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Vulnerability of Inland Water Matrices in India to Anthropogenic and Climate Change Stressors Impacting Fish and Associated Organisms: A review

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ABSTRACT

The various water matrices in India the rivers, wetlands, ponds, waste water has been extensively used by human beings for various urban, agricultural, and industrial activities thereby subjecting these ecosystems to multiple stressors over time. A review of the impact various anthropogenic and climate induced stressors have been made in the presen communication. Sewage and industrial effluents containing metals, pesticides and antimicrobials have significantly degraded water quality. Physical stressors manifested by reduced flow pattern, obstruction to fish movement, siltation and climate change have altered the habitat status of water bodies. Habitat alterations in rivers induced changes in riverine fish composition manifested by dominance of small bodied cyprinids. Reduced flow induced dominance of exotic fish species *C. carpio* and *O. niloticus* in the middle stretch of the river. Geographic shift of warm water gangetic fishes *G. giuris*, *P. ticto*, *X. cancila*, *M. vittatus* upstream due to rise in annual mean minimum water temperature by 0.99°C is evident in Haridwar stretch of river Ganga. Risk assessment of pesticide and antimicrobial contamination in water matrices show alarming risk to fish and associated biota and human beings. Suggestion has been made for creating a common framework synchronizing permissible water quality contaminants targets and important physical attributes targets of environmental flow requirements for maintaining ecological health of fish and other associated biota in the different water matrices.

Keywords Anthropogenic stressors, Climate change,Water matrices, Pesticide residue, Antimicrobial residues.

INTRODUCTION

The varied inland freshwater matrices viz., rivers, wetlands, lakes, groundwater and waste water from STPs has been extensively used by human beings worldwide for various urban, agricultural and industrial activities subjecting these ecosystems to multiple stressors over time. Consequently degradation of

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these freshwater ecosystems have occurred, disrupting valued ecosystem services, like the provision of fish, other sources of food and fiber, drinking water as well as places for recreation, tourism and cultural activities affecting stakeholders (Strayer and Dudgeon 2010). Keeping pace with the global scenario the inland aquatic ecosystems in India have also degraded over the years by different pollutants from domestic, industrial and agricultural wastes (Das *et al*. 2014). Disconcertingly in recent years antibiotics improperly discharged through effluents from pharmaceutical industries, hospitals and domestic waste water treatment plants has become a major source of contamination of the inland aquatic environment in India. Mutiyar and Mittal *et al*. (2014) of serious concern is the fact that anti microbial drug residues combined with other existing environmental pollutants in various water matrices have resulted in sustenance and spread of antimicrobial resistance (AMR) and pathogenic bacteria in the aquatic environment (Gothwal *et al*. and Sharmal 2017, Taneja 2019). With the diminishing per capita availability of water at present projected at 1545 m^3/person/yr (2011 Census) an understanding of the vulnerabilities of the inland freshwater ecosystems and their impact on the fish fauna and associated biota is essential for sustainable management of the aquatic ecosystems.

With this scenario the present paper reviews the currently available research data on (i) The pattern of habitat alterations induced in the inland water matrices due to anthropogenic and climate change stressors, (ii) Their potential impact on fish and associated biota of importance, (iii) Suggestions for amelioration of these polluted water matrices.

Pattern of anthropogenic stressors induced aquatic habitat alterations

Research conducted by various workers in India analyzing data on some of the aquatic habitat stressors inducing perceptible habitat quality alterations relevant to fish and associated organisms in various water matrices are elucidated.

Chemical water quality stressors in rivers

Sewage : The severity of degradation of water quality of rivers is exemplified by the largest river Ganga in which more than 70% of the total pollutional load is contributed by the sewage. Sewage generation in India from urban areas is estimated at 72,368 MLD whereas installed treatment capacity of STPs is 31841 MLD (43.9 %). A huge amount of untreated waste water from rural areas goes into the major rivers, other water bodies and even percolates into the ground every day. Industrial pollutants constitute around 20% of the total pollutional load by volume. The problem of instream pollution is further aggravated by disposal of solid wastes, religious offerings, idols, dead bodies and carcasses (Das 2015). The CPCB report of 2015 reveals around 302 polluted stretches due to sewage and industrial wastes on 275 rivers in India. The estimated polluted riverine length is 12,363 km. The top five Indian states showing maximum number of polluted stretches are in Maharashtra, Assam, Madhya Pradesh, Gujarat and West Bengal.

