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STATUS OF BENTHIC MOLLUSCS AS POLLUTION BIOINDICATORS IN RIVER GANGA

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Benthic fauna of river Ganga is diversified and distributed over a vast stretch of land. These organisms are often used as biomarkers of the environment to detect the pollution status of the river. Based on the availability of the common molluscan species in the Gangetic river, the bioindicators are identified. A detailed description about the benthic molluscan community has been depicted the study. A health card has been shown for easy detection of the pollution status of the riverine health. This detects the pollution indicator species in the river stretch. The article sums up the knowledge of riverine health through molluscan community of river Ganga.

River Ganga originates from the southern part of the Greater Himalayas, the Gangotri glacier (Gomukh), travels through the cold hilly terrains of Uttarkashi, the Indo-Gangetic plains of Uttar Pradesh, Bihar, Jharkhand and West Bengal, to the tropical brackishwater regions of Sundarban deltas. The river on its way covers a vast stretch of geological landscape and goes through vivid climatic alterations. This perennial river is also supplied with an ample amount of rainwater brought down by the south westerly monsoon winds and accompanied by the tropical cyclones from the Bay of Bengal from June to October. The Ganga river is an open ecosystem that is highly susceptible to human interference. The fertile basin of Ganga supports more than 1 million people covering half of India's population. Since 1990, pollution in the Ganga River has been steadily increasing. The major source of pollution in the river is the discharge of untreated sewage, industrial effluents, agriculture runoffs and anthropogenic wastes like washing, cleaning and ritualistic practices. The wastes tend to deposit in the sediment or dissolve in the riverine water thus affecting the sedentary benthic organisms. Different indicators are used to assess the state of the river's health. Biomonitoring is one of the most prevalent and low-cost ways of detecting river water quality. From a management standpoint, the benthic macroinvertebrate has long been employed as a biological indicator of water quality and biological integrity. Throughout the year, any change in population, diversity, or life cycle of these benthos can reflect the extent of water pollution.

The benthic fauna is made up of all the organisms that reside at the bottom of any aquatic body or even terrestrial land, either stationary or motile. The benthic zone is the lowest layer of a lake, sea, stream, or river, and it is where the benthos live. This zone includes everything from the shallow depths where water meets land to the deepest depths that are yet to explore. Benthos, on the other hand, can be found crawling, burrowing, swimming near the bottom, or remaining connected to the substrate. Many benthos eat food that sinks to the bottom, such as inorganic debris and dead organisms, but the benthos also eat each other. In the benthic zone, the phytobenthos, zoobenthos, and benthic microflora correspond to primary producers, consumers, and decomposers, respectively. Some of the freshwater macrobenthic faunal diversity constitutes Phylum Mollusca primarily *viz*. Class Gastropoda and Pelecypoda. In India, Ganga being the largest river in the country acts as a reservoir for many

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benthic invertebrates. The most common and abundantly found gastropod species are *Filopaludina bengalensis*, *Melanoides tuberculata*, *Brotia costula*, *Tarebia granifera*, *Lymnaea acuminata* and *Pila globossa*, whereas the bivalve species comprise *Novaculina gangetica*, *Lamellidens marginalis, Parreysia corrugata* and *Corbicula sp.* Among the estuarine species, *Telescopium telescopium*, *Nassarius stolatus* and *Vittina smithii* are common available species sustaining the Ganga River.

Classification of Benthos

Benthic organisms use the total bottom area of an aquatic environment. According to Yuxin[1], they are divided into three types based on their habitat. 1. *Hyperbenthos*- are the species that can swim and live near the water surface but are not linked to it. Organisms like ostracods, copepods, isopods, amphipods mysids etc. ranging from 0.5 mm to less than 500 µm size are termed Hyperbenthos[2]. 2. *Epibenthos*- which includes sponges and coral reefs ecosystem, spend their lives adhering to the floor, on rocks, or shells, and 3. *Endobenthos*- they have evolved to live within the sediments, often forming underground tunnels, rather than on top of the river floor primarily polychaetes, oligochaetes, mussels, sand dollar etc.

