International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2020; 2(2): 136-147
Received: 02-05-2020
Accepted: 10-06-2020

Indrani Dubey
Department of Zoology, D.B.S. College, Kanpur, Uttar Pradesh, India

Corresponding Author:
Indrani Dubey
Department of Zoology, D.B.S. College, Kanpur, Uttar Pradesh, India

Heavy metal pollution of river Ganga: A review

Indrani Dubey

Abstract
The Ganga is the largest river in India with an extraordinary religious importance for Hindus. Situated along its banks are some of the world's oldest inhabited cities like Kanpur and Varanasi. The total stretch is 2525 km from Gangotri up north to Kolkata on east provides water to about 40% of India's population across 11 states serving an estimated population of around 500 million people, which is larger than any other river in the world in terms of dependence of natural source. It provides ecosystem services which are of vital importance for the inhabitants of the Ganges river basin. Anthropogenic activities have generated important transformations in aquatic environments during the last few decades. Advancement of human civilization has put serious questions to the safe use of river water for drinking and other purposes. The water quality of the Ganges River deteriorates downstream. The river water pollution due to heavy metals is one of the major concerns in most of the metropolitan cities of developing countries. Indian cities, e.g., Kanpur and Varanasi, are local hotspots of pollution and poor water quality. Downstream of these cities the river's water quality improves, but never restores to its original state. These toxic heavy metals entering the environment may lead to bioaccumulation and biomagnifications. These heavy metals are not readily degradable in nature and accumulate in the animal as well as human bodies to a very high toxic amount leading to undesirable effects beyond a certain limit. Heavy metals in riverine environment represent an abiding threat to human health. Exposure to heavy metals has been linked to developmental retardation, kidney damage, various cancers, and even death in instances of very high exposure. The following review article presents the findings of the work carried out by the various researchers in the past on the heavy metal pollution of river Ganga. The results revealed alarmingly high levels of nutrient- and organic pollution in the Ganges along Kanpur.

Keywords: River, religious, transformations, accumulate

Introduction
Water is the most key resource required to sustain the life on this planet. Riverine wetlands are among the most productive life support systems in the world and are of immense socio-economic, ecological and bio-esthetic importance to mankind. The Ganga (or Ganges river) is a 2525 km long river crossing the northern part of the Indian craton. The Ganges river basin houses about 40% of the Indian population (Ganga River Basin Environment Management Plan, 2012d). The River Ganga is the most important river system in India. Due to the copious availability of water throughout the year, it has played a major role in the growth of Indian civilization and economy (D. Paul and S.N. Sinha, 2013) [1]. It sustains diverse group of flora and fauna. Record of 268 fishes from the Ganga was the first-ever scientific documentation of the fauna of the river. It accounts for 25% of India's water resources. The Ganga is the thirtieth longest river in the world, covering a basin area of 861,404 km2 (M.M. Rahaman, 2009) [2]. The Ganga basin is among the most heavily populated areas in the world with an average density of 520 persons/ km2 (P. Das and K.R. Tamminga, 2012) [3]. The basin sustains more than 300 million people in India, Nepal, and Bangladesh (B. Gopal, 2000) [4]. It is expected that this number will grow to 1 billion by 2030. The basin of river Ganga, which has very rich heritage, cultural and religious values, drains about 1,060,000 km2 area and it is the fifth largest in the world (R.L. Welcomme, 1985) [5]. The river system drains about one-fourth of the Indian subcontinents. In India, the river Ganga passes along 29 class I cities, 23 class II cities and approximately 50 towns because of which different types wastes such as industrial, sewage etc are released into this mighty river eco-system (A. Agrawal, R.S. Pandey & B. Sharma,2010) [6], (K. Biswas, D. Paul & S.N. Sinha, 2015) [7].

The river Ganga originates from the Gangotri glacier at Gomukh (30360 N; 79040 E) in the Uttar Kashi district of Uttarakhand province in India, at an altitude of about 3800 m above mean sea level in the Garhwal Himalaya (K.K. Vass, S.K. Mondal, S. Samanta, V.R. Suresh &P.K. Katiha, 2010) [8] (Fig. 1).

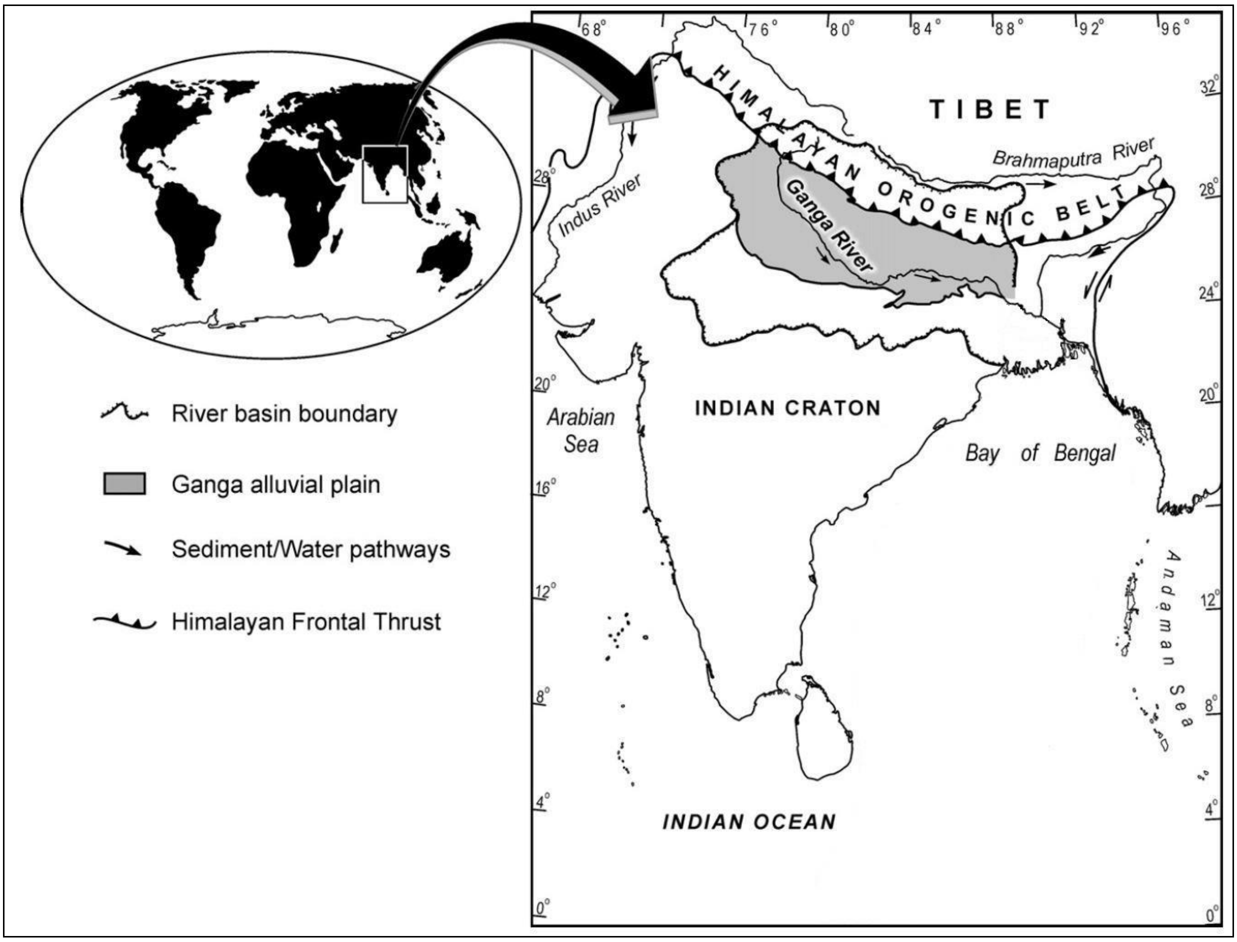

Fig 1: The Ganga fluvial system is located on the Indian subcontinent, It's source originates in the Himalayan orogenic belt. Together with the Brahmaputra, the Ganga River is responsible for the creation of the Ganga-Brahmaputra delta (Singh *et al*., 2007)

It flows from the Himalayan mountains, over the Indian subcontinent, towards the Bay of Bengal (Fig. 1) (Singh *et al.*, 2007; Singh, 2009). The Ganga river basin covers an area of 1086 x 106 km2, encompassing the Himalaya orogenic belt, northern Indian craton and the Ganga alluvial plain (Singh *et al.*, 2007). The length of the main channel from the traditional source of the Gangotri glacier in India is about 2550 km. After flowing through the Sivalik hills it enters plains at Haridwar. Then it flows southwards, passing through the plains of Uttar Pradesh. After leaving Uttar Pradesh, the Ganga enters Bihar in the Rohtas district. From Bihar, it entersWest Bengal province and starts flowing south. Nearly 40 km below Farakka it is divided into two arms. The left arm flows eastwards into Bangladesh and the right arm, called Bhagirathi, continues to flow south through West Bengal.

