Health of Inland Aquatic Resources and its Impact on Fisheries

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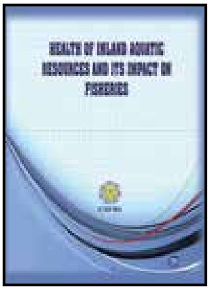

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1. Introduction

The inland fisheries resources of India are noted as much for their heterogeneity in composition as for as their opulent productive potential. India is endowed with a vast expanse of open inland waters in the form of rivers, canals, estuaries, lagoons, reservoirs, lakes, ponds, tanks *etc.* (Table 1).

Table 1 Inland fishery resources of India

Type	Quantity
Rivers and canals	1.95 lakh km
Reservoirs	3.15 million ha
Estuaries	0.26 million ha
Brackish water	1.24 million ha
Floodplain wetland	0.35 million ha
Ponds and tanks	2.407 million ha

Source (Hand Book of Fisheries Statistics 2005)

These resources are one of the major sources of livelihood for the rural poor, especially the fishermen community. At present, an estimated 14 million people are engaged in fishing, aquaculture and ancillary activities (Fisheries Division, ICAR, 2006).

Inland aquatic system and the organisms that they support are among the most vulnerable natural system on the planet. Almost all natural and human activities taking place within a basin are reflected by the quality of the water, its quantity and timing and on the form of the system.

The fish production in the inland open waters is also greatly dependent on ecosystem health of these waters. Any perturbation in health is reflected in form of deteriorated habitat conditions. Ecosystem health management is therefore extremely important for obtaining sustainable fish harvest from these waters.

2. Habitat status of inland water bodies for fish

2.1 Rivers

There are 14 major rivers in India (Ganga, Brahmaputra, Brahmani, Cauvery, Godavari, Indus, Krishna, Mahanadi, Mahi, Narmada, Periyar, Sabarmati, Subarnarekha, Tapti) covering 83% of the drainage basin and account for 85% of the surface flow (Fig. 1). Brahmaputra, Ganga, Indus and Godavari basin cover more then 50% of the country's surface flow. Apart from this, there are 44 medium and 55 minor rivers which mostly originate from the coastal mountains. Only 4 out of 14 major rivers are perennial. These are Brahmaputra, Ganga, Mahanadi and Brahmani. The Cauvery, Mahi, Sabarmati and Periyar pass through low rain fall areas. The major rivers apart from the river Ganges system, with a catchment area of more than 10 million ha each are the Indus (32.1 mha), Godavari (31.3 mha), Krishna (25.9 mha) and the Mahanadi (14.2 mha). The total catchment area of medium rivers is about 25 mha and Subarnarekha with a 1.9 mha catchment area, is the largest amongst the medium rivers in the country.

The average production from these riverine resources in India is only 360 kg/km. In fact, the production potential of the riverine resources of India is much higher. The potential of the lower reaches of river Ganga is estimated at 198.3 kg/ha/yr, whereas the actual yield is 30 kg/ha/yr and thus, only 15.2% of the production potential is harvested (Sinha, 1999). This is because the rivers have degraded and do not serve as a good habitat for fish. Very often fish kills are reported from the rivers (Table 2).

Table 2. Fish kill reports from Indian rivers

Place	Year	Cause	Source
River Gomti, Lucknow	1983, 1984, 1986	Distillery waste	Joshi, 1994.
River Chahar, Alwage	1974	Pesticide	Joshi, 1994.
River Tungabhadra, Harihar	1984 1994	Poly fibre, rayon effluents	Murthy, 1984.
River Ganga, Munger, Bihar	1968	Oil refinery effluents	Sunderesan *et al.*, 1983
River Adyar, Madras	1981-82	Tannery effluents	Joshi, 1994.
River Gomti, Tripura	1988	Epizootic ulcerative syndrome (EUS)	Das and Das, 1993.
River Shella, Meghalaya	1988	EUS	Das and Das, 1993.
River Churni, West Bengal	1993 1997	Sugar mill effluents	Ghosh & Konar, 1993. Konar, 1997.
River Yamuna, Haryana	1999	Sudden increase in turbidity due to sugar factory discharge	Anon, 1999.
River Bhavani Tamil Nadu	1999	Untreated effluent of South India Viscose	Bhavani River Protection Council
River Burhi Gandak, Bihar	2000	Effluent from sugar mill	Alam *et al.*, 2001.
River Sutlej	2001	Probably effluents of NFL and Punjab Alkalis and Chemicals Limited.	The Tribune, Chandigarh. 24th November, 2001.
River Gomti Lucknow	2003	Effluent from sugar mill, paper mill, Sugar mill and distilleries, upstream of Sitapur and Lakhimpur-Kheri	India-ej News,13th July.2003
River Gedilam Tamil Nadu.	2005	Sugar mill effluents of Nellikuppam,	The Hindu, 11th May 2005
River Brahmaputra	2007	Chlorine in Wastewater	CIFRI report, 2007
River Karola, Jalpaiguri, WB	2011	Pesticide poisoning	CIFRI report, 2011

Fig. 1 Major rivers in India

The various anthropogenic activities, which have degraded the rivers follows:

Domestic wastes: Domestic and municipal effluents are estimated to constitute 75% of India's wastewater by volume (Ministry of Environment & Forest, 1992). The enormity of sewage pollution is reflected in the river Ganga, in which more than 70% of the total pollution load is contributed by the sewage (Chaudhury, 1985). Municipal sewage is very often accompanied by trade waste synthetic detergents and heavy metals from small scale industries sprawling around thickly urban areas.

The CPCB systematically collects data on industrial wastewater and domestic wastewater generation from big cities. According to the 1996 figures, 229 class I cities in India generate about 16662 MLD of waste water whereas the capacity to treat only 4037 MLD exists. 345 Class II towns generate about 1650 MLD of waste water whereas capacity to treat only 61.5 MLD exists, (CPCB, 2000). Estimates for the waste water generated by the rural households are not available. The current practices adopted for disposal of industrial wastewater includes discharge into public sewers, rivers, reservoirs or seas through creeks and estuaries with little or no treatment.

Industrial wastes: There are over 3 million small-scale industrial units (SSIUs) about 35.30% of them are of polluting nature. In case of large water polluting industrial units discharging effluents into the rivers and lakes, only 29% have adequate effluent treatment plants (Ministry of Environment & Forests, 1997). CPCB has identified 17 categories of highly polluting industries for priority action like sugar sector followed by pharmaceutical, distillery, cement and fertilizer.

Agricultural runoff: Agricultural activities are one of the important causes of environmental degradation. The problem of water pollution becomes more severe as the magnitude of agricultural runoff is very vast. The fertilizer ($N+P_2O_5+K_2O$) consumption in India has increased from 7.7 million tonnes in 1984 to 17.54 million tonnes in 2000-01 (Ministry of Chemicals & Fertilizers, 2003). Use of pesticides also increased from 24,305 tonnes in 1971 to 61,357 tonnes in 1994-95. The pesticide use, however, decreased to 47,020 tonnes in 2001. It is interesting to note that only 25-30% of total cultivated area is under pesticide cover. Yet the pesticides and their residues have polluted agricultural produce and different components of environment. This is mainly due to improper handling, wrong use schedule, non-awareness about chemicals and their residue behaviour.

Abstraction of water: The projected water requirement of India for irrigation and other uses from the different water course as estimated during 2025 is approximately 1100 billion cubic meter (Sunderesan, 1982). According to the Ministry of Water resources,1999 (MoWR) 80% of India's utilizable water is devoted to agriculture in the form of irrigation. Demand for domestic sector has remained low and accounts for only 5% of the annual freshwater withdrawals in India. According to MoWR, industrial water use in India stands at about 40 billion cubic meters or nearly 6% of the total fresh water abstraction. According to Central Pollution Control Board (CPCB), in 2000, India's annual freshwater withdrawals were about 500 billion cubic meter and the Indian industry consumed about 10 billion cubic meter of water as process water and 30 billion cubic meter as cooling water. This accounts for 8% consumption by the industry. The large scale abstraction alters the water quality by reducing the load bearing capacity of down stream water. Although water abstracted for the various needs are drained back into the water system, but it is contaminated by a variety of substances detrimental to aquatic life.

Siltation: Nearly 5334 million tons of soil is eroded annually from the cultivable land and forests of India. On cropland, the erosion can range from less than 3 to more than 50t $acre^{-1}yr^{-1}$. The country's rivers carry approximately 2050 million tons of soil of which nearly 480 million tons is deposited in the reservoirs and 1572 million tons is washed into the sea every year. The loss of storage capacity of reservoir due to silting is by far the most serious problem created by soil erosion (Gupta, 1975). The sediment loads of the river Ganga and Brahmaputra are the highest in the country with 586 million t to 470 million t respectively. Of the major river basins studied in the country more than one third carry sediment loads of 100 million t or more (Jhingran,1991)

River training: As flood control measures various forms of river training *viz.* guide, banks, spruce and river revetments have been constructed in our country.

Construction of dams: The dams, barrages, rivers and other hydraulic structures constructed on riverine ecosystem disturb the river continuity. The discharge downstream is reduced leading to habitat destruction both downstream and upstream. The migratory pathways of fishes are obstructed.

Climate warming: The climate of the earth in the past few decades is showing perceptible changes both in global and regional scale manifested by increase in atmospheric and water temperature. Historical data show an increase in temperature by 0.3°C to 0.6°C between1890 to 1990 and projections for the next 100 years indicate rise by 1.1 °C to 3.3 °C (Sen. *et al.*, 1991). The New Indian Express (2001). Some observed changes in climate parameters in India has been consolidated by India's Initial National Communication, 2004 (NATCOM) to UNFCCC. Some of the changes of relevance to inland fisheries are described below:

Surface Temperature: At the national level, increase of -0.4° C has been observed in surface air temperatures over the past century.

Rainfall: While the observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years) while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala (-6% to -8% of the normal over the last 100 years).