Phytobenthos is a term used to describe the principal producer (e.g. different types of algae and aquatic plants). Zoobenthos, on the other hand, encompasses all predators (such as benthic animals and protozoa). Dissociative communities are formed by benthic microflora (bacteria, fungus, and numerous protozoa). They participate in the recycling of energy and vital nutrients by churning the sediments thoroughly.

Benthos can be further categorized according to their size. Macrozoobenthos or macroinvertebrates are large benthic animals (1 mm) that can be seen without a microscope. They are devoid of vertebrae. They spend a portion of their lives on or at the bottom of specific reservoirs. Snails, oysters, insects, amphipods, crayfish, and the larvae of many aquatic insects are among them (such as dragonflies, stoneflies, caddisflies, chironomid midges and blackflies). Meiozoobenthos are species that measure upto (0.1 mm) like ciliates, annelids, kinorhynchs etc., while macrobenthos comprises bacteria and ciliates (100-500 µm).

Importance of Benthos on Aquatic Ecosystem

Benthic macroinvertebrates serve a crucial role in nutrient cycling and ecosystem nutrient outflow management. The benthos converts organic waste from sedimentary storage into dissolved nutrients that can be blended with overlying waters and used to boost primary productivity by macrophytes (rooted plants) and phytoplankton (algae). Omnivorous benthic species graze on macrophytes, algae, and Zooplankton. Fish eat a variety of benthic organisms. Benthic invertebrates can impact microbial production and release of greenhouse gases (CO_2 and CH_4), toxic gases (H_2S and NH_4), and nitrogen, both directly and indirectly, by mixing sediments and consuming a variety of nutrients (N_2).

Phytoplankton, zooplankton, and fish populations are all connected through benthic macroinvertebrates. Monthly benthos measurements can be used to determine the productivity of an aquatic environment. The ability to measure trophic bases for fish requires an understanding of the net production and absorption of benthic organisms. Many benthic species play an essential role in biological water cleaning in addition to being used as fish food.

Benthos are also important food sources for creatures in the ecosystem. This shows how productive water is. Fish farming in controlled water bodies is made possible by these creatures, which provide the essential food for the fish. The distribution of benthic creatures varies dramatically from season to season. Seasonal changes in benthos abundance and amplitude, as well as the influence of physicochemical conditions at various depths, affect benthos abundance and amplitude.

Benthic molluscs are sentinel species to determine the aquatic environmental changes. Molluscan species maintain an intimate association with the sediments of lotic and lentic ecosystems. These organisms remain attached to the bottom substratum for a consecutive time and undergo the stress and cofactors affecting the river's health. Therefore, they can be considered major biomonitoring agents to reveal the effects of pollutants and their toxicity on the biotic organisms of the river. The determination of heavy metal accumulation, residues of pesticides, industrial toxic effluents, microplastic disposition etc. are well observed in these molluscan species. The macroinvertebrate population of the order Prosobranchia depicting families like Viviparidae, Ampullariidae and Thiaridae shows dominance during premonsoon and monsoon. These organisms are tolerant of organic-rich sediments[3]. Molluscs are bioindicators of heavy metal accumulations like copper, cadmium and lead[3]. The metal contamination in gastropod species is represented in increasing order *Theodoxus jordani* >*Bellamya unicolor* >*Physella acuta* >*Biomphalaria alexandrina* >*Bulinus truncates* >*Planorbella duryi* >*Cleopatra bulimoides*[3]. Since these species are often edible and belong to the lower food chain, they can biomagnify the pollutants through the food web and food chain and slowly affect the human race.

Types of Benthic Molluscan Diversity at Different Stretches of River Ganga

According to ICAR-CIFRI sampling status (2017-2021), a total of around 33 different dominant molluscan species are distributed from Harshil to Frasergunj. The details of the available species are tabulated in Table 1. All the stations were found to be dominated by Gastropods, among them the most dominant benthic fauna was *Filopaludina bengalensis* at the Lower stretch, *Tarebia granifera* in the Middle Stretch and *Assiminea*

