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Review article

Heavy metal pollution in surface water bodies of India: A review

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Abstract: Water is essential for living beings, and constitutes one of the vital assets for a country. Monitoring and assessment of water quality has become an environmental concern due to enormous anthropogenic activities. Availability of drinking water may be one of the most important crises of the 21st century. Globally, only 0.3-0.5% of the total water is available as fresh water and the maximum water bodies of that are becoming polluted, thus decreasing the availability and potability of the water bodies. India is rich in water resources having 4000 km^3 annual precipitation of water. In last few decades, due to the rapid increase in the population, large scale industrialization and newer methods of farming the surface water quality of India has deteriorated. The pollution of aquatic ecosystem by heavy metals is of a great concern due to their toxicity and accumulative behaviour. The heavy metals can change the trophic status of an aquatic ecosystem and make them unsuitable for various purposes. They also pose a serious threat to human health. This article reviews the heavy metals contamination in the water of Indian rivers, lakes, reservoirs and other ecosystems. It also discusses the possible sources of pollution in these areas.

Key words: Water, India, Heavy Metals, Pollution, Aquatic ecosystem

Introduction

Water is a vital resource for living beings. Globally only 2.4 % of the total water is distributed on the main land, of which a very small amount (hardly 0.3-0.5% of the total water) is available as fresh water (Shanthi *et al*., 2006). 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.

In India the per capita surface water availability in the years 1991 and 2001 were 2309 and 1902 m^3 of which the utilizable water were 816 and 672 m^3, respectively. These are projected to reduce to 495 and 421 m^3 in the years 2025 and 2050, respectively (Table-1). The maximum water is used in irrigation sector and minimum in energy sector.

India is a developing country having total population 1,027,015, 247 spread over 3.28 million sq. km. of which 72.2% (741, 660, 293 people) live in rural areas and 27.78% (285,354,954) in urban areas (Provisional Population Totals, 2001). The density of population in India has also increased from 77 in 1901 to 324 per sq km in 2001.

Due to increase in the density of population and growing industrialization the people are migrating from rural to urban areas, so the urban population is increasing more rapidly. According to Sengupta (2007) about 28.5 crores population was living in urban areas during 2001 (Figure 1). This burgeoning population, clustering of industries, unplanned development and intensive human activity are the matter of great concern as they put immense pollution pressure on our natural resources and thus decreasing the quality and quantity of our water bodies.

In India 29 billion liters of waste water is generated per day and only 6 billion liters water (MLW) 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 and rest of the municipal solid wastes and municipal waste water is discharged into the water bodies (Sengupta, 2007). These wastes have a huge amount of nutrients load and heavy metals, which are non-biodegradable in nature (Ikem *et al*., 2005). During recent years the pollution of heavy metals in surface water bodies has attracted the attention of the scientific community because aquatic ecosystem is the ultimate recipient of almost all substances including heavy metals. In surface water bodies heavy metals pose serious threat because of the toxicity, long persistence, bioaccumulation and biomagnification in the food chain (Singh *et al*., 2003; Sarkar *et al*., 2007). In India the aquatic water bodies 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 surface water pollution (Brandon and Homman, 1995).

Urban water bodies is depleting more than the rural ones due to receiving external pressure from human settlement and adversely affecting nearby aquatic ecosystem. Urbanization has direct negative impact on water bodies (Khan *et al*., 1988).

Sources of Pollution

Heavy metal pollution in water bodies may result from various sources, namely, natural, agricultural, domestic, industrial and other anthropogenic sources. Domestic and industrial sources

Table-1: Water used and projected water use in India (in km^3)

Use	Year 1997-98	Year 2010			Year2025			Year 2050		
		Low	High	%	Low	High	%	Low	High	%
Surface water										
Irrigation	318	330	339	48	325	366	43	375	463	39
Domestic	17	23	24	3	30	36	5	48	65	6
Industries	21	26	26	4	47	47	6	57	57	5
Power	7	14	15	2	25	26	3	50	56	5
Inland navigation		7	7	1	10	10	1	15	15	1
Environment-Ecology		5	5	1	10	10	1	20	20	2
Evaporation losses	36	42	42	6	50	50	6	76	76	6
Total	399	447	458	65	497	545	65	641	752	64
Ground water										
Irrigation	206	213	218	31	236	245	29	253	344	29
Domestic	13	19	19	2	25	26	3	42	46	4
Industries	9	11	11	1	20	20	2	24	24	2
Power	2	4	4	1	6	7	1	13	14	1
Total	230	247	252	35	287	298	35	332	428	36
Grand total	629	694	710	100	784	843	100	973	1180	100
Total water use										
Irrigation	524	543	557	78	561	611	72	628	807	68
Domestic	30	42	43	6	62	62	7	90	111	9
Industries	30	37	37	5	67	67	8	81	81	7
Power	9	18	19	3	33	33	4	63	70	6
Inland navigation	0	7	7	1	10	10	1	15	15	1
Environment-Ecology	0	5	5	1	10	10	1	20	20	2
Evaporation losses	36	42	42	6	50	50	6	76	76	7
Total	629	694	710	100	784	843	100	973	1180	100

Source: Ministry of Water Resources (1999)

are most responsible to decrease the quality of aquatic ecosystem (Table-2).

Domestic source: Indian planning commission in its Tenth Plan Document reported sewage as a highly polluting source contributing to about 80% of the total water pollution, which increased over some decades, but the treatment facility is not quite enough. During 2003, class I cities of India had 1850 lakh population in 423 cities. They generated 23826 MLD wastewater but a very small amount (about 29% of generated wastewater) has been treated (Figure 2) (Sengupta, 2007). In the case of class II towns of India about 370 lakh peoples were residing in about 498 towns during 2003. Wastewater generation in these towns was less than the cities due to the fewer water supplies. Practically they did not have good treatment facilities and treated a negligible amount of generated wastewater (Figure 3) (Sengupta, 2007).

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- 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 more responsible for aquatic pollution than others. About 78% of the total biological oxygen demand (BOD) load of waste water comes from only four industries (28% from distillery, 26% from textile, 15% from engineering and 9% from pulp and paper industries) and 22% comes from other industries. In case of chemical oxygen demand (COD) load, 71% is induced by these four industries (26% from distillery, 17% from textile, 17% from engineering and 11% from pulp and paper industries) and the rest 29% comes from others (Sengupta, 2006). India also 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-3). In terms of pollution load generation from domestic and industrial sources, the industrial source has less BOD level than the domestic source (Figure-4) (Sengupta, 2006).

