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Water quality hot spots in Indian rivers

JAKIR HUSSAIN[1] **& IKBAL HUSAIN**[2]

1 National River Water Quality Laboratory, Central Water Commission, New Delhi – 110016, India
drjakirhussain@gmail.com

2 Public Health Engineering Department, Bhilwara – 311001, Rajasthan, India
ikbalhusain@gmail.com

Abstract Deteriorating water quality has become a serious problem in developing countries. Almost 70% of India's surface water resources have become contaminated due to the discharge of untreated sewage and industrial effluents. The CWC and CPCB are monitoring all rivers in 22 basins, monthly, bimonthly or quarterly. The water quality monitoring of major rivers indicates that organic pollution is predominant and almost all the surface water sources are contaminated to some extent by Coliform group bacteria, making their water unfit for human consumption unless disinfected. Specific stretches of the following rivers: Sabarmati, Godavari, Satluj, Yamuna, Cauvery, Ganga, Krishna, Tapi, Mahanadi and Brahmani, are grossly polluted with respect to organic and bacterial pollution. Data reveal that at water quality stations on the Chenab, Jhelum, Ganga, Mahi, Sabarmati, Tapi, Narmada, Bharigathi, Brahmani, Subarnarekha, Mahanadi, Brahmaputra, Cauvery, and Krishna rivers and tributaries, there are high levels of trace and toxic metals.

Key words Indian rivers; water quality; pollution; DO; BOD; coliform; metals; hot spots

INTRODUCTION

India occupies the south-central peninsula of the Asian continent and lies between 8°4′N and 37°6′N latitude and 68°7′E and 97°25′E longitude. It occupies 3.29 million km^2, which is 2.4% of the world's land area. Out of the total annual precipitation including snowfall of 4000 km^3 over the entire land mass, the rainfall during monsoon months (June–September) is of the order of 3000 km^3. It has also been estimated that 700 km^3 is lost immediately to the atmosphere, 2150 km^3 soaks into the ground and 1150 km^3 flows as surface runoff. India is gifted with a river system comprising more than 20 major rivers with several tributaries. Many of these rivers are perennial and some are seasonal. Rivers like the Ganga, the Brahmaputra and the Indus originate from the Himalayas and carry water throughout the year. More than 50% of the water resources of India are located in various tributaries of the Himalayan river system (CWC, 2012a).

Water pollution is a serious problem as almost 70% of India's surface water resources and a growing number of its groundwater reserves have become contaminated. In many cases these sources have been rendered unsafe for human consumption as well as for other activities, such as irrigation and industrial needs. Thus water quality (WQ) decline can, in effect, contribute to water scarcity as it limits the availability of water for both human use and the ecosystem. Water quality assessment and management is thus one of the most important aspects of water management, and has attained significant importance over the years in view of growing concerns and awareness of environmental and health related impacts.

RIVER WATER SYSTEM

India is blessed with many rivers. On the basis of size, the river basins of India can be divided into major, medium and minor river basins. Besides these, some desert rivers flow for a short distance and are lost in the desert. According to the classification, the numbers of major and medium river basins are 12 and 46 respectively, and these contribute nearly 92% of the total runoff in the country. Minor rivers account for about 8% of the total runoff. Of the major rivers, the Ganga–Brahmaputra–Meghna system is the biggest, with a catchment area of about 10 97 588 km^2, more than 43% of the catchment area of all the major rivers within the country. The other major rivers with catchment areas of more than 1 00 000 km^2 are the Indus (321 289 km^2), Godavari (321 812 km^2), Krishna (258 948 km^2) and Mahanadi (141 589 km^2). The catchment area of medium rivers is about 0.25 million km^2. The other rivers with catchment areas >10 000 km^2 are the Palar, including the Cheyyar tributary (17 871 km^2), the Ponnaiyar (14 130 km^2), Baitarni (12 789 km^2)