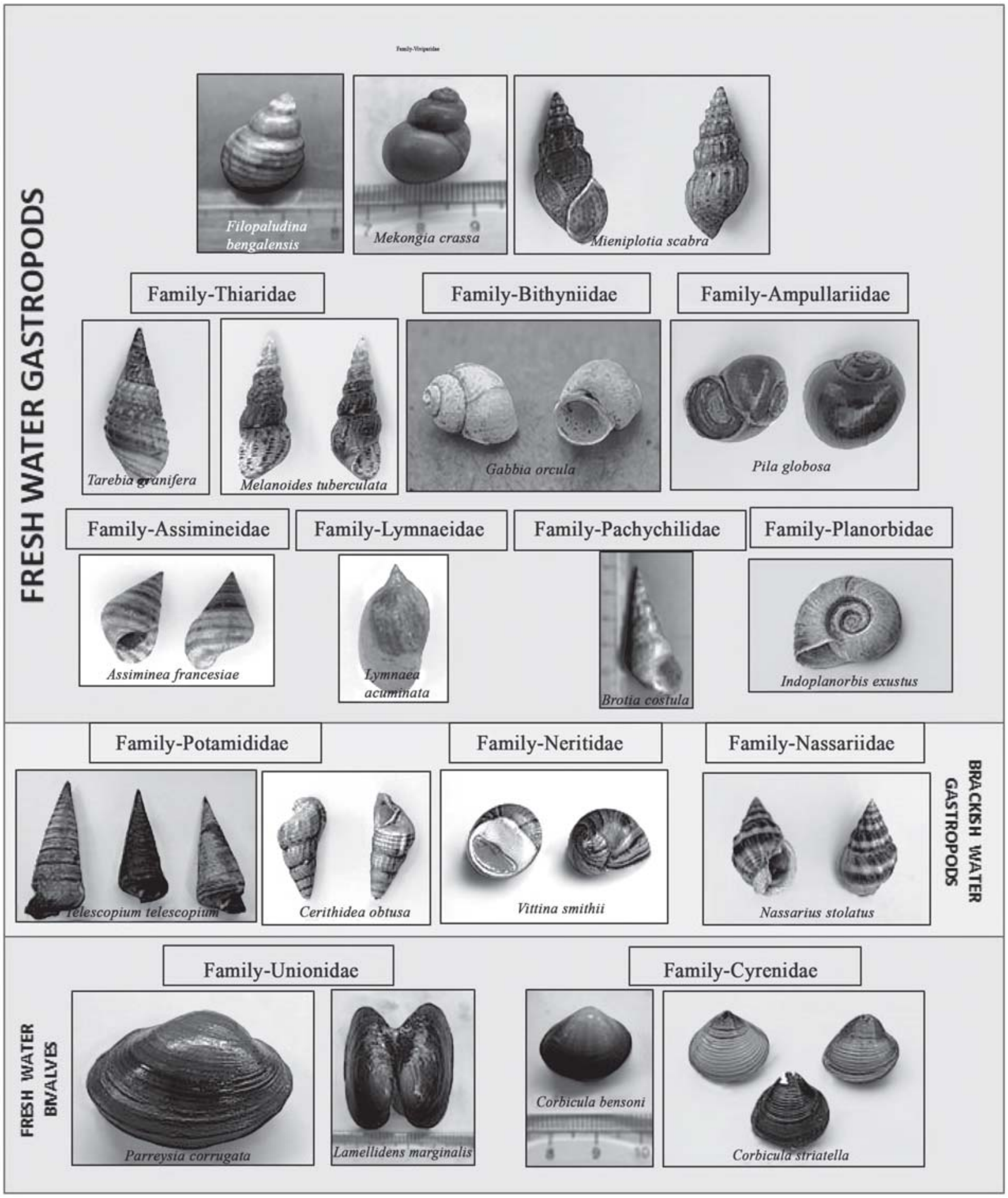

Fig. 1 Benthic Molluscan Diversity in Ganga

Table 1 Freshwater benthic molluscan diversity recorded along the river Ganga from Harshil to Fraserganj. Numerical "1" denotes the presence of macroinvertebrates and "0" denotes the absence of the species at a particular site.