Heavy Metals in Water Bodies of India

Water is an important natural resource and there are many competitive demands upon it, but nowadays due to the increasing use of the chemicals and agricultural practices, our water bodies are getting polluted. 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 in the ecosystem through the

Table-2: Polluted river stretches in India

River	Polluted stretches	Possible source of pollution
Sabermati	Immediate upstream of Ahmedabad up to Sabarmati Ashram Sabarmati Ashram to Vautha	Domestic and industrial waste form Ahmedabad Domestic and industrial waste form Ahmedabad
Subamakha	Hatia Dam to Bharagora	Domestic and industrial waste form Ranchi and Jamshedpur
Godavari	Downstream of Nasik and Nanded	Waste form sugar industries distilleries and food processing industries
Krishna	Kared to Sangli	Waste form sugar industries and distilleries
Sutlej	Downstream of Ludhiana to HaikeDownstream of Nangal	Industrial wastes form hosieries, tanneries, electroplating and engineering industrial and domestic waste form Ludhiana and JalandherWaste from fertilizer and chlerakali mills from Nangal
Yamuna	Delhi to confluence with ChambalIn the city limits of Delhi, Mathura and Agra	Domestic and industrial waste from Delhi, Mathura and AgraDomestic and industrial waste from Delhi, Mathura and Agra
Hindon	Saharanpur to confluence with Yamuna	Industrial and domestic wastes from Saharanpur and Ghaziabad
Chumbal	Downstream of Nagda and downstream of Kota	Domestic and industrial waste from Nagda and Kota
Damodar	Downstream of Dhanbad	Industrial wastes from Dhanbad, Durgapur, Asanosl, Haldia and Burnpur
Gomti	Lucknow to confluence with Ganges	Industrial waste from distilleries and domestic wastes from Lucknow
Kali	Downstream of Modinagar to confluence with Ganges	Industrial and domestic wastes from Modinagar

Source: CPCB (1999)

Table-3: 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 and Gundimeda (2001)

geoaccumulation, bioaccumulation and biomagnification processes (Lokeshwari and Chandrappa, 2006). The most important heavy metals from the point of view of water pollution are Zn, Fe, Pb, Cd, Hg, Ni and Cr. Some metals, *i.e*., Fe, Cu, Ni, and Zn are essential trace metals for living organisms for proper functioning of biological system but may become toxic at higher concentration, while, some other metals i.e., Pb and Cd have no known biological function, but are toxic elements (Bruins *et al*., 2000; Lasat, 2002; Cheng, 2003). Contamination of heavy metals in food chain has become a burning issue in recent years because of their potential accumulation in biosystems through contaminated water. Several studies have shown that the concentration of heavy metals in aquatic ecosystem is principally controlled by pH, concentration and type of ligands and chelating agents, oxidation-state of the mineral components and the redox environment of the system (Jain, 2004; Singh *et al*., 2005).

River Ecosystem

The rivers have a great significance in the history of Indian culture, development, religious and spiritual life. These are the 'heart and soul' of Indian life. These are also the source of the prosperity of rural and agriculturally oriented population of India. India is blessed with many rivers, out of them 12 are classified as major rivers having the total catchment area of 2528×10^3 sq km.

Ganges river system: The Ganges is the biggest river of India. It is 2525 km long having a catchment area of about 861452 sq km. It receives approximately 1.3 billion litres waste water per day from the riverside cities, towns and villages (Khan *et al*., 1998). The water of the Ganges is used for drinking, domestic, industrial and many other purposes in riverside towns. The river carries more than 2% of the total flow of water available in the world's existing river systems (Rao, 1979). It acts as the chief artery for river borne traffic and development of the linear urban industrial belt. The various industries like jute, textile, chemical, paper, electrical and light engineering, consumer goods and other ancillary industries discharge their effluents into the river and deteriorating the water quality of the river day by day. In Uttar Pradesh Kanpur is the major industrial town, having about 150 tannery industries. About $1.35\times10^5 M^3$ day^{-1} waste water from only tannery industries are dumped into the Ganges. So at this site Cr concentration was high (0.2925 mg L^{-1}) (Khwaja *et al*., 2001). The concentrations of heavy metals in the Ganges were Fe 0.03-0.56, Cu 0.001-0.090, Mn 0.06-0.49, Zn 0.02-0.52, Pb 0.011-0.076 and Hg 0.10-0.95 mg L^{-1} (Sarkar *et al*., 2007) (Table-4). The higher concentration of Hg at Babughat station of Calcutta was due to the several sources of contamination such as industrial discharges (paper industries, electrical industries etc), agricultural run-off (Hg-containing fungicides) and sewage from the highly urbanized city of Calcutta directly into the river (Sarkar *et al*., 1999). Pollution of the Ganges at Vindhyachal ghat of Mirzapur was due to the pilgrim activities. About 5-6 lakh people come here during Navratri pooja and pollute the river. Accorting to Chaturvedi and Pandey (2006) the river contained 1.9, 0.18, 0.72, 1.35, 0.57 and 0.14 mg L^{-1} for Cu, Cr, Ni, Fe, Zn and Cd, respectively during Navratri pooja (Table-4). Cd and Cr were found in higher amount due to the uses of paints and other colours in idol. The Ganges was polluted by Fe, Cu, Mn, Zn

Table-4: Heavy metals concentration (mg L^{-1}) in Indian rivers

Heavy metals	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Cd	Co	Hg	Source of pollution	Reference
Permissible limit for drinking water	**0.3** **-**	**0.5** **-**	**1.5** **0.05**	**-** **-**	**15** **5**	**0.05** **-**	**0.1** **0.10**	**0.01** **0.01**	**-** **-**	**0.001** **0.001**	**-**	**BIS (1991)** **WHO (1996)**
Surface water tolerance limit	**50**	**-**	**1.5**	**-**	**15**	**0.05**	**0.1**	**0.01**	**-**	**-**	**-**	**BIS (1982)**
Ganges river	0.7275	0.204	0.9475	0.628	0.3765	0.311	0.029	0.13	-	0.367	Domestic, industrial and pilgrim activities	Chaturvedi et al. (2006) and Sarkar et al. (2007)
Adyar river	-	-	-	-	0.0058	-	0.0003	0.00001	-	-	Domestic & industrial waste	Gowri et al. (2008)
Yamuna river	0.805	0.28	0.135	1.06	0.085	0.1	0.235	0.185	0.17	-	Industrial waste	Rawat et al. (2003)
Cooum river	-	-	-	-	0.0058	-	0.0004	0.00002	-	-	Domestic & industrial waste	Gowri et al. (2008)
Gomti river	0.071	0.0037	traces	0.013	0.019	0.0025	0.029	traces	-	-	Domestic & industrial waste	Singh et al. (2005)
Varaga river	1.84	-	-	-	-	-	-	-	-	-	Domestic waste	Shanthi et al. (2006)
Godavari river	0.223	0.199	2.4195	-	-	1.021	-	-	-	-	Domestic and commercial sources	Bansode et al. (2006) and Khan et al. (2006)
Hindon river	0.003	0.001	0.001	0.004	0.0008	0.002	0.01	0.0005	-	-	Domestic & industrial waste	Jain and Sharma (2001)
Chopan river	0.192	-	traces	-	0.033	-	traces	-	-	-	Fertilizer industry	Rai & Shrivastava (2006)
Kasardi river	14.66	-	48.32	14.46	23.11	26.71	38.21	24.51	-	-	-	Lokhande et al. (2011)
Meenachil river	1.25	0.286	0.120	-	0.082	-	0.432	0.084	-	-	-	Nair et al. (2011)

Table-5: Heavy metals concentration (mg L^{-1}) in Indian lakes, reservoirs and other ecosystems

