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Review Paper

Risk assessment of heavy metal pollution in middle stretch of river Ganga: an introspection

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Abstract

The present review focuses on water quality of the river Ganga with respect to heavy metals and their toxicity effects on fish and human health. Some heavy metals like copper, cadmium, lead and chromium are the main pollutants of river Ganga which affect aquatic life and human health. The pollution status of river Ganga in the middle stretch was described in terms of heavy metal concentration and physical appearance of river water due to presence of organic and inorganic pollutants. The reported value of metal concentration in the river Ganga and its major tributaries such as Ramganga, Kali, Yamuna and Gomati are as: Cr (Ganga,0.00-366.91µg/L >Yamuna,3.245-290 µg/L >Kali, 3.00-200 µg/L > Ramganga,0.00-108.7 µg/L > Gomati,1.5-68.8 µg/L), Cu (Ganga,10.00-140.64 µg/L > Ramganga,57.15-99.10 µg/L > Yamuna,00.871- 84.88 µg/L >1.3-4.3 µg/L), Cd (Yamuna,00.018 - 330 µg/L > Kali,2.00-80 µg/L > Ganga,0.6-36 µg/L > Gomati 0.1-0.5 µg/L), Pb (Kali,22-340µg/L > Yamuna,0.067-254 µg/L > Ganga,4.7- 86.9 µg/L > Ramganga,10.1-48.92 µg/L > Gomati,15.8-27.6 µg/L). These reported values of heavy metal concentration were compared with BIS, USEPA, ICMR, CPCB and WHO standards. The values in the water are above permissible limit which may have potential health risks to aquatic ecosystem and organisms living around Ganga river basin. These metals accumulate into the fish tissues and cause damage to the its body organs like central nervous system, kidneys, lungs, liver, bone and endocrine glands. Thus, the objective of this review is to i. give an insight about pollution status in the middle stretch of river Ganga, ii. collect the information of heavy metal concentration present in the river Ganga and its tributaries, and iii. provide the information about pollution index, bioconcentration factor, bioaccumulation factor, biomagnification factor, homeostasis of metal ions and toxicity effects of Pb, Cu, Cr and Cd on fish and human health.

Keywords: Ganga river, Tributaries, Pollution status, Permissible limit, Heavy metal toxicity, Health risks.

Introduction

Ganga is the largest riverine system of India with well developed ecosystem and has several important cultural, economical and environmental values. It provides water for approximately 450 million people with an average density of over 550 individuals per square kilometre[1]. Therefore, the river water is being utilized for fishing, aquaculture, irrigation and domestic purposes, river basin for cultivation of vegetables and cereals. These activities are indispensable for the nutritional requirement and uplift of economic status of the millions of households. Ganga water is continuously degrading due to direct discharge of industrial wastes, agricultural run of and anthropogenic activity along the river bank. Such activities culminate into the accumulation of domestic, industrial and agricultural wastes in the river. These wastes contain health hazard chemicals like salts of chromium, copper, cadmium, arsenic, mercury and lead which interact with aquatic environment and affect the river ecosystem. Therefore, the aquatic ecosystem of river Ganga is suffering a huge loss in terms of aquatic biodiversity. Heavy metal containing pollutants accumulate into water column, sediment and tissues of aquatic organisms like plant and animals. The gradual increasing of metal concentration in the aquatic environment favors the entry into biogeochemical cycle and leading to toxicity in the aquatic biota[2]. Generally fishes and humans are badly affected through these accumulated metals because they are top consumers in aquatic ecosystem and food chain respectively[3]. Heavy metal accumulation in the aquatic bodies show direct consequence to the living beings and aquatic ecosystem[4]. The water laden with heavy metals is also used for irrigation and drinking purposes that may adversely affect plant growth, animal health and people living in that area.

The people of those areas where staple food includes fish and river water for drinking are mostly affected by heavy metal pollution. There are several reports on metal toxicity that the metal contaminated food, water and fish affect the human health[5-7]. In humans, heavy metals may cause genotoxicity, joints and muscles pain, gastrointestinal disorders, mental disorder, vision problem, cancer and increase susceptibility to microbial infections.