Extreme Weather Events: Trends are observed in multi-decadal periods of more frequent droughts, followed by less severe droughts. There has been an overall increasing trend in severe storm incidence along the coast at the rate of 0.011 events per year. While the states of West Bengal and Gujarat have reported increasing trends, a decline has been observed in Orissa.

Rise in Sea Level: Using the records of coastal tide gauges in the north Indian Ocean for more than 40 years, Unnikrishnan and Shankar (2007) have estimated, that sea level rise was between 1.06-1.75 mm per year. These rates are consistent with 1-2 mm per year global sea level rise estimates of IPCC.

As global warming continues to increase the atmospheric temperature, it will lead to a continuous shift of zero temperature line (snow line) toward higher altitude. Thus, glaciers will receive more liquid precipitation and less monsoonal solid precipitation. Shift in snowline will result in lesser input to glacier mass balance during summer periods. Therefore, higher atmospheric temperature and more liquid precipitation at higher altitude in the Himalayas will lead to rapid retreat of glaciers and downstream flooding in the coming future (Hasnain, 2002; Kadota *et al.*, 1993). Its impact will be felt in the rivers and associated ecosystems. This alteration in the hydrologic pattern of the rivers and associated wetlands will definitely impact inland fisheries.

With this background an assessment of the present status of our rivers as habitat for fish is given below

Ganga river system

The river Ganga is the fourth largest river in the world with a length of 2525 km and drains about ¼ of the country's area. The water quality of the river system indicates an appreciable improvement in DO content in the middle stretch and lower stretch but the average oxygen levels are still below the acceptable limit of 4 ppm. Very high level of phosphate is recorded at the effluent discharge sites of Kanpur (2.5 ppm), Allahabad (0.8 ppm) and Varanasi (1.05 ppm) in the recent past as compared to 1960 and 1985-90 periods.

Although, data are available on the metal content in water in different stretches of river Ganga, it is not clear, in which zone (upstream, midstream or downstream) maximum heavy metal loads are present. This is because, in the mid and downstream, the metal is point source pollutant and since metal gets adsorbed or precipitated very quickly on particulate matters, its effect is not observed. The high pH level (> 7.5) also facilitates metal precipitation in the Ganga river system in addition with heavy silt load. Since, fresh silt is also deposited every year, the cumulative impact of metal accumulation on sediments is not observed. However, as point source pollutant, Joshi (1991) reported that the samples below the out fall of Pandu nallah and tannery industry effluent, Kanpur exhibited highest value of all the heavy metals, Zn (285 $\mu g\ l^{-1}$), Cu (178.9 $\mu g\ l^{-1}$), Cr (200 $\mu g\ l^{-1}$), Cd (13.7 $\mu g\ l^{-1}$), Pb (26.1 $\mu g\ l^{-1}$) and Hg (1.3 $\mu g\ l^{-1}$). In the downstream of Ganga, although the zone is heavily industrialised, the high tidal flushing activity is not allowing the metals to accumulate at alarmingly high levels (Samanta, 2000).

In the river Hooghly and Haldi at Haldia, the average content of metals estimated were Cd 2-14, Cu 5-19, Mn 8-88, Pb 17-41 and Zn 22-27 ppb. Comparison of these values with Criterion Continuous Concentration (CCC) of USA reveals that Cd, Cu and Pb are present at high level to disturb the aquatic life processes in the zone. The other two metals, *viz.* Mn and Zn are probably less harmful to the aquatic ecosystem (Samanta, 2005).

Yamuna

The combined length of Yamuna river system is 1370 km. The Okhla area of the river receiving the Delhi city effluents was found most polluted site with its least DO content (up to 2 ppm) and is thus unsuitable for desired aquatic organisms. In the sediment high content of Cu (44.9-89.0 ppm), Pb (5.6-127.5 ppm) and Zn (174.8-1467.5 ppm) was recorded at Okhla. As such very often the cases of fish mortality are recorded.

Brahmaputra river system

The Brahmaputra river originates from a glacier (Kubiangiri) in Tibet and has a combined length of 4025 km including its tributaries. In general the river water quality does not indicate pollution.

Indus river system

The major portion of Indus river system lies in Pakistan but its five tributaries, *viz*. the Jhelum, the Chenab, the Ravi and the Sutlej originate from western Himalayas. Very little information is available on their pollution status.

Sutlej

The Sutlej covers 1,370 km in India and Pakistan, specific conductivity of the river water at Ludhiana exhibited very high value, up to 2510 μScm^{-1} indicating effluent entry. In sediment, very high amount of organic matter was also noticed in the region (average 2.46%) with high content of available nitrogen also (average 50.12 mg/100g).

Beas

The Nallas discharging their effluent into the river Beas are the point source pollutants. Chakwal Nalla having DO in traces (0.53 ppm), BOD 28.5 ppm and COD 82 ppm and Kalibein nalla having BOD 20 ppm and COD 59.5 ppm are putting stress on the river Beas due to their high organic load.

Godavari

The river Godavari is the largest of the peninsular rivers and the third largest in India covering about 1465 km, next to Ganga and Brahmaputra. The metal content in sediment was Zn 119.6-198.4 ppm and Cu 46.9-117.9 ppm while in water relatively high content of lead was recorded which reflects moderate contaminations.

Krishna

The river Krishna runs about 1400 km. A number of the molasses and sugar factories are located mostly on the catchment of tributaries as well as main Krishna river in the upper stretch. The factory effluents find their way into the rivers through first monsoon flood. Significant level of different heavy metals (Zinc 40.25-292.30 ppm, Cu 31.39-188.68 ppm and Cadmium 0.10-8.46 ppm) are reported in sediments. (Anon; 2002-2003)

Cauvery

The river Cauvery covers 765 km. The discharge of untreated effluents from innumerable industries, thermal power plants, sugar and paper mills, bleaching and dyeing units, municipalities, *etc*. into the river stretch especially the lower stretch right from Mettur to Grand Anicut has stressed the Cauvery river system itself. Deterioration of water and soil qualities due to contamination has adversely affected the fish and fisheries of the ecosystem. Accumulation of heavy metals in the gills, tissues and other organs of fish suggest that the flow in the river is insufficient for dilution of pollutants and self purification, which has further damaged the aquatic system. In Arkavathy at Mekedatu Sangam, BOD was in the range of 3.0 to 4.6 while COD was registered at 28.0 to 63.5 year round. Toxic chemicals, *viz*. Vinyl chloride, Methylene chloride, Chloroform, Diclorobenzene, Benzene, and Trichloroethane were recorded from river Cauvery. The pollutants emanated from the Chemplast Sanman chemical hub consisting of 26 chemical factories situated in Caddalore district of Tamil Nadu as reported by Indian Peoples Tribunal on Environment & Human rights (Bartaman, 14/9/2007)

Mandovi and Zuari

Heavy metal content studies showed high level of manganese in the water phase (up to 388 ppb in the river Mandovi (77 km) and Zuari. Very high level of Mn was also present in the sediment samples. The recorded average value was 3386-7287 ppm. Highest amount of Mn (9845 ppm) was observed in Cortalium post monsoon sample. Mining activity at the zone is responsible for such unusual concentrations.

River Damodar

Industry and the coalmine effluents have degraded middle stretch of river Damodar to a great extent. In the water phase, high level of unionised ammonia (up to 5.6 mg/l), phenol (up to 2.2 mg/l), nitrate (up to 10.6 mg/l), heavy metals and COD (up to 1235 mg/l) have been recorded.

Table 3. List of some polluted river stretches in India

State	River	Polluted stretch	Source	BOD level (mg/l)
Andhra Pradesh	1. Godavari	Pollavaram to D/S of Rajamundary	Sewage	6-12
	2.Musi	D/S Hyderabad	Sewage	16-44
Assam	Bharalu	D/S Guwahati	Sewage	38
Delhi	Yamuna	Wazirabad to Okhla	Industrial and domestic sewage	6-77
Jharkhand	Subarnarekha	Ranchi to D/S of Jamshedpur	Industrial and domestic waste	-
Gujarat	Sabarmati	Ahmedabad to D/S of Vantha	Industrial and domestic waste	56-504
Haryana	1.Ghagger	Interstate border with Punjab to Otter weir at Sirsa	Industrial and municipal waste	8-50
	2.Yamuna	Okhla to Kosi Kalan	Industrial and domestic waste	16
Himachal Pradesh	Markanda	Kala Amb D/S to Haryana border	Industrial & domestic waste	55
Karnataka	1.Kali	Along Dandeli Town	Paper Mill waste	-

	2.Tungabhadra	Harihar D/S to Hara eahalli bridge	Harihar sewage & Grasim waste	6-8
Madhya Pradesh	1.Khan	Indore city to Confluence with Kshipra	Sewage	65-120
	2. Kshipra	Ujjain to confluence With Chambal	Sewage	8-24
	3. Chambal	D/S of Nagda	Industrial waste and sewage	8-24
	4.Tapi	D/S of Napanagar to Burhanpur city.	Domestic & Industrial waste	-
Maharashtra	1.Godavari	Nasik to (Raher) Nanded.	Sewage from Nasik, Chanderpur,Nanded, Raher.	6-66
	2. Ulhas	Mohane to Baddapur.	Industrial and Domestic Runoff of Ulhasnagar.	6-8
	3.Tapi	M.P. Border to Bhusawal	Bhusawal sewage.	6-9
Meghalaya	Kharkhala	Near Sutnga Khlieri, Jaintia Hills.		8-10
Orissa	1.Brahmani	Panposh D/S to Dharamsala	Sewage & Industrial waste from Panposh, Rourkela, Talcher, Dharmasala.	6-7
	2.Mahanadi	Cuttack D/S	Cuttack sewage	6-8
Rajasthan	1.Ghaggar	Ottu weir to Hanumangarh	Industrial & domestic waste from Haryana & Punjab	-
	2.Chambal	D/S Kota city	Industrial & domestic waste from Kota city	6-6.4
	3.Banas /Berach	Udaipur to Chittorgarh	Municipal waste from Udaipur & Chittorgarh	-
Tamil Nadu	1.Vaigai	Along Madurai	Madurai-Industrial & domestic waste water	7-9
	2.Cauvery	D/S of Mettur Dam to Erode city	Municipal sewage of Erode	6.4-7
Sikkim	Ranichu	Along Ranipur	Wastewater Ranipur	24