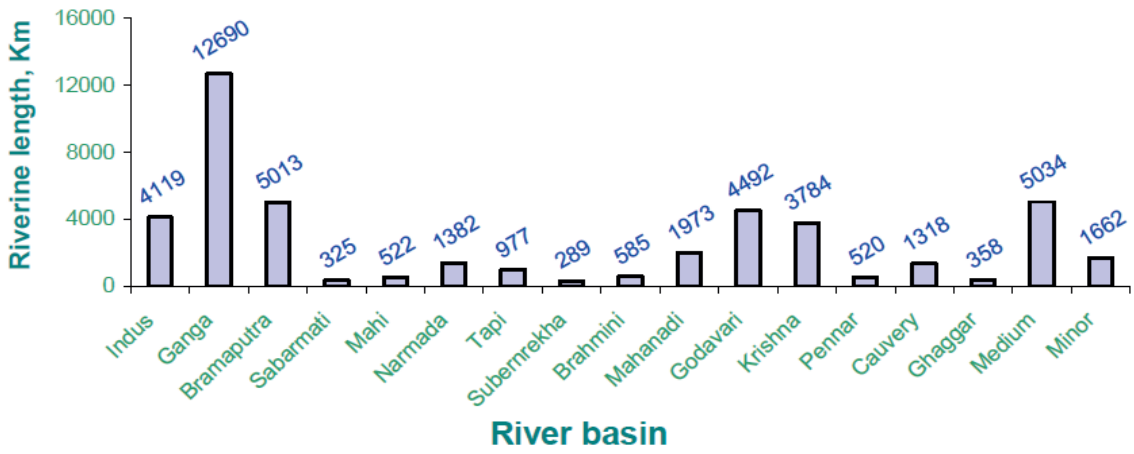

Fig. 1 River basin-wise perennial riverine length.

and the Vamshadhra (10 830 km^2) (CWC, 2012a). Length-wise, the Ganga is the longest river in India, followed by the Godavari, and then the Krishna (Fig. 1).

Not all of the major river basins are perennial. Only four of the 13 major basins include areas of high rainfall, i.e. the Brahmaputra, Ganga, Mahanadi and Brahamani, which have a minimum annual average discharge of 0.47×10^6 m^3 km^{-2}, and they are perennial. Six basins (Krishna, Indus, Godavari, Narmada, Tapi and Subarnarekha) occupy the area of medium rainfall and have annual average discharges greater than 0.26×10^6 m^3 km^{-2}, and the remaining four (Cauvery, Mahi, Sabarmati and Pennar) occupy the area of low rainfall and have annual average discharges between of 0.06 and 0.24×10^6 m^3 km^{-2}. Thus, many of the major river basins also go dry during summer, leaving no available water for dilution of wastewater discharged to them. State-wise perennial riverine length in India is given in Fig. 2.

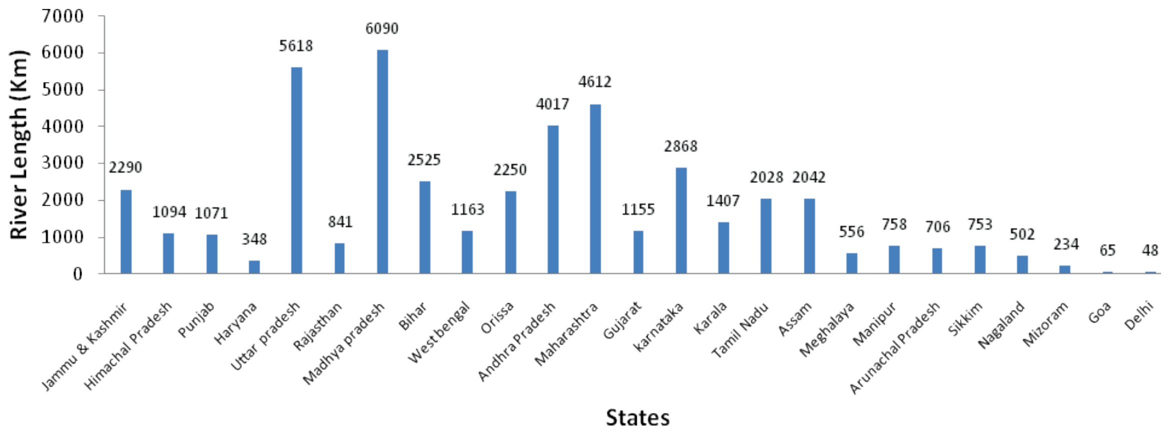

Fig. 2 State-wise perennial riverine length.

