination is potentially alarming in the urban sector where 32.4% of the population residing in 6.8% of the total Lucknow monitoring area, especially in the western parts, is at high to very high-risk probability (Raju *et al.*, 2019).

Approaches to improve pollution level in Ganga:

In India, Ganga Basin witnessed large-scale industrialization and urbanization after independence, due to its mineral-rich land. A survey by CPCB (2018) showed that 317 major industrial units are operating all along the bank of the river Ganga and its tributaries. These industries depend upon River Ganga and its tributaries for their primary water resource. But unfortunately, only 37% of these units followed some controlled measures and the remaining ones pose pollution hazards, as they pour water with or without treatment into the river. In this light, the Ganga Action Plan (GAP) was launched on 14th January 1986, with the objective to reduce pollution and improve the River water quality (Sanghi and Kaushal, 2014). The project aimed to achieve this in two important ways. First by increasing the capacity of existing sewage treatment plants and second by interception and diversion of domestic and industrial sewage. In this extension, the Ganga Action Plan Phase-II (GAP-II) came into existence in the year 1993. Programs of other major rivers including Yamuna and Gomati were subsequently approved in 1995 under National River Conservation Plan (NRCP).

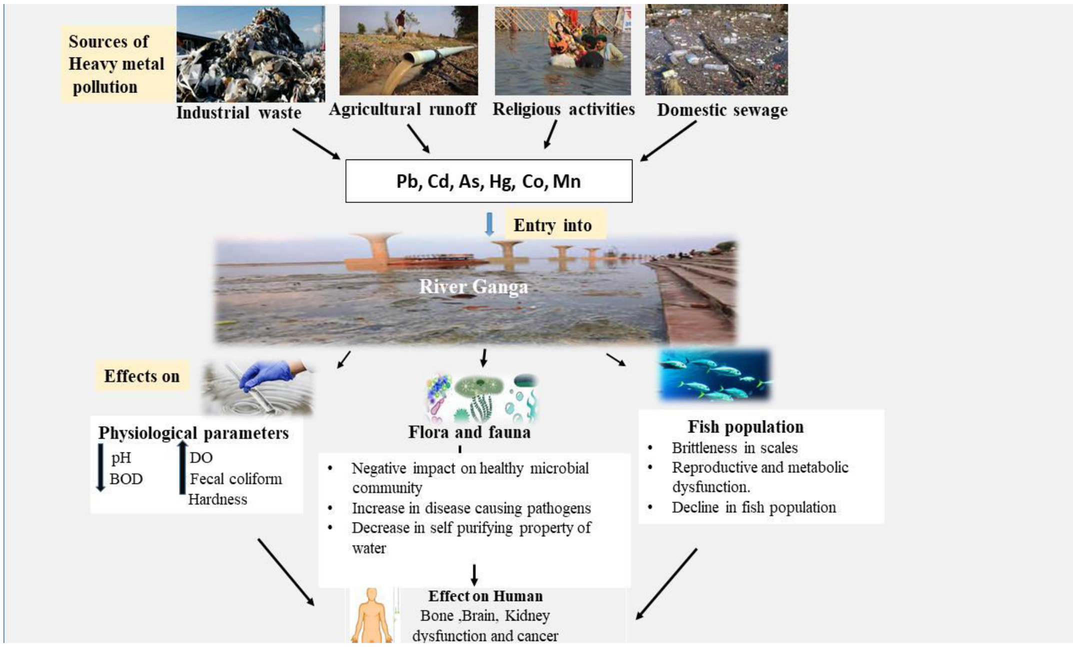

Fig. 3: Heavy metals affect the growth of flora, fauna, and various aquatic vertebrates and invertebrates including fishes.

The GAP eventually merged with the NRCP (Sanghi and Kaushal, 2014).

Ganga was declared the National River in 2008, by the Prime Minister of India, and the National Ganga River Basin Project (NGRBP) was formed for its cleanup. The NGRBP was the first basin-level initiative in India that manages the inter-state river for water quality and environmental protection.

On 20 February 2009, the National Ganga River Basin Authority (NGRBA) was established for the cleaning and conservation of the Ganga under Section 3(3) of the Environment Protection Act. Nevertheless, after nine years of the establishment of NGRBA, the quality of river water does not seem to improve and comprehensive data on the status of different pollutants in River Ganga is still lacking in 2014, with the approval of the *Namami Gange Programme* by the Union Government, an Integrated Conservation Mission, came into effect to accomplish double objectives of effective pollution control, conservation, and rejuvenation of National River Ganga. Several Bio-Diversity conservation projects namely: Bio-diversity Conservation and Ganga Rejuvenation, Fish and Fishery Conservation in Ganga River, and Ganges River Dolphin Conservation Education Programme have been initiated. India collaborated with several foreign countries like Australia, the United Kingdom, Germany, Finland, Israel, etc. by signing Memorandums of Understanding (MoUs) for rejuvenating Ganga. (National Mission for Clean Ganga). Despite these efforts, Ganga still needs more public awareness and strict government norms under the Clean Ganga mission.

Conclusion

This review summarizes the impact of metal pollution on the biochemical and biological health of river Ganga. The biological and biochemical water and sediment analysis, concerning metal, indicates that River Ganga is contaminated with metal pollution.

Long-term sewage and sludge disposal in the river have resulted in the accumulation of toxic heavy metals in river water, which may adversely affect the growth of flora, fauna, and various aquatic vertebrates and invertebrates including fishes (Fig. 3), ultimately make them a big risk to human health and welfare. Therefore, various sources of heavy metals should be closely monitored, and industrial effluent and domestic sewage discharge should be reduced. Hence, steps must be taken to minimize the metallurgical effluent load deposited into the river Ganga. Effective management by increasing the number of effective sewage treatment plants is required to prevent the surplus leakage of heavy metals in the environment on a priority basis. Therefore, spontaneous involvement of the public and private sectors with obligatory involvement of local as well as national level regulatory and monitoring authorities should be the prime thrust for the nation regarding the effective effluent management of domestic and industrial waste. The information obtained from this review could be helpful for governmental and environmental organizations to monitor and save our cultural heritage, Ganga, and management of the natural environment and human health practices.

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