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Review Research Paper

Heavy Metals in Sediments of Inland Water Bodies of India: A Review

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ABSTRACT

In last few decades, due to the rapid increase in the population, industrialization and newer agricultural practices, the aquatic resources of India have been deteriorating. The pollution of aquatic ecosystems by heavy metals is of a great concern due to their persistence, toxicity and accumulative behaviour. The heavy metals can change the trophic status of aquatic ecosystems and make them unsuitable for various purposes. They also pose a serious threat to human health. This paper reviews the heavy metal contamination of sediments of Indian inland water bodies. It also discusses the possible sources of pollution. Different standards for sediment pollution which are in use have also been discussed. It showed that environmental degradation has become a major societal issue in India due to uncontrolled anthropogenic activities, besides natural factors. There is an urgent need of creating awareness amongst the public of these problems and find preventive and remedial solutions for management. Expensive high-tech remedial measures are not suitable for the country, and hence emphasis has to be given on prevention. Indigenous research towards mitigation and remediation has to be encouraged, keeping in mind India's unique problems of poverty, crowding and malnutrition.

INTRODUCTION

Developing countries of the world are facing pollution problems due to toxic elements in the environment. Among these elements heavy metals are stable and persistent environmental contaminants (Karadede & Unlu 2007). Some metals like Zn, Cu, Fe and Mn, are required for biological functioning (Karadede & Unlu 2007) while others like Cd, Cr, Pb and Hg have no known significant contribution, but may exhibit extreme toxicity even in trace amounts. These toxic elements enter into the environment both as a result of natural processes and as pollutants from human activities. India is one of the wettest countries in the world having 1,170 mm average annual rainfall. It has annual precipitation of water (including snowfall) to the extent of 4000 km^3, of which 1869 km^3 water on an average is annually available. Ganga-Brahmaputra-Meghna system is the major contributor (60%) of total water resource potential of the country.

India's environment is becoming fragile and environmental pollution is one of the undesirable side effects of industrialization, urbanization, population growth and unconscious attitude towards the environment. At present, environmental protection is the main need of the society. Though industrialization and development in agriculture are necessary to meet the basic requirement of people, at the same time it is necessary to conserve the environment.

Domestic and municipal wastes are more responsible to degrade the quality of aquatic environment. According to Sengupta (2007), in India 29 billion litres of wastewater is generated per day and only 6 billion liters water (BLW) is collected and treated. While 1,20,000 tonnes of municipal solid waste is generated per day, 70% is collected and only 5% is treated. These wastes have a huge amount of nonbiodegradable matter including heavy metals which pose serious threat because of their toxicity, long persistence, bioaccumulation and biomagnification (Singh et al. 2007, Malik et al. 2010). The aquatic water bodies of India are being lost at a rate of 2-3% every year and about 59% of the major annual environmental costs have also been spent in aquatic pollution (Brandon & Homman 1995). Urban water bodies are depleting more than the rural ones due to receiving external pressure from human settlement and adversely affecting nearby aquatic ecosystems. Urbanization has direct negative impact on water bodies (Khan et al. 1988).

Sediment acts as a reservoir for contaminants including heavy metals. Because sediments reflect the actual degree of pollution at a given site, metal analysis of sediments can be used to identify the sources of trace metal pollution in an aquatic environment (Aston & Thornton 1977, Forstner & Salomons 1980). According to Luoma (1990), level of heavy metal in sediments can be a sensitive indicator of contaminants in hydrological systems. The solubility and availability of heavy metals in sediment is principally controlled by pH, concentration and type of ligands, chelating agents, particle size and composition of the sediments (Foster & Hunt 1975, Throne & Nickless 1981, Sakai et al. 1986, Jain 2004). Metals can be introduced both in particulate and soluble form and are subject to numerous physical, chemical, hydrological and biological processes i.e., adsorption, complexation, transportation, inactivation and incorporation (da Silva et al. 2000).

Metals dissolved in soil solution, surface and interstitial waters and those adsorbed on the sediment by cation exchange processes are usually readily available to aquatic and benthic organisms as well as to plants (Kumar et al. 2011). Metals strongly bound to the sediments and complexes with other chemical compounds are of less concern as they are most likely unavailable to the biota. Sediments accumulate metals and affect the near-bottom water layer due to mobilization/immobilization processes (Kumar et al. 2011). Due to differences in chemistry and biochemistry, the fate and transport of metals are not uniform and varying from one element to another. Different metals have different bioavailability and toxicity although all forms of a given metal have an equal impact on the environment.

SOURCES OF POLLUTION

Heavy metal pollution arises from natural as well as anthropogenic sources. Natural sources include seepage from rocks into water, volcanic activity, forest fires, etc. Anthropogenic sources mainly include domestic and industrial wastes. Natural sources contribute less pollution while a good amount of toxic elements enter through sewage and industrial wastes.