Uttar Pradesh	1.Yamuna	Kosi kalan to Confluence with Yamuna	Sewage from Agra, Vrindavan, Mathura & Etawah	6-37
	2.Hindon	Saharanpur to confluence with Yamuna	Sewage & Industrial effluents from Muzafarnagar & Mansoorpur.	9-36
	3.Western Kalii	Muzafarnagar to confluence with Hindon	Sewage & Industrial effluents from Muzafarnagar & Mansoorpur	21-44
	4.Buri Yamuna	Pilkhani to confluence with Yamuna	Industrial effluents from Pilkhani Distillery	-
	5.Kali Nadi Eastern	Merrut to Kannauj	Industrial & Municipal Waste from Merrut, Modi Nagar,Bulandsahar, Hapur, Gulwati and Kannauj.	43-135
	6.Gomti	Lucknow to confluence with Ganga	Sewage & Industrial effluents from Lucknow, Sultanpur, Jaunpur.	6-8.2
	7.Ganga	Kannauj to Kanpur D/S.	Discharge through Kalindi & Ramganga sewage & Industrial effluent from Kannauj and Kanpur.	6-10
		Varanasi D/S	Varanasi sewage & Industrial effluent.	6.5-16.5
West Bengal	Damodar	Durgapur	Industrial waste & sewage from Durgapur & Asansole.	6.4-32

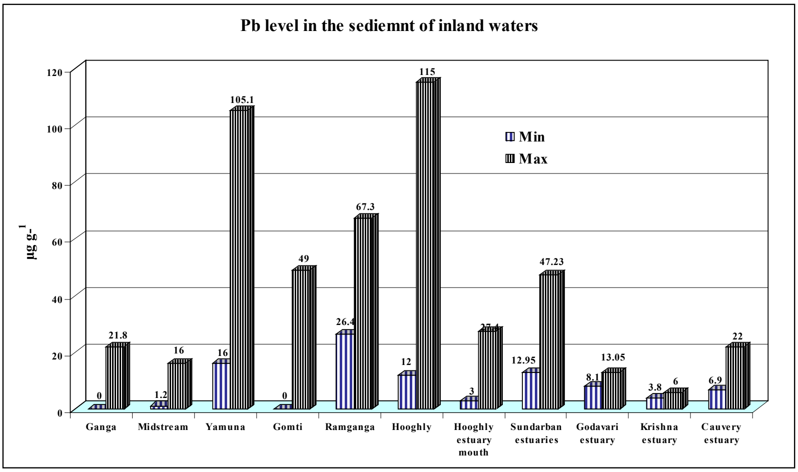
(Source ENVIS, CPCB, Delhi. http:// cpcbenvis.nic.in);D/S: downstream

Heavy metal level in the riverine environment

The heavy metal concentrations in water at upper stretch of river Ganga were below the toxic limit for aquatic organisms, while at middle stretch in most of the places level of metals in water exceeded the USEPA permissible limit for aquatic organisms. Relatively high concentration of Cu, Zn and Pb were recorded in the water of river Ganga from Meerut to Bulandshahar stretch, which exceed the US EPA permissible limit for aquatic organisms. Concentrations of all the metals were high at Ghaziabad due to discharge of huge quantity of domestic and industrial waste effluent.

Sediment metal contents of river Ganga at midstream were in the category of moderate to high range on the basis of USEPA criteria. Yamuna river sediment in and around Delhi had Pb, Zn and Cu content in the level of high range while sediment of other rivers, Krishna, Cauvery and Godavari estuaries were in the category of low to moderate range in respect of metals. The Haldia stretch of river Hooghly and Haldi were found to be moderately polluted with respect to the metal concentrations in the sediment phase.

The comparative levels of Pb, Zn, Cd, Cr, Cu, Ni in sediment and water as compiled from the investigations conducted by various investigators in India, *viz.* Saikia *et al.* (1988), Israili (1991), Singh and Mahaver (1997), Vass *et al.* (1998), , Mohammad *et al.* (1987), Subramanian (1985), Mitra *et al.* (1996), Ramesh *et al.* (1999), Samanta *et al.* (2007), , Samanta *et al.* (2005), Jhingran and Joshi (1987), Singh and Mahaver (1997), Mukhopadhya (2003), Krishnamurti and Bharat (1994), Koushik *et al.* (1999) are presented in Figs 2-9



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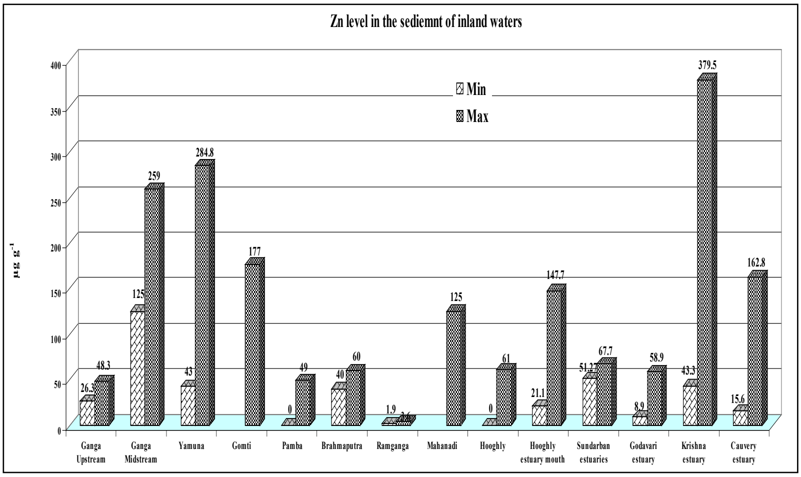

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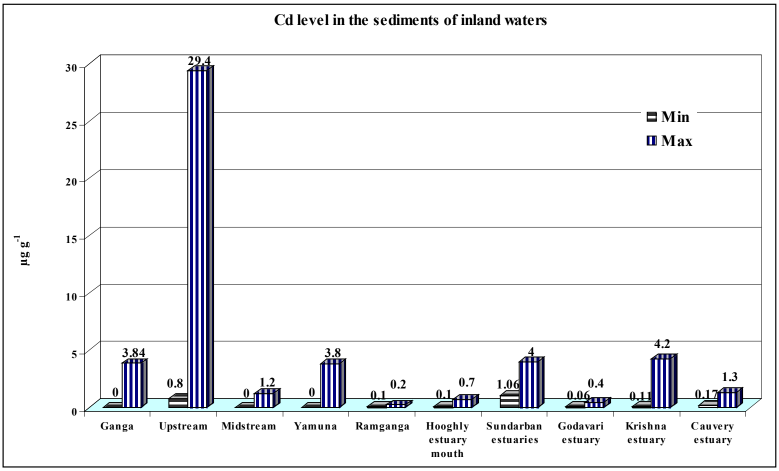

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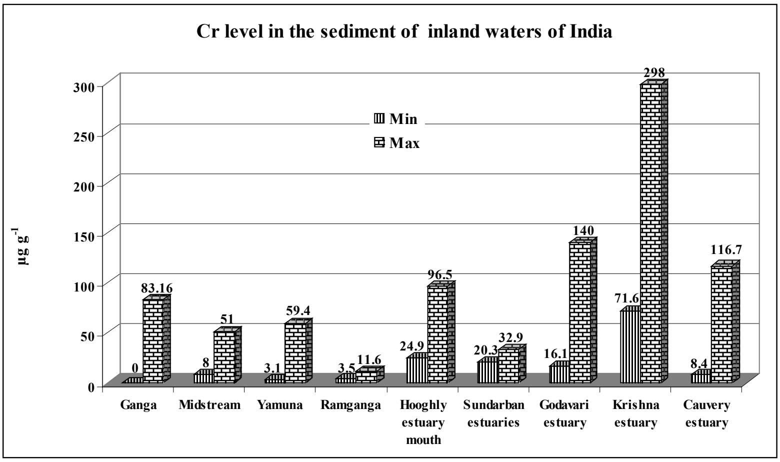

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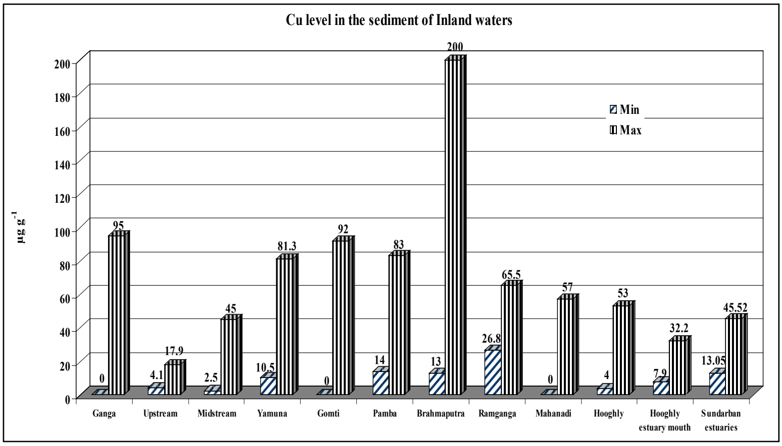

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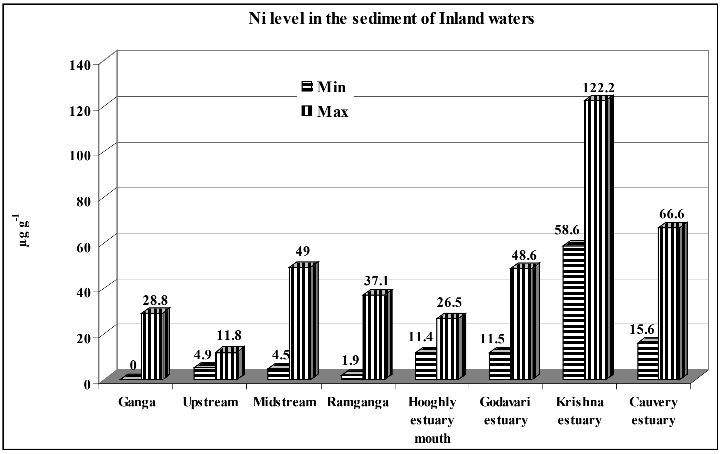