Class	Species	Harsil	Tehri	Haridwar	Bijnor	Narora	Farrukhabad	Kanpur	Praygraj	Varanasi	Buxar	Patna	Bhagalpur	Farakka	Jangipur	Berhampore	Balagarh	Tribeni	Godakhali	D. Harbour	Fraserganj
	Physella acuta	0	0	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0
	Filopaludina bengalensis	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Mieniplotiascabra	0	0	0	0	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0
	Mekongiacrassa	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0
	Melanoidestuberculata	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0
	Assimineafrancesiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
	Brotiacostula	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Gastropoda	*Tarebiagranifera*	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
(Freshwater)	*Gyraulusparvus*	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	0
	Gyraulusconvexiusculus	0	0	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
	Lymnaea acuminata	0	0	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0	0	1	0
	Racesinaluteola	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	Gabbiaorcula	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	0	0
	Indoplanorbisexustus	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0
	Pila globossa	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
Gastropoda	*Neritabalteata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
(Estuarine)	*Neripteronviolaceum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Vittinasmithii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Volegaleacochlidium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Cerithideaobtuse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Pirenellacingulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Telescopium telescopium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Nassariusstolatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Nassariusfoveolatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Ancilla ampla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Murex Tribulus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bivalvia	*Novaculinagangetica*	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0
(Freshwater)	*Lamellidenscorrianus*	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
	Lamellidensmarginalis	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	Parreysiacorrugata	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	Parreysiaoccata	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0
	Corbicula striatella	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0
	Corbicula bensoni	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0

francesiae is dominant at the Estuarine Stretch of the river Ganga (Fig. 1).

Other species in the benthic community of river Ganga includes class Insecta and Clitellata. 12 different types of insects were recorded form Harsil to Buxar. *Anax* sp., Dragonfly, *Enallagma* sp., *Notonecta* sp., *Caenis* sp., *Leptophlebia* sp., *Heptagenia* sp., *Cinygma* sp., *Beatis* sp., *Psephenus* sp., *Rhycophila* sp. etc are found along the banks of river Ganga. Chironomid larvae is a common freshwater diptera species which dominate the sediment of the river. It is a good source of food for the benthic scavenging fish species. Annelid species recorded during the study period showed the abundance of *Tubifex tubifex* in the upper stretches of river primarily at Kanpur, Hardiwar and Varanasi. These species move through the sediments, charn the soil particles and therby enhance the nutrient content of the soil.

Molluscs as Bioindicator Species

***Bioindicators*:** Bioindicators are sentinel species or a community in an ecosystem which predicts the hazardous changes occurring in the environment. These species indicate the degree of contamination and changes in the normal state of the environment[3]. The process of biomonitoring through the implication of bioindicators in the ecosystem shows behavioral changes which provide factual information about the past and present condition of that ecosystem[4]. Bioindicators like planktons, molluscs, benthic macroinvertebrates, fish etc. diversities and abundance are highly affected by the presence of pollution[5]. According to Kumari and Paul[2], some stress proteins are released in these organisms due to environmental stress which causes ecological variations (changes in the population density), behavioural changes (dispersal of organisms from the polluted sites) and physiological alterations.

Significance of Bioindicators: Biotic and abiotic components of an ecosystem reflect the impact of pollution on the environment. The physical and chemical properties of an aquatic system cannot detect the effects of pollution; it is only the presence of living organisms or communities in the ecosystem which depicts the changes first. These organisms provide clues about the alterations in the habitat. Since these organisms remain in the sediment, they are the first affected by the different polluting agents like metal, pesticides like PAH, microplastics, industrial effluents, microbiological blooms, nutrient pollution etc. The presence and detection of bioindicators in a system is a cost-effective process for analysing ecosystem health[6].

Reasons for Selecting Molluscsas Indicator Species

1. Molluscs are widely distributed all over the world in a wide range of ecosystems from terrestrial to freshwater as well as marine.
2. They have extremely low mobility which enables the deposition of pollutants easily.
3. Freshwater molluscs have a pelagic larval stage which disperses into the contaminated zones where sexually matured organisms have been extinct.
4. Pollution highly influences the reproductive stages of the gastropods and bivalves which helps in the estimation of contamination levels.
5. These species are large and prominent, thus they can be easily handled in the field as well as in the laboratory for active and passive monitoring.
6. Molluscs lack exoskeleton structure like arthropods, hence a greater deposition of chemicals and metals in the gastrointestinal tract and gills are prominent.
7. For ecotoxicological research and test animals, molluscan species are regarded as non-controversial organisms.