Pesticides : India is ranked in the green peace report as the largest pesticide-producing country in Asia, with an annual production of 90,000 tonnes (Khan *et al*. 2010, Kumaraswamy *et al*. 2012). Approximately 50,000 tonnes of pesticides were utilized in the Indian agricultural field from 2011 to 2012 (Devi *et al*. 2017).

In recent years the concentration levels of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) synthetic pyrethroids and organophosphates recorded by investigators in the surface water of major Indian rivers Ganga ,Yamuna, Cauvery Brahmaputra, Hooghly, Tapti and Chilika along with their global standard guidelines are depicted in Table 1.

Antimicrobials : Large quantities of antimicrobials are produced and used in India as human and veterinary medicine which ultimately contaminate aquatic environment (Kurunthachalam 2012). A prime driver of antimicrobial resistance in India is because India is the highest human antibiotic user at 10·7 units per person, Van Boeckel *et al*. (2015). While clinical facilities have been investigated extensively for antimicrobials occurrence but prevalence of antimicrobial residues in the various water matrices have received little attention. Presently some investigation reports are available from water matrices

Table 1. Occurrence of pesticide concentration (µg/l) levels recently reported in some Inland water matrices in India. N.B.: AV (Acute Value), GV (Guideline Value), USEPA (United State Environmental Protection Agency), WHO (World Health Organization).

Pesticide	Rivers								Standard guidelines	
	Hooghly	Brahmaputra	Tapti	Chilika/ Daha	Yamuna	Ganga Haridwar	Ganga Varanasi	Ganga Patna	USEPA (AV)	WHO (GV)
α-HCH	ND- 0.022 (0.003)	ND- 0.006 (0.001)		0.025- 0.265						
β-HCH	ND-0.016 (0.003)	ND-0.006 (0.0004)								
γ-HCH	ND-0.028 (0.013)	ND-0.014 (0.006)		0.03- 6.08						
δ-HCH	ND-0.114 (0.019)	ND-0.012 (0.001)		0.05- 0.26						
ΣHCHs	8-0.114 (0.003)	ND-0.022 (0.008)				0.0052	0.0002- 0.0007	0.0003- 0.0050	2.00	
o,p'-DDD				8.99- 23.4						
o,p'-DDE				0.116						
o,p'-DDT	ND-0.026 (0.003)	ND- 0.113 (0.015)								
p,p'-DDT	ND- 0.005 (0.0003)	ND- 0.007 (0.001)			0.11- 0.13					
ΣDDTs	ND- 0.026 (0.004)	ND- 0.225 (0.030)					0.0001- 0.0019		1.10	2.00
Heptachlor	0.005-0.026 (0.014)	ND- 0.010 (0.001)		0.04- 1.0					0.52	0.03
Aldrin	ND-0.00 9 (0.004)	ND-0.005 (0.0003)							0.36	0.03
Dieldrin	ND-0.007 (0.0004)	ND- 0.019 (0.004)							0.36	0.03
ΣAldrin	ND- 0.009 (0.004)	ND-0.019 (0.004)				0.00012	0.0005- 0.0025	Nd-0.0011		
α-Endos- ulfan	ND-	ND- 0.009 (0.001)	0.43- 35.25		0.219- 0.324					
β-Endo- sulfan	ND- 0.010 (0.002)	ND-0.045 (0.003)	1.32- 37.56		0.236	0.00016				
ΣEndo- sulfan	ND- 0.010 (0.002)	ND- 0.053 (0.003)							0.22	
Chlorpyrifos			0.17- 0.86	0.02- 2.7			0.0845	0.0050	0.083	
Methyl parathion			0.28- 0.43							
References	Chakraborty *et al*. 2016		Hashmi *et al.* 2020	Nag *et al.* 2020	Saha *et al.* 2012	Mutiyar and Mittal. 2012			Hamilton *et al.*2003 and Copela- nd. 1999	Hamilton *et al.*2003 Helmar *et al.*1991

in India. Wastewater samples from STPs in South India quantified for antimicrobial concentrations of chloramphenicol, trimethoprim, sulfamethoxazole and ofloxacin by Akiba *et al*. (2015) revealed alarmingly high levels compared to regulatory PNEC concentrations (Bengtsson Palme and Joakim 2016) (Table 2). Rivers Isakavagu-Nakkavagu, Musi and adjoining water areas around Pharmaceutical industry PETLin Hyderabad recorded alarming prevalence of Flouroquinolones (Fick *et al*. 2009, Lubbert *et al.* 2017, Gothwal *et al*. 2017). Ramaswamy *et al.* (2011) reported high levels of Triclosan in Tamarapani river. Mutiyar and Mittal (2014) reported Ciprofloxacin, Ampicillin,Gatifloxacin,Sparfloxacin and Cefurox-

Table 2. Reported prevalence of antimicrobial concentration levels (μgl^{-1}) in Inland water matrices of India.