Domestic sources: Discharge of untreated sewage in water is the most important water pollution source in India. Indian Planning Commission in its Tenth Plan Document reported sewage as a highly polluting source contributing to about 80% of the total water pollution. Out of about 38000 million litre per day of sewage generated, treatment capacity exists for only about 12000 million litre per day. Thus, there is a large gap between generation and treatment of wastewater in India. Even the treatment capacity existing is also not effectively utilized due to operation and maintenance problems. Operation and maintenance of existing plants and sewage pumping stations is not satisfactory, as nearly 39% plants are not conforming to the general standards prescribed under the Environmental (Protection) Rules for discharge into streams. In Class I cities of India, about 2277 lakh population lives in 498 cities. They generate about 35558 MLD wastewater out of which a very little amount (11553 MLD about 32%) is treated (CPCB 2009-10). In Class II towns of India, about 300 lakh population lives in 410 towns. They generate 2696 MLD wastewater but only 234 MLD (8.6%) is treated (CPCB 2009-10). The rest of the wastes are discharged into aquatic systems.

Industrial source: About 57,000 polluting industries of India generate about 13,468 MLD of wastewater, out of which nearly 60% is treated, which comes from large and medium industries (Sengupta 2006). Pollution through major and small industries is also a great concern nowadays. The CPCB has listed the major polluting industries in India as cement mills, sugar, thermal power plants, distilleries, fertilizers, oil refineries, caustic soda production, petrochemicals, zinc smelting, copper smelting, aluminium smelting, sulphuric acid, integrated iron and steel, pulp and paper, tanneries, pharmaceuticals, dye and dye intermediates and pesticides industries. In these, distilleries, textile, engineering and pulp and paper industries are added impetus effects on aquatic water bodies than others. The main pollution contributing metals and their sources are listed in Table 1.

Besides the industrial sources of lead, listed in Table 1, lead exposure also occurs through gasoline additives, ceramic glasses, drinking water system, cosmetics, folk remedies, and battery/plastic recycling industry. Ash dumps from thermal power plants contain many polluting metals and complexes, which are carried to nearby water bodies. Volatile complexes such as those from uranium, enter the atmosphere via chimney emissions.

India has 3.2 lakh units of small-scale industries out of which many are highly polluting, and the wastewater generation of these small-scale industries is about 40% of the major industries (Maria 2003). Engineering sector of these industries is the major wastewater contributor, while the edible oil and vanaspati is the lowest contributor (Table 2).

Table 1: Heavy metals and their sources.

Metal	Industry
Chromium (Cr)	Mining, industrial coolants, chromium salts manufacturing, leather tanning
Lead (Pb)	Lead acid batteries, paints, E-waste, Smelting operations, coal- based thermal power plants, ceramics, bangle industry
Mercury (Hg)	Chlor-alkali plants, thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
Arsenic (As)	Geogenic/natural processes, smelting operations, thermal power plants, fuel burning
Copper (Cu)	Mining, electroplating, smelting operations
Vanadium (Va)	Spent catalyst, sulphuric acid plant
Nickel (Ni)	Smelting operations, thermal power plants, battery industry
Cadmium (Cd)	Zinc smelting, waste batteries, e-waste, paint sludge, incinerations & fuel combustion
Zinc (Zn)	Smelting, electroplating

Table 2: Wastewater generation by small-scale industries in some Industrial sectors.

Industry	Wastewater generation (MLD)
Engineering	2125
Paper and board mills	1087
Textile	450
Organic chemicals	60
Tanneries	50
Pharmaceuticals	40
Dye and dye intermediates	32
Soaps, paints, varnishes and petrochemicals	10
Edible oil and vanaspati	7

Source: (Kathuria & Gundimeda 2001)

Due to the adding of huge amount of wastes, some sites of the India have become hot spots for heavy metals i.e., the Ranipet area of Tamil Nadu, Kanpur of Uttar Pradesh and Vadodara of Gujarat are Cr- polluted sites. Ratlam of Madhya Pradesh and Vadodara of Gujarat are contaminated with Pb. Similarly, Kodaikanal of Tamil Nadu is heavily polluted by Hg. Tuticorin of Tamil Nadu and West Bengal is contaminated with As (CPCB 2009-10).

Gujarat, Maharashtra and Andhra Pradesh contribute to 80% of pollution load in India (CPCB 2009-10). To control the aquatic pollution in India, Central Pollution Control Board started national water quality monitoring in 1978 under global environmental monitoring system (GEMS). But our water bodies have reached a point of crisis due to the unplanned urbanization and industrialization (Singh et al. 2002).