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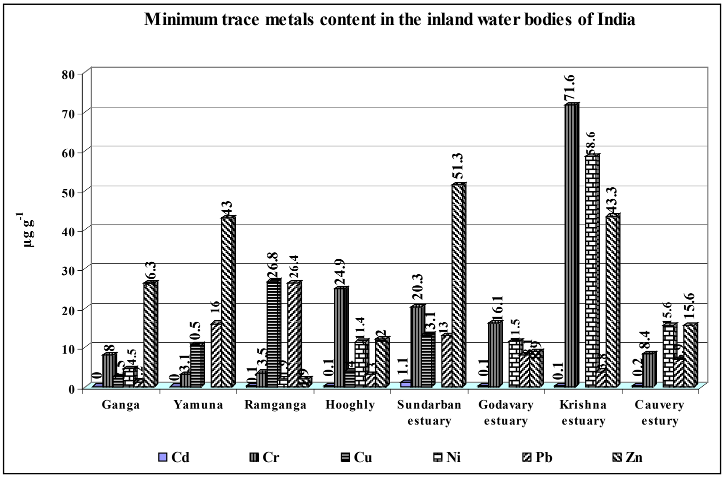

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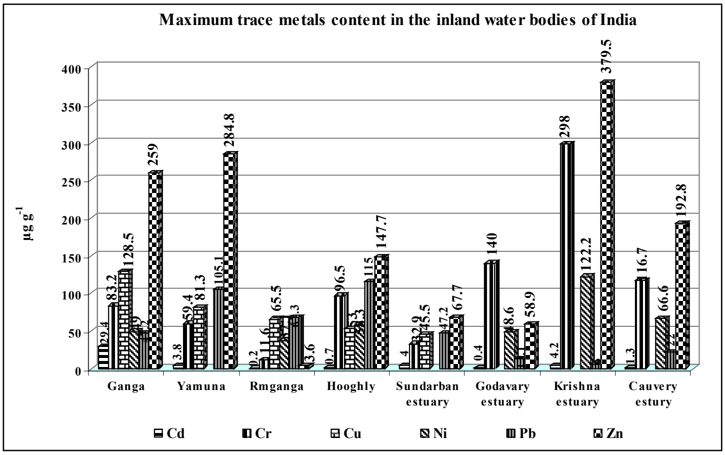

Fig. 9

Pesticide levels in the riverine environment.

The pesticide residues from Indian aquatic environment are limited to the organochlorines. This is because organochlorine insecticides were the only group of chemicals used in the initial phase (almost entire amount) and were also the dominant group in the latter stages (>50%). The organophosphates, carbamates, *etc*. are esters and are relatively quickly degraded in the environment. Organochlorines, on the other hand, are lipophilic and persistent, which accumulate in the food chain and, therefore, are the compounds routinely encountered in the samples derived from nature.

The comparative levels of residues of organochlorine insecticides from the Indian rivers are presented in Fig. 10&11. As compiled from investigations conducted by Ray (1992), Singh (1992), Agnihotri (1993), Nayak *et al.* (1995), Kumari and Sinha (2001), Agrawal *et al.* (1986), CPCB (2000),), Singh *et al.* (2005), Singh (1996), Ramesh *et al.* (1990a), Veeraiah and Prasad (1996), Pathak *et al.* (1992), Kulshrestha (1989), Sarkar *et al.* (2003), Thakar (1986), Halder *et al.* (1989), Nigam *et al.* (1998), Bakre *et al.* (1990), Rajendra Babu *et al.* (1983), Kumar. (1989), Samanta *et al.* (2005), Chowdhury *et al.* (1994). Most of these studies are restricted to the Ganga river system. In general, higher residues were reported from the upper portion of the estuaries and the riverine zone, the sites of effluent and agricultural field washing discharges. In the study conducted by Singh (1992), the detected residue of DDT was found to decrease gradually with time. In comparison to the US EPA permissible limits of organochlorine pesticides for an aquatic environment (Table 4), it is observed that the Indian water bodies have pesticide levels that can harm the aquatic organisms and their consumers.

The residue levels in fish samples of Indian rivers and estuaries observed to be low (Figs. 12-13). When compared with the US FDA safe value for human consumption, it is found that the residue levels are harmless.

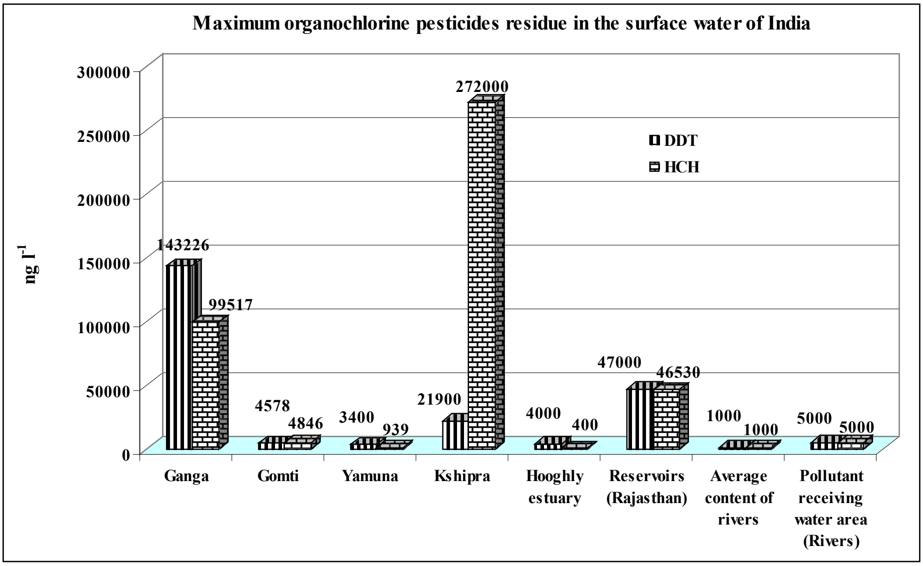

Fig. 10

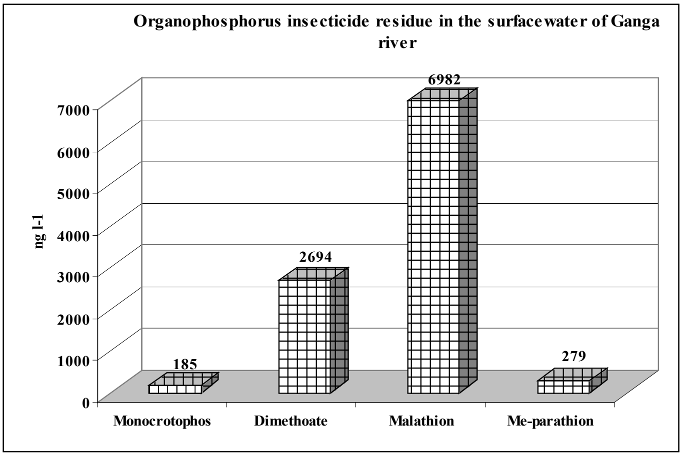

Fig. 11

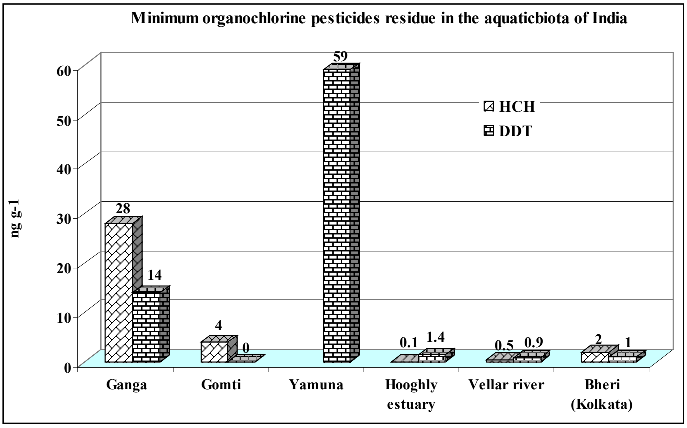

Fig. 12

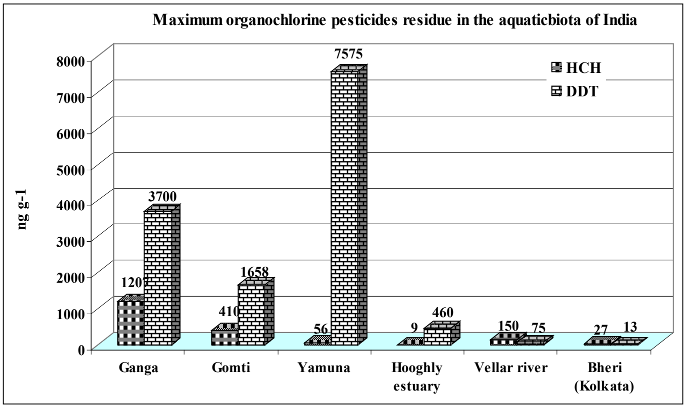

Fig. 13

Table 4. US EPA limit of organochlorine pesticides (ng l-1) for a water body.

Pesticide	For human health	CCC for Aquatic organism
α -HCH	2.6	---
β -HCH	9.1	---
γ -HCH	19.0	---
4,4′-DDT	0.22	1.0
4,4′-DDE	0.22	---
4,4′-DDD	0.31	---
Aldrin	0.049	---
Dieldrin	0.052	56 / 19 (fresh water / saline water CCC)
α/β -Endosulfan	62000	56
Heptachlor	0.079	3.6/3.6 (fresh water/saline water CCC)

2.2 Reservoirs

India has 3,153,366 ha of reservoirs, spread in 15 states of the country. It consists of 1,485,557 ha of small reservoirs, 507,298 ha of medium reservoirs and 1,160,511 ha of large reservoirs. The fish yields from these reservoirs have remained in the range of 12-15 kg/ha in case of large and medium ones while it is 50 kg/ha in small reservoir (Sugunan, 1995, 2001). Presently average fish production in the reservoirs in India has risen to 110 kg/ha due to increased efforts in stocking of large-sized fingerlings (CIFRI reports).