RIVER POLLUTION

With increasing population pressure and associated activities, Indian rivers are affected both in terms of water quality and quantity. Each time water is used for some activity, its quality becomes degraded. Unfortunately, the sanctity attached to rivers in the country does not ensure that rivers are kept clean. Flowing water has a significant self-purification capacity. However, after the construction of a barrage or dam, or diversions to the irrigation canal network on a river, the downstream stretches of the river do not receive enough water, in particular during the premonsoon season. As a result the pollutants discharged through drains and sewage streams, and other effluents joining the rivers affect the self-purification capacity of rivers. Use of poor quality irrigation water also raises problems of soil permeability, salinity and toxicity (CWC, 2012a). The sources of pollution are classified broadly into two categories:

Point sources where pollution load can be measured. Surface drains carrying municipal sewage or industrial effluents, sewage pumping stations and sewerage systems, effluents from industries, etc., are important point sources. Municipal sewage contributes 75% of point source pollution, while industrial pollution contributes the balance, 25%.

Non-point sources These are non-measurable sources of pollution such as runoff from agricultural fields carrying chemicals and fertilizers, runoff from areas used for dumping of solid waste and open defecation, dumping of un-burnt/half burnt dead bodies and animal carcasses, dhobi ghats, cattle wallowing, mass bathing, floral offerings, etc.

MAJOR THREATS TO SURFACE WATER

Oxygen depletion

A large portion of wastewater is discharged into watercourses without any treatment and the major portion of it originates from domestic sources which contain high amounts of organic matter. Industries also discharge effluents containing high organic matter. This organic matter when oxidised in water through microbial activities, consumes dissolved oxygen. When water has limited availability of oxygen, if consumption exceeds the availability, oxygen depletion results and the survival of aquatic life becomes difficult.

In many water bodies, massive input of organic matter sets off a progressive series of chemical and biological events in the downstream water. The stretch is characterised by high bacterial populations, cloudy appearance, high BOD and a strong disagreeable odour, indicating general depletion of oxygen. Masses of gaseous sludge rising from the bottom are often noticed floating near the surface of the water. During the monsoon, due to flooding, the sludge deposited in such stretches is flushed and stays in suspension, causing a rise in oxygen uptake downstream. Due to such sudden oxygen depletion, heavy fish mortality occurs every year during the first flushing after onset of the monsoon.

Eutrophication

The discharge of domestic wastewater, agricultural runoff water and many industrial effluents contributes nutrients such as phosphates and nitrates that promote excess growth of algae in water bodies leading to a state called eutrophication. In a eutrophic water body, during day-time the water becomes supersaturated with oxygen; however, at night, due to respiratory consumption the oxygen is depleted to a large extent.

Toxicity

Due to discharge of toxic effluents from many industries and increased use of chemicals in agriculture, many water bodies in the country are polluted due to the presence of toxic substances. Their presence impairs the water quality, making it unfit for human consumption, aquatic life and irrigation. The presence of organic pollutants (mostly organochloro compounds and some persistent toxic substances) is also becoming an important water quality issue because of their carcinogenic character. They enter water bodies from point sources, non-point sources as well as through long-range atmospheric transportation. The process of bio-accumulation and bio-magnification of these organic pollutants in freshwater ecosystems is of great importance.