HEAVY METALS IN SEDIMENTS OF INLAND WATER BODIES OF INDIA

The environmental pollution due to toxic metals has become a cause of serious concern in most parts of the country. These toxic metals are entering the ecosystems through the geoaccumulation, bioaccumulation and biomagnification processes. The most important heavy metals from the point of view of aquatic pollution are Zn, Fe, Pb, Cd, Hg, Ni and Cr. Pollution from various sources i.e., industrial effluent, urban run-off, atmospheric deposition as well as upstream run-off are absorbed into deposits and incorporated into the sediments, which plays an important role as pollutants and reflect the history of the water pollution (Jain 2004). Sediment acts as both carrier and sink for contaminants including heavy metals in aquatic environment (Singh et al. 2005) and their occurrence in water bodies indicate the presence of natural and anthropogenic sources. The sediment also acts as a useful indicator of long and medium term metal flux in industrialized water bodies and helps to improve management strategies as well as to assess the sources of recent pollution controls. In sediments, sometimes, the heavy metals can be adsorbed or accumulated to toxic levels and exhibit different physical and chemical interaction, mobility, biological availability and potential toxicity (Singh et al. 2005). Therefore, the bioavailability and subsequent toxicity of metals have been a major research area (Srivastava et al. 1994, Sharma et al. 1999, Singh 2001). In the Asian continent, the aquatic ecosystems are the chief transporting agents of continental weathering product as they supply about 30% of the global sediment input to the world's ocean.

River Ecosystems

Sediments are important source for the assessment of man-made contamination in the rivers (Forstner & Wittmann 1983). In last few decades the quality of the rivers has deteriorated everywhere due to the exponential growth of human population and discharging of waste products into the river. The world oceans have >70% of the mass transport of metals (Gibbs 1977), which is associated with river sediments. Several factors like geology, change in land use pattern, agricultural activity, industrialization and biological productivity controlled the metal load in the river sediment (Warren 1981, Aurada 1983).

Ganga- Brahmaputra-Meghna (G-B-M) system: This system occupies the total Bengal basin, which has a unique position among the world's basin due to its location and size, density of population and castrophic deposition of sediments. This system carries about 1060 million tons of suspended solids, more than 1330 km^3 of water, 744×10^6 tons of sediment and more than 173 million tons of total dissolved loads annually to the Bay of Bengal (Milliman et al. 1995). It is the largest sediment dispersal system in the world (Kuehl et al. 1989) and shows the highest rate of chemical denudation in the Bengal basin on a global scale (Datta & Subramanian 1997a). This system has an area of approximately 2,00,000 km^2. The industrialization is very less in this region but in case of population density, it is one of the highest in the world, ranging from 400 to 1200 people per km^2 (Milliman et al. 1989). In the surface sediment of G-B-M system the heavy metals range from 460-2655, 48-267, 46-160, 18-51, 12-81 and 10-46 ppm for Mn, Zn, Cr, Ni, Cu and Pb, respectively (Datta & Subramanian 1998). Among these channels, the Ganga was relatively more polluted and the sediment of this river could serve as a sink for metals. Damodar and Hooghly stretch of this system have the higher concentration of metals because they carried petroleum refinery wastes, industrial, mining effluents and agricultural run-off (Subramanian et al. 1988). Fe and Mn were higher in the Meghna main channel, Zn was higher in the Meghna tributaries and Cr was higher in the Brahmaputra and Meghna compared to the standard shale value.

Table 3: Major heavy metals contaminated sites in India.

Chromium	Lead	Mercury	Arsenic	Copper
Ranipet, Tamil Nadu	Ratlam, Madhya Pradesh	Kodaikanal, Tamil Nadu	Tuticorin, Tamil Nadu	Tuticorin,Tamil Nadu
Kanpur,Uttar Pradesh	Bandalamottu Mines, Andhra Pradesh	Ganjam, Orissa	West Bengal	Singbhum Mines,Jharkhand
Vadodara, Gujarat	Vadodara, Gujarat	Singrauli, MadhyaPradesh	Ballia and other districts, Uttar Pradesh	Malanjkahnd, Madhya Pradesh
Talcher, Orissa	Korba, Chattisgarh			

Source: (CPCB 2009-10)

Ganga river: In India, the River Ganges is the third largest sediment transporting river in the world, after the Yellow and Amazon rivers (Subramanian et al. 1987a). The mean annual flow of river is 5.9×10^{11} m^3 $year^{-1}$ and sediment load is 1600×10^{12}g $year^{-1}$. The average concentration of heavy metals in the sediment of Ganges river were Cr 147, Mn 1765, Fe 40350, Co 19, Ni 47, Cu 55, Zn 105, Cd 0.58 and Pb 22 in mg/kg amount (Singh et al. 2003) which was reflected by textural composition of the sediment and geochemical characteristics of its tributaries (Jha et al. 1990, Jain 2004). The highest concentration of Mn, Fe, Co, Cu and Cd were recorded in the upper Ganges, while in the lower Ganges Cr, Zn, Ni and Pb were found in highest concentration.