Heavy metals	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Cd	Co	Source of Pollution	References
Permissible limit for drinking water	**0.3** **-**	**0.5** **-**	**1.5** **0.05**	**-** **-**	**15** **5**	**0.05** **-**	**0.1** **0.10**	**0.01** **0.01**	**-** **-**	**-** **-**	**BIS (1991)** **WHO (1996)**
Surface water tolerance limit	**50**	**-**	**1.5**	**-**	**15**	**0.05**	**0.1**	**0.01**	**-**	**-**	**BIS (1982)**
Bellandur lake	1.041	-	0.0165	0.00678	0.146	0.0115	0.0095	0.00175	-	Sewage waste	Lokeshwari and Chandrappa (2006)
Lalbagh tank	0.924	-	0.006	0.002	0.081	0.002	0.003	0.0001	-	Sewage waste	Lokeshwari and Chandrappa (2006)
Nal Sarovar lake	-	-	9.42	12.90	94.03	-	4.87	0.34	17.58	Sewage & agricultural run-off	Kumar et al. (2006)
Upper lake	-	-	0.0217	-	-	0.0142	0.0215	-	-	Waste of medical, domestic and pilgrim activities	Magarde et al. (2006)
Shahpura lake	0.2635	0.1125	0.0062	0.0385	0.019	0.0295	0.0235	-	0.049	Sewage waste	Shrivastava et al. (2003)
Puliathengal, Vanapadi and Thandalam lakes	-	-	0.095	0.036	3.760	0.247	0.467	0.051	-	Industrial waste	Gowd and Govil (2008)
Madivala lake	-	-	-	0.0028	-	0.0012	0.0029	0.002	-	Sewage & agricultural run-off	Begum et al. (2009)
Karanja reservoir	0.5854	0.2252	0.2108	0.7777	0.2103	-	1.1030	-	-	Domestic & agricultural run-off	Majagi et al. (2008)
Kanewal reservoir	-	-	4.84	3.88	201.16	-	6.27	1.81	0.47	Sewage and agricultural run-off	Kumar et al. (2008)
Keoladeo wetland	3.9	0.08	0.01	0.02	0.11	0.02	0.04	-	-	Mainly from agricultural run-off	Prusty et al. (2007)
Bheris pond	3.1	2.6	0.62	-	6.1	0.96	0.46	-	-	Domestic & industrial waste	Chatterjee et al. (2006)

and Pb and severely polluted by Hg as reported by several authors (Chaturvedi and Pandey, 2006; Sarkar *et al*., 2007).

Yamuna river system: River Yamuna is the major tributary of the river Ganga. Delhi (one of the most polluted cities in the world) is situated on the bank of river Yamuna, having the largest clusters of small-scale industries (0.12 million industrial unit) in India. Wazirabad and Okhla barrage in Delhi (about 22 km stretch of the river Yamuna) is only 2% of its catchment area, but it contributes about 80% of the river's total pollution load. Delhi disposes untreated municipal wastewater, approximately 2270 million litres per day into the Yamuna, of which approximately 300 million litres per day are from the industrial sector. So this stretch of the river Yamuna was highly polluted, having Fe, Mn, Cu, Zn, Ni, Cr, Co, Cd and Pb in 0.62-0.99, 0.24-0.32, 0.12-0.15, 0.05-0.12, 1.06, 0.09-0.11, 0.12-0.22, 0.17-0.2 and 0.11-0.36 mg L^{-1} amount, respectively (Rawat *et al*., 2003) (Table-4). Yamuna river was severely polluted by Fe, Cr, Pb and Cd due to battery-based units, anthropogenic inputs of Cd and effluents of pulp and paper industries into the river Yamuna.

Gomti river system: The Gomti is another major tributary of the Ganges river. The average flow of the river varies between 500 million litres per day in summer and 55,000 million litres per day during the monsoon at Lucknow only (Singh *et al.,* 2005). The occurrence of heavy metals in Gomti river is due to the discharge of industrial effluents, untreated sewage, municipal water and agrochemical runoff from the nearby cities and villages directly into the river. In this river system the metals were in the range of Cr 0.0013-0.0057, Fe 0.034-0.117, Mn 0.0013-0.0053, Ni 0.009-0.017, Pb 0.019-0.039 and Zn 0.011-0.032 mg L^{-1} (Table-4), while Cu and Cd were in negligible amount (Singh *et al.,* 2005), but from Neemsar to Jaunpur (about 500 km. long stretch) the Cd and Cu was also present with other metals in the range of 0.001-0.005, 0.0013-0.0043, 0.0015-0.0688, 0.0791-0.3190, 0.0038-0.0973, 0.0066-0.011, 0.0158-0.0276 and 0.0144-0.0298 mg L^{-1} for Cd, Cu, Cr, Fe, Mn, Ni, Pb and Zn, respectively (Singh *et al*., 2005).

Hindon river system: River Hindon is one of the important rivers in western Uttar Pradesh. It is a tributary of the river Yamuna having a basin area of about 7000 sq km. Municipal waste of Saharanpur, Muzaffarnagar and Ghaziabad districts and industrial effluents of sugar, pulp and paper, distilleries and other miscellaneous industries are the main source of heavy metal pollution, which enters into the river system through tributaries as well as direct outfalls. The extent of heavy metal pollution in this river were Fe 0.003, Mn 0.001, Cu 0.001, Ni 0.004, Zn 0.0008, Cr 0.002, Pb 0.01 and Cd 0.0005 mg L^{-1} (Jain and Sharma, 2001) (Table -4).

Godavari river system: This river is also known as the 'Ganga of the South'. It is 1465 km long with a catchment area of about 312812 sq km. On the east coast, the delta of Godavari is one of the country's main rice-growing areas. It is also one of the important water sources to people for different purposes in Nasik. It is surrounded by human habitations and prone to heavy metal pollution from the direct dumping of domestic and commercial pollutants in this system. The concentrations of heavy metal in the Godavari river were Cu 1.755-3.640, Cr 0.473-1.630 (Khan *et al*., 2006) and Fe 0.1-0.25 and Mn 0.1-0.35 mg L^{-1} (Bansode *et al*., 2006) (Table-4).

Cauvery river: The Cauvery is one of the major rivers of India, originating from Talakaveri of Karnataka. It has approximately 72000 sq km basin area. The river water is used for irrigation, human consumption and the generation of electricity. In Mandya district sugar factories, jaggery producing units, milk product producing factory, edible oil producing factory, BPL battery factory and several small scale distilleries units were discharging their effluents into the river. So this stretch of the river was polluted by heavy metals. Begum and Harikrishna (2008) reported that concentrations of Fe, Mn, Zn, Cu, Cr, Cd, Ni and Pb were 2.145, 0.49, 0.037, 0.857, 0.105, 0.233, 0.15 and 0.2 mg L^{-1} respectively.

Cooum river system: The Cooum river originates from the surplus water of the Cooum tank and runs from west to east. The catchment area of this river is about 290 sq km and the length is about 65 km. Approximately 80 million litres of domestic sewage and 0.4 million litres of industrial effluents are allowed to flow into this river per day (Nammalwar and Pakshirajan, 1995). According to Gowri *et al*. (2008) Cooum river transported 0.003-0.021 kg of Cd, 0.02-0.44 kg of Pb and 1.36-3.87 kg of Zn per day.