The source of water is the melting of snow in the Himalayas and monsoon rains. The river system covers cool upland streams and warm water stretches, including deltaic habitats (K.K. Vass, S.K. Mondal, S. Samanta, V.R. Suresh & P.K. Katiha, 2010) [8]. Ganga river water is used routinely for drinking and outdoor bathing by millions of people who take a holy dip at least once a year throughout the course of the river, from Gangotri to Ganga Sagar, owing to its socio-religious significance (Z. Rehana, A. Malik & M. Ahmad, 1996) [12].

River pollution is a serious and emerging problem in the majority of developing countries. India is a developing country, rapid urbanization and industrialization around the bank of rivers have deteriorated the quality and quantity of various water resources including river Ganga. Industrial effluents and sewage entering the water bodies are one of the prime sources of environmental toxicity, which endangers aquatic biota and deteriorates water quality (S.N. Sinha & D. Paul,2012) [14], (S.N. Sinha, D. Paul, K & Biswas, 2016) [15]. Major pollutants found in water include volatile, biodegradable and recalcitrant organic compounds, toxic metals, plant nutrients, suspended solids, microbial pathogens and parasites (G. Bitton, 1994) [17], (D. Paul & S.N. Sinha, 2015) [18], (D. Paul & S.N. Sinha, 2016) [19]. n. Out of various water pollutants, heavy metals are considered to be one of the most important group of contaminants because of their toxicological effects Higher concentrations of heavy metals can form harmful complex compounds, which critically effect different biological functions (A. Rajbanshi, 2009) [22]. Heavy metal includes; chromium, iron, cobalt, lead, copper, manganese, zinc, and nickel etc. and these are founded to have degradability issue (Coral *et al.*, 2005, Nagajyoti *et al.*, 2010, Gupta *et al.*, 2014) [20]. The presence of heavy metals in the wastewater of industry is a potential risk to aquatic ecosystem, animal, and human. High concentrations of heavy metals often pose a serious threat to biota and the environment of any ecosystem (S. Cheng, 2003) [23]. Heavy metal pollution can be a much more serious problem because they cannot be degraded by natural processes and persist in soil and sediment from where they are released gradually into water bodies as sink (S.N. Sinha, D. Paul,2014) [24]. Bioremediation is one such process by which these toxic and hazardous metals can be degraded by using naturally occurring microorganisms and gets converted into less toxic or non-toxic form (Patel *et al.*, 2019, Patel *et al.*, 2019) [21]. The following review article presents the findings of the work carried out by the various researchers in the past on the heavy metal pollution of river Ganga.

Sources of heavy metal

"Heavy metals" is a collective term, which applies to the group of metals and metalloids with a atomic density greater than 4 g/ cm3, or 5 times or more, greater than water (J.S. Hawkes, 1997) [25]. Two types of sources, i.e. natural and anthropogenic sources, are mainly responsible for the presence of heavy metals in our environment. Occurrence and distribution of heavy metals depends; on hydrology, local geology, and geochemical characteristics in case of natural source, while rapid globalization and industrialization in case of anthropogenic source. Generally, most of the heavy metals enter the in river from different sources, it be can be either natural by erosion and weathering and or anthropogenic (N. Gupta, K.K. Yadav, V. Kumar, D. Singh, 2013) [29], (R. Kashyap, K.S. Verma, S.K. Bhardwaj, P.K. Mahajan, J.K. Sharma, R. Sharma, 2016) [30], (V. Sheykhi, F. Moore, 2016) [31] (Fig. 2). In view of the intense human activity, natural sources of heavy metals from leaching and weathering of rocks in the environment, are usually of little importance (A. Kabata-Pendias, 2009) [32], (M. Varol, B. S, 2012) [33], (R. Dixit, D. Malaviya, K. Pandiyan, U.B. Singh, A. Sahu, R. Shukla, B.P. Singh, J.P. Rai, P.K. Sharma, H. Lade, D. Paul, 2015) [34]. The presence of heavy metals in sediments is due to precipitation of their carbonates, hydroxides, and sulfides, which settle down and form the part of sediments. The industries which attribute heavy metals in river water are generally metal industries, paints, pigment, varnishes, pulp and paper, tannery, distillery, rayon, cotton textiles, rubber, thermal power plant, steel plant, galvanization of iron products and mining industries as well as unsystematic use of heavy metal-containing pesticides and fertilizer in agricultural fields (S. Suthar, A.K. Nema, M. Chabukdhar a & S.K. Gupta,2009) [39], (S. Dan'Azumi, M.H. Bichi,2010) [40]. These heavy metals have accumulative effect at the low level in drinking water and ground water (S. Prabha & P. Selvapathy, 1997) [50].

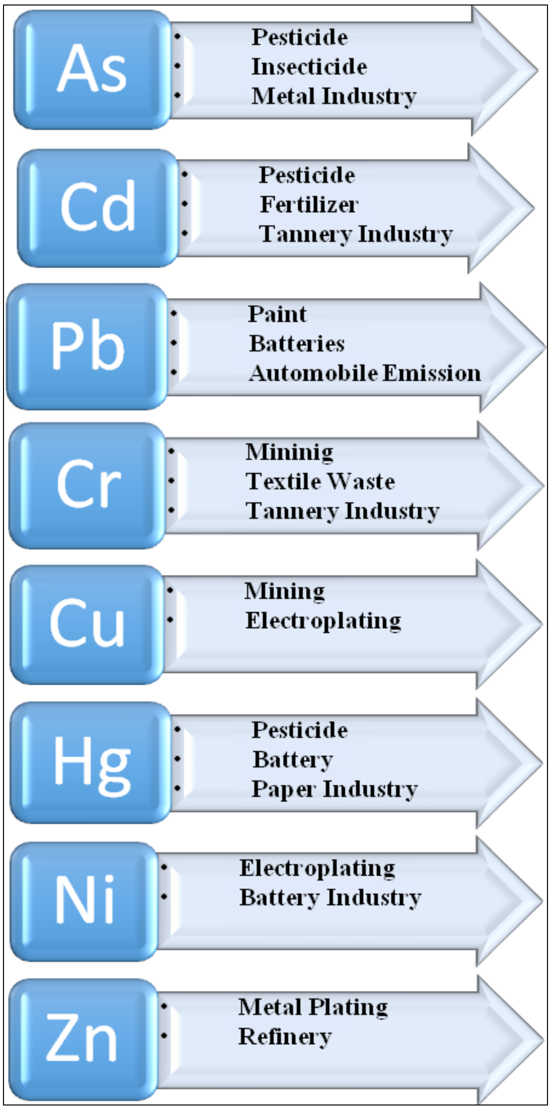

Fig 2: Sources of heavy metals

Heavy metals and its effects

The most important heavy metals from the point of view of water pollution are Zn, As, Cu, Pb, Cd, Hg, Ni, and Cr. Some of these metals (e.g. Cu, Fe, Mn, Ni, and Zn) are required as nutrients in trace amount for life processes in plants and microorganisms but become toxic at higher concentrations (Table 1). Other such as Pb, Cr, and Cd has no known biological function, but are toxic elements (S. Dudka &D.C. Adriano,1997) [51], (M. Sa'idi,2010) [52], (R.A. Wuana, F.E. Okieimen,2011) [53], (H.E. Ghannam, E.S. El Haddad & A.S. Talab,2015) [54]. These heavy metals are not readily degradable in nature and accumulate in the animal as well as human bodies to a very high toxic amount leading to undesirable effects beyond a certain limit (J.A. Adakole & D.S. Abolude, 2012) [55], (P.U. Singare, R.M. Mishra & M.P. Trivedi,2012) [56], (P. Govind & S. Madhuri, 2014) [57]. The fatal diseases such as eyelid edema, nephritis, renal tumour, extensive lesions in the kidneys, anuria, nasal mucous membranes and pharynx congestion, increase blood pressure and cardiovascular diseases, osteoporosis, cancer, headache and malfunctions of different systems of the body caused by heavy metals have been reported by several authors (A.M. Florea & D. Büsselberg,2006) [58],(M. Jaishankar, T. Tseten, N. Anbalagan, B.B. Mathew & K.N. Beeregowda,2014) [59], (N.V. Solenkova, J.D. Newman, J.S. Berger, G. Thurston, J.S. Hochman & G.A. Lamas,2014) [60], (A.G. Vaishaly, B.B. Mathew, N.B. Krishnamurthy,2015) [61]. They are also known to interfere with synthesis and metabolism of the hormones (B. Sharma, S. Singh, N.J. Siddiqi,2014) [62].

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
Cupper (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.

Table 1: Concentration of heavy metals in Ganga river water and other selected river from literature.