Yamuna river: The sediment of the Yamuna river had the average concentration of heavy metals as 22.2, 60.3, 9.5 and 59.2 mg/kg for Cu, Pb, Cd and Zn, respectively (Jain 2004). The concentration of Pb and Cd was higher than the average shale value due to the alkaline nature and high organic content in sediments. The heavy metals were found in excess amount near Delhi area due to the discharge of huge amount of sewage and industrial wastes from municipal and industrial areas. It is worth mentioning that Delhi is the largest contributor of pollution to this river, contributing to almost 80% of pollution load through various drains. Rawat et al. (2003) reported 821, 678, 44515, 31, 516, 2301, 1507, 44 and 211 ppm concentration of Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd and Pb, respectively only at Delhi. These values were higher than the average shale value (except Mn) due to the presence of municipal waste, electroplating, steel processing and battery based industries. Jain (2004) reported that Cd and Pb were under high risk category, whereas Cu and Zn were under medium risk category.

Gomti river: It receives the discharge of industrial effluents, sewage, municipal waste and agricultural runoff directly into the river. According to Singh et al. (2005), the average concentrations of heavy metals in the sediment of the river Gomti were Cd 2.43, Cr 8.15, Cu 4.99, Fe 2661, Mn 148, Ni 15.17, Pb 40.33 and Zn 41.66 mg/kg. The sediment of the river is alkaline in nature (pH b/w 7.62 and 8.27) so most of the heavy metals precipitated and settled as carbonates, oxides and hydroxides and show higher exposure risks to the benthic biota of the river. The concentrations of heavy metals in this system were lower than the corresponding shale value except in cases of Cd and Pb which showed high to very high risk at some points of the river.

Cauvery river: The river Cauvery is one of the important and utilized rivers of India. It is about 764 km long, covering approximately 90000 km^2 basin area with 1.5×10^6 t/year sediment load (Alagarsamy & Zhang 2005). It is highly important for irrigation purposes, mainly in its Tanjore delta region. Subramanian et al. (1985) found the heavy metal content to the extent of 1300, 150, 150, 60, 500 and 40 ppm for Mn, Cr, Ni, Cu, Zn and Pb, respectively. The values of Mn, Cr, Ni and Zn were relatively higher than the world average due to the adding of agricultural, industrial and domestic wastes.

Damodar river: Damodar is one of the largest rivers of eastern India. It is about 542 km long with a catchment area of about 23170 km^2 and 1200 mm annual rainfall. At different stretches the river was fed by several tributaries, i.e., Bokaro, Konar, Jamunia and Barakar. The concentration of heavy metals in the sediment of this system were 7894-30188, 294-819, 10-33, 23-58, 3-28 and 10-33 ppm for Fe, Mn, Cu, Zn, Ni and Cr, respectively (Singh & Hasnain 1999). At some points of the river Cu and Zn were in higher amount due to the anthropogenic inputs but the heavy metal pollution in the Damodar river basin was not so high.

Subernarekha river system: The River Subernarekha is one of the major rivers of the south Chhotanagpur plateau of Jharkhand. It is a rain-fed river having 470 km length. Near the city of Jamshedpur the river was contaminated with heavy metals because this city is the centre of Indian's major metallurgical industry. Upadhyay et al. (2006) reported 32.84 ppm of Zn, 9.77 of Pb, 35.55 of Cu and 0.036 ppm of Cd in this system. Some points of the river had higher levels of metals due to the lithogenic and anthropogenic effects of its Kharkhai tributary.

Jhanji river system: Jhanji river is the tributary of the Brahmaputra river. The catchment area of the river is 1350

Table 4: Heavy metals concentration (ppm) in the sediments of Indian rivers.