Adyar river system: Adyar river is a small river having 860 sq km catchment area and 42 km length. About 58 drain outlets of the Chennai city bring raw sewage and sullage into this river. About 8.1 million litres of domestic sewage and 0.775 million litres of industrial effluents which contains the heavy metals are allowed to flow into this river per day (Nammalwar and Pakshirajan, 1995). This river transported 0.004-0.09 kg of Cd, 0.15-1.29 kg of Pb and 3.03-17.58 kg of Zn per day (Gowri *et al*., 2008).

Kasardi river: The Kasardi river receives heavy pollution load from nearby Taloja industrial area, which is one of the most rapidly developing and heavily polluted industrial belts of Mumbai. The industrial area is consisting of about 600 large and medium scale industries i.e. engineering units, steel processing industries, chemical units, paints, pharmaceutical units, textile industries etc. The effluent discharge from these industries, including both treated and untreated amounts is about 28,750m^3/day (approximately 64% of the total industrial effluents). Except for a few major industries, the medium and the small scale industries discharge their effluents into the river. Also atmospheric fallout from the chimneys and vehicle exhausts reach the river after washout. Lokhande *et al*. (2011) reported 8.0 - 27.5 mg L^{-1} of Cr, 7.1 - 26.7 of Cd, 3.9 - 18.9 of Ni, 8.3 - 21.5 of Zn, 6.3 - 77.0 of Cu, 5.2 - 46.3 of Pb and 6.0 - 19.3 mg L^{-1} of Fe in river's water which showed that the river has become heavily polluted by metals and creating health hazards for local population and also disturbing the aquatic life of the river.

Table-6: Standards for industrial effluents discharge into surface waters

Parameters	Maximum Tolerance limit (mg L^{-1})
Arsenic (As)	0.2
Cadmium (Cd)	2.0
Chromium (Cr^{6+})	0.1
Total chromium (Cr)	2.0
Copper (Cu)	3.0
Lead (Pb)	0.1
Mercury (Hg)	0.01
Nickel (Ni)	3.0
Zinc (Zn)	5.0
Manganese (Mn)	2.0
Iron (Fe)	3.0
Selenium (Se)	0.05
Silver (Ag)	0.1
Vanadium	0.2
Cyanide (CN)	0.2
Fluoride (F)	2.0

Source: Environmental Protection Rules (1989)

Meenachil river: Meenachil river is one of the important river of Kerala. It is also known as Kavanar splits into number of tributaries before ending into Vembanad lake. The total length of the river is 78 km and its catchment area is about 1272 sq.km. It has 38 tributaries including major and minor ones. According to Nair *et al*. (2011) the water of the river had 0.03 – 0.35 mg L^{-1} of Cu, 0.3 - 2.53 of Fe, 0.09 - 2.83 of Mn, ND - 0.86 of Pb, ND - 0.18 of Zn and 0.04 - 0.13mg L^{-1} of Cd. The data revealed that the concentration of metals is very high. Since most of the metal ions are extremely toxic, the consumption of this river water may cause serious health hazard.

Lake Ecosystem

Lakes have a complex and fragile ecosystem and they do not have self-cleaning ability. Due to the rapid urbanization and industrialization with improper environmental planning their discharge is often leading into lakes and therefore they are accumulating pollutants.

Upper lake: The Upper lake of Bhopal is one of the most important natural resources, having 31 sq km catchment area. It is a source of potable water in city. Till the middle of the last century, the water of Upper lake was good and was not required for any treatment but due to the various anthropogenic and religious activities it has become

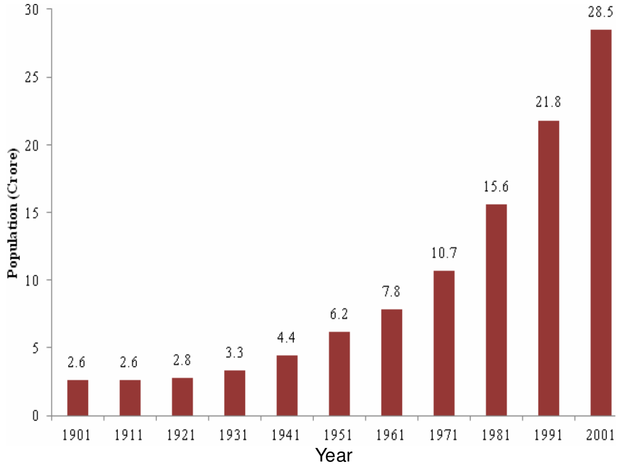

Fig. 1: Increase in urban population

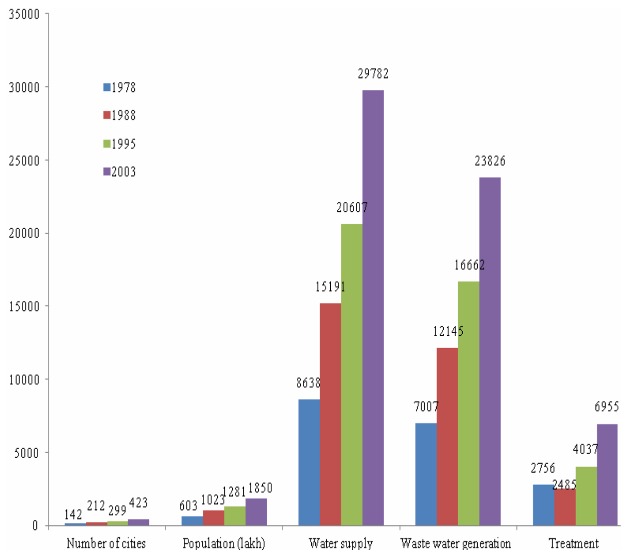

Fig. 2: Water supply, wastewater generation and treatment facilities in class I cities of India

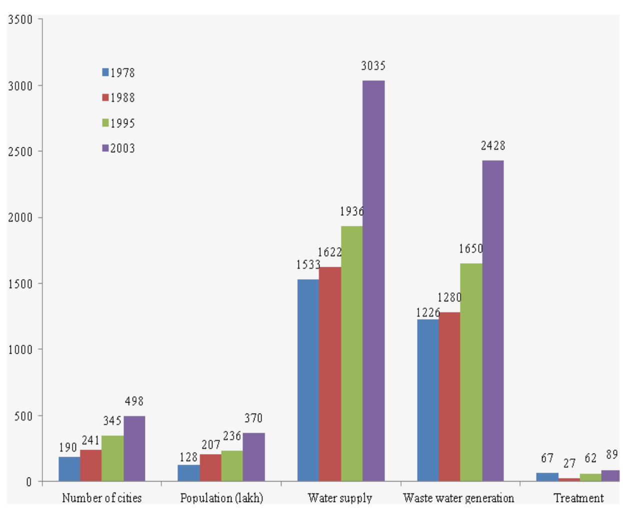

Fig. 3: Water supply, wastewater generation and treatment facilities in class II towns of India