APPROACH TO WATER QUALITY MANAGEMENT AND ITS CRITERIA

Water quality management in India is accomplished under the Provision of Water (Prevention and Control of Pollution) Act, 1974. The basic objective of this Act is to maintain and restore the wholesomeness of national aquatic resources by prevention and control of pollution. It was considered ambitious to maintain or restore all natural water bodies at a pristine level. Planning pollution control activities to attain such a goal is bound to be deterrent to developmental activities and cost prohibitive. Because the natural water bodies have got to be used for various competing as well as conflicting demands, the objective is aimed at restoring and/or maintaining natural water bodies or their parts to such a quality as needed for their best uses.

Thus, a concept of "*designated best use*" (DBU) was developed. According to this concept, out of the several uses a water body is put to, the use which demands highest quality of water is termed as the "designated best use", and accordingly the water body is designated. Primary water quality criteria for different uses have been identified. A summary of the use-based classification system is presented in Table 1.

Table 1 Use-based classification of surface waters in India (Central Pollution Control Board, CPCB).

Designated-Best-Use	Class of water	Criteria
Drinking water source without conventional treatment but after disinfection	A	1. Total Coliforms organism MPN/100 ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 6 mg/L or more 4. Biochemical oxygen demand 5 days 20°C 2 mg/L or less
Outdoor bathing (organized)	B	1. Total Coliforms organism MPN/100 ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 5 mg/L or more 4. Biochemical oxygen demand 5 days 20°C 3 mg/L or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved oxygen 4 mg/L or more 4. Biochemical oxygen demand 5 days 20°C 3 mg/L or less
Propagation of wild life and fisheries	D	1. pH between 6.5 to 8.5 2. Dissolved oxygen 4 mg/L or more 3. Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, controlled waste disposal	E	1. pH between 6.0 to 8.5 2. Electrical conductivity at 25°C max.2250 micro mhos/cm 3. Sodium absorption ratio max. 26 4. Boron max. 2 mg/L

RESULTS AND DISCUSSION

pH

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality. In most rivers pH is within the acceptable limit of BIS:10500 (6.5–8.5). High values of pH (> pH8.5) are observed during the monsoon season at the water quality stations at Seondha (Sind RIVER) in Datia district of Madhya Pradesh and Gummanur (Ponniyar RIVER) in Dharmapuri district of Tamilnadu state. During the non-monsoon season pH > 8.5 was found at 12 water quality stations: Seondha (Sindh River), Kora (Rind River), Garrauli (Dhasan River), A.B. Road Xing and Khatoli (Parwati River), Aklera (Parwan River), Barod (Kalisind River), Tekra (Pranhita River), Gummanur (Ponniyar River), Maighat (Gomti River), Bawapuram (Tungabhadra River) and Tilga (Sankh River). Gummanur water quality station on the Ponniyar River (Tamil Nadu) was reported to have the highest monsoon and non-monsoon pH values, 9.91 and 8.78, respectively (CWC, 2011). Some areas of Gujarat (Ankleshwar and Vapi), Andhra Pradesh (Patancheru), and Madhya Pradesh (Ratlam and Nagda) have low pH due to discharge of acidic industrial effluents. The Bandi River in Rajasthan at Pali is alkaline (pH is about 10) (CPCB, 2010; GPCB, 2010; Hussain & Husain, 2012).

Dissolved oxygen

Dissolved oxygen is one of the most important components of aquatic systems. Oxygen is required for the metabolism of aerobic organisms, and it influences inorganic chemical reactions. Oxygen is often used as an indicator of water quality; high concentrations of oxygen usually indicate good water quality. The amount of dissolved oxygen gas depends greatly on temperature and somewhat on atmospheric pressure.