The present fish production from reservoirs in the country is still much below the potential. It is evident from CIFRI studies that existing reservoir fishery resource in the country has the potential to yield around 8-10 lakh tonnes of fish. Of concern is the fact that degradation of reservoirs is increasing due to industrial discharges and poor environmental management of the varied catchment areas.

The major sources of habitat deterioration are:

Pollution from thermal power plants: Various thermal power plants in the country are estimated to generate 10 billion m^3 of hot water (40-45°C) and 17 million t of fly ash every year. Fly ash contains heavy metals such as Zn (6%), Cu (1.3%), As (0.02%), V (0.08%), Ti (0.02%) and Mn (0.03%), which may find its way to the nearest river stretch of a reservoir. To take a specific example of Rihand a large lake of 46000 ha into which coming waters from the power plants Singrauli, Vindhyachal, Anpara and Rihand located within a small area of 30 km^2 affects its ecosystem.

The aquatic ecosystem subjected to hot water discharge experience increase in water temperature, change in chemical composition and change in metabolism and life history of aquatic communities. The most severe effect of thermal power plant associated pollution is the blanketing effect on the reservoir bed by fly ash. This affects the reproduction by deposition in the breeding grounds of fishes, blanketing off the substratum causing elimination of benthic communities and in course of time sealing the nutrients away from the water phase affecting productivity.

Domestic wastes: Reservoirs like Hussainsagar, Mansarovar, Byramangala and Sandynulla contiguous to cities are impacted by sewage pollution. Adverse impact associated with the sewage pollution in these reservoirs is deoxygenation, high BOD load and rapid eutrophication. These stressors impact fish and related aquatic organisms.

Industrial effluents: Several instances of degradation of the reservoirs ecosystem by industrial effluents have been documented. The polluting industries are mainly chemical plants, textile mills, heavy engineering plants, paper mills, iron, steel factories etc. These effluents very often cause considerable harm to the aquatic environment, fish and other biotic communities. Industrial effluents include a wide variety of chemical toxicants, pesticides and heavy metals, apart from those contributing substantially to the BOD load. Natarajan (1979) stressed the importance of protecting the upstream zone, which is biologically sensitive. So is the head zone of the reservoir where the fish concentration is much higher. Discharge of effluents into the upstream can throw up a chemical barrier for breeding migration of economic carps apart from causing considerable mortality to spawn and hatchlings.

Siltation: Siltation causing drastic decrease in the water holding capacity of reservoirs is a chronic environmental problem. As a result, from fisheries point of view the productivity is depleted. Anthropogenic deleterious activities in the catchment areas of the concerned rivers like removal of forest cover and prolonged dry season followed by turbulent monsoon cause soil erosion and high sediment load in the rivers.

It is observed that many of the reservoirs in India recorded much siltation rates, than envisaged during planning stage of the project (Table5).

Table 5. Rate of siltation in some selected reservoirs of India

Reservoirs	Annual Rate of Silting in ha m/100 km^2	
	Assumed	Observed
Gobindsagar	4.29	6.00
Nizamsagar	0.29	6.57
Tungabhadra	4.29	6.11
Hirakund	2.52	3.98
Shivajisagar	324	15.24
Gandhisagar	3.61	10.05

(Source: Joshi, H.C. 1994. Contribution to the fisheries of inland open water system in India.)

Apart from administering the water holding capacity of the reservoir and diminishing its life, siltation also affects the biota by blanketing the benthic and periphytic community. It also hampers the recruitment by destroying the breeding grounds and retards the overall productivity of the ecosystem.

Major sources causing degradation of reservoirs in India are depicted in Table 6

Table 6. Pollution in Reservoirs

State	River	Reservoirs	Pollutant	Reference
Andhra Pradesh	--	Hussainsagar, Mansarovar, Byramangala	Hypereutrophication (Sewage) Sewage	Hingorani *et al.*, 1977 Raghavan *et al.*, 1977
Andhra Pradesh	Krishna	Nagarjunasagar	Steel industries	Das, 2001
Andhra Pradesh	Godavari	Nizamsagar	Dye industries, pulp and paper factories	
Assam	Brahmaputra	Kamdong, Umrong	Dyes, city sewage	CIFRI
Jharkhand	Barakar	Tilayia	Distillery effluent	
Jharkhand	Konar	Konar	Pulp and paper factories	
Jharkhand	Damodar	Panchet	Coal washings, Synthetic rubber	Gopalakrishnan *et al.*, 1966
Jharkhand	Barakar	Maithon	Pulp and paper factory	
Jharkhand	Subarnarekha	Getalsud	Heavy engineering, Chemical and Sewage	Sugunan, 1995
Karnataka	Cauvery	Krishnarajasagar	Paper mill, pulp	
Orissa	Mahanadi	Hirakud	Sugar mill effluents	Dash *et al.*,1983
Tamil Nadu	Cauvery	Stanley	Mettur chemicals, chlorine, lime	Agarwal and Kumar, 1978
Tamil Nadu	--	Sandynulla	Sewage gelatine	Sugunan, 1995
Tamil Nadu	Bhavani	Bhavanisagar	Viscose rayon and fabric	Sreenivasan, 1964.
Karnataka	Tungabhadra	Tungabhadra	Harcher polythene	Joshi and Sukumaran, 1987; Singit *et al.*, 1987
Madhya Pradesh	Chambal	Gandhi Sagar	Textile, Chemical, trade effluent from Indore, Ujjain and Kota	Sugunan, 1995
Uttar Pradesh	Rihand	G.B.Pantsagar (Rihand)	Thermal power plant, coal washing, chemicals	Sugunan, 1995
Andhra Pradesh	Musi	Hussainsagar	Trade effluent and sewage, Hyderabad	Sugunan, 1995

Karnataka	Harangi	Harangi	Coffee processing plants	Das, 2001
U.P	Saryu Betwa Rihand Sarda	Nanaksagar, Matatila, Rihand, Sardasagar (Gorakhpur)	Wool, Textile, Kanorea Chemicals, Chlorine Paper mill	Chandra *et.al.,* 1983 Arora *et.al.,* 1970 Natarajan, 1979b, Desai, 1993
West Bengal	--	Mayurakshi	Coal washings	

2.3 Floodplain wetlands

The resources of floodplains and associated wetlands are significant in the states of Assam, Bihar, West Bengal and Uttar Pradesh while lake resources are available in northern states and southern uplands. These have significant fish biodiversity, indigenous and exotics, and are sustaining livelihoods of large number of people and providing nutritional security to local population. Majority of the floodplains are in various stages of eutrophication, are choked with submerged or floating vegetation and have sub-optimal water quality (Sugunan and Bhattacharjya, 2000). This has affected the general fish health condition of fishes, which are stressed and have retarded growth. The water quality of Garapota Beel, a typical wetland fairly representative of the ecological status of such water bodies in India, is given in Table 7. The dissolved oxygen (DO) level is reduced to nearly 3.5 mg/l at around 10 PM, and remains below this level for nearly eight hours, causing stress to resident fish. Moreover, un-ionised ammonia levels are in the range of 0.05-0.25 mg/l, which also act as a stress factor. As a result, the normal growth of fish has been affected, and the average yield of fish from this beel was 550 kg/ha.

Table7. Physico-chemical characteristics of Ganrapota Beel during 1991*.

	Range	Diurnal Variation of Water Quality Parameters											
		10AM	12PM	2PM	4PM	6PM	8PM	10PM	12PM	2AM	4AM	6AM	8pm
Temp	26-36	22.5	24.0	24.5	24.0	22.0	21.0	21.5	20.5	20.5	21.5	22.0	22.5
Alk	133-212	212	214	201	206	214	209	212	210	209	210	215	210
Hard	120-199	195	199	187	190	193	195	198	198	190	197	199	196
Amm	0.05-0.25	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
CO_2	1.0-8.0	1.0	1.0	1.0	1.0	1.5	1.0	1.5	2.0	2.0	2.0	1.5	1.0
Chl	3.7-9.5	7.5	7.0	7.8	6.9	7.2	7.5	7.5	7.3	7.4	7.9	7.8	7.0
DO	6.0-9.0	6.5	8.0	9.0	9.0	7.5	5.2	3.5	3.0	2.0	2.0	2.0	3.0
pH	7.8-8.0	8.0	8.0	8.1	8.0	8.0	8.0	7.9	7.9	8.0	7.8	8.0	8.0

Temp = temperature (°C), Alk = alkalinity (mgl-l), Hard = hardness (mgl-l), Amm = un-ionised ammonia (mgl-1), CO2 = carbon dioxide (mgl-1), chl = chloride (mgl-l), DO = dissolved oxygen (mgl-1)

* Data from Das (1999)

In West Bengal, the sewage-fed bheries where fishes are reared in nearly 4,000 ha of water area can be cited as an example where, although it is a unique and inexpensive system of rearing fish, the ecological conditions limit the average production to only 1,500 to 2,000 kg/ha (Patnaik 1990). A picture of the water quality in these bheries is presented in Table 4 to emphasise the point that the water quality is creating stress to fish. Here the high microbial consumption of dissolved oxygen (1.8 mg/l/hr) indicates exhaustion of DO for a significant time at night, creating stressful conditions for fish. Moreover, un-ionised ammonia level is also high (Table 8).