Heavy metal		Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	References
Average shale		90	850	46,700	19	68	45	95	0.30	20	Turekian & Wedepohl (1961)
World average		100	1050	48,000	20	90	100	350	-	-	Martin & Meybeck (1979)
Indian river sediment average		87	605	29,000	-	37	28	16	-	-	Subramaniam et al. (1987a)
River	***Stretch***										
G-B-M system	Bengal basin	108	873	-	-	31.4	27.8	89.6	-	19.0	Datta & Subramanian (1998)
Subernarekha	Singhbhum district	-	-	-	-	-	35.55	32.84	0.036	9.77	Upadhyay et al. (2006)
Gangan	Moradabad	205	traces	3.5	-	107	903	4.87	-	-	(Sharma et al. 2003)
Bhagirathi	Gangotri	497	2982	80412	259	155	416	295	-	614	Purushothaman & Chakrapani (2007)
	Azimghanj	477	9755	146724	246	215	321	345	-	414	Purushothaman & Chakrapani (2007)
Ganga	Moradabad	20	457	18130	-	11	17	41	-	-	Sharma et al. (2003)
	Haridwar to Farraka	147	1765	40,350	19	47	55	105	0.58	22.0	Sharma et al. (2003)
	Rishikesh	594	9514	123055	235	151	439	301	-	653	Purushothaman & Chakrapani (2007)
Mahawan	Moradabad	205	traces	3.5	-	107	903	4.87	-	-	Sharma et al. (2003)
Ghagra	Patna	246	12838	178486	293	250	357	406	-	373	Purushothaman & Chakrapani (2007)
Yamuna	Delhi	5167	10487	122286	249	216	579	847	-	603	Purushothaman & Chakrapani (2007)
		70	460	25000	-	20	40	70	-	-	Jha et al. (1990)
Damodar	River basin	20	457	18130	-	11	17	41	-	-	Singh & Hasnain (1999)
Achankovil		-	699	11858	-	-	224	415	6.23	72.42	Prasad et al. (2006)
Jhanji		171	-	-	49.57	48.62	44.37	103	-	14.78	Baruah et al. (1996)
Sot	Moradabad	89	traces	4.2	-	41	142	152	-	-	Sharma et al. (2003)
Gondak	Patna	254	12699	177354	230	213	336	2633	-	332	Purushothaman & Chakrapani (2007)
Gomti	Neemsar to Jaunpur	8.15	148	2661	-	15.16	5.0	41.67	2.43	40.33	Singh et al. (2005)
	Lucknow	588	14979	210712	365	374	760	834	-	570	Purushothaman & Chakrapani (2007)
Godavari		-	-	-	11.08	12.08	11.23	72.32	-	6.96	Krupadam et al. (2007)
Aril	Moradabad	77	traces	3.5	-	51	139	105	-	-	Sharma et al. (2003)
Betwa		212	1435	51000	35.5	89	69	108	0.44	19	Sharma et al. (2003)
Chambal		197	1950	50900	29.8	89	64	113	0.53	19	Sharma et al. (2003)
Son	Patna	223	22520	231244	624	487	926	458	-	326	Purushothaman & Chakrapani (2007)
Ken		189	1590	48000	27.8	89	65	107	0.50	13	Singh et al. (2003)
Cauvery		95	560	29950	25	55	26	92	2.1	20	Vaithiynathan et al. (1993)
Ramganga	Moradabad	205	traces	3.5	-	107	903	4.87	-	-	Singh et al. (2003)
Uppanar		1.38	1.83	1.15	1.20	1.29	2.16	1.43	1.17	0.902	Ayyamperumal et al. (2006)
Alaknanda	Vishnu Prayag	507	6,779	95,467	176	129	574	624	-	449	Purushothaman & Chakrapani (2007)
Dikrong river		50.7	548	1.75	-	11.2	189	26.4	-	39.1	Chakravarty & Patgiri (2009)
Haldi river		-	-	-	11.8	22.4	17.0	48.7	1.3	13.9	Kumar et al. (2011)
Rupnarayan		-	-	-	11.8	22.4	15.1	49.5	1.6	14.3	Kumar et al. (2011)

km^2. It is a major source of water for the people residing downstream but nowadays it has become a site for the disposal of wastes. It carries approximately 100 tonnes per day of wastewater through different sources. Tuli, Nagaland industrial township and the tea gardens are the major source of pollution in the river. So, due to the direct and indirect dumping of wastes the river is more or less becoming a reservoir for a variety of organic and inorganic chemicals. Baruah et al. (1996) reported the heavy metals concentration as 14.78, 103.53, 44.37, 48.62, 49.57 and 171.44 ppm for Pb, Zn, Cu, Ni, Co and Cr, respectively in this system. So due to the continuous dumping of wastes for a long time the river has come under stress with metal pollution.

Achankovil river system: Achankovil is one of the major rivers of Kerala with a drainage area of 1484 km^2 and annual average discharge of about 1.5 km^3/year. The annual rainfall is 2000-5000 mm in this area. The river receives discharge from the Pamba and Manimala tributaries. According to Prasad et al. (2006), the sediment of Achankovil has 415 ppm of Zn, 224 of Cu, 11858 of Fe, 72.42 of Pb, 6.23 of Cd and 699.26 ppm of Mn. These concentrations are lower than the other major Indian rivers; Godavari (Biksham & Subramanian 1988), Krishna (Ramesh et al. 1989), Cauveri (Subramanian et al. 1985), Ganges (Datta & Subramanian 1998) and Indian average (Subramanian et al. 1985). This indicates the pristine nature of the Western Ghats river system.