The level of DO is observed to be more than 4 mg/L in the River Tuni, Giri, Brahmaputra throughout the year whereas the lowest values (0.1 mg/L) are observed in the Yamuna downstream of Delhi, Krishna at Vijaywada and Cauvery at Mohanur Sabarmati (0.8 mg/L) downstream of Ahmedabad city; Mahanadi (1.4 mg/L) at Sheorinarayan has the lowest value due to discharge of untreated municipal wastewater (Sharma & Singh, 2009; Mandal *et al*., 2010). The Central Pollution Control Board (CPCB) has recommended a minimum 5.0 mg/L concentration of dissolved oxygen for outdoor bathing. Dissolved oxygen below 5.0 mg/L is observed at 17 water quality stations in Delhi, Karnataka, Utter Pradesh, Rajasthan, Chhattisgarh, Jharkhand, Haryana, Maharashtra and Gujarat states. Alarmingly low concentrations were recorded at Darrighat in Mahanadi basin (0.8 mg/L – monsoon, 0.9 mg/L – non monsoon), MBPL in Hasdeo basin (0.3 mg/L – monsoon, 0.5 mg/L – non monsoon) and Baridhinala in Subarnarekha basin (0.8 mg/L – monsoon and 0.9 mg/L – non monsoon) (Sundaray, 2006; CPCB, 2010; CWC, 2011).

Biochemical oxygen demand, BOD

Biochemical oxygen demand (BOD) is usually defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. BOD is an indicator of the potential for a water body to become depleted in oxygen and possibly become anaerobic because of biodegradation. It is one of the most important instream pollution-control activities. It is of prime importance in regulatory work and in studies designed to evaluate the purification capacity of receiving bodies of water. BIS and CPCB have recommended a maximum 3.0 mg/L biochemical oxygen demand for water for outdoor bathing.

Relatively high values of BOD, > 3.0 mg/L are observed at 37 water quality stations in the Uttar Pradesh, Rajasthan, Delhi, Madhya Pradesh, Tamil Nadu, Karnataka, Chhattisgarh, Haryana, Maharashtra, Orissa, Jharkhand, Bihar, Kerala and Gujarat state. The highest BOD values are observed in the River Sabarmati (475 mg/L) downstream of Ahmedabad, followed by Hasdeo (276 mg/L) at MBPL, Apra (241 mg/L) at Darrighat, Godavari (78 mg/L) downstream of Nanded city, Subarnarekha (76.6 mg/L) at Baridhinala, Satluj (45mg/L) downstream of Ludhiana city, Yamuna (36 mg/L) downstream of Delhi, Cauvery (27mg/L) downstream of Tiruchirapalli, Hindon (32 mg/L) at Galeta, Yamuna (21 mg/L) at Agra, Ganga (17 mg/L) downstream of Varanasi, Krishna and Tapi (both 10 mg/L) downstream of Sangli and Uphad, respectively (Shrivastava & Patil, 2002; Prasad & Patil, 2008; Sharma & Singh, 2009; Suthar *et al*., 2009; CPCB, 2010; CWC, 2011). Relatively low values of BOD (<6 mg/L) are measured throughout the length of the rivers Mahi, Narmada, Brahmaputra and Beas.

The water quality monitoring results obtained in the last ten years indicate that the organic and bacterial contamination continue to be critical in rivers of India. This is mainly due to discharge of domestic wastewater mostly in untreated form from the urban centres of the country. The municipal corporations in general are unable to treat the increasing loads of municipal sewage. Secondly the receiving water bodies also do not have adequate water for dilution. Therefore, the oxygen demand and bacterial pollution increase day by day.

Coliforms

Coliform organisms are used as indicators of water pollution. The coliform is a very common rod-shaped bacterium. Because pathogenic bacteria in wastes and polluted waters are usually much lower in numbers than coliforms, which are usually in high numbers in polluted water, total coliforms is used as a general indicator of potential contamination with pathogenic organisms. However, many coliform bacteria live in the soil, and these organisms may be the source of those that appear in water, especially surface water. Faecal coliforms, on the other hand, are more specific because they refer to the coliforms that live in the intestinal track of humans and many other animals. Pathogens are relatively scarce in water, making them difficult and time consuming to monitor directly. Instead, faecal coliform levels are monitored, because of the correlation between faecal coliform counts and the probability of contracting a disease from the water.