Table 8 Environmental Parameters Of sewage-fed wetlands(average values) *

Brachak Bheri	Maligada Bheri	Beel samity	Kathore Bheri	Tripley Bheri	Agamura Bheri	Barachak Bheri
Transparency (cm)	17	21	15	18	25	20
pH	8.6	8.5	8.6	9.0	8.3	8.3
Alkalinity (mgl^{-l})	125	126	127	147	127	114
Hardness (mgl^{-l})	3,000	3,000	2,800	3,200	11,000	2,300
Un-ionised ammonia (mgl^{-l})	1.1	0.5	0.3	0.2	0.1	0.4
Microbial O_2 consumption(mg/l/h)	-	1.8	-	-	-	-

*Data from Das (1994)

Sedimentation in Wetlands

Sediment deposition in the floodplain wetland is an important limiting factor for fisheries development. The increase in sediment yield from the watershed has its impact on the watershed itself and on the river systems and the wetlands. The storage space is reduced. The loss in water storage space changes the entire ecology of the wetlands (Jame and Padmini, 1992).

Pollution in wetlands:

Pesticides as runoff from agricultural fields are a major source of pollution in floodplain wetlands

Pesticide status in Suguna and Bansdah beels

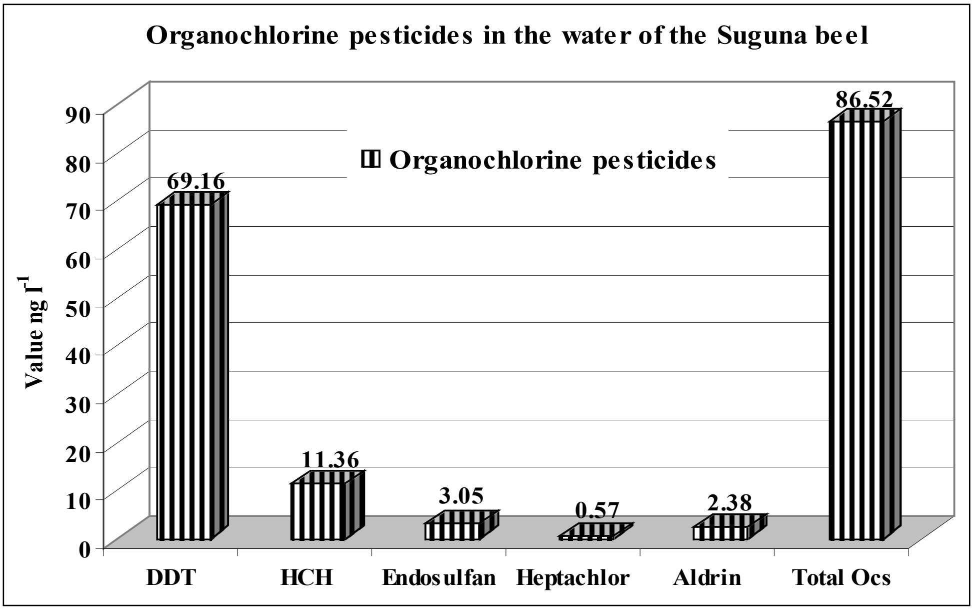

Fig. 14

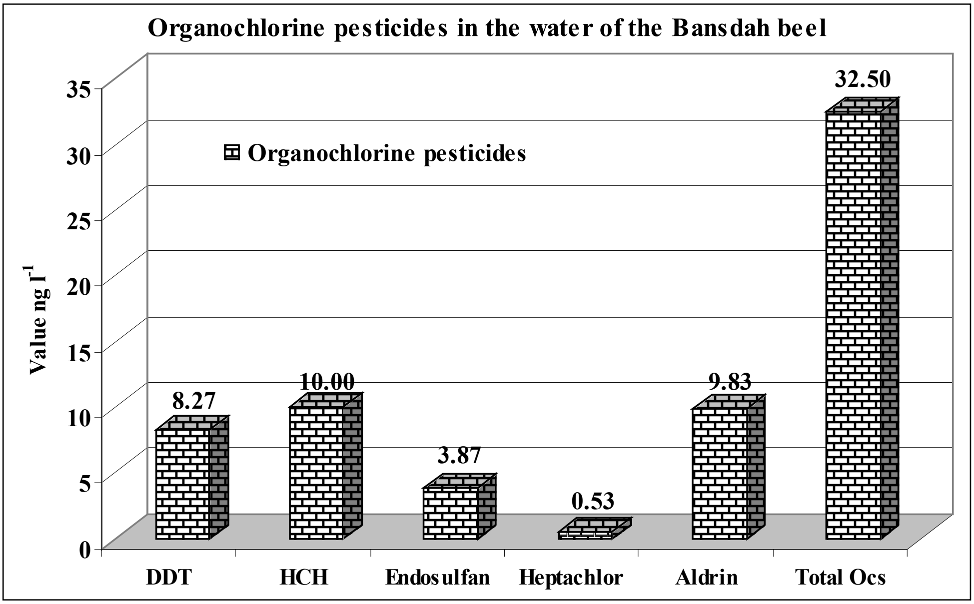

Fig. 15

Studies on total organochlorine pesticide residue content in water of the beels Suguna and Bansdah (Figs. 14 & 15) indicated that in the Suguna water the residue level was much higher. The observed total organochlorine pesticide range was 64-153 ppt at Suguna while 12-70 ppt at Bansdah. Although, Bansdah beel is surrounded with agricultural fields, the pesticide residue levels were found low compared to municipal and industrial area dominated Suguna beel. The seasonal difference on the pesticide residue contents was not prominent except the HCH and its analogues. In all the samples the DDT and its metabolites shared the major portion. As a whole, the aquatic life has certain levels of risk due to the residues of organochlorine pesticides.

3 Impact on fisheries

3.1 Water quality alteration

3.1.1 Temperature : Fishes are often subjected to the hazards of rapid temperature changes in tropical waters either due to daily variations in water temperature in shallow waters or thermocline in deeper water bodies, due to thermal effluents or simply due to stocking of fishes into warmer receiving water. These effects often become additive or synergistic with those of other adverse stimuli (*eg.* low water pH, algae, oxygen shortage). The sublethal temperature changes can place a stress of considerable magnitude on the homeostatic mechanism of fishes.

High temperature : Experiments conducted by Das *et al.* (2002) on juveniles of fish *L. rohita* and *R. rita* subjected to a rapid (5 min) sublethal temperature increase from 28 to 35 °C showed significant increase in cortisol and decrease in interrenal ascorbic acid. Hypercholesterolemia, hyperglycemia and hyperlactemia were also evident accompanied by increased blood haemoglobin and haematocrit and stable protein levels. Compensatory responses were initiated within 72 hr in both the fishes. *R. rita* recovered more quickly indicating it to be more resistant to the heat stress than *L. rohita*. Hence, fishes subjected to sublethal temperature stress should be given a metabolic recovery period of 72 hrs.

Low temperature : The physiological effect of cold shock on *Labeo rohita* was studied in the laboratory by Dutta *et al.* (2002). The low temperature shock at 5°C was given to juveniles of the fish for 5 min. and subsequently transferred to aquarium water of 28°C for recovery. A significant decrease occurred in anterior kidney ascorbic acid level. There was a rise in plasma cortisol within 20 minutes after the shock. Plasma chloride levels decreased significantly but subsequently recovered. Plasma glucose level increased due to glycogenolysis in muscle and liver. Plasma lactic acid level increased and persisted up to 24 hrs of recovery.

In another study (NPCC/CIFRI annual report) conducted to assess the impact of low temperature on fish, *L. rohita* juveniles were subjected to gradual lowering of the ambient temperature from 28°C to 13°C (critical temperature for *L. rohita*). The result indicated significant rise in plasma cortisol with hyperglycemia. There has been a cessation of feeding and sudden burst of activity followed by a state of total cessation of activity. But death did not occur as the fishes recovered when placed in warmer waters after thirty minutes.

3.1.2 pH - In aquatic ecosystem, the pH of water is one of the most important water quality parameter influencing the health of fishes. Most natural waters have pH ranging from 6.5 to 9.0. In water bodies having pH less than 6.5 or more than 9.0, the stress exerted on the resident fishes affects reproduction and growth over a period of time. Experiments were conducted by Acharya *et al.* (2005), in *Labeo rohita* fingerlings exposed to sublethal acidic pH of 5.5 and alkaline pH of 9.0 for duration of 30 days to make a comparative assessment of the physiological changes occurring in the fishes.

In fishes at pH 5.5, from 7 day onwards elevated levels of haemoglobin, haematocrit, plasma cortisol, glucose, cholesterol, protein and lactic acid with reduced levels of plasma chloride, hepatosomatic index, RNA/DNA ratio of muscle and condition factor were recorded. No indication of metabolic recovery was observed at the acidic pH. Fishes exposed to pH 9.0 also showed similar changes in the various parameters only after 21days of exposure. Ultrastructural alterations of gills in fish at acidic pH were rugose lamellar surface, destruction of normal secondary lamellae, release of blood cells, increased mucous production and loss of microridged patterns on the epithelial cells of filaments. At pH 9.0 fusion of secondary lamellae occurred. The extent of alterations in blood parameters with the ultrastructural changes in gills of the exposed fish was greater at pH 5.5 than at pH 9.0. These results suggest that the fish are under greater physiological stress at the acidic pH.

3.1.3 Unionised ammonia - Ammonia (NH_3) has long been recognized as one of the principal fish toxicants encountered in intensive culture systems. Two major sources of NH_3 are from fish excretion and decomposition of nitrogenous organic compounds in fish rearing water bodies. The accumulation of toxic metabolites, mainly ammonia, is one of the important factors limiting stocking densities in ponds.

Effects of ammonia toxicity in some blood and tissue parameters of *L. rohita* fingerlings subjected to sublethal level of unionized ammonia (UIA-0.132 mg/l) for 30 days were studied (Acharya *et al.*, 2005). The 96h LC_{50} was found to be 0.512 mg/l of UIA for the fishes.

Fingerlings of *Labeo rohita* subjected to sublethal unionized ammonia (0.132 mg/l) for 30 days exhibited significant changes. Increase in haemoglobin, haematocrit, plasma cortisol, plasma glucose, plasma cholesterol and plasma lactic acid levels whereas, decrease in plasma chloride, liver and muscle glycogen, hepatosomatic index and DNA/RNA ratio of muscles with stable plasma protein was observed. Metabolic recovery was not observed within 30 days of exposure.

