**Poll Res. 42 (2) : 290-299 (2023)**

ISSN 0257–8050
**DOI No.: http://doi.org/10.53550/PR.2023.v42i02.018**

# MACRO-INVERTEBRATES AS ECOLOGICAL MONITORS OF LOTIC WATER RESOURCES AND CURRENT STATUS IN INDIA: A REVIEW

**ANNU GOEL*, V. HIMA JWALA, ALOK KUMAR MEHER AND V.K. SHUKLA**

[1]*Central Pollution Control Board, Ministry of Environment, Forest & Climate Change, Delhi 110 032, India*

(Received 28 January, 2023; Accepted 22 March, 2023)

**ABSTRACT**

**The water quality assessment of lotic ecosystems using physico-chemical parameters does not accurately reflect the impact of pollutants on the biota. The life span of the inhabiting biota integrates both the past and present environmental conditions and predicts the long-term impact of pollutants. Bio-monitoring- the systematic study of biota- is a powerful tool to assess the degree of impact of pollutants on aquatic environment. Bio-monitoring began in World during 1840s but, in India, it started during 1980s. But, proper coordination among all the stakeholders is required to fill the gap on available information of lotic resources of India. The current article calls for the inventory of the biological water quality of lotic ecosystems and bio-monitoring specific policy framework under regulatory regime in the country. This would help the environmentalists and the policymakers for the sustainable management of both the lotic ecosystems and the inhabiting biodiversity.**

**KEY WORDS :** Bio-monitoring, Ecological, Invertebrates, Lotic, Water quality.

## INTRODUCTION

The lotic- term finds its origin from the word lotus (in Latin) means washing or free-flowing-ecosystems namely, rivers and streams are the lifelines of human civilization. Some of the great civilizations may be listed as the Nile River for ancient Egypt, the Tigris and Euphrates Rivers for Mesopotamia, the Indus and Ganges Rivers for ancient India, and the Yellow and Yangtze (Changjiang) Rivers for China (Marsh and Fairbridge, 1999; Bollinches, 2020). The lotic ecosystems support the establishment of the human race but get deteriorated in return. Presently, almost all the lotic ecosystems are facing depreciation due to various human activities prominent among them are urbanization and industrialization. Discharge of untreated /partially treated municipal sewage and industrial effluents impair the free flowing ecosystems. Also, river engineering to meet human demands for irrigation, navigation, hydroelectric power etc. at the varied magnitude adversely affects the density and diversity of the aquatic biota (Srivastava, 2007).

The water quality assessment using the traditional approach through physico-chemical parameters does not accurately reflect the impact of environmental conditions and pollutants on the biota (Selvanayagam and Abril, 2016) and requires highly sophisticated machines at a high cost to measure very low concentrations of pollutants. In the other contrast, biological monitoring has wider dimensions. The life span of the inhabiting biotaintegrates both the past and present environmental conditions and their tolerance range can provide a more meaningful picture of the term-long impact of pollutants at a much lower cost (Holt and Miller, 2011).

Bio-monitoring- the systematic study of biota- is one of the most powerful tools to assess the degree of impact on the aquatic environment (Li *et al.*, 2010). The terms bio-monitoring and bio-indication are often used interchangeably but have a more specific meaning. The qualitative assessment of biotic responses to the environment is termed bio-indication, for example, the presence of

Ephemeroptera families indicates good water quality but the quantitative measurement is termed bio-monitoring like increase in species diversity reflects good quality (Holt and Miller, 2011).

## INDICATOR ORGANISMS USED FOR BIO-MONITORING

The dynamism of the lotic ecosystems provide habitat to a wide range of organisms from viruses and bacteria (microscopic), to invertebrates,fishes, amphibians, reptiles and mammals (macroscopic). Each group of organisms can indicate the anthropogenic impact on the ecosystem characteristics in one way or another but a specific approach makes the bio-monitoring study more relevant. The ecologists always quest for the ideal indicator organisms, the monitoring of which can represent the impact of environmental conditions and pollutants on the entire inhabiting biota. An ideal indicator organism should have two main attributes: 1. It should be macroscopic (clearly visible to naked eyes) and 2. It should be sedentary (fixed/ should not migrate with the impact of pollution) (Helawell, 1977).

The entire spectrum of animal life inhabiting lotic water bodies can be broadly classified as Invertebrates and Vertebrates. Invertebrates can be classified into 8 major phyla. Members of the Phyla Porifera and the Coelentrata are microscopic, so do not serve as ideal indicators of water quality. Members of the phylum Aschelmintha are macroscopic but their endoparasitic life style makes them misfit for biomonitoring study. Members of the phylum Echinodermata are mostly marine and are insignificant for the bio-monitoring of lotic water bodies. Members of the Vertebrata are macroscopic but are migratory, so are not a good choice as bio-monitors. The members of the phyla Platyhelminthes, Annelida, Arthropoda and Mollusca are both macroscopic and spend one part or the entire life attached to the substratum of the river, thus, qualify as the ideal indicators for the purpose of bio-monitoring of lotic ecosystems. These organisms are collectively referred to as the benthic macro-invertebrates (Fig. 1). Macro-invertebrates: invertebrates visible to the naked eyes and retained on a US standard no. 30 sieve ofmesh size 595 – 600 µm (APHA, 2017).