Rivers	Cd	Cr	Pb	Cu	Mn	Zn	Unit	Reference
Hindon, India	NA	NA	37	3.45	NA	272.3	µg/l	Reza & Singh 2010
Gomti, India	0.0005	0.004	0.027	0.003	0.008	0.0287	µg/l	Vinod *et al.* 2005
Shur, Iran	0.026	NA	0.116	0.771	NA	0.688	µg/l	Karbassi *et al.* 2008
Tigris Turkey	ND	NA	ND	0.075	ND	0.1	µg/l	Hulya *et al.* 2007
Sakarya Turkey	0.236	0.027	1.786	0.851	NA	0.173	µg/l	Mustafa *et al.* 2007
Orontes Turkey	11	15.3	27	40.3	NA	39	µg/l	Ayse Baher 2010
Anujang Korea	BDL	2.72	BDL	1.43	47.6	8.11	Mg/l	Sanghoon Lee 2003
Khoshk Iran	NA	0.19	0.07	0.03	0.25	1.7	Mg/l	Salati 2010 [80]
Ganga India	0.010	0.887	0.053	0.061	0.048	0.39	Mg/l	Present Study

Status of heavy metal in river Ganga water and sediments

Extensive studies have been carried out by several researchers on heavy metal pollution of river Ganga.

Subramanian *et al*. (V. Subramanian, R. Van Grieken, L. Van't Dack, 1987) [65] analyzed the temporal and spatial variations in the heavy metals distributions in the river Ganga sediment.

Ajmal *et al*. (M. Ajmal, A.A. Nomani, M.A. Khan, 1984) [64] also studied the concentrations of cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc in the water and sediments of the river Ganga in Uttar Pradesh and reported that there was considerable variation in the elements from one sampling station to the other.

Ansari *et al*. (A.A. Ansari, I.B. Singh, H.J, 1999) [71] determined the concentrations of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn and Zn in sediments of the river Ganga in the Kanpur-Unnao industrial region. According to them about 90% of the contents of Cd, Cr, and Sn; 50e75% of organic carbon, Cu and Zn; and 25% of Co, Ni and Pb in sediments are derived from the anthropogenic input in relation to the natural background values.

Ansari *et al*. (A.A. Ansari, I.B. Singh, H.J. Tobschall, 2000) [72] also studied the role of monsoon rain on concentrations and dispersion patterns of metal pollutants in sediments of the river Ganga in the Kanpur-Unnao industrial region and reported that the monsoon rain reduces the contents of Co, Cr, Fe, and Ni, and enhances the contents of Cd, Sn and Zn in sediments of post-monsoon period. A similar study was also conducted in upper Ganga by Saikia *et al*. (D.K. Saikia, R.P. Mathur, S.K. Srivastava, 1988) [66]. Heavy metals distribution in the sediments and sewer-river confluence points of river Ganga in Varanasi-Mirzapur region were also studied by Prasad *et al*. (S. Prasad, A. Mathur, D.C. Rupaniwar, 1989) [67].

Khwaja *et al*. (A.R. Khwaja, R. Singh, S.N. Tandon, 2001) [73] studied Ganga river water and sediments pollution due to tannery industries at Kanpur.

Sinha *et al*. (R.K. Sinha, S.K. Sinha, D.K. Kedia, A. Kumari, N. Rani, G. Sharma, K. Prasad, 2007) [81] studied mercury pollution in the Ganga River system at Varanasi. Their study on mercury describes its presence and variation in different biotic and abiotic components of the river system.

Beg and Ali(K.R. Beg, S. Ali,,2008) [82] studied the sediment quality mainly trace metals from upstream and downstream area of Ganga river at Kanpur city where effluents from tannery industries are discharged and reported that Cr in downstream sediment was 30-fold higher than in upstream sediment and its concentration was above the probable effect level.

Sharma *et al*. (Y.C. Sharma, G. Prasad, D.C. Rupainwar, 1992) [68] studied the heavy metal pollution of River Ganga in the Mirzapur region and came to the conclusion that the river was polluted. A similar study was also conducted at Kanpur by several researchers (N. Garg, N. Mathur, D.P. Modak, K.P. Singh, R.C. Murthy, S. Ahmed, S.V. Chandra, P.K. Ray, 1992) [69], (R.P. Singh, G. Dayal, A. Taneja, C.K. Kapoor, 1993) [70].

Purushothaman and Chakrapani (P. Purushothaman, G.J. Chakrapani, 2007) [79] assessed the heavy metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb) associated with different chemical fractions of sediments of the river Ganga. Sarkar *et al*. (S.K. Sarkar, M. Saha, H. Takada, A. Bhattacharya, P. Mishra, B. Bhattacharya,2007) [80] also analyzed the level of dissolved heavy metals such as Fe, Zn, Mn, Cu, Pb, Hg at three ecologically distinct zones along the course of the river Ganga- Babughat, Diamond Harbour and Gangasagar in West Bengal and reported high values for Hg and Pb which can be attributed to the discharge from pulp and paper manufacturing units and to atmospheric input and runoff of automobile emission.

Bhattacharya *et al*. (.K. Bhattacharya, S.N. Mandal, S.K. Das, 2008) [83] studied the Accumulation of heavy metals in water, sediment, and tissues of different edible fishes at Rishra-Konnagar region situated on the upper stretch of Gangetic West Bengal during 2006-2007. According to them the concentration of Zn, Cr, Cu, Cd, and Pb in sediment and water as well as in commercially edible fish samples at the sampling station exhibited a unique seasonal oscillation. The concentrations of heavy metals follow the trend: Zn > Cr > Cu > Cd > Pb.

Singh *et al*. (M. Singh, G. Müller, I.B. Singh, 2002) [74] studied the heavy metals in freshly deposited stream sediments of rivers associated with urbanization of the Ganga Plain in Lucknow, Kanpur, Delhi, and Agra urban centers and classified by the proposed Sediment Pollution Index as highly polluted to dangerous sediments. Singh *et al*. (M. Singh, G. Müller, I.B. Singh,2003) [75] studied the geogenic distribution and baseline concentration of heavy metals (Cr,Mn Fe, Co, Ni, Cu, Zn, Cd, and Pb) in the sediments of the Ganga river.

Dutta *et al*. **(**S. Dutta, R.K. Kole, S. Ghosh, D. Nath, K.K. Vass,2005**)** [76] assessed the impact of lead on water quality of river Ganga in West Bengal. Chaturvedi and Pandey (J. Chaturvedi, N.K. Pandey, 2006) [77] analyzed physicochemical parameters as well as few toxic metals of river Ganga at Vindhyachal Ghat of Varanasi. According to their study, this site was polluted and the water is not suitable for domestics, irrigation, and other purposes.

Nath and Banerjee(A.K. Nath, S. Banerrjee,2006) [78] assessed pollution of Ganga river considering the heavy metals (Cu, Pb, Cd, and Zn) in water, soil, benthic macro invertebrates (Thiara lineate) and fish (Rita rita). The overall study reveals that the Ganga River is moderately polluted.

Kar *et al*. (D. Kar, P. Sur, S.K. Mandai, T. Saha, R.K. Kole, 2008) [84] analyzed various heavy metals such as Fe, Mn, Zn, Cu, Cd, Cr, Pb and Ni from the surface water samples of river Ganga in West Bengal and found a significant seasonal variation for Fe, Mn, Cd, and Cr. The presence of different studied heavy metals in the surface water of the river Ganga followed the sequence: Fe > Mn > Ni > Cr > Pb > Zn > Cu > Cd.

Katiyar (S. Katiyar, 2011) [93] investigated the effect of tannery effluent associated with the seasonal variation in physicochemical characteristics as well as heavy metal concentration (Cr, Pb, and As) of river Ganga water near Jajmau area at Kanpur.

Gupta *et al*. (A. Gupta, D.K. Rai, R.S. Pandey, B. Sharma,2009) [85] studied the occurrence and bioaccumulation of several heavy metals (Cu, Cr, Cd, Pb, Zn) in the river water, sediment, and the muscles of two catfish species procured from the river Ganga at Allahabad. According to them the order of occurrence of different heavy metals to be Zn > Pb > Cu > Cr > Cd, respectively. The heavy metals analysis in sediment indicated that among the five heavy metals, Zn was maximally accumulated followed by Pb, Cr, Cu, and Cd.

Aktar *et al*. (M.W. Aktar, M. Paramasivam, M. Ganguly, S. Purkait, D. Sengupta, 2010) [89] analyzed the heavy metal concentrations (Fe, Mn, Cu, Zn, Pb, Cd, Cr, and Ni) of surface water at four different locations of the river Ganga around Kolkata and evaluated that the studied heavy metals showed no significant variation with respect to sampling sites as well as discharge points. However, those metals concentration varied with season, being a higher in rainy season and lower in winter season.

Purkait *et al*. (S. Purkait, M. Ganguly, M.W. Aktar, D. Sengupta, A. Chowdhury A,2009) [88] assessed the impact of various parameters including heavy metals, polluting Ganga water in Kolkata region.

Chatterjee *et al*. (S. Chatterjee, B. Chattopadhyay, S.K. Mukhopadhyay, 2010) [90] assessed the waste metal pollution at Ganga Estuary via the East Calcutta Wetland areas. Pandey *et al*. (J. Pandey, K. Shubhashish, R. Pandey, 2010) [91] investigated the midstream water quality of river Ganga as influenced by aerially driven heavy metals at Varanasi. They reported that the concentrations of all the heavy metals were high in downstream sampling stations and The overall concentration of heavy metals in water showed the trend: Zn > Ni > Cr > Pb > Cu > Cd. Rai *et al*. (P.K. Rai, A. Mishra, B.D. Tripathi, 2010) [92] analyzed water samples from three sewage treatment plants which frequently release into the river Ganga at Varanasi and reported a very high concentration of heavy metals (Zn, Cu, Cd, Pb, and Cr).