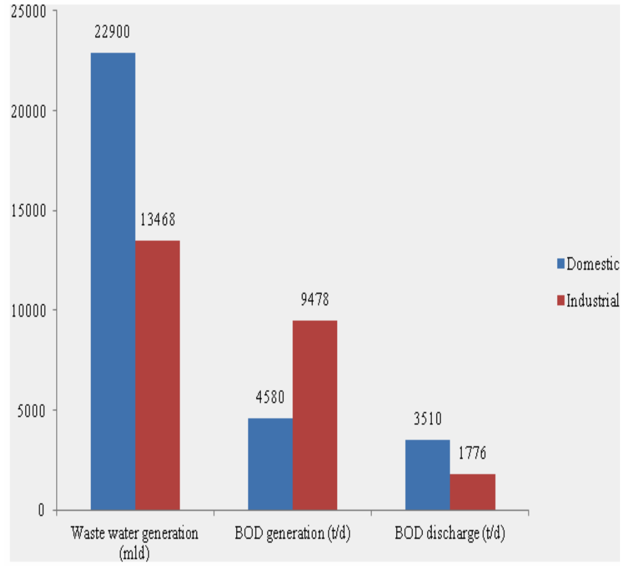

Fig. 4: BOD load generation and discharge from domestic and industrial sectors

polluted. According to Magarde *et al.* (2006) the water of Upper lake was pollution free by Cu, Cr, Pb and Hg (Table-5) but at the time of idol immersion it becomes extremely polluted having maximum concentration of Cr 0.09 mg L^{-1} and Pb 0.512 mg L^{-1} at Prempura ghat (Vyas *et al.*, 2008). Malik *et al.* (2010) reported that heavy metal content of water has increased by manifold, but was within the maximum permissible limit of BIS (1991).

Shahpura lake: Shahpura lake of Bhopal covers an area of 2.6 sq km and a catchment area of 8.3 sq km. It receives a huge amount of pollution load, which is discharged by surrounding areas. Approximately 110 tonnes per day solid waste is generated within the catchments and 9.6 liters per day of sewage enters into this lake (Shrivastava *et al.*, 2003). Concentration of heavy metals was higher ranged from 0.16-1.4, 0.1-2.9, 0-0.11 and 0.01-0.19 mg L^{-1} for Cu, Pb, Cd and Mn, respectively (Dixit and Tiwari, 2008). This lake is also used for fishing purposes, so there are maximum chances of heavy metals accumulation in the food chain through the process of biomagnification.

Hussainsagar lake: The lake is the heart of Hyderabad and Secunderabad cities, constructed across Kalvaleru stream. It is 3.2 km long and 2.8 km wide with a surface area of 4.46 sq km. It receives domestic and industrial wastewater. It also receives a huge amount of heavy metal due to the idol immersion activities, which are made up of plaster of paris, clay and paints such as varnish and watercolors. Study has shown that Hussainsagar lake is polluted by Fe and heavily to chronically polluted by Pb and Hg, which also increased after immersion of idols (Reddy and Kumar, 2001).

Bellandur lake: Bellandur lake of Bangalore is 130 years old and spreads across an area of 892 acres near the Bellandur village. The water of Bellandur lake is being used for farming purposes. For the last few decades, the treated, partially treated and untreated wastewater especially sewage effluents from residential areas near the Bangalore international airport is directly discharging into the lake through the main drain. The extent of heavy metal pollution in Bellandur lake were Fe 0.777-1.305, Cu 0.016-0.017, Ni 0.0065-0.007, Zn 0.113-0.179, Cr 0.005-0.018, Pb 0.006-0.013 and Cd 0.002-0.0023 mg L^{-1} (Lokeshwari and Chandrappa, 2006) (Table 5). Heavy metal contamination is also transferred from water to soil and vegetation through agricultural practices. There is a need to control the dumping of sewage into the lake.

Nal Sarovar lake: Nal Sarovar lake is a proposed Ramsar site of Gujarat. The lake has a great importance, because human populations of the twelve surrounding villages depend mostly on the food and fish produced from the lake. The lake has more than 300 islets and occupies 120 sq km areas. It receives household sewage and agricultural run-off from village pockets through Brahmini and Bhogavo rivers. Kumar *et al*. (2006) found the heavy metal concentration in this lake for Cu 9.42, Ni 12.90, Zn 94.03, Pb 4.87, Cd 0.34 and Co 17.58 mg L^{-1}.

Kodaikkanal lake: The Kodaikkanal lake of Tamil Nadu is a popular tourist hill-resort having an area of about 24 hectares. According to Mody (2001) this lake is contaminated with Hg originating from thermometer making factory. It is also contaminated from a huge inflow of domestic sewage. Karunasagar *et al*. (2006) recorded 356.36-465.54 µg Hg L^{-1} in the water of Kodaikkanal lake (Table-5), which was <300 µ gL^{-1} in earlier study URS Dames and Moore (2002).

Lonar lake: Lonar lake of Maharashtra is one of the soda lake (having pH 10) like the Mono, Owens (USA), Karakul (Russia) and Magadi (Kenya) lake. It has a unique ecological system being the only meteoritic crator in basaltic rock in the world. It is a circular depression having 1830 m across and nearly 150 m deep. Water of the lake was not contaminated with heavy metals Surakasi *et al.* (2007) probably due to the alkaline nature of the lake.

Nainital lake: Nainital lake (or Naini lake) is a eutrophic lake and the sole source of drinking water for the local people and tourists. The lake is spread over an area of 4.65 sq km having a catchment area of about 4.9 sq km. The annual rainfall in the catchment is 2200 to 2500 mm. The lake receives the toxic metals through high soil erosion, illegal construction activies and tourism development, heavy litter inputs, automobile exhaust and domestic discharge, but the domestic waste and municipal sewage are the major sources of pollution in the lake. Ali *et al*. (1999) reported that the lake had 0.02-0.08 mg L^{-1} of Cu, 0.43-1.04 of Fe, 0.02-0.39 of Mn, 0.27-0.53 of Ni, 0.15-0.48 of Pb and 0.05-0.13 mg L^{-1} of Zn.

Puliathengal, Vanapadi and Thandalam lakes: These are important lakes of Chennai and highly polluted near the Ranipet industrial area, which is one of the biggest tanned leather exporting centers. Central Pollution Control Board of India has declared it as a 'Chronic Polluted Area'. There are 240 tannery industries in this area along with ceramic, refractory, boiler auxiliaries' plant and chromium chemicals. These industries are located in Palar river basin and discharging their effluents into Puliathengal, Vanapadi and Thandalam lakes. So the surface water of the Ranipet area is extremely contaminated with heavy metals due to the industrial effluents. A very high concentration of the metals 0.051 for Cd, 0.247 for Cr, 0.095 for Cu, 0.036 for Ni, 0.467 for Pb and 3.760 mg L^{-1} for Zn was found in this area Gowd and Govil (2008) (Table-5) and are hazardous for health.

Madivala lake: Madivala lake of Karnataka covers 114.3 hectare area. It receives sewage and storm water from surroundings areas specially untreated sewage from Bommanahally CMC area. It also received agricultural runoff. Begum *et al*. (2009) reported 0.0002-0.0025, 0.001-0.0056, 0.001-0.0049 of and 0.0006-0.0072 mg L^{-1} level of Cr, Ni, Cd and Pb, respectively. All the metals were lower in concentration and are not toxic at all however; the lake is dirty, and full of hyacinth weeds. Owing to hydrographic, morphometric and drainage conditions of the area, the lake was strongly predisposed to environmental degradation due to the presence of waste water especially from domestic and municipal sewage.