Role of Molluscs as Bioinidicators

Molluscs are the second largest phylum in the invertebrate group. Among the 7 classes of Mollusca, gastropods comprise 80% of the species while bivalves comprise 15%, 5% belong to the other classes of phylum Mollusca like Cephalopoda, Aplacophora, Monoplacophora, Polyplacophora and Scaphopoda[7]. Sediment is considered the sinkhole for the pollutants to aggregate in the aquatic system. The molluscan community mainly remains attached to the bottom substratum and undergoes all the ecophysical and chemical alterations the river is going through. “Mussel Watch” was an approach taken by the United States of America in 1976, to perform large-scale environmental surveillance over a vast geographical area[7-9]. Marine bivalves (*Crassostrea virginica*, *Mytilus* sp. and *Ostrea equetris*) were used to measure the level of pollutants. Tissues taken from 100 bivalve samples were collected from the coasts of North America to analyse heavy metals, halogenated hydrocarbons, petroleum hydrocarbons and radionuclides. Gastropods and bivalves are the keystone species of an ecosystem (terrestrial, marine and freshwater) that respond to the negative impacts of the total ecosystem.

Heavy metals like mercury (Hg), arsenic (Ar), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), zinc (Zn), manganese (Mn) and iron (Fe) do not degrade in the natural environment. Hence, they accumulate in the soft tissues of benthic organisms primarily molluscs and tend to magnify in the next trophic level. Bioaccumulation of metallic deposition in living organisms results due to environmental factors like pH, hardness, alkalinity, salinity etc.[10]. Metal concentrations of Cd and Zn were found to be higher in females than in male, thus sexual dimorphism plays an important role in the bioaccumulation of metals[11, 12].

Plastic particles accumulate on the sediments for many years while some particles tend to resuspend in the water column[13]. The epifaunal molluscs take up the microplastics through the filter-feeding mechanism, while the infaunal organisms ingest the microplastic particles within the sediment and remnants are assimilated in the digestive tract[14]. *Mytilus edulis*, a common saltwater bivalve species is reported to have reproductive stress due to ingestion of microplastics and is considered an indicator species for MP contamination[14]. Bioturbation is another method of benthic organisms, through which the smaller particles of plastics are transported to different levels of sediment[15]. The impacts of these pollutants on living organisms are far more challenging. The phenomenon of imposex is

Table 2 Classification of Molluscan Species According to the Different Pollution Level

Range of Saprobic Score (0-10)	Range of Diversity Score (0-1)	Water Quality	Biological Water Quality Class	Species	Places	Sates
7 and more	0.2 – 1.0	Clean	A	*Physella acuta*	Harshil, Tehri and Haridwar	Uttarakhand
6 – 7	0.5 – 1.0	Slight Pollution	B	*Corbicula striatella* *Corbicula bensoni* *Lymnaea acuminata* *Physella acuta* *Lamellidens corrianus*	Haridwar, Varanasi, Bhagalpur, Farakka, Kolkata (Shibpur Ghat)	Uttarakhand, Uttar Pradesh, Bihar, West Bengal
3 – 6	0.3 – 0.9	Moderate Pollution	C	*Assiminea francesiae* *Filopaludina bengalensis* *Mekongia crassa* *Parreysia corrugata* *Pila globossa* *Gabbia orcula* *Corbicula striatella* *Corbicula bensoni* *Lymnaea acuminata* *Vittina smithii* *Novaculina gangetica* *Melanoide stuberculata* *Lamellidens marginalis*	Bijnor, Narora, Farrukhabad, Kanpur, Varanasi, Buxar, Patna, Bhagalpur, Sahibganj, Farakka (Upstream & FTPS), Nabadwip, Kolkata, Diamond Harbour	Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal
2 – 5	0.4 – less	Heavy Pollution	D	*Lymnaea acuminata* *Gyraulus convexiusculus* *Indoplanorbis exustus* *Filopaludina bengalensis* *Melanoides tuberculata*	Haridwar, Varanasi, Patna, Nabadwip, Tribeni,	Uttarakhand, Uttar Pradesh, Bihar, West Bengal
0 – 2	0 – 0.2	Severe Pollution	E	NA	NA	NA

Source: CPCB Report 2017

Clean, Slightly Polluted, Moderate Polluted, Heavily Polluted, Severely Polluted,