3.1.4 Salinity: There has been a overall decline in the salinity of Hooghly-Matlah estuary after commissioning of Farrakka barrage (Sinha *et al.*, 1996) with gradient and marine zones pushed down towards sea. This has brought about distinct change in the species composition of fishes caught, with freshwater species making their appearance in tidal zone and a few neritic species disappearing.

In river Narmada there would be 72.71 % reduction in water availability down stream at 30 years of commencement of construction. This shall effect the migratory fauna, particularly *Tenualosa ilisha* and *Macrobrachium rosenbergi*, and accordingly the fish yield downstream will decline.

Recent investigations conducted by CIFRI in Krishna river estuary in Andhra Pradesh revealed that the establishment of upper Krishna projects in Maharashtra, and Karnataka involving reservoirs, *viz*. Srisailam and Nagarjunasagar, the water availability in the river downstream of Prakasam Barrage has dwindled resulting in complete drying up of the upper estuary bed. The seawater incursion into the riverine stretch has increased salinity of ground water. The increase in salinity is due to reduction of freshwater river flows. Present investigations revealed the salinity amplitude in Krishna estuary to range from 20 to 35 ppt, a hyper-saline condition. During high tide the seawater reaches up to

Nadakudu covering about 90% of the tidal stretch. Only during monsoon the rainwater and discharges from Prakasam Barrage on account of attainment of full storage level, lowers the estuarine salinity. Thus, the Krishna estuary at present is wholly a tide-fed, polyhaline estuary threatened by the absence of freshwater from the main river. Thus, Mullets are dominant in catches (80%) represented by *Mugil cephalus, Liza parsia, Liza* spp. Clupeids, perches, sciaenids, catfishes, penaeid prawns and mud crabs *(Scylla serrata)* form other groups. The marine catch includes mackerels, sardines and pomfrets *etc.*

3.1.5 Contaminants

3.1.5.1 Sewage: It is the major cause of water quality deterioration of our rivers and floodplain wetlands. The major adverse impacts of sewage pollution are deoxygenation, high BOD load, rapid eutrophication and accumulation of heavy metals in the environment. Sharp fall in dissolved oxygen in water puts the biotic communities under severe stress. Bacterial population in river water and river bed gives a direct indication of the organic waste load. The mean concentration of total coliform organisms in Ganga water shows considerable seasonal and sectoral variations. The count is low in the sectors from Rishikesh to Kanauj (normally less than 2,400 MPN/l00 ml) and higher concentrations are noticed at Uluberia, Dakshineswar, Palta. Kalyani, and Darbhanga Ghat (Patna). It is estimated that domestic wastewater contains 100 million coliform per 100 ml and 7000 viral particles per 100 ml.

Synthetic detergents being absorbed into the body system of fish impair their growth and reproduction capacity. Detergents mixed with oil may be 60 times more toxic than oil alone. Synergistic action of detergents with insecticides has also been recorded. Its sub-lethal concentration causes thinning and elongation of respiratory epithelial cells (Jhingran, 1989).

Observations on river Kali (Qasim and Siddiqui, 1960) revealed deterioration of water quality by sugar mill effluent. It increases the BOD, which depletes DO in the river water and very often fish mortality occurred.

3.1.5.2 Toxicants: Impact of toxic discharge from Triveni paper and pulp mill is reflected in erratic movement and mortality of fishes spreading over an area of 50 sq. m (Das *et al.*1990). The fishes affected were *Mystus vittatus, Puntius sophore, Esomus danricus, Rita rita*. Bleaching powder present in the effluents release free chlorine, which is highly poisonous with corrosive properties and is responsible for fish mortality.

3.1.5.3 Suspended solids: Exposure of fishes in river Damodar to fly ash produced from thermal power plants cause respiratory distress. This is due to deposition of coal dust particles and fine silt on the gills. Damages occur in the primary and secondary gill lamellae with swollen tips (Banerjee *et al.*, 1998).

3.1.5.4 Heavy metals : Fishes in the industrial effluent outfall area in river Haldi at Haldia are exposed to an average metal concentration ($\mu g l^{-1}$) of Cd (2-14), Cu (5-19), Mn (8-88), Pb (17-41) and Zn (22-37).The levels of Cd and Pb were alarming (Samanta *et al.*, 2005).

Biopsy of the gills, liver and kidney of fish *A. gagora, A. aor* and *P. pama* showed gill hyperplasia and swelling. Necrotic hemopoitic tissue and renal tubular degeneration is evident.

Investigations conducted in 110 km stretch of river Hooghly passing through a densely industrialised zone indicated the levels of metals and pesticides to be within permissible limits. However, fish abundance and richness declined in the downstream sites of this stretch. This is because of sandification of the river with frequent sand extraction from the river bed and point source pollution (Das and Samanta, 2006).

3.2 Hydrological alteration

3.2.1 Dams and Fish passes

Dams have become a major impediment in ensuring continuous freshwater flow in rivers. A significant portion of the major, medium and minor rivers have been fragmented by dams several times impacting the river flow especially during the non-monsoon months. As a result the habitat requirements of fishes in the rivers for feeding, migration, spawning and growth have been irreparably altered impacting fishery. To ensure migration of fishes of the hydraulic structures constructed on the rivers very few of them have provision of fish passes, *viz.* a few fish passes built in India are on the Mahanadi barrage, Naraj barrage on river Mahanadi, the Hathnikund barrage on river Yamuna and Farakka barrage on river Ganga. The fish passes in the barrages on river Mahanadi are of the Denil type and in Farakka barrage on river Ganga it is Fish lock (Das & Hassan,2008). These passes were constructed to take care of the migratory requirement of the Indian major carps, *Macrobrachium rosenbergi* and *Tenualosa ilisha*.

Hilsa is a classical example of anadromous fishes being affected due to obstruction of their migratory pathways by dams. The natural migratory range of these fishes is 1500 km from the Hooghly estuary to Allahabad on the Ganga. The 1975 construction of the Farrakka barrage at the head of the Bhagirathi and Padma tributaries of the Ganga, some 470 km from the river mouth, has not affected the hilsa fishing in the tidal stretch of the delta. However; the barrage has nearly eliminated the riverine fishery upstream of Farrakka on the main stream of the Ganga, a fishery, which was based on runs of both Padma & Hooghly stocks (Natarajan, 1989).

River training and withdrawal of water (abstraction) also affect the flow regime of water in the rivers affecting the life habits of the organisms. The large scale abstraction alters the water quality by reducing the load bearing capacity of downstream water. Although, water abstracted for the various needs are drained back into the water system, but it is contaminated by a variety of substances detrimental to aquatic life. The dams, barrages, rivers and other hydraulic structures constructed on riverine ecosystem disturb the river continuity. The discharge downstream is reduced leading to habitat destruction both downstream and upstream. The migratory pathways of fishes are obstructed.

Siltation: Land use patterns in a watershed influence runoff, river hydrography and sediment load. Deforestation is a reason for the excessive silt load in most of the Himalayan river tributaries, a load, which has increased rates of siltation downstream in oxbow lakes, floodplain sloughs & backwaters (Natarajan, 1989). Reduction in forest cover has led to a great increase in both the dissolved and particulate solids in Ganga river system (Rao,1979). The Ganga and Brahmaputra carry highest sediment loads in the country. Of the major basins studied in the country more than one third carry sediment loads of 100 million tonnes or more, which is very high. According to Banerjee *et al.*, (1996), decreased discharges in Chilka lagoon through incoming rivers have made considerable negative impact on its fishery. Siltation of lagoon bed and its connecting channel with sea, profuse weed infestation, and decrease in salinity and qualitative and quantitative decline in the fishery of this lagoon have been observed

3.2.2 Recruitment

The impact of water abstraction is very obvious in river Ganga. Water abstraction and consequent reduced stream flow has affected the breeding and recruitment of fishes. The fish spawn availability index in river Ganga declined from 2984 ml in the 1960s to 27 ml in recent years (1994-2004) (CIFRI Annual Report, 1971-2004). It also showed a continuing deterioration of Indian major carps seed with decreasing percentage of major carps seed (78.62% in 1961-1965 to 34.48% in 2000-04) whereas minor carps (from 20.68% in 1961-65 to 52.95% in 1991-95) and other fish seed (from 0.7% in 1961-65 to 47.8% in 2000-04) showed an increasing percentage in total seed collection.

In the Ganga basin approximately 85 billion m^3 of water is diverted by canal project and by hydro-electric and storage reservoir for irrigation, power and flood control. Canal projects accounted for a little over 60% of the impounded water (Natarajan, 1989). The construction of flood control dykes and levees in flood prone low lying areas has deprived the major carps of their extensive breeding habitats, previously available in network of interlaced channels connected with the Kosi river (David,1959) and the flood plains of the Kosi, Gandak, Rapti, Sarju and other tributaries. Canal projects and flood control measures are the two major factors that are especially responsible for destruction of breeding habitat for major carps (Natarajan, 1989). The spawning grounds of Indian major carps are situated in the flood plains, which are inundated during the monsoon. It is believed that a flood level between 5-8 m helps the fish to migrate up to the breeding grounds and a moderate current (0.35 to 1.6km/hr) help the spawn to shift down. Breeding and recruitment are seriously hampered when the water level in the streams does not reach the spawning ground due to inadequate discharge rate. Flood levels have a close relationship with the spawn availability of major carps (Jhingran, 1989).

The oxbow lakes, deep pools and other lentic water bodies associated with the river act as sanctuaries for the brooders, which get connected to the mainstream during the monsoon, when the discharge rates become inadequate, these water bodies fail to get connected and the brooders get isolated.

3.3 Land use pattern alteration

It is expected that land use pattern in coming years will alter quite rapidly. As a result hydrological parameters of rivers and wetlands will be altered impacting fisheries development. A graphical representation of the likely changes to occur in hydrological parameters of importance to fisheries in response to alteration in land use pattern is depicted in figure 16.