Kansal *et al*. (A. Kansal, N.A. Siddiqui, A. Gautam, 2011) [94] assessed the heavy metal content and their interrelationships with some physicochemical parameters in eco-efficient rivers of the Himalayan region including river

Ganga. Singh (A.L. Singh, 2011) [95] also studied the toxicity of heavy metals (Cu, Cr, Fe, Mn, Zn, Cd, and Pb) in the water of Ganga river at Varanasi. This study suggests that Ganga river water is extremely polluted at Varanasi and industrial effluents are the main source of heavy metal pollution. Rai *et al*. (U.N. Rai, D. Prasad, S. Verma, A.K. Upadhyay, N.K. Singh,2012) [96] assessed the heavy metal concentration as well as Ganga river water quality at different ghats of Haridwar.

Sharma *et al*. (P. Sharma, P.K. Meher, K.P. Mishra, 2012) [97] studied the distribution of non-radioactive heavy metals (Zn, Cd, Cu, and Pb) inwater of river Ganga from Rishikesh to Allahabad. Their investigation reported that at some locations concentrations of measured heavy metals were exceeding the standard limits which correspond to more anthropogenic activities.

Singh *et al*. (L. Singh, S.K. Choudhary, P.K. Singh, 2012) [98] measured the concentration of five heavy metals i.e. Cu, Cr, Zn, Ni, and Cd inwater and sediments samples of river Ganga for a period of two years in Bhagalpur starting from Champanala Nathnagar to Burning ghat Barari. Based on their findings, the Ganga river sediments from Champanala to Barari can be considered as unpolluted with respect to the concentration of Cd, Cu, and Ni, whereas the concentration of Cr and Zn exhibit their pollutional status which may be harmful to the rich biodiversity of the river segment.

Bhatnagar *et al*. **(**M.K. Bhatnagar, S. Raviraj, G. Sanjay, B. Prachi,2013**)** [99] studied the effect of tannery effluents on sediments of river Ganga in special reference to heavy metals at Jajmau, Kanpur and found that the heavy metal such as Cr, As, Co, Fe, Cu, Mn, Zn, Pb, Cd, and Ni were present in significantly higher concentrations. Heavy metal concentrations in sediment collected from downstream Jajmau area were higher than upstream area. Pandey *et al*. (A. Pandey, P.W. Ramteke, O.P. Verma,2013) [100] also determined the concentration of several heavy metals such as Cr, Cu, Fe, Ni, Pb, and Zn in the water of river Ganga at Allahabad and reported that all the heavy metals at all the sampling sites were found above the permissible levels. The high concentration of these heavy metals in the study area indicated that the river is highly polluted. Singh *et al*. (H. Singh, S. Yadav, B.K. Singh, B. Dubey, K. Tripathi, V. Srivastava, D.N. Shukla, 2013) [101] investigated geochemical environment of the river sediment in the middle stretch of the river Ganga at Ghazipur, Buxar and Ballia urban centers. According to them the percentage of anthropogenic and lithogenic values of heavy metal concentration showed that Cd receives the highest value of anthropogenic addition into river water and it is followed by Cr, Cu, Zn and Co. Vaseem and Banerjee (H. Vaseem & T.K. Banerjee,2013) [102] investigated the heavy metal (Fe, Cr, Zn, Cu, Mn, Ni and Pb) contamination of the river Ganga and its toxic implication in the blood parameters of the major carp Labeo rohita (Ham).

Goswami and Sanjay (D.N. Goswami, S.S. Sanjay,2014) [103] determined the concentration of heavy metals *viz*. cadmium, copper, lead and zinc ions in the different matrices of the river Ganga from Rishikesh to Allahabad through differential pulse anodic stripping voltammetry. Their study suggested that the contamination of water and sediment at Narora Barrage and Jajmau Kanpur is alarming where the pollutants accumulated due to the point source discharges from tannery industries.

Kumar *et al*. (A. Kumar, A.K. Mishra, D.N. Shukla,2014) [104] investigated the seasonal variation of the heavy metals (Cr, Mn, Fe, Cu, Zn, and Pb) concentration in water of the river Ganga at five sites of Allahabad city and its possible effect on fish fauna. It has been observed from their study that all the parameters have more or less fluctuations mainly with seasons and sites. Pandey *et al*. (M. Pandey, S. Tripathi, A.K. Pandey, B.D. Tripathi,2014) [106] dealt with 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 using sequential extraction process (SEP) and total acid digestion (TAD). According to them Geo-accumulation index (Igeo) and Risk Assessment Code (RAC) exhibited higher concern for Cd and Pb whereas Mn, Fe and Ni exhibited negative accumulation index at all sampling stations.Pb, Cd, Cu, and Ni were present significantly in the available fraction;however, the Igeo of Ni was found negative at all sampling stations.

Singh and Pandey (A.V. Singh, J. Pandey,2014) [107] studied spatiotemporal trends of heavy metals in the midstream of the Ganga river at Varanasi and reported that the concentrations of heavy metals were highest in winter and concentration of cadmium exceeded their internationally recommended maximum admissible concentration. Singh *et al*. (S. Singh, D. Malik, J. Thakur, A. Kaur, R.K. Singh, S. Nijhawan, 2014) [108] also analyzed the heavy metal concentration of the Ganga river at Kanpur and Varanasi.

Pandey *et al*. (R. Pandey, D. Raghuvanshi, B. Tripathi, V. Pandey, D.N. Shukla,2014) [109] also analyzed the physicochemical parameters and some heavy metals (Fe, Zn, Cr, and Co) in riverine water from river Ganga at different Ghats of Allahabad. The impact of urban drains over river water and sediments by metal analysis were assessed using sequential extraction procedure and SEMeEDS at Varanasi by Pandey *et al*. (M. Pandey, A.K. Pandey, A. Mishra, B.D. Tripathi,2015) [110]. Pandey and Singh (J. Pandey, R. Singh,2015) [111] studied heavy metal concentration in sediments of Ganga River along a 37 km stretch to assess whether there is a significant difference between sites situated upstream and downstream of Varanasi urban core. According to them the concentration of heavy metal increased consistently along the study gradient, suggesting the influence of urban sources. The concentration of heavy metal in the river sediment was found highest for Fe followed by Mn, Zn, Cr, Cu, Ni, Pb, and Cd.

Chaudhary *et al*. (M. Chaudhary, S. Mishra, A. Kumar, 2017) [112] estimated the water pollution and the probability of health risk due to imbalanced nutrients in River Ganga. The river water has been found to be severely contaminated due to heavy metals and indicates the human health risk.

Nausad *et al*. (S.S. Naushad, A.A. Lall, A.A. Charan, 2014) [105] illustrated the distribution and levels of sediment contamination of river Ganga by heavy metals (Cd, Ni, Cu, Fe, Pb, Co, Ni and Zn) in the Allahabad city. The concentration of heavy metal except Fe in water, did not exceed WHO and EPA guidelines. Their results indicated that there were differences in trace metal concentration in water. According to them the Ganga basin has significant basal contamination levels that do not reach those of clearly polluted areas.

Paul and Sinha (D. Paul& S.N. Sinha,2013) [1] investigated the seasonal variations in the Ganga river water quality with respect to heavy metals (Zn, Pb, Cd, and Cr) contamination in West Bengal. It was observed from their study that the concentration of most of these heavy metals was much higher than the maximum permissible limits.

Tripathi *et al*. (I.P. Tripathi, A.P. Dwivedi, P. Ojha,2016) [113] analyzed the heavy metal content in Ganga River Water Samples collected from Kaushambi district, Uttar Pradesh. From their study, it was concluded that the water of all these sample stations is suitable for drinking and irrigation purpose with respect to the studied physicochemical parameters as well as heavy metals. A similar study was also conducted at Rishikesh by Haritash *et al*. (A.K. Haritash, S. Gaur, S. Garg, 2016) [114]. The concentration of heavy metals in various study sites conducted by many researchers in river Ganga is summarized in Table 2 and Table 3.