Pollution status in middle stretch of river Ganga

The Ganga river basin is the largest inland river basin of India draining a catchment of about 8,61,404 Km^2 and covers a long distance about 2,525 Km from Gangotri to Bay of Bengal. Ganga has many tributaries like Ramganga, Kali, Yamuna and Gomati around the middle stretch from Haridwar to Varanasi. Among these tributaries Ramganga, Kali and Yamuna are loaded with huge amount of heavy metals containing organic and inorganic pollutants. There are several major cities such as Haridwar, Farrukhabad, Kannauj, Kanpur, Allahabad and Varanasi are located close to the river bank in the middle stretch and their waste waters directly discharged into the river. According to CPCB's (2013) report from these cities about 2,723 million litres per day (MLD) of domestic sewage is discharged into the river[8]. The monitoring of river Ganga in between Rishikesh to Varanasi indicated that the middle stretch of river Ganga from Kannauj to Kanpur and Varanasi are the most polluted region[9,10]. Although the physical appearance of river water is generally good in quality before it reaches the Ghatiya Ghat, Farrukhabad. From Ghatiya ghat (Farrukhabad) to Menhadi ghat (Kannauj) the water quality of river gradually decreases due to discharge of approximately 500 MLD toxic wastes from domestic sewage and Kali and Ramganga rivers. Industrial wastes with organic and inorganic chemical constituents change the physical appearance of river water. Therefore; physical appearance of the river water gradually becomes brown to blackish colour around Kanpur city where approximates 1000 MLD toxic effluents of about 400 tanneries, untreated municipal waste and industrially polluted Pondu river discharge their waste to river Ganga[11]. The Ganga river water quality has been evaluated on the basis of pollution indicators like pH, alkalinity, DO, BOD, COD, coliform bacteria and presence of heavy metals.

Table-1: Range of heavy metal concentration in Ganga river water and its tributaries.

Rivers	Range of Heavy metal concentration in µg/L				References
	Cr	Cd	Cu	Pb	
Ganga	0.00-18	0.00-12	0.00-30	18-86	12
	NA	0.6-30.54	10.00-36.00	4.7-26.9	13
	55.14-366.91	NA	57.18-140.64	10.11-15.03	14
Ramganga	0.00-108.7	NA	57.15 - 99.10	10.1 - 48.92	14
Kali	3-200	2-24	NA	22 – 340	15
	60.00-90.00	60.00-80.00	NA	130 – 190	16
Yamuna	3.245-13.58	0.018-0.044	0.871-3.087	0.067 - 0.326	17
	NA	3.02-4.00	0.00-84.88	18.31 - 34.17	14
	3.00-290	20-330	NA	166-254	18
Gomati	1.5-68.8	0.1-0.5	1.3-4.3	15.8-27.6	19

Table-2: Prescribed limits of heavy metal concentration in river water.

Standards	Concentration of heavy metals in µg/L			
	Cr	Cd	Cu	Pb
BIS	50	10	50	10
ICMR	50	10	1500	50
WHO	50	50	1000	50
USEPA	100	5	1300	15
CPCB	No relaxation	No relaxation	1500	No relaxation

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

Measurement of metal contamination in river and fish

The heavy metal concentration increases in the environment by release of industrial and municipal waste directly into the stream, lake, river and ground water from where they accumulate into sediment, water column and in the body of living organisms. There are three possible routs by which heavy metals enter into the fish body i.e. through gills, digestive track and body surface. It is estimated that the fish gills are direct in contact with surface water hence it is the main site for direct uptake of heavy metals while the fish body surface is normally intake less amount[20-22]. The following equations help to measure the metal pollution in river water and fish tissues.

Contamination index (CI) and pollution index (PI): These indexes are used for calculation of actual concentration of heavy metal pollution with respect to the maximum permissible limit for standard discharge of environmental pollutant to inland water. The pollution index of individual heavy metal was calculated by the following formula:

$$\mathrm{PI} = \frac{\text{Measured concentration of individual heavy metal}}{\text{Standard permisible concentration of heavy metal}}$$

While the contamination index for potentially toxic heavy metal in the river was calculated by the following formula:

$$\mathrm{CI} = \frac{1}{5}\sum \mathrm{Pi}$$

Here, Pi = Pollution index of individual heavy metal, CI = Contamination index. If the value of CI is >5, water will be contaminated, in between 1-5, slightly contaminated and <1 the water is not contaminated[23]. The combination of both PI and CI called the Nemerow pollution index (PI) which is mostly applied to detect the total pollution level and evaluate aquatic environmental quality[24]. The total pollution level calculated by the following formula:

$$\mathrm{PI} = \sqrt{\frac{1}{2}\ (\mathrm{Pi}_{\mathrm{max}}\ 2 + \mathrm{CI}^2)}$$

Where: PI = Nemerow pollution index, Pi_{max} = Maximum value of pollution indices of total heavy metals considered at particular sampling location. If P≤1, potentially non contaminated water; 2<P≤3 less contaminated water and P>3 most contaminated water.