Antimicrobials	Class	Water matrices				
		STP-2 Domestic+ Hospital effluent	STP-3 Hospital effluent	Around Hyderabad PETL (pharmac-eutical factory)	Isakavagu river Upstream and downstream of PETL	Arkavati river
Ciprofloxacin	Flouroquinolones			19.4-44.7	12-10	ND
Enrofloxacin	Flouroquinolones				ND-0.064	ND
Norfloxacin	Flouroquinolones				0.68-0.14	ND
Lomefloxacin	Flouroquinolones				Nd-0.045	ND
Enoxacin	Flouroquinolones				7.5-2.6	ND
Ofloxacin	Flouroquinolones	1.715-2.469	0.5-0.537		0.91-0.63	ND
Amphicillin	B-lactams			BDL-29.1	ND	ND
Sulfamethoxozole	Sulfonamide	0.207-0.637	0.040-0.050	BDL-10.6	ND	0.018-0.108
Trimethoprim	Diaminopyrimidine	0.103-0.285	0.043-0.046		0.017- 4	ND
Triclosan	Antimicrobial				ND	0.297-1.761
Chloramphenicol (CLP)	Amide alcohol	< 0.01	< 0.01	ND	0.008-0.218	
Lomefloxacin	Flouroquinolones				0.045-1.100	ND
Sparfloxacin	Flouroquinolones					
Cefuroxime	cephalosporin					
Moxifloxacin	Flouroquinolones			7.1-694.1		ND
References		Akiba *et al*. 2015		Lubbert *et al*. 2017	Fick *et al*. 2009	Gopal *et al*.2021

ime in river Yamuna. Hanna *et al*. (2020)recorded Norfloxacin,Ofloxacin,Sulfamethoxazole in Khipra river. Gopal *et al*. (2021) recorded residues of Sulfamethoxazole, Triclosan and Chloramphenicol in Arkavathi river in southern India. A comparative assessment of the mean maximum concentrations of

Table 2. Continued.

Antimicrobials	Class	Water matrices				
		Yamuna river	Kaveri river	Musi river	Khipra river	PNEC
Ciprofloxacin	Flouroquinolones	BDL- 1.44	ND	6.5-5528	ND	0.064
Enrofloxacin	Flouroquinolones	ND	ND	2.57-123.4	ND	0.064
Norfloxacin	Flouroquinolones	ND	ND	16.14-217.5	0.67-0.98	0.5
Lomefloxacin	Flouroquinolones	ND	ND	3.59-10.32	ND	
Enoxacin	Flouroquinolones	ND	ND	ND	ND	
Ofloxacin	Flouroquinolones	ND	ND	1.55-318.1	0.64-1.23	0.5
Amphicillin	B-lactams	0.2-13.75	ND	ND	ND	0.25
Sulfamethoxozole	Sulfonamide	ND	ND	ND	0.2-4.66	16.0
Trimethoprim	Diaminopyrimidine	ND	ND	ND	ND	0.5
Triclosan	Antimicrobial	ND	0.0407 (mc) 0.139(hc)	ND	ND	
Chloramphenicol (CLP),	Amide alcohol	ND		ND	ND	
Lomefloxacin	Flouroquinolones	ND	ND	3.59-10.32	ND	
Sparfloxacin	Flouroquinolones	ND-2.09			ND	0.064
Cefuroxime	Cephalosporin	ND-1.7			ND	0.5
Moxifloxacin	Flouroquinolones	ND	ND	ND	ND	0.125
References		Mutiyar and Mittal 2014	Ramaswamy *et al*. 2011	Gothwal *and Thatikonda* 2017	Hanna *et al*. 2020	Palme and Larsson 2016

some of the most commonly used antibiotics in Indian rivers (Table 2) reveal concentrations levels of Flouroquinolones (ciprofloxacin, norfloxacin, ofloxacin and enrofloxacin) and sulfomamide (Sulfamethoxazole) to be manifold times higher compared to predicted no effect concentration (PNEC) guideline values.