Ramganga river system: The River Ramganga forms the eastern boundary of the Moradabad area. It receives the effluents from brass, paper, paperboards, textiles and food-processing industries. All the urban sewage is also dumped into this river. It is the highest polluting river of Moradabad area. The heavy metals concentrations in this river were 205, 3.5, 107, 903 and 4.87 ppm for Cr, Fe, Ni, Cu and Zn, respectively (Sharma et al. 2003). The high values of Cu and Zn were due to the presence of several brass industries and steel industries in the area. It showed that the industries of the Moradabad area were disposing their effluents into the Ramganga without any pre-treatment.

Mahawan river system: Mahawan river is a tributary of the Ganga river and flows on the western margin of the Moradabad area. The industrial area of Gajraula is the main source of pollution in this river. The concentration of heavy metals in this system was 68 ppm for Cr, 3.5 for Fe, 38 for Ni, 156 for Cu and 268 ppm for Zn (Sharma et al. 2003). The concentrations of metals were higher due to paper, metallurgical, agrochemicals, pharmaceuticals and textile industries, which discharged their effluents into this river. Similarly the River Sot has also become polluted due to the receiving of urban and industrial wastes from Amroha, Joya and Chandausi (Sharma et al. 2003).

Uppanar river: The average value of Fe was 1.146 ppm, Mn 1.827, Cr 1.372, Cu 2.162, Ni 1.297, Co 1.201, Pb 0.902, Zn 1.430 and Cd 1.174 ppm in the sediment of Uppanar river (Ayyamperumal et al. 2006). The reported levels were below the average shale value (except Cd) and moderately polluted by these metals but could act as a future source of heavy metals.

Aril river system: The River Aril is a tributary of the Ramganga river. Urban wastes and agro-based industries of the Bilari area are the main contributors of the pollution in this system. The river was less polluted with heavy metals by contained 77, 3.5, 51, 139 and 105 ppm of Cr, Fe, Ni, Cu and Zn, respectively (Sharma et al. 2003).

Gangan river system: The river Gangan serves as a natural drain for the western part of the Moradabad urban area. It receives the sewerage and industrial wastes of this area. So, it is fed with heavy metals having 102, 3.5, 53, 226 and 1.03 ppm concentration for Cr, Fe, Ni, Cu and Zn, respectively (Sharma et al. 2003). The high concentration of heavy metals was due to the discharge of brass industries and urban waste in this river.

Dikrong river: The Dikrong river originates near the Senkeng mountains at an altitude of 2579 m in the Lesser Himalayan ranges of Arunachal Pradesh. It is a tributary of the Subansiri river lying on the north bank of the River Brahmaputra. There is no major industry in this area, but a few minor handicraft and small scale steel and iron factories are situated. Chakravarty & Patgiri (2009) reported the levels of Al, Fe, Mn, Zn, Cu, Cr, Ni and Pb as 4.39, 1.75, 548, 26.4, 189, 50.7, 11.2 and 39.1 ppm, respectively. The sediment was contaminated with Cu and Pb which was due to dispersion from the mineralized zone of the upper catchment area.

Haldi and Rupnarayan rivers: These are two estuarine tributaries of lower stretch of Hugli estuary in West Bengal. Water of both the rivers is used for navigation, irrigation, power generation. It also supplies potable water to the riverside towns. These rivers carry waste discharges of Kolaghat thermal power station, Haldia industrial city and nearby Haldia port and their inputs to river Ganga are higher during low tides. The average concentrations of Ni, Pb, Co, Zn, Cu, and Cd in sediments were 22.4, 13.9, 11.8, 48.7, 17.0, 1.3 mg/kg for Haldi river and 22.4, 14.3, 11.8, 49.5, 15.1, 1.6 mg/kg, respectively for Rupnarayan river (Kumar et al. 2011). So the sediments of these rivers were enriched with metals may be continuously disposed off the river during tidal water fluxes, although these rivers do not reflect any severity of heavy metal contamination.

Lake Ecosystems

Lakes have a complex and fragile ecosystem and do not have

Table 5: Heavy metals concentration (ppm) in the sediments of Indian lakes and other ecosystems.