Considering the significance of benthic macro-invertebrates in assessing the cumulative impact of all the pollutants and habitat alterations, the present study reviews their ecosystem service as bio-monitors of lotic water resources and the current status in India.

## MECHANICS OF BIO-MONITORING

The mechanics of bio-monitoring has three aspects: 1. Macro-invertebrates sample collection, 2. Processing of the sample to convert it into numeric index/ score and, 3. Translation of numerical data into biological water quality class.

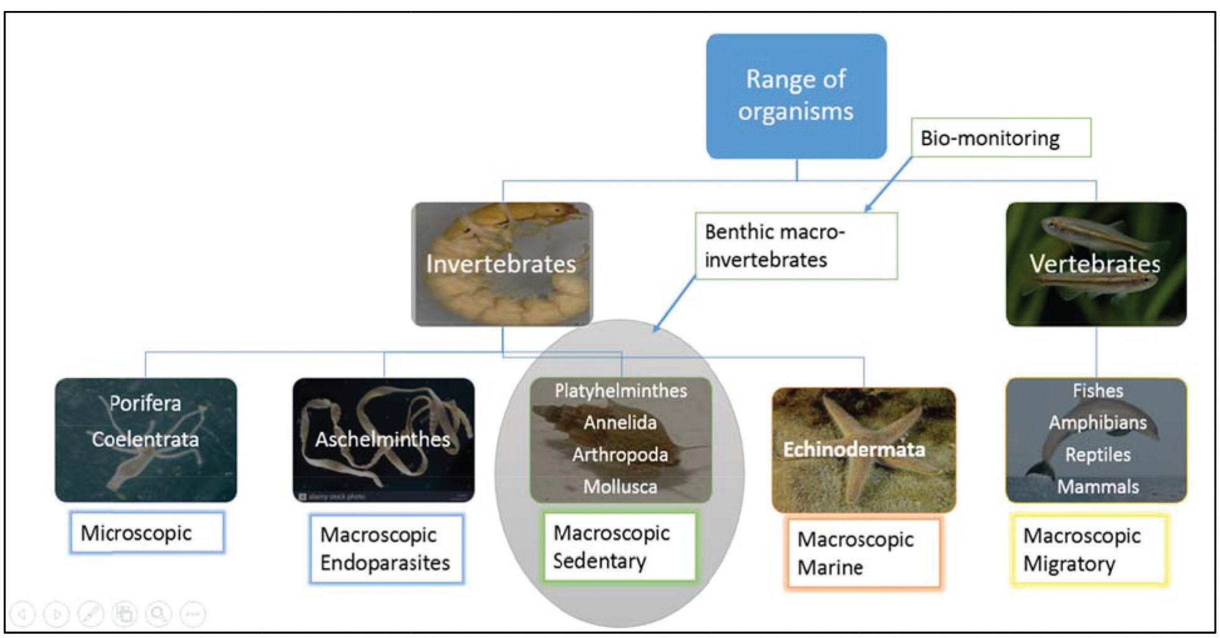



**Fig. 1.** Ideal Indicator organisms used in Bio-monitoring

**Macro-invertebrates Sample Collection**

The benthic macro-invertebrates samples are collected from the substrata of lotic water bodies, the nature of which varies as per the geographical conditions. In the mountainous stretch, the substratum is mainly formed of boulders (>256 mm), cobbles (64-255 mm), pebbles (16-63 mm) and gravels (2-15 mm) while in the plains, it is mainly composed of sand (0.0625 mm), silt (0.002 mm) and clay. Samples can be collected either quantitatively or qualitatively depending upon the objective of the study. The qualitative sample collection is preferred because of the ease of sample collection, analytical results calculation and data interpretation with a little difference in overall water quality class (Hawkes, 1998).

Both the quantitative and qualitative approaches, require the use of various standard devices and techniques as follows:

**Quantitative sample collection**

The quantitative sample is collected using devices that cut the definite area from the substratum of the water body. The number of invertebrates in one grab represents its density in the water body. Suitable number of grab samples are collected and a representative composite sample is formed. The Standard devices used for quantitative sample collection from lotic ecosystems along with their suitability in type of substrata and manufacture type (APHA, 2017) are described in Table 1.