Strategies to improve the heavy metal pollution of river Ganga

It's been almost 35 years for first Ganga action plan, launched in year 1985 by CPCB (Central Pollution Control Board, India) to abate the increasing pollution. The main aim was to control pollutants to reach to river water and hence improving the water quality to acceptable limits. The main objective laid in the first Ganga action plan was modified in year 1987, and new objectives drafted with aim to make water quality to at least bathing standard (NRCD2009). The heavy metal pollution of the river Ganga has drawn the attention of the scientists and others concerned with the endangerment of the environment. Regulatory standards for emission and discharges from different industries should be strict. Recycling of wastewater containing heavy metals needs to be given greater importance not only from environmental and health concerns but also as a resource conservation initiative. Monitoring of wastewater from toxic heavy metal processing units of the different industries needs to be executing more vigorously. The government should outline a plan or strategy to comprehensively survey the Ganga in order to identify and specify the sources of the pollution. In India, many states and departments of central Government are dealing with the matter of decreasing pollution in the major rivers of the country. Gap I (Ganga Action Plan I) and GAP II were implemented one after another with the main agenda to clean river Ganga but the quality of Ganga kept deteriorating even after executing these plans. The main reason behind the failure of GAP I was the lack of incorporation of integrated river basin management approach as it focused only on effluent from major cities and towns. A survey of CPCB, showed that 317 major industrial units are operating all along the bank of river Ganga and its tributaries. Only 37% of these units followed some controlled measures and the remaining ones pose pollution hazards, and none of them has any treatment facilities (S. Parveen, A.A. Khan, S.A. Untoo, 2003) [132]. In the year 2008, the Prime Minister of India announced Ganga a National River and set up the National Ganga River Basin Project (NGRBP) for its clean up. The NGRBP will be the first basin-level initiative in India to manage an inter-state river for water quality and environmental protection (P. Das, K.R. Tamminga, 2012) [3], (S. Parveen, A.A. Khan, S.A. Untoo, 2003) [133].

The effect of heavy metals present in water and sediments of river Ganga on the biotic community were studied only to a limited extent. From the published research articles of many authors it is revealed that the presence of heavy metal in the river may cause of the reduction in growth, size, and survival of fish population or may also cause extinction of some fish species and river dolphins(D.R. Khanna, P. Sarkar, A. Gautam, R. Bhutian,2007) [134], (A. Mitra, R. Chowdhury, K. Banerjee,2012) [135], (H. Vaseem, T.K. Banerjee, 2013) [136], (K. Kannan, R.K. Sinha, S. Tanabe, H. Ichihashi, R. Tatsukawa, 1993) [137]. Daphnia and Cyclops are most sensitive to heavy metals. Presence of such heavy metal pollutants in water course not only creates unfavourable environment but also causes paucity of the fish organisms (S. Parveen, A.A. Khan, S.A. Untoo,2003) [132]. The occurrence of very large amount of heavy metal pollutants into surface water and sediment 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. A better pollution control plan is needed to be adopted at the known pollution points. Periodic monitoring and evaluation mechanism along with continuous sample collecting and analyzing unit is needed to be established. Some help can be taken from the other similar projects like remediation of Hudson River that flows in the US. Each individual needs to understand their role for protection and prevention of the sacred river Ganga. Regular and systematic monitoring and strict law implementation are required to achieve sustainable way for enhancing the water quality. At last, awareness should be raised among the common people. The information obtained from this review could be helpful for environmental organizations to monitor river Ganga system and finally to the management of human health practices.

Table 2: Concentrations of heavy metals (μg I.$^{-1}$) in the river Ganga water at different study sites.

Study area	Concentrations of different heavy metals (μg L^{-1})											References
	As	Cd	Cr	Cu	Co	Fe	Hg	Mn	Ni	Pb	Zn	
Allahabad	–	ND-10	ND-18	ND-30	–	–	–	–	–	18–86	26–122	[85]
	_	–	5–68	8–46	–	6300–11,900	–	18–94	–	9–181	4–79	[104]
	_	20–330	3–290	–	–	536–1939	–	–	60–345	166–284	10–55	[105]
Berhampore	–	1–2	10–18	3–7	–	365–1744	–	181–712	41–84	8–21	65–95	[84]
Bhagalpur	–	ND	BDL-1090	ND-120	–	–	–	–	BDL-120	–	BDL-870	[98]
Dakshineswar	–	ND-3	16–22	4–8	–	792–1413	–	85–436	35–44	5–97	42–83	[84]
Diamond Harbour	–	–	–	5–90	–	30–560	150–620	90–350	–	12–62	150–710	[80]
Gangasagar	–	–	–	2–90	–	40–320	100–490	60–290	–	11–38	30–520	[80]
Haridwar	–	–	43–196	101–178	–	–	–	28.7–16	–	108–690	113–219	[96]
Kanpur	–	–	ND-390.8	0.6–52.1	–	59.3–27,956	–	17.7–272.6	ND-63.7	4.3–57.5	0.1–49.49	[69]
	_	75	20	20	–	–	–	–	700	10	150	[107]
Kaushambi	–	–	–	ND-1000	–	ND-600	–	–	–	ND-9	ND-980	[112]
Kolkata	–	–	–	1–49	–	90–420	160–950	90–490	–	17–76	20–280	[80]
	_	5–6	ND	3–33	–	13–5490	–	22–1780	45–240	50–530	5–293	[89]
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	[68]
Palta	–	ND-3	13–21	4–7	–	884–2345	–	123–417	35–53	5–15	68–111	[84]
Rishikesh	–	–	–	32.1–58.1	–	–	–	–	BDL-36.7	BDL	BDL-1349.7	[114]
Rishikesh-Allahabad	–	600–13100	–	ND-36000	–	–	–	–	–	2400–26900	ND-106300	[103]
Rishra-Konnagar	–	0.043–0.088	0.281–0.391	0.155–0.322	–	–	–	–	–	0.041–0.058	0.545–0.691	[83]
Uluberia	–	ND-3	13–24	3–6	–	353–1584	–	139–172	34–83	3–52	58–84	[84]
Varanasi	–	100–160	160–1090	1700–2000	–	120–150	–	–	100–900	–	500–600	[77]
	_	–	–	–	–	–	0.23	–	–	–	–	[81]
	_	ND - 8.4	1.2–29.6	2.4–18.1	–	–	–	–	1.6–60.8	–	31.2–185.2	[91]
	_	ND-51	17–72	47–168	–	342–1981	–	23–67	–	36–86	15.8–217	[95]
	_	–	100–480	273–305	–	2950–6870	–	1000–2800	643–1120	20–240	9440–15320	[102]
	_	43	20	20	–	–	–	–	550	10	200	[108]
	_	11.41–39.24	41.8–70.16	19.42–43.72	–	83.17–117.7	–	40.62–68.83	31.28–61.11	80.55–134.8	31.73–71.37	[110]
	_	20–150	30–90	20–80	–	590–680	–	–	220–305	60–190	200–270	[116]

BDL- Below detection limit; ND- Not detected.

Table 2: Concentrations of heavy metals (μg g^{-1}) in the river Ganga sediment at different study sites

Study area	Concentrations of different heavy metals (μg g^{-1})											References
	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	[85]
	_	0.47–0.91	121–142	48–62	–	–	–			18–29	87–111	[115]
Bhagalpur	–	ND	BDL-140	BDL-90	–	–	–	–	BDL-90		BDL-870	[98]
Ghazipur, Buxar, Ballia	–	0.45–0.95	113–230	39–73	11–29	–	–	–	32–75	15–27	72–140	[101]
Haridwar-Kolkata	–	–	16–134	2–62	–	8040–82700	–	183–523	7–49	–	22–101	[65]
Kanpur	0.25	2.5–6.0	5.0–250.0	7.0–17.0	–	3950–8400	85–254	–	5.0–13.0	2.5	23–70	[82]
	0.3–0.66	4–12	110–178	38–68	16–35	4800–7250	1–3.1	–	42–66	5–12	65–96	[99]
		2.3–4.1	2.4–3.9	3.2–4.52				1.5–2.6	2.0–5.0	0.5–2.3	–	[117]
Kanpur-Unnao	–	9.8	3.40	408	–	–	–	–	502	646	4000	[71]
Rishra-Konnagar	–	0.672–0.791	3.682–5.816	2.191–5.671	–	–	–	–	–	0.099–0.109	10.641–11.771	[83]
Varanasi	–	–	–	–	–	–	0.067	–	–	–	–	[81]
	_	9.52–79	126.84–196.11	12.67–84	29.98–102.24	7175.5–9385	–	350.87–409.44	14.63–82.5	148.83–211.36	137.25–201.2	[106]
	_	30.01–128.13	133.75–247.05	15.3–70.7	–	7493.91–10,343	–	322.43–439.75	18.38–97.1	151.85–269.38	185.15–278.61	[110]
	_	0.94–2.86	39.05–93.28	12.71–36.68	–	21,924.07–41,170.13	–	296.02–529.08	11.77–43.02	10.94–44.89	41.05–92.48	[111]

BDL- Below detection limit; ND- Not detected.

Conclusion

This review article gives an overview about the recent status of heavy metals and summarizes the current situation of heavy metal pollution in the river Ganga. Through various studies, it has been found that the water of river Ganga contains enormous amount of heavy metals and shows that the levels of various heavy metals in the river Ganga water and sediment are far above the acceptable concentrations. These metals are responsible to several health effects. Though after implementing several plans by Government of India, still the water pollution level of river Ganga remains pathetic. Therefore, there is need of serious and urgent steps to be taken for betterment of sacred river Ganga and hence helping human beings. This review suggested that different sources of heavy metals in water along with other plans to rejuvenate river Ganga should be monitored closely, along with other improvement of conditions and effluents both from industries and domestic is needed to be minimized.