Bioconcentration: It refers to the entry of chemicals into the body of organisms from the surrounding medium and accumulates in the certain tissues. The degree of bioconcentration is expressed as bioconcentration factor (BCF). The bioconcentration factor (BCF) for heavy metal contaminated water is calculated as the ratio of heavy metal concentrations in the fish tissues and in water during steady state or equilibrium[25]. For heavy metals in aquatic ecosystem the BCF is expressed as:

$$\mathrm{BCF} = \frac{\text{Concentration of heavy metal in fish tissues}}{\text{Concentration of heavy metal in surrounding water}}$$

Biomagnification: It refers to the gradual increase in the concentration of heavy metals in the tissues as it passes through the food chain. In this process the level of metal concentration increases as the position of the organism increases in the food chain. For heavy metals contamination in aquatic ecosystem during equilibrium condition the biomagnification factor (BMF) is expressed as:

$$\mathrm{BMF} = \frac{\text{Concentration of heavy metals in top aquatic consumer}}{\text{Concentration of Heavy metal in fish tissues}}$$

Bioaccumulation

The persistent hydrophobic chemicals in the aquatic system may accumulate in aquatic organisms through different routes such as direct uptake from water by gills or body surface[26]. Accumulation of chemical substances (Heavy metal) into the body of an organism is called bioaccumulation. Bioaccumulation factor (BAF) is the ratio of concentration of heavy metals accumulated in the tissue of fish with respect to the concentration of heavy metal in surrounding water and suspended food materials.

$$\mathrm{BAF} = \frac{\text{Concentration of heavy metal in fish tissues}}{\text{Concentration of heavy metal in water and food}}$$

The mechanism of bioconcentration, bioaccumulation and biomagnifications is easily showed by the using following model (Figure-1).

Human health risk assessment

The health risk assessment in human was estimated by the amount of accumulated heavy metal in fish tissue and amount transfer to the human body by daily intake of fish flesh[27].

$$\mathrm{EDI} = \frac{\mathrm{E_f\ x\ E_d\ X\ F_{ir}\ x\ C_f\ x\ C_m}}{\mathrm{W_{ab}\ x\ T_a}}\ \mathrm{X}\ 10^{-3}$$

Where: EDI = Estimated daily intake, E_f = The exposure frequency 365 days/year, E_d = The exposure duration, equivalent to average life time (65 years), $F_{i\,r}$ = The fresh food ingestion rate (g/person/day) which is considered to be India 55 g/person/day, C_f = The conversion factor (= 0.208) (The content of fresh weight (fw) to dry weight (dw) considering 79% of moisture content), C_m = The concentration of heavy metal in food stuffs (mg/kg dw), W_{ab} = Average body weight (60kg), T_a = The average exposure time for non carcinogens (T_a = $E_f \times E_d$)[28,29].

Homeostasis of heavy metal

Organisms have specific ability to regulate heavy metals up to a certain concentration and protect themselves against adverse effects of metal ions. However, continuous exposure of heavy metals into the aquatic organisms disturbs the ability of regulatory processes and initiates metal accumulation in their body beyond the limits. The homeostasis and detoxification of toxic metals in the organisms are maintained by low molecular weight protein; called metallothionein (MT)[30,31]. They are cytosolic proteins with highly conserved cystein residue that allow MT to bind with various heavy metals such as copper, cadmium and zinc through metal- thiolate bonding[32,33]. MT gene transcription is induced by metals via metal responsive elements (MRE) that bind transcription factor (MTF) and starts the MT gene transcription[34]. Metalothionein provides protection against oxidative stress from metal toxicity and also participate in the regulation of essential metal ions such as Copper and Zinc[35]. The mechanism of MT gene expression and regulation is described in the (Figure-2).