			------------ **Activity** --------										
			Modification of land cover or land form			Water supply		Waste disposal			River modification		
			Removal of plant cover	Gravel extraction	Terracing	Major impoundments	Water abstraction (Irrigation)	Domestic sewage	Return of treated wastewater	Industrial wastewater	Bridge	Flood protection works	Canalization of rivers
Hydrological parameters	**Water quantity**	Precipitation	●	◦	◦	○							
		Surface run off	■	▫	▫	□	□				□	□	□
		Flood height	▫	▪	▪	▪	▪					□	◦
		Evaporation	•	•	•	●	◦						
	Water quality	Sediment level	●	●	◦	□	▫			•			
		Organic level	•	•	•	•	•	●		●			•
		Trace elements	•	•	•	•	•			●			●
		Dissolved oxygen	◦	•	•	•	◦	○	●	○			
	Fluvial geomorphology	Channel stability	□	□	▪	□	□				□		●
		Bank erosion	■	■	▫	□					□		○
		Silt deposition	●	■	●								

Type of effect				
	Positive/Increase		Negative/Decrease	
	Major	Minor	Major	Minor
Onsite	●	•	○	◦
Down Stream	■	▪	□	▫

Canter, 1996 (Modified)

Fig. 16. Impact of land use and changes on selected hydrological parameters

3.4 Climate change

Perceptible changes on a global and regional scale are evident in earth climate. In India observed changes are visible by an increase of air temperature, regional monsoon variation frequent droughts and regional increase in severe storm incidence in coastal states of India along with indication of Himalayan glacier recession. The impact is being felt in the inland aquatic resources and inland fisheries. Analysis of time series data of 30 years from published literature and from present investigation on River Ganges and water bodies in its plains indicate enhanced minimum water temperature by 0.99^{o}C in colder stretch of river Ganges and by 0.2 to 1.6^{o}C in the aquaculture farms of the State of West Bengal in the Gangetic plains. The rainfall also indicates a seasonal pattern of increase in the post-monsoon months of September –December. The impact is manifested in the breeding failure of the Indian Major Carps (IMC) and consequent decline in fish spawn availability in river Ganges. But in fish farm hatcheries in the plains a positive impact on breeding is evident by the advancement and extension of the breeding period of IMC by 45-60 days. A geographic shift of warm water fish species G*lossogobius gurius*, *Xenentodon. cancila* to the colder stretch of the river Ganges is recorded. The predator prey ratio in the middle stretch in the river Ganges has also narrowed down from 1:4.2 to 1: 1.4 in the last three decades. The fish production has recorded a distinct change in the last two decades in the middle stretch of river Ganges where the IMC has decreased from 4.1% to 8.3% and the miscellaneous and cat fishes increased. Climate change in India will put an additional stress on ecological and socio-economic systems that are already facing pressure (Das *et al.*, 2013).

3.5 Invasion of exotic fish species in Indian rivers

Investigations conducted by CIFRI revealed that in the stretch of river Ganga at Allahabad and Varanasi, the contribution of exotics, mainly common carp is approximately 15 to 30 % of the total catch, while in Yamuna both tilapia and common carp formed around 50-60% of the catch in Agra and Mathura stretch. Similar trend is recorded in peninsular rivers also. Reductions of flow rate and water volume resulting in stagnant waters with feeble current have helped in establishments of exotic species, *viz.* common carp and tilapia in Indian rivers. Since, these fishes got optimum condition for breeding and recruitment they have established in the system and their contribution is becoming significant. It is noteworthy that these exotics are not recorded below Varanasi in the river Ganges, may be due to improved hydrological regime with fast current and increased water volume (Das *et al.*, 2013)

4. Policy governing inland water management in India

Water is the most critical component of life support system. India shares about 16% of the global population but it has only 4% of the total water resource. The irrigation sector with 83% of use is the main consumer of water. Based on 1991 census, the per capita availability of water works out to 1,967 m^3. About 40% of the utilizable water resources are presently in Ganga-Brahmaputra-Meghna system. In majority of river basins the present utilization is significantly high and is in the range of 50% to 95% of utilizable resources. However, in rivers such as Narmada and Mahanadi, the percentage utilization is quite low viz., 23% and 34% respectively. It is expected that the pace of river and floodplain modifications will intensify in the coming years in response to the economic imperatives of development. This implies that inland fisheries will be placed under increasing pressure.

For inland fisheries water in the river and reservoir or lake serves as habitat for fish. For suggesting any measure or policy for inland fisheries development it is essential to understand the structure and mechanism of water quality governance in India. Basically it has three aspects; policy frame work to deal with water quality issues, a legal framework for violators of the policy and institutional framework to implement the policies.

4.1 Policy Framework

The policy framework of Govt. of India for management of water resources in India is elucidated in National Water Policy (2002); National Conservation Strategy and Policy Statement on Environment and Development (1992); Policy statement for Abatement of Pollution (1992) and Draft National Environment Policy (2004). The policy statements and strategies advocated are technological measures like use of clean technologies and water pollution control systems; zoning strategy like setting up of source specific and area wise water quality standards and time bound plans to prevent and control pollution; fiscal incentives and economic instruments like incentives for environmentally clean technologies for pollution command and control.

4.2 Legal Framework

Some of the environmental laws of importance are:

a. The Water (Prevention and Control of Pollution) Act, 1974 : It created the Central and State Pollution Control Boards (CPCB and SPCBs)

b. The Water Cess Act, 1977: It was amended in 2003 and its main attention is to enhance the finance of the CPCB and SPCBs by imposing a levy (cess) on water consumed by certain industries and by local authorities.

c. The Environmental (Protection) Act, 1986: It empowers the Central Government to decide emission standards, restricting industrial sites, laying down procedures and safeguards for accident prevention and handling of hazardous waste investigation and research on pollution issues.

d. The Environment Impact Assessment introduced in 1994, empowered Central Government to impose restrictions and prohibitions on installation expansions or modernization of 30 types of activities unless an environmental clearance is granted.

4.3 Institutional Framework

Water supply and sanitation is a state responsibility under the Constitution of India. The states may give the responsibility and powers to the Panchayati Raj Institutions (PRIs) and Urban Local Bodies (ULBs). At present, states generally plan, design and execute water supply schemes. In addition, a variety of different government institutions at the centre have a role in the management of declining of water supply.

Ministries of Water Resources, industry, power, agriculture, environment and forests, rural development, urban development are some of the major stakeholders that have a mandate in water resource management.

Other important institutions that have a major role in water resource/quality management are Central Water Commission, Central Groundwater Board/Authority, Central Water Quality Authority, Central and State Pollution Control Boards.

5. Strategies

- The inland aquatic resources in recent years are being subjected to increasing stress. On one hand these finite resources are getting stressed and depleted while on the other hand the sectoral demand is growing.
- In such a situation to develop a strategy or management policy for inland fishery where the inland aquatic resources serve as a habitat for fish, is very complicated. A rational water allocation policy needs to be developed and practiced which takes care of water requirement for aquatic flora and fauna including fish and fisheries, besides need for irrigation.

A reorientation of the water demand strategies is suggested laying emphasis on the following aspects

i. Participation of central water commission, ministry of agriculture, ministry of industry, MOEF, CPCB and SPCBs for rational physical resources allocation practices for all concerned institution including fisheries.

ii. Technology intervention to reduce misuse or overuse of the gradually depleting water resources in agricultural, industrial and domestic sector.

iii. Normally, the polluter of water, affecting some other party, in the form of health damage, reduction of agricultural output, costly industrial option, and reduction in fish production and loss of diversity is not held accountable. It is absolutely essential to quantify and monetize these effects for developing remedial plans for future.

iv. Proper pricing be applied in all water use sectors - agriculture including fisheries, industries and domestic so as to reduce demand.

v. Public participation and awareness creation. Local communities need to be involved in conservation practices for proper water management.

vi. Participation of all stakeholders in decision- making at local, regional, state and national level needs to be ensured.

6. Recommendations

The present paper has described the habitat status of major inland fisheries resources viz., rivers, estuaries, reservoirs and floodplain wetlands. The factors causing habitat degradation have been discussed and the impact of habitat degradation on fisheries has been elucidated. Policy paradigms with proper strategies for rational water management have been outlined. Below we give some recommendations to be adopted for proper health management in inland waters for sustainable fisheries:

1. River connectivity with their associated wetlands needs to be maintained to improve recruitments and restore aquatic biodiversity.
2. Although there is tremendous demand for water for irrigation, power generation, industrial uses, etc, the environmental flow requirements for protecting the biodiversity of aquatic resources should be given due emphasis.
3. Since siltation is the major cause of habitat degradation and loss of water volume, afforestation schemes should be given due priority in the water shed areas
4. Due to construction of dams the migration of fishes has been affected. Therefore construction of fish passes should be given due priority in all river valley projects.
5. Entry of untreated sewages should be stopped to avoid eutrophication and associated problems.
6. Impact of stocking in reservoirs with hatchery bred seeds to be studied keeping in view the natural population.
7. Aquatic weeds assume alarming proportions in number of wetlands. Proper management of wetlands to be done to manage the infestation of weeds.
8. Although there is huge demand of space, wetlands are to be protected and conserved realizing their tangible and intangible values.
9. Persistent anthropogenic pollutants in agriculture to be replaced phase wise with ecologically tailored safer chemicals.
10. Sanctuary areas be demarcated and conserved for maintenance of biodiversity in rivers and estuaries.
11. Importance and value of aquatic flora and fauna should be properly highlighted in any developmental projects to avoid long-term damage.
12. Emphasis should be given on maintaining the aquatic environments for harnessing the benefits in a sustainable manner and keeping in mind the role of all the stakeholders.
13. Rivers may be stocked with seed produced from the brood stock raised from rivers to restore the population of indigenous fish species.
14. A common framework should be created at the country level that can be used towards implementing the integrated watershed management strategy

starting from Gram Panchayet (village council) to the river-basin level in a unified manner. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. It also requires the collection of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions. This would greatly help inland fisheries development in future.

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