The vast majority of aquaculture farms directly discharge both left over antibiotics and organic matter (faeces and fish alimentation residues) into the surrounding water. Investigation on the use of aquadrugs in freshwater fish hatcheries of West Bengal,India (Bharath Kumar and Jawahar Abraham 2011) showed regular use of drugs such as oxytetracycline, althrocin, ampicillin, sparfloxacin, enrofloxacin, acriflavine, formalin, potassium, permanganate, malachite green for prophylactic and curative purposes. Unfortunately the current Indian standard do not include antibiotic residues in water and thus they are not monitored in the various water matrices in India (CPCB Effluent Standard 2017).

Physical water quality stressors

Reduced flows : Tributaries are the major source of water in the Ganges, but flow of most of them has been affected due to water development works for irrigation, hydropower development and flood control. Major river systems in India are interrupted by construction of series of dams disrupting their connectivity and flow pattern. The mean water level in the Ganges at Allahabad has decreased to approximately 1 meter .The mean water velocity has also decreased ranging from 0.2-0.7 m sec−1 in the upper stretch, 0.03–2.1 m sec−1 in the middle stretch and 0.04–0.1 m sec−1 in the lower stretch. (Das *et al.* 2013a). Loss of habitat connectivity has resulted in the extinction of many migratory fish species especially Hilsa and mahseers (Gopal 2003).

Siltation: Studies reveal that the river Ganga mobilizes a total of $729x10^6$ tons of sediment annually within its river valley (Vass *et al*. 2011). The increase in sediment load has altered the water regime of the biologically sensitive deep pools and flood plain lakes of the river which play a vital role in the eco-restoration of the river.

Climate change induced water quality alteration

Global and regional scale changes is being witnessed in earth's climate. Recent assessments (IPCC 2014) on climate variability in India predict i) Increased incidence of flood, drought, tropical cyclones ii) Without additional mitigation, global mean temperature is projected to increase by 3.7 to 4.8°C iii) Sea level to rise by ~50 cm by 2100 iv) Increasing water stress.

Researches conducted to have an understanding of the specific alteration in the aquatic habitat quality occurring over the years in India due to climate change are elaborated.

Enhanced temperature : Analysis of time series data of 30 years from published literature and from current investigations indicate an enhancement of 0.99ºC of minimum water temperature in upper stretch of River Ganga (Haridwar) (Das 2013b).

Rainfall variations : Time series analysis of the monthly data of rainfall in the middle stretch of the river Ganga at Allahabad revealed that the percentage of total rainfall during (May- Aug) declined by 7% whereas it increased by 4% in (September-December) the post- breeding period of Indian Major Carps (Vass *et al.* 2009, Das *et al*. 2013b).

Storms and cyclones : The sustainability of the existing ($6000km^2$) of mangroves in India may undergo major alteration in coming years due to climate change leading to further destruction (Center for Science and Environment 2012).

Pattern of alteration in wetlands

Most of the wetlands in India are directly or indirectly linked with major river systems such as the Ganges, Cauvery, Krishna, Godavari and Tapti . Wetlands support large biological diversity and also provide a wide array of ecosystem goods and services. India has lost more than 38% of the wetland in the last decade with the loss rate being as high as 88% in some districts (Wetlands Rules 2010).

The coastal wetlands of Sunderbans mangrove area is witnessing rise in sea surface temperature and sea level rise which has the potential of affecting the fish distribution pattern and destruction of the mangrove ecosystem.

Potential impact of stressors on fish and associated organisms

Impacts on fish and associated biota is evident from the investigations conducted by researchers utilizing either field based time series data or simulated experimental data of physical , chemical and biotic components of different aquatic matrices.

Fish recruitment : The fish spawn availability index in river Ganga declined. It also showed a continuing trend of decreasing percentage of major carps seed (Anonymous 1994–2017). Absence of adequate flood levels in floodplains required during the monsoon months for breeding of gangetic carps is a major reason for the decline (Das 2013a).

Fish composition : The large bodied Indian major carps (IMC) with periodic life-history strategies have significantly declined in the middle stretch of the river Ganga. The gradual dominance of small bodied cyprinids exhibiting an opportunistic as well as periodic type life history in the river initiated a trophic shift towards carnivores in the river as reflected by the increased abundance of catfishes(37.07–59.92%)with equilibrium life history strategies (Das *et al*. 2013a).