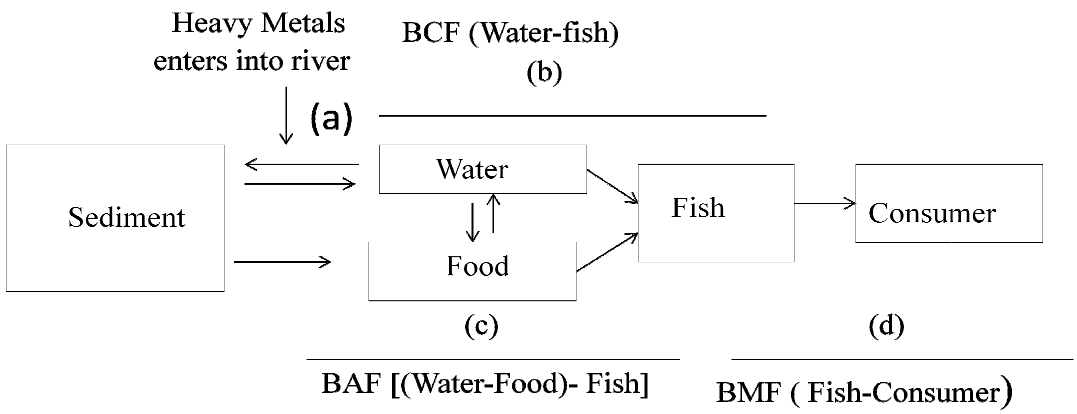

Figure-1: Mechanism of Bioconcentration, Bioaccumulation and Biomagnification. (a). Entry of HM into the river where accumulate into water column, sediment and suspended foods (b). Entry of HM into the fish tissue from water (C). Accumulation of HM in fish from water and suspended foods (d). Gradually transfer of HM into consumer through food chain.

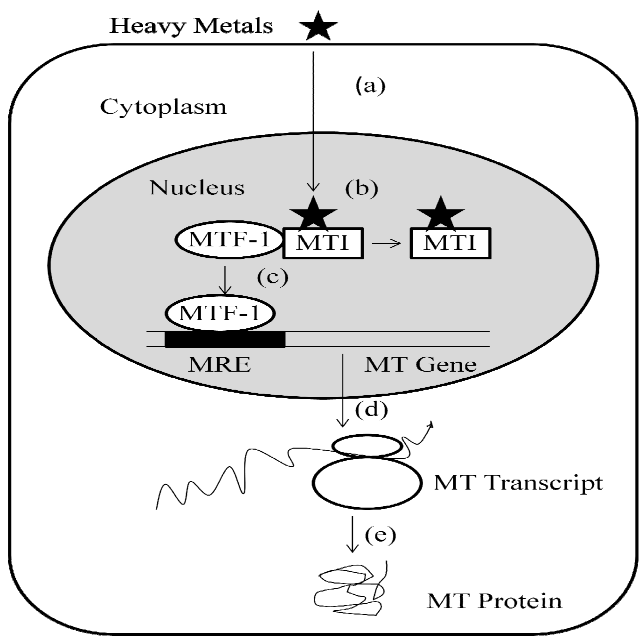

Figure-2: Mechanism of Expression and Regulation of MT gene. (a). The entrance of heavy metal ion into the cytoplasm through plasma membrane (b). The interaction with complex of MTF-1 and MTI. (c). As the metal ion is bounded with MTI, MTF-1 is separate and binds to the regulatory region of metal responsive element (MRE). (d). MT gene is transcribed to produce mRNA (e). On translation of mRNA, synthesis of metallothionein (MT) protein, this metallothionein protein binds with the metal present in the cell and protects the body from oxidative stress.

Metal toxicity in fish and human

Several studies have been reported that the presence of various heavy metals in the water column, sediments and fish organs. These pollutants not only affect the physico-chemical properties of the river water and sediments, but also affect the biological components which are responsible for decreasing the quality and quantity of fish stocks[36]. A study on heavy metals containing aquatic environment shows strong influence in the haematological parameters such as concentrations of red blood cells, blood glucose levels and total cholesterol level significantly elevated in fresh water fish common carp (*Cyprinus carpio*)[37]. The following heavy metals were described with their toxic effects on fish and human health.

Lead (Pb): It is a naturally occurring heavy metal characterized as health hazardous substance[38]. In environment, concentration of Pb is significantly increased by anthropogenic sources such as fossil fuel burning, mining, battery manufacturing, metal product like solder and pipes for water supply, X-ray shielding devices, leaded gasoline, glass containers of food and beverages[39,40]. In aquatic system Pb come from industrial discharge, lead containing pesticides, through precipitation, street runoff, and municipal waste water. The absorption of Pb takes place into the sediment and water columns containing natural organic and inorganic substances that influence the pH, alkalinity and hardness of surface water[41].