Heavy metal	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	References
Average shale	90	850	46,700	19	68	45	95	0.30	20	Turekian & Wedepohl (1961)
World average	100	1050	48,000	20	90	100	350	-	-	Martin & Meybeck (1979)
Nainital lake	98.87		47.23	22.93	-	-	119	-	-	Jha et al. (2002)
Kolleru lake	52.31	-	-	-	1.34	409	510	0.02	4.11	Sekhar et al. (2003)
Hussainsagar lake	72.19				45.07	113	337	7.28	74.55	Rao et al. (2004)
Mansar lake	51.0	0.05	2.80	42.0	46.3	26.4	67.0	-	32.67	Das et al. (2006)
Dal lake	-	0.08-0.23	0.84-1.26	12-27	11-32	70-193	184-309	-	17-32	Jeelani & Shah (2006)
Nal Sarovar lake	-	-	-	64.83	50.33	32.88	553	8.83	5.59	Kumar et al. (2006)
Lonar lake	-	-	7900	3.7	8.25	-	-	-	-	Surakasi et al. (2007)
Kanewal reservoir	-	-		26.29	50.47	47.73	1012	66.40	8.01	Kumar et al. (2008)
Bheris pond	8.7	68.2	1353	-	-	74.92	3723	-	7.52	Chatterjee et al. (2006)
Lalbagh tank	17.0	-	4230	-	17.0	45.0	49.0	-	29.0	Lokeshwari & Chandrappa (2006)

self-cleaning ability. Due to the rapid urbanization and industrialization with improper environmental planning and the discharge is often leading into lakes and, therefore, they are accumulating pollutants.

Dal lake: Dal lake is a tectonic lake of Srinagar covering an area of approximately 11.50 km^2. The total volume of the lake is 9.83×10^6 m^3 (Trisal 1987). The lake is a source for drinking water, irrigation, fisheries, recreation, tourism and many other activities in the city. It has been fed with municipal and domestic wastes leading to eutrophication. The Telbal drain, Peshpaw drain, Shalimar drain, Merakhsha drain and Harshikul are the sources of pollution in this lake. Telbal drain is the main polluter, which contributes about 80 % of the total inflow to the lake (Trisal 1987). Jeelani & Shah (2006) reported 0.84-1.26, 0.08-0.23, 184-309, 12-27, 70-193, 17-32 and 11-22 ppm level of heavy metals for Fe, Mn, Zn, Co, Cu, Pb and Ni, respectively. Higher concentration of metals in the sediment of lake was due to the metal mining, industrial and municipal wastes (Thuy et al. 2000). The atmospheric deposition of Pb activities from different sources was also responsible for the higher concentration of Pb. So the river was polluted by Zn, Cu and Pb, and was threat for aquatic life.

Hussainsagar lake: Hussainsagar lake is the heart of Hyderabad and Secunderabad cities, having an area of 446 hectare. It receives domestic and industrial wastewaters. Rao et al. (2004) reported the Cr, Ni, Zn, Cu, Hg, Cd, and Pb with 72.19, 45.07, 337, 113, 1.99, 7.28, and 74.55 ppm concentration, respectively. High amount of metals was due to cultural activities around the lake, especially during festivals. The concentration of heavy metals in Hussainsagar lake was above the average shale value (except Cr and Ni) and in under the stress of heavy metals.

Nainital lake: The Nainital lake is the only source of drinking water to the Nainital town, but due to the increased human activity and modern agricultural practices the heavy metal concentration is increasing as anthropogenic load in this lake. According to Jha et al. (2002), the concentrations of heavy metals in the sediment of Nainital lake were Cr 98.87, Fe 47.23, Co 22.93 and Zn 119 ppm, which were higher than the average shale value. The Nainital lake has been fed with heavy metals and there are maximum chances of heavy metals to enter in the food chain and may cause deleterious effects to aquatic life.

Kolleru lake: Kolleru lake is the biggest natural freshwater lake of Andhra Pradesh, having approximately 4763 km^2 catchment area, which is occupied by agricultural fields and aquatic ponds. It is a great source of aquaculture and fishing activity of the people, living in this basin. Agricultural runoff, and domestic and industrial effluents are the major source of heavy metals in this system, which entered into the lake directly or as well as through drains and channels. Sekhar et al. (2003) found 52.31, 1.34, 409, 510, 0.02 and 4.11 ppm of Cr, Ni, Cu, Zn, Cd and Pb, respectively. Those were below the average value (except Cu and Zn) and less available for accumulation in the food chain.

Nal Sarovar lake: The average concentration of heavy metals in the sediment of Nal Sarovar were Co 64.83, Ni 50.33, Cu 32.88, Zn 553, Cd 8.83 and Pb 5.59 mg/kg (Kumar et al. 2006) due to the agricultural runoff and sewage effluents, coming through several drains along the washing, bathing, cattle wading and agricultural runoff from peripheral villages boundary. On the basis of average shale value the toxicity status of the studied heavy metals (except Zn and Cd) was not very alarming in this lake but some prevention to control the alarming status of Zn and Cd in the studied area have been recommended.