Other ecosystems

Other aquatic ecosystems, such as, reservoirs, ponds and tanks are also important ecosystems for fresh water resources and spread all over the country, which have varying degrees of environmental degradation. India has 19370 reservoirs with 31533.66 sq km area of which large (56) reservoirs has 11402.68 sq km, medium (180) reservoirs has 5275.41 sq km and small (19134) reservoirs has 14855.57 sq km (Sugunan, 1995). These are largely spread in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orrisa, Rajasthan and Uttar Pradesh while, Andhra Pradesh, Karnataka, Tamil Nadu, West Bengal, Rajasthan and Uttar Pradesh are rich in tanks and ponds having 62% of the total area of these ecosystems (2.9×10^{-2} m. km ^{2}). The presence of heavy metals in these systems is causing chain effects and the end of this chain is human being. Several studies were conducted on the heavy metals load in Indian rivers and lakes, but only a very few studies have been done in other ecosystems.

Kanewal reservoir: It is an internationally important reservoir of Gujarat, listed in Asian Directory of Wetlands and designated as a "Wetland of National Importance". The area of Kanewal reservoir is 15 sq km. It is a good source of food and fishing for the communities of surrounding eight villages. The reservoir does not have any industrial effluent but it carries sewage effluent and agricultural run-off from the nearby village pockets from all directions and hence fed with pollutants. The study of Kumar *et al*. (2008) showed that water of the reservoir had a high amount of heavy metals with a mean range of 1.81, 0.47, 4.84, 3.88, 6.27 and 201.16 mg L^{-1} for Cd, Co, Cu, Ni, Pb and Zn, respectively (Table-5).

Karanja reservoir: The Karanja reservoir is a perennial water body of Bidar district of Karnataka and located at Byalhalli village. The total catchment area of the reservoir is 625.75 sq km and the maximum depth of the reservoir was 10 m. There are no drainage systems in the villages around this reservoir. So the effluent was directly dumped into the reservoir and decreased the water quality. According to Majagi *et al.* (2008) the reservoir is also fed with heavy metals and was at alarming level for Pb and Fe (1.1030 and 0.5854, respectively).

Lalbagh tank: Lalbagh tank of Bangalore is situated in the south of Bangalore, covering an area of 0.13 sq km inside the famous Lalgabh botanical garden. It is maintained by the Department of Horticulture, Government of Karnataka. This tank has been spoilt due to the flow of untreated sewage water from the surrounding areas. The concentrations of heavy metals in Lalbagh tank were Fe 0.226-2.170, Cu BDL-0.039, Ni BDL-0.008, Zn 0.006-0.278, Cr BDL-0.041, Pb-0.030 and Cd BDL-0.002 mg L^{-1} (Lokeshwari and Chandrappa, 2006) (Table-5).

Bheris pond: Bheris pond is a wastewater- fed pond of East Calcutta wetland, which spread over 125 sq km. It receives the industrial effluents (from 6000 large and small-scale industries) and wastewater from the Calcutta city. So the huge amount of composite, heavy metals contaminated effluents has flown through a web of canals into the wetlands, which are also utilized by local farmers in Pisciculture. Chatterjee *et al.* (2006) observed the heavy metal concentration in Bheris pond for Fe 3.1, Mn 2.6, Cu 0.62, Zn 6.1, Cr 0.96 and Pb 0.46 mg L^{-1} (Table 5). Except Zn and Cu, all the metals had high level. So, there is easy likelihood of the food chain getting contaminated by heavy metals and consequently affecting human health.

Keoladeo wetland: Keoladeo National Park of Bharatpur is a world Heritage and Ramsar site of India. It encompasses 29 sq km areas. Heavy metals in the water of wetland had the mean range of 3.9, 0.08, 0.02, 0.01, 0.02, 0.04 and 0.11 mg L^{-1} for Fe, Mn, Cr, Cu, Ni, Pb and Zn, respectively (Prusty *et al*., 2007) (Table 5) and safe for various purposes.

Water is a vital resource for living beings. In India the per capita surface water availability is projected to reduce to 495 and 421 m^3 in the years 2025 and 2050, respectively. During recent years the pollution of heavy metals in surface water bodies has attracted the attention of the scientific community, because aquatic ecosystem is the ultimate recipient of almost all substances including heavy metals. In surface water bodies heavy metals pose serious threat because of the toxicity, long persistence, bioaccumulation and biomagnification in the food chain. Heavy metal pollution in water bodies may result from various sources, namely, natural, agricultural, domestic, industrial and other anthropogenic sources. Domestic and industrial sources are most responsible to decrease the quality of aquatic ecosystem. In terms of pollution load generation from domestic and industrial sources, the industrial source has less BOD level than the domestic source. Several studies have shown that the concentration of heavy metals in aquatic ecosystem is principally controlled by pH, concentration and type of ligands and chelating agents, oxidation-state of the mineral components and the redox environment of the system.

The quality of surface water resources is deteriorating everywhere. Sewage and industrial effluents are the main source of pollution in surface water bodies of India. Part of pollution also comes from the agricultural and pilgrim activities. The major rivers of India, i.e., Ganges, Yamuna and Godavari are depleting more than others. Anthropogenic and other inputs are very high in holi river of India (Ganges), which has reached at an alarming level of pollution. River Yamuna is also under stress due to the dumping of industrial effluents from Delhi. Kasardi river has also come under threat due to the dumping of industrial effluents. Most of the Indian lakes are polluted by pilgrim activities, while some others are also polluted by sewage and industrial effluents. Puliathengal, Vanapadi and Thandalam lakes are highly polluted due to the nearness of a toxic hotspot of the country, and public health is a matter of grave concern at this site. Kodaikkanal lake is heavily polluted by Hg due to the industrial wastes. So there is a prior need of remediation processes near the factory site. On the other hand Naini lake is mainly polluted by domestic and municipal sewage and are highly polluted by Fe, Ni and Pb. Hence there is a maximum possibility of heavy metal toxicity into the food chain which can cause serious health hazards for local population, if remedial measures are not taken immediately. Other ecosystems have also a concern for heavy metal pollution. Heavy metal content in Kanewal reservoir has reached at a critical condition and there is a maximum chance of decreasing the human health by the process of bioaccumulation and biomagnification over time. The level of Pb and Fe in Karanja reservoir was also at alarming level and a cause of concern.

There is a need for increasing the availability of water and reducing its demand. For maintaining the quality of freshwater, water quality management strategies are required to be evolved and implemented, while, in polluted areas recycling and remedial techniques are the effective tools to minimize the pollution.

Government Efforts

Government of India has taken several initiatives to control the pollution of aquatic ecosystems and restore to natural resources.

Standard limit for industrial waste discharge: Government has declared a standard limit for industrial effluents discharging into surface water bodies (Table-6).