Lead toxicity on Fish health: The lead is mainly accumulated in fish gill, liver and kidneys, and also in digestive tract. Castro et al, have reported lead accumulation induced disorders in fish body of different fish species[42]. The exposure of 5 ppm concentration of lead nitrate into the *Clarias batrachus* till the period120 days that show the inhibition of gonadal growth, decrease the level of cholesterol and lipid in brain, testes and ovary while liver shows an increase in both[43]. Study of lead toxicity in the present day is very important because of its effect on human health[44,45]. Exposure to high lead levels in the aquatic system can cause generative damage and alteration in blood and nerves cells in fish and other aquatic organisms[46,47].

Lead toxicity on human health: The lead enters in our body via breathing with contaminated air, contaminated drinking water, food and beverages that solubilise lead from glass containers. EPA has reported that lead is a human carcinogen which affects organ and physiology of the body. The accumulation of lead takes place in the bones and teeth with a biological half-life of 20-30 years. Although bones and teeth only act as reservoirs for lead, from where it is released into the bloodstream and binds with erythrocyte. In blood the half life of lead is about one month which is eliminated through urine[48]. The People taking less calcium containing diet may accumulate more lead in their bones and cause greater toxicity. The greater lead toxicity inhibits the function of two key enzymes that are required for the synthesis of hemoglobin; results in reduction of hemoglobin level that cause anemia[49,50]. Pregnant women and young children are may be more susceptible to lead toxicity due to deficiency of iron[51].

Chromium (Cr): It is found in soil, rocks, plants and animals in the form of liquid, solid or gas. It is used in preparation of metal alloys such as stainless steel, magnetic tapes and electroplating etc. Chromium compounds binds to soil and persist into the ground water sediments. In the ground water Cr comes from adsorbed Cr sludge (Cr_2O_3) which comes from manufacturing of Basic Chrome Sulphate (BCS, $Cr(OH)_2SO_4$). This sludge form during the BCS manufacturing from incinerated chromite ore ($FeCr_2O_4$) containing water soluble Cr (VI). Basic Chrome Sulphate is generally used in local tanneries. In India, the high concentration of Cr (VI) into ground water is due to release from various industries[52]. In surface waters, chromium exist into two stable forms i.e. trivalent Cr (III) and hexavalent Cr (VI) oxidation states. Hexavalent state is more toxic than trivalent due to its powerful oxidative potential[53,54].

Chromium toxicity on Fish health: Chromium enters into the aquatic ecosystem mainly through discharged of effluents from tanneries, textiles and pharmaceutical industries[55]. The effect of Cr on fish health shows hematological, histological, morphological alterations, growth inhibition, reactive oxygen species (ROS) production and loss of immune function[56]. The depletion in the level of lipid, protein and liver glycogen in fish has been observed in water containing hexavalent chromium[57].

Chromium toxicity on human health: It is an essential trace element for lipid and carbohydrates metabolism in humans and its deficiency causes diabetes and cardiovascular disease[58]. The trivalent Cr (III) is an essential micro nutrient while Cr (VI) is dangerous to human and animal health mainly for those people who work in the steel, leather and textile industry and live around industrial areas. An in vivo study has reported that over concentration of chromium causes different types of genetic defect in the body tissues[59]. It has also been reported that exposure of high dose of Cr compounds in human beings may lead to lung cancer[60]. It present in the products of leather and textiles that may cause allergic reactions like skin rash, breathing with Chromium (VI) contaminated air may cause nose irritations and nosebleeds[61].

Cadmium (Cd): It is the most toxic metal to both fish and human life. Soils, rocks, burning of fossil fuels and municipal waste are major source of cadmium in the environment[62]. Tobacco smoking is an important source of cadmium exposure into the body. Smoking one pack a day, can raised 5-10 times the amount of cadmium in the body. Cadmium is used in batteries; metal coatings, plastics and electroplating. The accumulation of cadmium takes place in the liver and kidneys with a biological half-life of 30 years.

Cadmium toxicity on fish health: Cadmium can enter into the water body through disposal of wastes from households or industries. It affects the rate of reproduction of aquatic organisms and can lead to a gradual extinction of their generations in polluted waters[63]. Fish is one of the major sources of protein for human beings**.** The lethal concentration of cadmium has showed variations on the electrophoretic patterns of proteins segments in the muscle and gills of *O. mossambicus*[64]. The effect of cadmium on the histology of kidney in *Cirrhinus mrigala,* has been observed, leading to rupture of tubular boundary cells, formation of melanomacrophage, congregation of nuclei, damage of epithelial cells and coagulated mass of blood cells[65]. Cadmium chloride in *Channa punctatus* on kidney tissues resulted in the shrinkage of glomerulus[66]. The proximal tubules of the kidney were fully damaged when *Channa punctatus* was exposed to cadmium chloride[67].