References

1. Paul D, Sinha SN. Assessment of various heavy metals in surface water of polluted sites in the lower stretch of river Ganga, West Bengal: a study for ecological impact, Discov. Nat. 2013;6:8e13.
2. Rahaman MM. Principles of transboundary water resources management and Ganges treaties: an analysis, Water Resour. Dev. 2009;25:159e173.
3. Das P, Tamminga KR. The Ganges and the GAP: an assessment of efforts to clean a sacred river, Sustainability. 2012;4:1647e1668.
4. Gopal B. River conservation in the Indian subcontinent, in: P.J. Boon, B.R. Davies, G.E. Pelts (Eds.), Global Perspectives on River Conservation: Science, Policy and Practice, Wiley, London, 2000, 233e261.
5. Welcomme RL. River Fisheries, Food and Agriculture Organization, Technical paper 262, Rome, Italy, 1985.
6. Agrawal A, Pandey RS, Sharma B, Water pollution with special reference to pesticide contamination in India, J. Water Resour. Prot. 2010;2:432e448.
7. Biswas K, Paul D, Sinha SN. Prevalence of multiple antibiotic-resistant coliform bacteria in the water of river Ganga, Front. Environ. Microbiol. 2015, 44e46.
8. Vass KK, Mondal SK, Samanta S, Suresh VR, Katiha PK. The environment and fishery status of the River Ganges, Aquat. Ecosyst, Health Manag. 2010;13:385e394.
9. Rahaman MM. Integrated Ganges basin management: conflict and hope for regional development, Water Policy. 2009;11:168e190.
10. Sarkar UK, Pathak AK, Sinha RK, Sivakumar R, Pandian AK, Pandey A, *et al.*, Freshwater fish biodiversity in the river Ganga (India): changing pattern, threats and conservation perspectives, Rev. Fish. Biol. Fish. 2012;22:251e272.
11. Joshi DM, Kumar A, Agrawal N. Assessment of the irrigation water quality of river Ganga in Haridwar district, Rasayan J. Chem. 2009;2:285e292.
12. Rehana Z, Malik A, Ahmad M. Genotoxicity of the Ganges water at Narora(UP), India, Mutat. Res./Genet. Toxicol. 1996;367:187e193.
13. Singh M, Singh AK. Bibliography of environmental studies in natural characteristics and anthropogenic influences on the Ganga River, Environ. Monit. Assess. 2007;129:421e432.
14. Sinha SN, Paul D. Detoxification of heavy metals by biosurfactants, Bull.Environ. Sci. Res. 2012;1:1e3.
15. Sinha SN, Paul D, Biswas K. Effects of Moringa oleifera Lam. and Azadirachta indica A. Juss. leaf extract in treatment of tannery effluent, Our Nat. 2016;14:47e53.
16. Sinha SN, Paul D. Impact of sewage water on seed germination and vigour index of Cicer arietinum L. and Pisum sativum L, Int. J Food Agric. Vet. Sci. 2013;3:19e26.
17. Bitton G, Wastewater Microbiology, John Wiley & Sons, Inc., USA, 1994, 63e65.
18. Paul D, Sinha SN. Biological removal of phosphate using phosphate solubilizing bacterial consortium from synthetic wastewater: a laboratory scale, Environment Asia. 2015;8:1e8.
19. Paul D, Sinha SN. Isolation and characterization of phosphate solubilizing bacterium Pseudomonas aeruginosa KUPSB12 with antibacterial potential from river Ganga, India, Ann. Agrar. Sci. 2016;15:130e136.
20. Praveena SM, Aris AZ, Radojevic M. Heavy metals dyanamics and source in intertidal mangrove sediment of Sabah, Borneo Island, Environment Asia M 2010;3:79e83.
21. Paul D, Sinha SN. Isolation and characterization of a phosphate solubilizing heavy metal tolerant bacterium from river Ganga, West Bengal, India, Songklanakarin J. Sci. Technol. 2015;37:651e657.
22. Rajbanshi A. Study on heavy metal resistant bacteria in Guheswori sewage treatment plant, Our Nat. 2009;6:52e57.
23. Cheng S. Heavy metal pollution in China: origin, pattern and control, Environ. Sci. Pollut. Res. 2003;10:192e198.
24. Sinha SN, Paul D. Heavy metal tolerance and accumulation by bacterial strains isolated from waste water, J. Chem. Biol. Phys. Sci. 2014;4:812e817.
25. Hawkes JS. What is a “heavy metal”, J. Chem. Educ. 1997;74:1374.
26. Renberg I, Persson MW, Emteryd O, Pre-industrial atmospheric lead contamination detected in Swedish lake sediments, Nature. 1994;368:323e326.
27. Sharma M, Tobschall H, Singh I. Environmental impact assessment in the Moradabad industrial area (rivers Ramganga-Ganga interfluve), Ganga Plain, India, Environ. Geol. 2003;43:957e967.
28. F€orstner U, Wittman G. Metal Pollution in the Aquatic Environment, Springer-Verlag, New York, 1983.
29. Gupta N, Yadav KK, Kumar V, Singh D. Assessment of physicochemical properties of Yamuna river in Agra city, Int. J. Chem. Tech Res. 2013;5:528e531.
30. Kashyap R, Verma KS, Bhardwaj SK, Mahajan PK, Sharma JK, Sharma R. Water chemistry of Yamuna river along Ponta Sahib industrial hub of Himachal Pradesh, India, Res. Environ. Life Sci. 2016;9:277e281.
31. Sheykhi V, Moore F. Environmental risk assessment of heavy metals pollution in aquatic ecosystem-a case study: sediment of Kor River, Iran, Hum. Ecol. Risk. Assess. 2016;22:899e910.
32. Kabata-Pendias A. Trace Elements in Soils and Plants, CRC Press, Boca Raton, Florida, USA, 2001.
33. Varol M, en BS, Assessment of nutrient and heavy metal contamination in surface water and sediments of the upper Tigris river, Turkey, Catena 92 (2012) 1e10.
34. Dixit R, Malaviya D, Pandiyan K, Singh UB, Sahu A, Shukla R, *et al*. Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes, Sustainability. 2015;7:2189e2212.
35. Wang Y, Yang Z, Shen Z, Tang Z, Niu J, Gao F. Assessment of heavy metals in sediments from a typical catchment of the Yangtze river, China, Environ. Monit. Assess. 2011;172:407e417.
36. Martín JR, De Arana C, Ramos-Miras JJ, Gil C, Boluda R. Impact of 70 years urban growth associated with heavy metal pollution, Environ. Pollut. 2015;196:156e163.
37. Ali MM, Ali ML, Islam MS, Rahman MZ. Preliminary assessment of heavy metals in water and sediment of Karnaphuli river, Bangladesh, Environ. Nanotechnol. Monit. Manag. 2016;5:27e35.
38. Capangpangan RY, Pagapong NK, Pineda CP, Sanchez PB. Evaluation of potential ecological risk and