Legal provisions: Government has also passed several laws and rules to control the pollution. Some of them are:

The Factories Act (1948); The River Board Act (1956); The Insecticides Act (1968); The Wildlife (Protection) Act (1972); The Water (Prevention & Control of Pollution) Act (1974); The Water (Prevention and Control of Pollution) Rules (1975); The Water (Prevention and Control of Pollution) CESS Rules (1978); The Environment (Protection) Act (1986), The Indian Fisheries Act (1987) and The National Environment Policy (NEP; 2006). Some amendments have also made according to the requirements.

Monitoring program: A regular monitoring program is also being done in all over the country by Central and State Pollution Control Boards of the Govt. to check the water quality of Indian rivers and lakes.

Conservation plan/scheme: Ministry of Environment and Forest of India has started a National River Conservation Plan (NRCP) to improve the water quality of major rivers. The Ministry has also started National Lakes Conservation Plan (NLCP) to restore and conserve the urban and semi-urban lakes of the country.

Recommendations

The following recommendations are put forward for effective water quality management in India:

1. **Protection of water resources:** Treatment of domestic and municipal wastes and industrial effluents before they are discharged into surface water bodies, and management of agricultural run- off should be initiated.
2. **Proper Implementation of laws and rules:** Govt. has made several laws and rules to control the water pollution in aquatic ecosystem but there is a lacking in implementation. Strict follow-up is necessary.
3. **Efficient water use:** A system of incentive and disincentives should be adopted to encourage efficient water use.
4. **Water safety:** BIS/WHO guidelines should be adopted and effective methods should be designed in providing adequate safe water to people.
5. **Capacity building:** Facilities should be created to edify and train personnel in water management skills. Mechanism of laboratory inspection and accreditation must be introduced for ensuring the quality of data generated.
6. **Public awareness and participation:** The public should be made aware of the dangers of pollution especially in rural/slum areas. Academia, NGO's and local communities should be involved to aware the people so that they can also participate in the management and conservation of water resources.
7. **Water security:** Water security should be achieved by harvesting of rainwater and recycling of municipal waste water.
8. **Remediation techniques:** Remediation techniques can be an effective tool for the conservation of surface water bodies. Amongst them, phytoremediation is the best technique that does not required much efforts and money also.

References

Ali, M.B., Tripathi, R.D., Rai, U.N., Pal, A. and Singh, S.P.: Physico-chemical characteristics and pollution level of lake Nainital (U.P., India): Role of macrophytes and phytoplankton in biomonitoring and phytoremediation of toxic metal ions. *Chemosphere*, **39**: 2171-2182 (1999).

Bansode, A.S., Sontakke, N.M., Munde, D.R., Sirsat, S.B., Patthebahadur, M.M. and Raut, M.: Impact of city sewage discharge and anthropogenic activity on water quality at different ghats of river Godavari at Nanded, Maharashtra. *Curr. World Environ.*, **1**: 165 - 168 (2006).

Begum, A. and Harikrishna: Study on the quality of water in some streams of Cauvery river. *E- J. Chem.*, **5**: 377-384 (2008).

Begum, A., HariKrishna, S. and Khan, I.: Analysis of Heavy metals in water, sediments and fish samples of Madivala lake of Bangalore, Karnataka. Int. J. Chemtech. Res., **1**: 245-249 (2009).

BIS: Drinking water specification IS: 10500. Bureau of Indian Standard, New Delhi, India (1991).

Brandon, C. and Homman, K.: The cost of inaction: Valuing the economy-wide cost of environmental degradation in India. Asia Environment Division, World Bank, 17 October (1995).

Bruins, M.R., Kapil, S. and Oehme, F.W.: Microbial resistance to metals in the environment. *Ecotox. Environ. Safe.,* **45**: 198-207 (2000).

Chatterjee, S., Chattopadhyay, B. and Mukhopadhyay, S.K.: Trace metal distribution in tissues of Cichlids (*Oreochromis niloticus* and *O. mossambicus*) collected from wastewater-fed fishponds in east Calcutta wetlands, a. ramsar site. *Acta Ichthyol. Piscat.,* **36**: 119-125 (2006).

Chaturvedi, J. and Pandey, N.K.: Physico-chemical analysis of river Ganga at Vindhyachal ghat. *Curr. World Environ.*, **1**: 177-179 (2006).

Cheng, S.: Heavy metals and phyto-remediation. *Environ. Sci. Pollut. Res.*, **10**: 335-340 (2003).

CPCB: Water quality status and statistics 1996 & 1997. Central Pollution Control Board, New Delhi (1999).

Dixit, S. and Tiwari, S.: Impact assessment of heavy metal pollution of Shahpura lake, Bhopal, India. *Int. J. Environ. Res.*, **2**: 37-42 (2008).

Ministry of Environment and Forests: Environment Protection Rules. Govt. of India, New Delhi, EPR (1989).

Gowd, S.S. and Govil, P.K.: Distribution of heavy metals in surface water of Ranipet industrial area in Tamil Nadu, India. *Environ. Monit. Assess.*, **136**: 197-207 (2008).

Gowri, V.S., Ramachandran, S.,Ramesh, R., Pramiladevi, I.R.R. and Krishnaveni, K. Application of GIS in the study of mass transport of pollutants by Adyar and Cooum rivers in Chennai, Tamilnadu. *Environ. Monit. Assess.*, **138**: 41-49 (2008).

Ikem, A. and Egiebor, Nosa O.: Assessment of trace elements in canned fishes (Mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama (United States of America). *J. Food Compos. Anal.*, **18**: 771-787 (2005).

Integrated water resources development- A plan for action: Report of The National Commission for Integrated Water Resources Development, Ministry of Water Resources, New Delhi (1999).

Jain, C.K. and Shrma, M.K.: Distribution of trace metals in the Hindon river system, India. *J. Hydrol.*, **253**: 81-90 (2001).

Jain, C.K.: Metal fractionation study on bed sediments of river Yamuna, India. *Water Res.*, **38**: 569-578 (2004).

Karunasagar, D., Balarama Krishna, M.V., Anjaneyulu, Y. and Arunachalam, J.: Studies of mercury pollution in a lake due to a thermometer factory situated in a tourist resort: Kodaikkanal, India. *Environ. Pollut.*, **143**: 153-158 (2006).

Kathuria, V., Gundimeda, H.: Industrial pollution control: need for flexibility. In K. Parikh, J. Marikh (Eds.) India Development Report 2001, IGIDR (2001).

Khan, A.A., Bhatnagar, B. and Saxena, R.: An introduction of Bhopal Lakes. In S.K. Kulshreshtha (Eds.), Proc. Nat. Symp. Present, Past and Future of Bhopal Lakes. Department of Zoology, Bhopal (1988).

Khan, A.K., Ansari, N.T., Hashmi, S. and Sayyad, N.R. Heavy metal concentrations in surface water from Godavari river near Aurangabad, Maharashtra. *J. Aquat. Biol.*, **21**: 119-122 (2006).

Khan, Y.S.A., Hussain, M.S. and Hossain, S.M.G. and Hallimuzzaman, A.H.M.: An environmental assessment of trace metals in Ganga-Brahmputra-Meghna estuary. *J. Rem. Sens. Environ.*, **2**: 103-117 (1998).