Cadmium toxicity on human health: In human body the entry of cadmium takes place through contaminated foodstuffs such as liver, mushrooms and dried sea weed[68]. Through blood circulation Cadmium first transport in to the liver and bind with metal binding protein metallothionein that sequestered and transported to the kidneys. In kidney, it accumulates and interferes with blood purification mechanisms. Cadmium has been reported to be carcinogenic, embryotoxic, teratogenic, and mutagenic and may cause hyperglycemia, reduced immunopotency, and anemia, as it interferences with iron metabolism[69]. Furthermore, Cd in the body has been shown to result in kidney and liver damages and deformation of bone structures[70].

Copper (Cu): It is an essential trace metal which play important role as a precursor for some enzymes in metabolic reaction[71]. Copper pollution in environment increases through the use of excess amount of fungicides, algaecides, molluscicides, insecticides, mining, and electroplating[72].

Copper toxicity on fish health: In commercial fish pond or aquaculture, copper sulphate is used as an aquatic weedicide to control the growth of algae, phytoplankton and also in the treatment of certain fish diseases[73]. The accumulation of copper in the fishes generally via diet or direct exposure[74]. Copper shows distinct affinity at low concentrations and accumulate in the fish liver and causes its morphological and histological changes[75,76]. The histological alterations induced by copper are reported in the fish gills, hematopoietic cells, chemoreceptors, kidney and other tissues[77]. The higher exposure of copper in the fish such as *Carassius auratus, Cyprinus carpio* and *Corydoras paleatus* are show external lesions into the tissues that result to necrosis of liver and other cells[78]. Radi and Matkovics have been reported that the exposure of high copper concentration in *Cyprinus carpio* shows the inhibition of catalase enzyme in muscles, gills and liver[79]. The chronic toxic effects of copper may affect the growth, immunity, fertility, life span and also changes in physical appearance and natural behavior of organisms[80].

Copper toxicity on human health: In human, copper intake from by foods, drinking water and dietary supplements. The tolerance limit of copper in the body recommended by Environmental protection Agency (EPA) is 1.3mg/L while the WHO tolerance limits of copper in drinking water is 2.00mg/L [81]. On long term exposure of Cu can cause irritation in mouth eyes and nose and also causes headaches, vomiting and diarrhoea. In India, Indian childhood cirrhosis is reported where large amount of copper are rapidly deposited in the liver[82]. Some visceral organs (liver, kidney) and some fruits and nuts have high copper contents[83]. Copper accumulation in the liver is being reported in a variety of pediatric hepatic diseases like idiopathic copper toxicosis (ICT), Wilson’s disease, and Indian childhood cirrhosis[84].

Conclusion

The studies show that river Ganga is loaded with heavy metal pollutants as cadmium, lead, chromium and copper. Their quantities are far above the permissible levels according to national guidelines of drinking water and WHO standards. Therefore, untreated Ganga river water is not fit for daily use such as drinking, bathing, fish culture and irrigation. It needs to be treated to reduce the metal contamination otherwise aquatic ecosystem and human health would be at high risk. Metal alters the biochemical functions of gene encoding specific enzymes which affects immune system of metal exposed organisms and increase their susceptibility to bacterial infection. From the published data of many authors it is indicated that the presence of heavy metal in the river may cause of reduction in survival, growth and size of fish population or may also cause extinction of some fish population. The presence of huge amount of metal pollutants into surface water can affect the self purifying nature of the river. As soon as the river loses its self purifying nature, it results in the growth of high level of pathogenic bacteria. The regular monitoring and strict law enforcement is necessary to achieve sustainable way for enhance the water quality, and at last awareness should be created among the common people. The main objective of cleaning the river Ganga under the Scheme *“Ganga Action Plan”* will not be completed with the Ghats development program alone but the most important part should be prevention of discharge of heavy metal pollutants present in industrial effluents into the river. The prevailing condition of the river Ganga is of serious concern so the future research work would be done on surface water chemistry of river Ganga to save our precious natural resources for sustainable living for all life forms.

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