contamination assessment of heavy metals in sediment samples using different environmental quality indicesea case study in Agusan River, Caraga Philippines, J. Biodiver. Environ. Sci. 2016;8:1e16.
39. Suthar S, Nema AK, Chabukdhara M, Gupta SK. Assessment of metals in water and sediments of Hindon river, India: impact of industrial and urban discharges, J. Hazard. Mater. 2009;171:1088e1095.
40. Dan' Azumi S, Bichi MH. Industrial pollution and heavy metals profile of Challawa river in Kano, Nigeria, Appl J, Sci. Environ. Sanit. 2010;5:23e29.
41. Salati, Moore F. Assessment of heavy metal concentration in the Khoshk river water and sediment, Shiraz, Southwest Iran, Environ. Monit. Assess. 2010;164:677e689.
42. Hejabi AT, Basavarajappa HT, Karbassi AR, Monavari SM. Heavy metal pollution in water and sediments in the Kabini river, Karnataka, India, Environ. Monit. Assess. 2011;182:1e3.
43. Lokhande RS, Singare PU, Pimple DS. Pollution in water of Kasardi River flowing along Taloja industrial area of Mumbai, India, World Environ. 2011;1:6e13.
44. Sinha SN, Biswas M, Paul D, Rahaman S. Biodegradation potential of bacterial isolates from tannery effluent with special reference to hexavalent chromium, Biotechnol. Bioinform. Bioeng. 2011;1:381e386.
45. Rahman MS, Molla AH, Saha N, Rahman A. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi river, Savar, Dhaka, Bangladesh, Food Chem. 2012;134:1847e1854.
46. Shikazono N, Tatewaki K, Mohiuddin KM, Nakano T, Zakir HM. Sources, spatial variation, and speciation of heavy metals in sediments of the Tamagawa river in Central Japan, Environ. Geochem. Health 2012;34:13e26.
47. Banerjee S, Kumar A, Maiti SK, Chowdhury A. Seasonal variation in heavy metal contaminations in water and sediments of Jamshedpur stretch of Subarnarekha river, India, Environ. Earth Sci. 2016;75:1e12.
48. Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Hoque MF. Preliminary assessment of heavy metal contamination in surface sediments from a river in Bangladesh, Environ. Earth Sci. 2015;73:1837e1848.
49. Sindern S, Trem€ohlen M, Dsikowitzky L, Gronen L, Schwarzbauer J, Siregar TH, *et al*. Heavy metals in river and coast sediments of the Jakarta Bay region (Indonesia)-geogenic versus anthropogenic sources, Mar. Pollut. Bull. 2016;110:624e633.
50. Prabha S, Selvapathy P. Toxic metal pollution in Indian Rivers, Indian Environ J. Prot. 1997;17:641e649.
51. Dudka S, Adriano DC. Environmental impacts of metal ore mining and processing: a review, Environ Qual J. 1997;26:590e602.
52. Sa'idi M. Experimental studies on effect of heavy metals presence in industrial wastewater on biological treatment, Int. Environ J. Sci. 2010;1:666e676.
53. Wuana RA, Okieimen FE. Heavy metals in contaminated soils; a review of sources, chemistry, risks and best available strategies for remediation, ISRN Ecol. 2011, 402647.
54. Ghannam HE, El Haddad ES, Talab AS, Bioaccumulation of heavy metals in tilapia fish organs, Biodivers J. Environ. Sci. 2015;7:88e99.
55. Adakole JA, Abolude DS. Pollutional status of Kubanni Lake through metal concentrations in water and sediment columns, Zaria, Nigeria, Res Environ Earth J. Sci. 2012;4:424e427.
56. Singare PU, Mishra RM, Trivedi MP. Sediment contamination due to toxic heavy metals in Mithi River of Mumbai, Adv. Anal. Chem. 2012;2:14e24.
57. Govind P, Madhuri S. Heavy metals causing toxicity in animals and fishes, Res. Anim J Vet. Fish. Sci. 2014;2:17e23.
58. Florea AM, Büsselberg D. Occurrence, use and potential toxic effects of metals and metal compounds, Biometals. 2006;19:419e427.
59. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals, Interdiscip. Toxicol. 2014;7:60e72.
60. Solenkova NV, Newman JD, Berger JS, Thurston G, Hochman JS, Lamas GA. Metal pollutants and cardiovascular disease; mechanisms and consequences of exposure, Am. Heart J. 2014;168:812e822.
61. Vaishaly AG, Mathew BB, Krishnamurthy NB. Health effects caused by metal contaminated ground water, Int. J. Adv. Sci. Res. 2015;1:60e64.
62. Sharma B, Singh S, Siddiqi NJ. Biomedical implications of heavy metals induced imbalances in redox systems, Biomed. Res. Int, 2014, 640754.
63. Kumar M, Puri A. A review of permissible limits of drinking water, Indian, Occup Environ J Med. 2012;16:40e44.
64. Ajmal M, Nomani AA, Khan MA. Pollution in the ganges river, India, Water Sci. Technol. 1984;16:347e358.
65. Subramanian V, Van Grieken R, Van't Dack L. Heavy metals distribution in the sediments of Ganges and Brahmaputra rivers, Environ. Geol. Water Sci. 1987;9:93e103.
66. Saikia DK, Mathur RP, Srivastava SK. Heavy metals in water and sediments of upper Ganga, Indian Environ J. Hlth. 1988;30:11e17.
67. Prasad S, Mathur A, Rupaniwar DC. Heavy metal distribution in the sediment and river confluence points of river Ganga in Varanasie Mirzapur region, Asian Environ. 1989;11:73e82.
68. Sharma YC, Prasad G, Rupainwar DC. Heavy metal pollution of river Ganga in Mirzapur, India, Int. Environ J Stud. 1992;40:41e53.
69. Garg N, Mathur N, Modak DP, Singh KP, Murthy RC, Ahmed S, *et al*. Trace metals trend analysis in river Ganges at Kanpur, Environ. Int. 1992;18:297e305.
70. Singh RP, Dayal G, Taneja A, Kapoor CK. Enrichment of Zn, Cd, Pb, and Cu, in the surface micro layer of river Ganga along Kanpur city, Poll. Res. 1993;12:261e165.
71. Ansari AA, Singh IB, Tobschall HJ. Status of anthropogenically induced metal pollution in the Kanpur-Unnao industrial region of the Ganga Plain, India, Environ. Geol. 1999;38:25e33.
72. Ansari AA, Singh IB, Tobschall HJ. Role of monsoon rain on concentrations and dispersion patterns of metal pollutants in sediments and soils of the Ganga Plain, India, Environ. Geol. 2000;39:221e237.
73. Khwaja AR, Singh R, Tandon SN. Monitoring of

Ganga water and sediments vis-a-vis tannery pollution at Kanpur (India): a case study, Environ. Monit. Assess. 2001;68:19e35.
74. Singh M, Müller G, Singh IB. Heavy metals in freshly deposited stream sediments of rivers associated with urbanisation of the Ganga plain, India,Water Air Soil Poll. 2002;141:35e54.
75. Singh M, Müller G, Singh IB. Geogenic distribution and baseline concentration of heavy metals in sediments of the Ganges River, India, Geochem J. Explor. 2003;80:1e7.
76. Dutta S, Kole RK, Ghosh S, Nath D, Vass KK. Impact assessment of lead on water quality of river Ganga in West Bengal, India, Bull. Environ. Contam. Toxicol. 2005;75:1012e1019.
77. Chaturvedi J, Pandey NK. Physico-chemical analysis of river Ganga at Vindhyachal ghat, Curr. World Environ. 2006;1:177e179.
78. Nath AK, Banerrjee S. In-situ accumulation of heavy metals in the Ganga river system-an overview, Ecol. Environ. Conserv. 2006;12:435e440.
79. Purushothaman P, Chakrapani GJ. Heavy metals fractionation in Ganga river sediments, India, Environ. Monit. Assess. 2007;132:475e489.
80. Sarkar SK, Saha M, Takada H, Bhattacharya A, Mishra P, Bhattacharya B. Water quality management in the lower stretch of the river Ganges, east coast of India: an approach through environmental education, Clean J. Prod. 2007;15:1559e1567.
81. Sinha RK, Sinha SK, Kedia DK, Kumari A, Rani N, Sharma G, *et al*. A holistic study on mercury pollution in the Ganga river system at Varanasi, India, Curr. Sci. 2007;92:1223e1227.
82. Beg KR, Ali S. Chemical contaminants and toxicity of Ganga river sediment from up and down stream area at Kanpur, Am. Environ J. Sci. 2008;4:362e366.
83. Bhattacharya AK, Mandal SN, Das SK. Heavy metals accumulation in water, sediment and tissues of different edible fishes in upper stretch of Gangetic West Bengal, Trends Appl. Sci. Res. 2008;3:61e68.
84. Kar D, Sur P, Mandai SK, Saha T, Kole RK. Assessment of heavy metal pollution in surface water, Int. Environ J. Sci. Technol. 2008;5:119e124.
85. Gupta A, Rai DK, Pandey RS, Sharma B. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad, Environ. Monit. Assess. 2009;157:449e458.
86. Kumar A, Jaiswal D, Watal G. Studies on chemical composition and energy transformation in river Ganga at Kanpur and Varanasi due to environmental degradation, Environ J. Biol. 2009;30:445e450.
87. Pandey J, Shubhashish K, Pandey R. Metal contamination of Ganga river (India) as influenced by atmospheric deposition, Bull. Environ. Contam. Toxicol. 2009;83:204e209.
88. Purkait S, Ganguly M, Aktar MW, Sengupta, Chowdhury AA. Impactassessment of various parameters polluting Ganga water in Kolkata region: a study for quality evaluation and environmental implication, Environ. Monit. Assess. 2009;55:443e454.
89. Aktar MW, Paramasivam M, Ganguly M, Purkait S, Sengupta D. Assessment and occurrence of various heavy metals in surface water of Ganga river around Kolkata: a study for toxicity and ecological impact, Environ. Monit. Assess. 2010;160:207e213.
90. Chatterjee S, Chattopadhyay B, Mukhopadhyay SK. Monitoring waste metal pollution at Ganga estuary via the East Calcutta wetland areas Environ. Monit. Assess. 2010;170:23e31.
91. Pandey J, Shubhashish K, Pandey R. Heavy metal contamination of Ganga river at Varanasi in relation to atmospheric deposition, Trop. Ecol. 2010;51:365e373.
92. Rai PK, Mishra A, Tripathi BD. Heavy metal and microbial pollution of the river Ganga: a case study of water quality at Varanasi, Aquat. Ecosyst. Health. Manag. 2010;13:352e361.
93. Katiyar S. Impact of tannery effluent with special reference to seasonal variation on physico-chemical characteristics of river water at Kanpur (UP),India, J. Environ. Anal. Toxicol. 2011;1:4.
94. Kansal A, Siddiqui NA, Gautam A. Assessment of heavy metals and their interrelationships with some physicochemical parameters in eco-efficient rivers of Himalayan region, Int. J. Environ. Sci. 2011;2:440e450.
95. Singh AL. Toxicity of heavy metals in the water of Ganga river at Varanasi, India: environmental implication, Poll. Res. 2011;30:107e110.
96. Rai UN, Prasad D, Verma S, Upadhyay AK, Singh NK. Biomonitoring of metals in Ganga water at different ghats of Haridwar: implications of constructed wetland for sewage detoxification, Bull. Environ. Contam. Toxicol. 2012;89:805e810.
97. Sharma P, Meher PK, Mishra KP. Distribution of non-radioactive heavy elements in water of river Ganges form Rishikesh to Allahabad: a study on possible health effects, J. Nehru Gram. Bharati Univ. 2012;1:52e58.
98. Singh L, Choudhary SK, Singh PK. Status of heavy metal concentration in water and sediment of river Ganga at selected sites in the middle Ganga plain, Int. Res J. Chem. Environ. 2012;2:236e243.
99. Bhatnagar MK, Raviraj S, Sanjay G, Prachi B. Study of tannery effluents and its effects on sediments of river Ganga in special reference to heavy metals at Jajmau, Kanpur, India, Environ J. Res. Dev. 2013;8:56e59.
100. Pandey A, Ramteke PW, Verma OP. Evaluation of heavy metals loading of rivers Ganga and Yamuna in, Int. Pharm J. Bio. Sci. 2013;4:1410e1417.
101. Singh H, Yadav S, Singh BK, Dubey B, Tripathi K, Srivastava V, *et al*. Assessment of geochemical environment from study of river sediments in the middle stretch of river Ganga at Ghazipur, Buxar and Ballia area, Proc. Natl. Acad. Sci. India Sec. B Biol. Sci. 2013;83:371e384.
102. Vaseem H, Banerjee TK. Contamination of the River Ganga and its toxic implication in the blood parameters of the major carp Labeo rohita (Ham), Environ. Sci. Pollut. Res. 2013;20:5673e5681.
103. Goswami DN, Sanjay SS. Determination of heavy metals, *viz*. Cadmium, copper, lead and zinc in the different matrices of the Ganges river from Rishikesh to Allahabad through differential pulse anodic striping voltammetry, Int. Adv J. Res. Chem. Sci. 2014;1:7e11.
104. Kumar A, Mishra AK, Shukla DN. Seasonal heavy metal concentration variation in the river Ganga at Allahabad, Kalash J,. Sci. 2014;2:1e7.
105. Naushad SS, Lall AA, Charan AA. Determination of heavy metals in water of Ganga and Yamuna river basin in Allahabad, Asian Environ J. Sci.