Lonar lake: Lonar lake of India is situated in the heart of a vast Indian peninsula. It is one of the soda lakes (having pH 10) after the Mono, Owens (USA), Karakul (Russia) and Magadi (Kenya) lake. It has a unique ecological system being the only meteoritic crater in basaltic rock in the world. It is a circular depression having 1830 m across and nearly 150 m deep. The sediment of this lake has 7900 ppm of Fe, 3.7 of Co and 8.25 ppm of Ni (Surakasi et al. 2007). Those were much below the average value because no disposal sites were present in this lake.

Mansar lake: Mansar lake is situated in the sub-Himalayan zone of the Jammu. It is the biggest and deepest (1015 m long, 35 m deep and 640 m wide) lake of this region with an area of 0.53 km^2 and circumference of about 3020 m. It is a non-drainage type of lake and fed from rainfall, catchment runoff and underground springs. During the rainy season about 1500 mm per year rainfall has reported in this region. In the sediment of this lake 2.80, 0.05, 32.67, 42.0, 46.3, 51.0, 26.4 and 67 ppm concentration were reported by Das et al. (2006) for Fe, Mn, Pb, Co, Ni, Cr, Cu and Zn, respectively. The concentration of Pb and Co was higher from the average shale value and the others are safe with respect to pollution.

Other Ecosystems

Kanewal reservoir: Kumar et al. (2008) reported the 66.40, 26.29, 47.73, 50.47, 8.01 and 1012 ppm concentration for Cd, Co, Cu, Ni, Pb and Zn, respectively. Concentration of Cd, Co and Cu were slightly higher than the average shale value but a very high amount of Zn showed the toxicity of sediments. It was due to the agricultural practices in this region.

Bheris pond: According to Chatterjee et al. (2006), Bheris pond contained Cr 8.7, Mn 68.2, Fe 1353, Cu 74.92, Zn 3723 and Pb 7.52 ppm, which was influenced by metal speciation, nature of complexes, metal-metal interaction and other factors i.e., temperature, pH and organic contents. The concentrations of heavy metals in the studied area were below the average shale value (except Cu and Zn) but under stress with Cu and Zn.

Lalbagh tank: The study of Lalbagh tank recorded the concentration of heavy metals for Cr 17, Fe 4230, Ni 17, Cu 45, Zn 49 and Pb 29 mg/kg (Lokeshwari & Chandrappa 2006) due to the adding of untreated sewage water. It was also controlled by seasonal factors. The sediment of Lalbagh tank is unpolluted with respect to Fe, Zn, Ni and Co but moderately polluted with Cu and Pb.

CONCLUSION

On the basis of the review it can be stated that Ganga-Brahamputra-Meghna system is under unpolluted category, while the river Ganges is enriched with heavy metals especially near urban or industrial belts. The Yamuna river is severely polluted by heavy metals due to the haphazard wastes disposal specially at Delhi and there are maximum chances for the bioavailability of heavy metals in food chain of this aquatic system, which can pose serious threats for human health also. The River Gomti is also under medium risk for heavy metal pollution although some stretches of the river are under high to very high risk for Cd and Pb. River Subernarekha is also enriched with Zn, Pb, Cu and other minerals. The land use pattern, lithology and anthropogenic factors are responsible for heavy metal contamination in Achankovil river. Cauvery river had the high amount of metals than the average shale value due to the adding of agricultural, domestic and industrial wastes. Jhangi river has also come under stress due to the dumping of wastes. Ramganga, Mahawan, Aril and Gangan rivers have also fed with urban and industrial wastes. Damodar river, Haldi river and Rupnarayan rivers are also contaminated but do not reflect any severity of heavy metal contamination.

In case of lakes and other ecosystems, Dal lake, Hussainsagar lake and Nainital lake are under threat due to the dumping of huge domestic and industrial wastes and also the wastes of pilgrim activities. The concentration of heavy metals in Kolleru and Lonar lake is not so high and can be consider safe for aquatic life. Other ecosystems i.e., Kanewal reservoir, Lalbagh tank and Bheris pond are also deepened with heavy metals. As a whole, the sediments of most of the Indian water bodies have contaminated with heavy metals, especially from domestic and industrial wastes.

RECOMMENDATIONS

- Protection of aquatic resources: To stop the dumping of domestic and industrial effluents and management of agricultural run-off are the most preventive methods.
- Implementation of laws and rules: There are several laws and rules for water pollution prevention and conservation but their proper/strict implementation is lacking.
- Effluent treatment plants: Large industries should be forced to set-up their own effluent treatment plants; common effluent treatment facilities can be considered for smaller industries.
- Remediation techniques: Once the metal is out of the rock it is difficult to put it back. Physico-chemical as well bioremediation solutions are being tried to reduce the environment load, preferably at the site of generation.
- Awareness: Public participation is necessary. Pollution of aquatic resources can be controlled by awareness in the public through different communication methods.

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