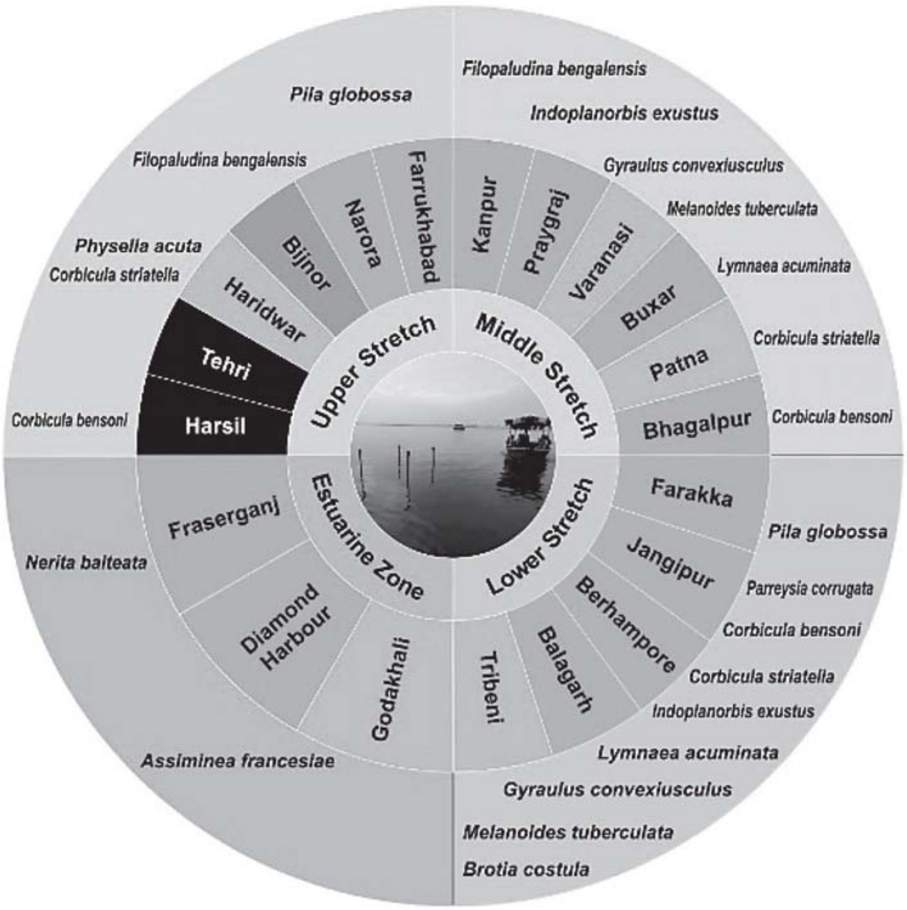

Fig. 2 Riverine Health Card: Based on the availability of macrobenthic mollusks along Ganga