Exotic fish species dominance : In the Allahabad and Varanasi stretch of river Ganga, the share of exotics is mostly that of common carp and is approximately 15 to 30 % of the total catch. In river Yamuna (Agra and Mathura) stretch *C. carpio*, *O. niloticus* and *C. garipenius* constitute approximately 18-25% of the catch (Vass *et al*. 2011, Das *et al.* 2013a). The reduced flow and depth especially in the middle stretch of the river provided an optimum habitat for the exotic fish species *C. carpio* and *O. niloticus* which were recorded in sizeable numbers.

Alteration in fish species richness in rivers : Time series data 1994–2009 of 7 climate related variables viz., Mean annual water temperature, Mean annual water temperature range, Mean annual rainfall in basin area, Mean annual discharge, Mean annual sediment load, Total surface area of drainage basin, Mean latitude of fourteen major rivers of India (Brahmaputra, Periyar,Cauvery, Sabarmati, Ganges, Godavari, Tapi, Krishna, Beas, Mahanadi, Sutlej, Mahi, Damodar, Narmada) for the years1994–2009 were quantitatively analzsed for determining their influence on fish species richness. The most influential determinants of species richness were i) Surface area of the river basin (0.439) followed by fish habitat availability potential (0.326) a synthesis of the variables rainfall, discharge and sediment load. The predicted loss of fish species is evident at a 10% alteration in the ecological variables of the rivers in most of the rivers (Das *et al.* 2012).

Geographic shift of fish species : Several warm water fish species viz. *Glossogobius giuris*, *Puntius ticto*, *Xenentodon cancila* and *Mystus vittatus* are now recorded in the colder upper stretch of river Ganga from Deoprayag to Haridwar. The increase in the minimum water temperature by 0.99ºC in the stretch of river Ganga around Haridwar during the period 1980-2009 has provided a congenial habitat for upward shift. These species were earlier found only in the middle warmer stretch of the river as revealed by published records (Vass *et al.* 2009,Das *et al.* 2013b).

Impact of cyclones : Assessment of the potential impact of extreme events like cyclones and storms in the coastal Gangetic districts of West Bengal (South 24 Parganas) conducted during the occurrence of cyclone Aila in May 2009 revealed that the average water salinity in the rivers Hooghly and Matla increased from 12 to 17 ppt and in the inland confined water from 8 to 23 ppt. As a result agriculture and aquaculture activities were disrupted (Das and Sharma 2010).

Digital Elevation Model generated for the coastal areas of South 24 Parganas district showed that during cyclones a 1 - 2 m rise in sea level, 11% land area constituting agricultural fields and aquaculture pond becomes highly vulnerable to inundation in the district (Das *et al.* 2013b).

Impact on wetland biota : As per estimates, India will lose about 84% of coastal wetlands and 13% of saline wetlands with climate change induced sea water rise of 1 m (Blankespoor *et al*. 2012). Decreased precipitation and rise in temperature can aggravate the problem of eutrophication, leading to algal blooms, expansion of aquatic macrophytes, and affecting the spawning and nursing grounds of fishes (Gopal *et al*. 2010, 2003).

Pesticides impact on aquatic biota : Pesticides contamination in surface water raises ecotoxicological concern . Chakraborty *et al.* (2016) assessed ecotoxicological risks for flora and fauna for sites of river Brahmaputra and Hooghly detected with OCP residues using the hazard quotient (HQ) approach. They observed algae, dinoflagellate and diatom, waterflea, scud and grass shrimps were affected by lindane, DDT and endosulfan in both the rivers. Elevated DDT and lindane concentration impacted phytoplankton and zooplankton. At the higher trophic level, insects like Mayfly were affected by DDT, endosulfan and lindane. Their study showed endosulfan had higher impact on edible fish species viz. *Catla catla*, *Anguilla anguilla*, *Lepomis macrochirus* and *Labeo rohita* in river Brahmaputra and *Catla catla* and *Lepomis macrochirus* in river Hooghly. Of concern is the fact that besides potential risk for the aquatic environment, endosulfan has potential to bioconcentrate and biomagnify in food chain causing risk for human health.

Impact of antimicrobial residues : Evaluation of ecological risk assessment due to contamination of antimicrobial residues in aquatic environment of India is limited. Three studies conducted on this important area of public health relevance are those of (Mutiyar and Mittal 2014, Ramaswamy *et al.* 2011 and Gopal *et al.* 2021). They attempted to quantify the ecological risk assessment of a chemical compound in terms of the Hazard quotient (HQ). The low, medium, and high risk of specific chemicals on the organism is indicated by 0.1, 0.1–1 and > 1 value of HQ/RQ respectively (Forum 1998, Ramaswamy *et al.* 2011).