Khwaja, A.R., Singh, R. and Tandon, S.N.: Monitoring of Ganga water and sediments vis-à-vis tannery pollution at Kanpur (India): A case study. *Environ. Monit. Assess.*, **68**: 19-35 (2001).

Kumar, J.I., Soni, H. and Kumar, R.N.: Evaluation of biomonitoring approach to study lake contamination by accumulation of trace elements in selected aquatic macrophytes: A case study of Kanewal community reserve, Gujarat, India. *Appl. Ecol. Environ. Res.*, **6**: 65-76 (2008).

Kumar, J.I.N., Soni, H. and Kumar, R.N.: Biomonitoring of selected freshwater macrophytes to assess lake trace element contamination: a case study of Nal Sarovar Bird Sanctuary, Gujarat, India. *J. Limnol.*, **65**: 9-16 (2006).

Lasat, M.M.: Phyto-extraction of toxic metals: A review of biological mechanisms. *J. Environ. Qual.*, **31**: 109-120 (2002).

Lokeshwari H .and Chandrappa, G.T.: Heavy metals content in water, water hyacinth and sediment of Lalbagh tank, Bangalore (India). *J. Environ. Sci. Eng.*, **48**: 183-188 (2006).

Lokeshwari, H. and Chandrappa, G.T.: Impact of heavy metal contamination of Bellandur lake on soil and cultivated vegetation. *Curr. Sci.*, **91**: 622-627 (2006).

Lokhande, R. S., Singare, P.U. and Pimple, D.S.: Pollution in water of Kasardi river flowing along Taloja industrial area of Mumbai, India. World Environ., **1**: 6-13. (2011).

Magarde, V., Iqbal, S.A. and Malik, S.: Pollution parameters including toxic and heavy metals contamination studies of Upper lake of Bhopal, India. *Curr. World Environ.*, **1**, 173-175 (2006).

Majagi, S.H., Vijaykumar, K. and Vasanthkaumar, B.: Concentration of heavy metals in Karanja reservoir, Bidar district, Karnataka, India. *Environ. Monit. Assess.*, **138**, 273-279 (2008).

Malik, N., Biswas, A.K., Qureshi, T.A., Borana, K. and Virha, R.: Bioaccumulation of heavy metals in fish tissues of a freshwater lake of Bhopal. *Environ. Monit. Assess.*, **160**: 267-276 (2010).

Maria, A.: The costs of water pollution in India. Revised Version Paper presented at the conference on *Market Development of Water & Waste Technologies through Environmental Economics*, 30^{th}-31^{st} October 2003, Delhi.

Mody, N. Dangerous mercury thermometer factory and waste dump in India has major links to US Company (2001).

Nair, I.V., Singh, K., Arumugam, M. and Clarson, D.: Monitoring of trace metal pollution in Meenachil river at Kottayam, Kerala (India). E- J. Chem., **8**, 257-263 (2011).

Nammalwar, P. and Pakshirajan, P.: Ecotoxicological effects of industrial pollution in the estuarine Grey mullets with reference to aquaculture along the Madras coast. Proc. IV Nat. Symp. "Environment", Anna University, Madrs: 52-56 (1995).

Provisional Population Totals: Census of India 2001, series 1, India, paper 1 (2001).

Prusty, B.A.K., Azeez, P.A. and Jagadeesh, E.P.: Alkali and transition metals in macrophytes of a wetland system. *Bull. Environ. Contam. Toxicol.*, **78**: 405-410 (2007).

Rai, M. and Shrivastava, R.M.: Assessment of water quality near Chopan river, Raghogarh, District Guna, (M.P.). *Curr. World Environ.*, **1**, 213-216 (2006).

Rao, K.L.: India's Water Wealth. Oxford Univ. Press, London, pp. 267 (1979).

Rawat, M., Moturi, M.C.Z. and Subramanian, V.: Inventory compilation and distribution of heavy metals in wastewater from small-scale industrial areas of Delhi, India. *J. Environ. Monit.*, **5**, 906-912 (2003).

Reddy, M.V. and Kumar, A.V.: Effects of Ganesh-idol immersion on some water quality parameters of Hussainsagar lake. *Curr. Sci.*, **81**: 1412-1413 (2001).

Sarkar S.K., Bhattacharya B., Bandhopadhaya G. and Debnath S.: Tropical coastal organisms as qualitative indicators of mercury and organomercury for sustainable use of living resources. *Environ. Dev. Sustainability.*, **1**: 1-13 (1999).

Sarkar, S.K., Saha, M., Takada, H., Bhattacharya, A., Mishra, P. and Bhattacharya, B.: Water quality management in the lower stretch of the river Ganges, east coast of India: an approach through environmental education. *J.Cleaner Prod.*, **15**: 1559-1567 (2007).

Sengupta, A.K.: Wastewater management and reuse for agricultural and aquaculture in India. Proc. CSE Conf. Health Environ., 24-25 March, New Delhi (2006).

Sengupta, B.: Water quality management in India. Paper presented at International conference on India's water economy: law and sustainable development. May (2007).

Shanthi, V.S., Muthumeena, A. Jeyaseeli and Borgia, F.V.J.: Physico-chemical status of Varaga river at Theni district, Tamil Nadu. *J. Aquat. Biol.*, **21**: 123-127 (2006).

Shrivastava, P., Saxena, A. and Swarup, A.: Heavy metal pollution in a sewage-fed lake of Bhopal, (M.P.) India. *Lakes Reservoirs Res. Manage.,* **8**: 1-4 (2003).

Singh, K.P., Mohan, D., Singh, V.K. and Malik, A.: Studies on distribution and fractionation of heavy metals in Gomti river sediments- a tributary of the Ganges, India. *J. Hydrol.*, **312**: 14-27 (2005).

Singh, M., Muller, G. and Singh, I.B. Geogenic distribution and baseline concentration of heavy metals in sediments of the Ganges river, India. *J. Geochem. Explor.*, **80**: 1-17 (2003).

Singh, V.K., Singh, K.P. and Mohan, D.: The status of heavy metals in water and bed sediments of river Gomti- a tributary of the Ganga river, India. *Environ. Monit. Assess.*, **105**: 43-67 (2005).

Sugunan, V.V.: Reservoir Fisheries in India: FAO Fisheries Technical Paper no. 345. Food and Agricultural Organization of the United Nations Rome: pp.413 (1995).

Surakasi, V.P., Wani, A.A., Shouche, Y.S. and Ranade, D.R.: Phylogenetic analysis of methanogenic enrichment cultures obtained from Lonar lake in India: Isolation of *Methanocalculus* sp. and *Methanoculleus* sp. *Microb. Ecol.*, **54**: 697-704 (2007).

URS Dames and Moore: Environmental site assessment and preliminary risk assessment for mercury, Kodaikkanal thermometer factory, Tamil Nadu, 2002, Prepared for Hindustan Lever Limited (HLL).

Vyas A., Bajpai, A. and Verma, N.: Water quality improvement after shifting of idol immersion site: A case study of Upper lake, Bhopal, India. *Environ. Monit. Assess.*, **145**: 437-443 (2008).

WHO: Guidelines for drinking water quality. World Health Organization, Geneva, **1**, pp. 188 (1996).