As per CPCB guidelines, for bathing (outdoor) the Total Coliforms Organism MPN/100 ml shall be less than 500. The main source of total coliforms in Indian rivers is sewage discharge, open defecation, cattle wallowing, disposal of animal carcasses and unburnt bodies. Most Indian river reaches (middle and lower) are high in total coliforms. It has been reported that reaches which are high in BOD have high total coliform and faecal coliform counts.

In respect of total coliform numbers and faecal coliform numbers, the River Yamuna leads with the highest count of 2.6 billion MPN/100 ml and 1.7 million MPN/100 ml, respectively, followed by the Sabarmati (2.8 and 1.4 million), Ganga (2.5 and 1.1 million), Brahmaputra (2.4 million and 24 000), Cauvery (1.6 million and 28 000), Brahmani (90 000 and 60 000), Satluj (35 000 and 3500), Krishna (33 300 and 10 000), Mahanadi (30 000 and 17 000), Baitarni (22 000 and 11 000) and Godavari (5260 and 3640). The rivers Mahi, Tapi, Narmada, Subernrekha and Beas are relatively clean rivers as the total coliform and faecal coliform counts are much lower than for other rivers and meet the criteria (CPCB, 2010)

Water pollution varies in severity from one region to another, depending on the density of urban development, agricultural and industrial practices and the systems for collecting and treating wastewater. The CPCB has identified some of the polluted river stretches and possible sources of pollution (Table 2). It is seen most of that of the polluted stretches exist in and around large urban areas. The river has been classified into different classes with regard to the level of pollution.

Toxic metals

Metals occur naturally and become integrated into aquatic organisms through food and water. Trace metals such as iron, copper, selenium, and zinc are essential metabolic components in low concentrations. However, metals tend to bio-accumulate in tissues and prolonged exposure, or exposure at higher concentrations, can lead to illness. Elevated concentrations of trace metals can have negative consequences for both wildlife and humans. Human activities such as mining and heavy industry can result in higher concentrations than those that would be found naturally.

Comprehensive study of the results reveals that out of the 377 river water quality stations monitored, water samples collected at 118 water quality stations are within the permissible limit for all purposes. However, 148 stations had concentrations beyond the permissible limit due to the presence of two or more toxic metals. There are 100 stations where the water was considered unfit for drinking purposes due to presence of iron beyond the permissible limit. Water is found to be unfit for drinking at one station due to the presence of cadmium, at six stations due to presence of chromium, and at four stations due to presence of lead (CWC, 2012b).

Iron is an essential element in human nutrition. In this regard, it may be mentioned that the presence of high concentrations of iron in drinking water make it taste unpleasant, however, living organisms can tolerate higher concentrations of iron without any serious damage to their system. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day (FAO/WHO, 1988).

Arsenic concentrations greater than the maximum desirable limit (10 μg/L) were found at ten water quality stations on the Ganga, Ramganga, Alaknanda, Bhagirathi, Churni, Jalangi and Mahananda rivers. Copper concentrations in excess of the acceptable limit (50 μg/L; BIS 10500) were found in 96 river water samples from 91 WQ stations. The highest concentration of copper was 2856.50 μg/L observed at Srikakulam water quality station on the Nagavali River. The concentrations of cadmium at Musiri (Cauvery River); Delhi Rly Bridge, Mohana, Mathura, Agra (Yamuna River) and Galeta (Hindon River) exceed the acceptable limit. On the Yamuna River

Table 2 Polluted River stretches in India (CPCB, 2011).