2014;9:106e108.
106. Pandey M, Tripathi S, Pandey AK, Tripathi BD. Risk assessment of metal species in sediments of the river Ganga, Catena 2014;122:140e149.
107. Singh AV, Pandey J. Heavy metals in the midstream of the Ganges river spatio-temporal trends in a seasonally dry tropical region (India), Water Int. 2014;39:504e516.
108. Singh S, Malik D, Thakur J, Kaur A, Singh RK, Nijhawan S. A comparative analysis of the physico-chemical properties and heavy metal pollution in three major rivers across India, Int. J. Sci. Res. 2014;3:1936e1941.
109. Pandey R, Raghuvanshi D, Tripathi B, Pandey V, Shukla DN. Analysis of physico-chemical parameters and some heavy metals in riverine water from river Ganges at different Ghats of Allahabad, Asian biochem J. Pharm. Res. 2014;3:143e151.
110. Pandey M, Pandey AK, Mishra A, Tripathi BD. Assessment of metal species in river Ganga sediment at Varanasi, India using sequential extraction procedure and SEMeEDS, Chemosphere 2015;134:466e474.
111. Pandey J, Singh R. Heavy metals in sediments of Ganga River: up-and downstream urban influences, Appl. Water Sci. 2015. In press, http://dx. Doi.org/10.1007/s13201-015-0334-7.
112. Chaudhary M, Mishra S, Kumar A. Estimation of water pollution and probability of health risk due to imbalanced nutrients in river Ganga, India, Int. J. River Basin Manag. 2017;15:53e60. http://dx.doi.org/10.1080/ 15715124.2016.1205078.
113. Tripathi IP, Dwivedi AP, Ojha P. Analysis of Ganga river water samples collected from Kaushambi district, Uttar Pradesh (India), Int. Res. Emerg J.Trends Multidiscip. 2016;2:19e30.
114. Haritash AK, Gaur S, Garg S. Assessment of water quality and suitability analysis of river Ganga in Rishikesh, India, Appl. Water Sci. 2016;6:383e392.
115. Pandey R, Raghuvanshi D, Sharma PK, Singh H, Tripathi B, Bajpai S, *et al*. Evaluation of the status of heavy metal contamination in sediment of the river Ganga at Allahabad, India, Int. J. Sci. Nat. 2016;7:852e859.
116. Niveshika S, Singh E, Verma AK, Mishra. Isolation, characterization and molecular phylogeny of multiple metal tolerant and antibiotics resistant bacterial isolates from river Ganga, Varanasi, India, Cogent Environ. Sci. 2016;2:1273750.
117. Madhulekha S, Arya. Evaluation of water quality in river Ganga due to contaminant of heavy metals, Kanpur, India, Int. Innov J Trends Eng. 2016;20:97e100.
118. Trivedi RC. Water quality of the Ganga riverean overview, Aquat. Ecosyst. Health Manag. 2010;13;347e351.
119. Agrawal PK. Ganga pollution control, in: Agrawal (Ed.) PK, Environment Protection and Pollution Control in the Ganga, Publications Pvt. Ltd. MD,New Delhi, India, 1994, 99e116.
120. Mishra AK. A river about to die: Yamuna, J Water Resour. Prot. 2010;2:489e500.
121. Jain SK, Agarwal PK, Singh VP. Hydrology and Water Resources of India, Springer, Dordrecht, 2007.
122. Mishra S, Kumar A, Yadav S, Singhal MK. Assessment of heavy metal contamination in Kali river, Uttar Pradesh, India, Appl. Nat. J. Sci. 2015 7 1016e1020.
123. Khan MY, Gani KM, Chakrapani GJ. Spatial and temporal variations of physicochemical and heavy metal pollution in Ramganga riverda tributary of river Ganges, India, Environ. Earth Sci. 2017;76:231.
124. Kumar R, Gupta AK, Tripathi RM, Chattree A. Monitoring heavy metals contamination in Yamuna river for its toxicity level in water, sediments and fish, Environ. Sci. Toxicol J. Food Technol. 2013;5:113e118.
125. Singh M. Heavy metal pollution in freshly deposited sediments of the Yamuna river (the Ganges river tributary): a case study from Delhi and Agra urban centres, India, Environ. Geol. 2001;40:664e671.
126. Singh VK, Singh KP, Mohan D. Status of heavy metals in water and bed sediments of river Gomtiea tributary of the Ganga river, India, Environ. Monit. Assess. 2005;105:43e67.
127. Singh H, Raghuvanshi D, Pandey R, Yadav A, Tripathi B, Kumar P, *et al*. Assessment of seven heavy metals in water of the river Ghaghara, a major tributary of the Ganga in northern India, Adv. Appl. Sci. Res. 2016;7:34e45.
128. Ahirwar MK, Gupta GS, Kirar N, Ahirwar P. Study of heavy metal pollution from effluent of orient paper mill, amalai,(Shahdol), MP, Int. Innov. Res Dev J. 2015;4:28e38.
129. Bhattacharyay G, Sadhu AK, Mazumdar A, Chaudhuri PK. Antennal deformities of chironomid larvae and their use in biomonitoring of heavy metal pollutants in the river Damodar of West Bengal, India, Environ. Monit. Assess. 2005;108:67e84.
130. Singh AK, Hasnain SI, Banerjee DK. Grain size and geochemical partitioning of heavy metals in sediments of the Damodar riverea tributary of the lower Ganga, India, Environ. Geol. 1999;39:90e98.
131. Srivastava VK. Indian rivers pollutiondcritical analysis: Ganga Action Plan, Indian Chem. Eng. 2010;52:155e156.
132. Parveen S, Khan AA, Untoo SA. Occurrence of heavy metals in river Ganga (a review), in: K. Gopal, Agarwal (Eds.) AK, River Pollution in India and its Management, APH Publishing Corporation, New Delhi, India, 2003, 97e110.
133. World Bank, Report No. AB6013, India-national Ganga River Basin Project, vol. 1, World Bank, Washington DC, USA, 2011.
134. Khanna DR, Sarkar P, Gautam A, Bhutiani R. Fish scales as bio-indicator of water quality of river Ganga, Environ. Monit. Assess. 2007;134:153e160.
135. Mitra A, Chowdhury R, Banerjee K. Concentrations of some heavy metals in commercially important finfish and shellfish of the river Ganga, Environ. Monit. Assess. 2012;184:2219e2230.
136. Vaseem H, Banerjee TK. Contamination of metals in different tissues of Rohu (Labeo rohita, Cyprinidae) collected from the Indian river Ganga, Bull. Environ. Contam. Toxicol. 2013;91:36e41.
137. Kannan K, Sinha RK, Tanabe S, Ichihashi H, Tatsukawa R. Heavy metals and organochlorine residues in Ganges river dolphins from India, Mar. Pollut. Bull. 1993;26:159e162.