Ramaswamy *et al.* (2011) determined high levels of antimicrobial Triclosan (TCS) with HQ values ranging from 4.7- 1,543 from the Vellar, Kaveri, and Tamariparani rivers. High HQs for (TCS) indicate high risk of impact on local algal communities, with possible effects extending to other trophic levels of the ecological web.

Mutiyar and Mittal (2014) determined potential ecological risks HQs for different antibiotics residues in Indian water matrices viz., hospital effluents, treated sewage water, industrial waste water, river water and ground water using data previously reported in the literature. Hospital waste water showing high concentration of ciprofloxacin showed the highest HQ (219) to test species like bacteria, algae, invertebrates and fish . The authors opined that 66 % of the drugs reported for Indian hospitals effluents had a HQ >1.

HQs developed for antibiotic residues present in the effluents from the Waste Water Treatment Plants receiving pharmaceutical industry effluents in India pose severe risk to most of the test species like bacteria, algae, fish and arthropods. The maximum HQ value obtained for ciprofloxacin (HQ=36,885), is the greatest HQ ever reported for an industrial effluent. Dilution of pharmaceutical industrial effluents in small to medium rivers may not completely remove the associated hazards, as toxic effects on test organisms are still reported from 60 to 500 times distilled water-diluted pharmaceutical industrial effluent (Larsson *et al*. 2007, Gunnarsson *et al*. 2009).

Specific Indian rivers polluted with high antimicrobial residues were evaluated in the tributaries of Manjira River and Tamariparani River, Tamilnadu which had alarmingly high levels of antibiotic residues. The estimated HQ for the antibiotic residues in these rivers showed extreme high risk (HQ=25–4,098) posed by ciprofloxacin . Other fluoroquinolones also pose high risks to test organisms viz., bacteria, algae, invertebrates fish and arthropods.

The detection of antibiotics residues is alarming for ecosystem sustainability. These compounds are specially engineered to show their effect at trace levels. Development of various resistant bacterial strains of pathogenic importance associated with discharges of antibiotics as opined by Kummerer (2004) has been reported by several workers in various Indian rivers.

Majority of the aquaculture farms directly discharge both leftover antibiotics and organic matter (faeces and fish alimentation residues) into the surrounding water. The major concern with antibiotic usage is acquisition of multiple antibiotic resistance (MAR) which has been reported in fish pathogens and bacteria from aquaculture environs associated with the variety of drugs or uncertain antibiotic usage (Abraham *et al*. 2004).

The use of antibiotics in aquaculture may contribute directly to an increase in the level of antimicrobial resistance among bacteria in the fish intestines, in the aquatic environment (De Paola 1995). Accumulation of average antibiotic residue concentration (in ppb) in farmed shrimps in the range of Chloramphenicol (0.087 -0.176), Sulphonamide (27.69– 65.60), Erythromycin (0.41 – 61.12), β-Lactams (ND -35.92), Streptomycin (ND) and Tetracycline (ND – 44.44) as reported by Swapna *et al*. (2012) is a matter of concern.

It is evident from the studies conducted in India that the concentrations of antimicrobial residues recorded for Flouroquinolones, Sulfonamides are well above the PNEC values used by environmental regulators globally and pose environmental risk to the aquatic environment (Table 2). Disconcertingly the risk arising from high levels of antibiotic residue in water matrices not only affect the resident aquatic organisms,but helps in the sustenance, propagation and dispersal of antimicrobial resistance (AMR) in human and other animals using water.

Suggestion for amelioration of aquatic environment

The impacts occurring in the water matrices specially rivers and wetlands due to antropogenic and climate change stressors cannot be looked at in isolation, it needs a holistic assessement. Water quality surveillance to maintain ecological integrity of the aquatic environment specially rivers in India need priority attention. India being a global hotspot of AMR a detailed information on antibiotic residues, antimicrobial bacteria and antimicrobial resistant genes in the aquatic environment will help to achieve a reliable basis of environmental risk assessment and take proactive steps to tackle antibiotic contamination. A common framework needs to be created for all the water matrices in each river basin of India with clear habitat health objectives for fish and other associated biota. This would entail containing multiple stressors effect by synchronizing permissible water quality contaminants targets and important physical attributes targets of environmental flow requirements for maintaining ecological integrity of the different water matrices. A unison of political will of the Central and State Governments is needed to implement the measures adopted in the plan stringently. Finally, it is felt that a mass movement involving all communities and ordinary people in implementing the ameliorative measures for restoration of the aquatic environment in India.

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