S. no.	River	Polluted stretch	Desired class	Existing class	Critical parameters	Possible sources of pollution
1	Chambal	Downstream of Nagda and Kota	C	D/E	DO, BOD	Domestic and industrial waste from Nagda and Kota
2	Damodar	Downstream of Dhanbad	C	D/E	BOD, Toxicity	Industrial waste from Dhanbad, Durgapur, Asansol, Haldia and Burnpur
3	Godavari	Downstream of Nasik and Nanded	C	D/E	BOD	Waste from sugar industries, distilleries and food processing industries
4	Gomti	Lucknow to confluence with Ganga	C	D/E	DO, BOD, Coliform	Industrial wastes from distilleries and domestic wastes from Lucknow
5	Hindon	Saharanpur to confluence with Yamuna	C	D/E	DO, BOD, Toxicity	Domestic and industrial waste from Saharanpur and Ghaziabad
6	Kali	Downstream of Modi nagar to confluence with Ganga	C	D/E	BOD, Coliform	Domestic and industrial waste from Modinagar
7	Krishna	Karad to Sangli	C	D/E	BOD	Wastes from sugar industries and distilleries
8	Sabar-matic	Immediate upstream of Ahmedabad up to Sabarmati Ashram	B	E	DO, BOD, Coliform	Domestic and industrial waste from Ahmedabad
		Sabarmati Ashram to Vautha	D	E	DO, BOD, Coliform	
9	Satluj	Downstream of Ludhiana to Harika	C	D/E	DO,BOD	Industrial wastes from hosieries, tanneries, electroplating and engineering industries and domestic waste from Ludhiana and Jalandhar
		Downstream of Nangal	C	D/E	Ammonia	Wastes from fertilizer and chloroalkali mills from Nangal
10	Subar-narekha	Hatia dam to Bharagora	C	D/E	Ammonia	Domestic and industrial waste from Ranchi and Jamshedpur
11	Yamuna	Delhi to confluence with Chambal	C	D/E	DO, BOD, Coliform	Domestic and industrial wastes from Delhi, Mathura and Agra
		In the city of Delhi, Mathura and Agra	B	D/E		

Table 3 Summary of the trace and toxic metals results.

Parameter	Acceptable limit	No of samples analysed	Stations > acceptable limit	Samples > acceptable limit	No of rivers
Arsenic	10 µg/L	940	8	10	7
Cadmium	3 µg/L	953	7	7	3
Chromium	50 µg/L	951	70	79	15
Copper	50 µg/L	943	91	97	65
Mercury	1 µg/L	112	11	11	11
Iron	3 mg/L	938	236	390	142
Lead	10 µg/L	939	68	84	39
Nickel	20 µg/L	673	45	79	27
Zinc	5 mg/L	949	0	0	0

a maximum cadmium concentration of 12.10 µg/L was observed. BIS 10500 recommends an acceptable limit of 50 µg/L for chromium in drinking water. The data reveal 79 water quality stations on 70 rivers with greater concentrations. The Kamalanga and Janapur water quality stations of Brahmani River having very high chromium, 21 141 and 2575 μg/L, respectively (CWC, 2012b).

Excessive iron (>0.3 mg/L) is observed in 367 river water samples. The highest concentration 12.4 mg/L was observed at Therriaghat on Umngot River. Lead concentrations above the acceptable limit (BIS 1050039) occurred on 39 rivers. Talcher water quality station on the Brahmani River was reported to have the highest lead concentration (77.49 μg/L). Lead concentrations greater than the acceptable limit (10 μg/L) were found in 84 samples from 68 water quality stations on 39 rivers. Mercury was analysed on 234 water quality samples from 112 water quality stations; the data reveal that 11 stations on 11 rivers have concentrations above 1 μg/L. Sankalan water quality station on the Teesta River has the maximum concentration of mercury (5.21 μg/L). Ghatshila water quality station on Subarnarekha River was reported to have the highest nickel concentration (4480 μg/L). Toxic behaviour of river water with respect to nickel may occur at 45 water quality stations on 27 rivers due to its concentration above 20 μg/L. Zinc concentrations at all stations were within acceptable limits as prescribed by BIS (CWC, 2012b).

CONCLUSION

The analysis of water quality monitoring data collected by CWC and CPCB indicates that organic pollution is predominant and almost all the surface water sources are contaminated to some extent by the coliform group of bacteria, which makes them unfit for human consumption. The rivers grossly polluted in specific stretches are the Sabarmati, Godavari, Sutlej, Yamuna, Cauvery, Ganga, Krishna, Tapi, Mahanadi and Brahamani.

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