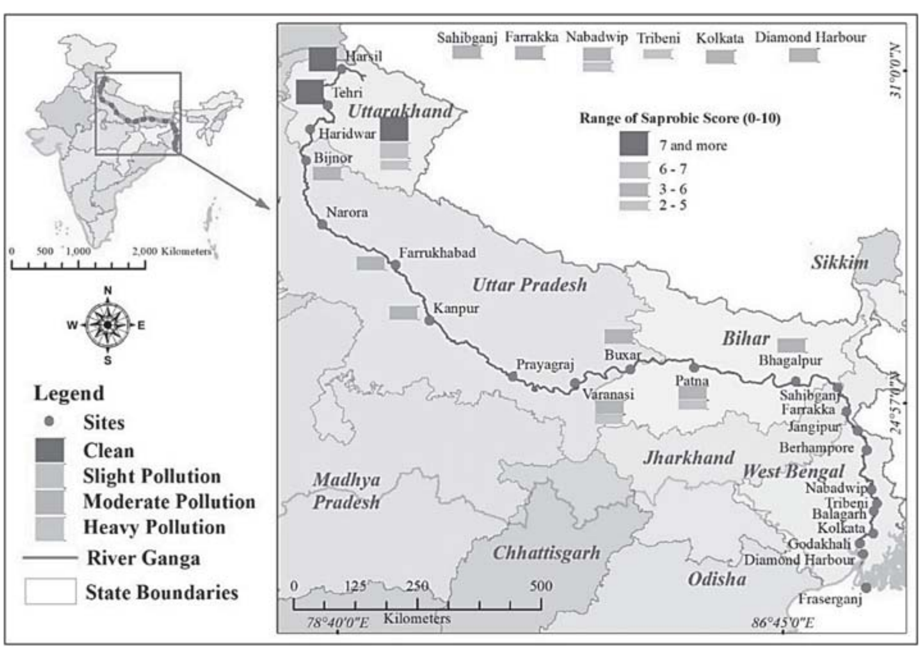

Fig. 3 Pollution levels at different stretches of river Ganga

another concerning aspect of the aquatic ecosystem. Studies showed that exposure to Tributyltin (TBT), used as an antifouling agent in paints, on these gonochoristic species results in the formation of vas deferens in females[7]. Therefore, these organisms are potential bioindicators of the aquatic ecosystem to quantify and qualify the levels of contamination.

Gangetic Molluscan Species as Bioindicators

The Ganga River holds a very important place in the socio-religious and traditional culture aspects of India. Passing through the oldest cities of the country, the quality of the river health has deteriorated throughout the years which thereby affected the faunal and floral biodiversity propagation. and assemblage. The Water Act (1974) was established to restore and maintain the ecological sustainability and the wholesomeness of the riverine quality[16]. The macrobenthic community is the sentinel species for detecting changes in the river quality, thus they are regarded as bioindicators. Species like *Filopaludina bengalensis* and *Physella acuta* are marked as potent bioindicators of heavy metal contamination like copper, lead and cadmium[17]. These organisms also indicate the presence of pesticides and poly aromatic hydrocarbons (PAH). They detect the hazard in the past and are recorded as a source of surveillance of the present riverine condition.

Health Card Report of River Ganga

Health report cards are used to examine environmental, social, and/or economic data in relation to predetermined goals or objectives. River health report cards offer performance-based numerical scores or letters that regularly indicate a river's state, much like report cards for schools. They effectively combine and synthesis copious amounts of frequently difficult information into straightforward scores that can be shared with decision-makers and aid the general public in making wise choices.

The Ganga River Health Report Card is an evaluation and communication tool based on Gangetic benthos population especially molluscs, to monitor community development, coordinate partners and initiatives, and spur change that enhances the health of the river and its watershed while safeguarding the local economy and livelihood.

The report card was developed based on sampling points distributed among four stretches namely upper stretch, middle stretch, lower stretch and estuarine zone. The availability of molluscan species has been included in the health card and based on their assessment, the health card has been developed.

A successful health report card is one that contains metrics that indicate a wide range of river availability and value. The process used to create the health card was adapted from the Center for Environmental Science at the University of Maryland. The molluscan species have been chosen as bio indicators after identifying the stretches that are threatened to get the big picture. The indicators' threshold values were then found, followed by calculations, grades were given to them, and lastly, the story was finished by communicating the results.

Anthropogenic Activity: A Threat to the Benthic Community

Human activity, such as waste, pollutants, and fertilizers, endangers the benthic ecosystems, altering the water chemistry and causing the formation of **"dead zones"**. Fortunately, one can conclude if water quality is degrading by looking at the populations of specific benthic species. When judging water quality, one should look for three species: mayflies, caddisflies, and stoneflies. These species are pollutant-sensitive and can be used to assess water quality based on their numbers. The greater the water quality, the more of these three categories present. Because these species have very sedentary lives, finding regions, where their numbers are low, is a reliable indicator of the source of the contaminant.

Conclusion

Benthic invertebrate species provide a variety of services that are critical to ecosystem operations such as energy flow in food webs. In complicated food webs, many benthic animals convert live plant and dead organic material into prey items for larger eaters. These benthic organisms concurrently supply vital ecosystem services, such as nutrient cycling and sediment aeration, while preserving energy flow. Different species belong to different functional categories that maintain ecological balance. Because these functional groupings may only be represented by a few species in some circumstances, any loss of species diversity could jeopardise ecosystem function. As a result, protecting the biodiversity of benthic ecosystems is becoming increasingly vital in order to reduce the danger of unintended and undesirable outcomes. ❐

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