**Qualitative sample collection**

Qualitative sample for bio-monitoring is collected

**Table 1.** Devices for quantitative sample collection from lotic ecosystems

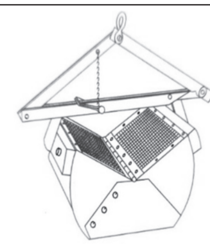
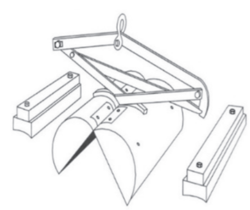
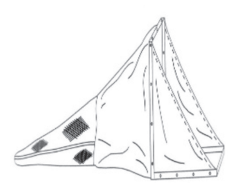
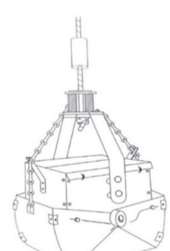
| Type of Sampler | Use in type of substratum | Manufacture type | Image |
|---|---|---|---|
| Petersen grab | - Suitable for use in hard bottom e.g. sand, gravel and clay and<br>- In rapid currents and deep waters | It is iron clam-type manufactured in various sizes; samples an area between 0.06 and 0.09 m$^2$; weighs between 13.7 – 31.8 kg. Its heavy weight make it stable in swift current and provide more cutting force in hard bottom |  |
| Ponar grab | - Best used in mud, sand and gravels but can be used in all substrates except bedrock.<br>- In medium to deep rivers | It is similar to Petersen grab in manufacture, size and weight but has additional side plates and a screen on the top of sample compartment to prevent sample loss during closure. Standard sampler is 23 × 23 cm and weighs 20 kg |  |
| Surber samplers | - Useful in shallow and flowing water (< 30 cm deep) because some organisms may flow over the top of the sampler in deeper water. | It consists of two brass frames- each 30.5 cm$^2$ - hinged together along one edge when in use, two frames are locked at right angles, one frame marking off the area of the substrate to be sampled and other supporting on net to collect organisms. The net is usually 69 cm long and US standard 30 mesh size (595 – 600 µm) |  |
| Ekman grab | - Suitable for sampling mud, silt and sludge<br>- In little current<br>- Not useful in areas with rocky or sandy bottoms or moderate macrophyte growth because small pebbles or grit or macrophyte stems prevent proper jaw closure | It weighs 3.2 kg and can be made in 3 sizes- 15 × 15, 23 × 23 and 30 × 30 cm |  |

**Table 2.** Bio-monitoring Scenario in the World

| Year | Events | Reference |
|---|---|---|
| 350 BC | First evidence of water pollution was given by Aristotle. Observed a white slime (*Beggiatoa* sulfur bacteria) in brooks of the city Megara polluted by municipal sewage; described the oxygen reduction as black mud; and oligochaete sludge worms and chironomids as red tubes. | Thienemann, 1912 |
| 1848 | The earlier knowledge rediscovered by Kolenati. Correlated the absence of Trichoptera larvae from a stream with the presence of factories upstream. **This marked the beginning of biological water quality assessment in the history; dates older than the term "ecology" as defined first by Ernst Haeckel in 1887.** | Kolenati, 1848 |
| 1887 | The concept of the use of a biological (plant and animal) community of rivers to assess the degree of organic pollution was given. | Forbes, 1887 |
| 1902-1908 | The concept of 'biological indicators of pollution' was developed. Observed the change in the invertebrate community structure downstream of a sewage discharge in the stream in Berlin; Coined the terms Saprobien and Katharobien for the organisms that inhabit wastewater and clean water, respectively. | Kolkwitz and Marsson, 1908 |
| 1951 | The concept of water quality mapping- the color bands to show the ecological status of rivers- was introduced. | Liebmann, 1951 |
| 1955 | The pollution level was first quantified and the Saprobic index was developed. | Pantle and Buck, 1955 |
| 1964 | The Trent Biotic Index was developed | Woodiwiss 1964 |
| 1967 | The Indice biotique was developed in France | Verneaux and Tuffery 1967 |
| 1968 | Sequential Comparison Index to measure the diversity was developed. | Cairns, 1968 |
| 1970 | First official use of biological methods in National River Pollution Surveys British Biological Monitoring Working Party (BMWP) Score system was developed by the Department of Environment, United Kingdom. | Hawkes, 1998 |
| 1973 | Sládecek published a book on "System of water quality from the biological point of view."This was used as a methodological bible by the ecologists for many decades and the saprobic system was widely used in Central and Eastern Europe. | Sládecek, 1973 |
| 1979 | BMWP was published as a standard method by an International Standard Organization (ISO)**.** | ISO-BMWP, 1979 |
| 1983 | The Belgian Biotic Index was developed. | De Pauw and Vanhoren, 1983 |
| 1987 | Surface Water Monitoring: A Framework for Change" initiated to develop biological monitoring techniques. | U.S. EPA 1987 |
| 1989 | The rapid bioassessment protocols (RBPs) was developed by Assessment and Watershed Protection Division | Plafkin *et al.*, 1989 |
| 1996 | Nepalese Biotic Score (NEPBIOS) system was developed | Nesemann *et al.*, 2007 |
| 2000 | The Water Framework Directive, an umbrella legislation to establish ecological assessment programs in its 27 member-states was passed in the European Union | EC (European Commission). Directive, 2000 |
| 2002 | South African Scoring System was developed from modified BMWP Score | Dickens and Graham. 2002. |
| 2004 | A community-based assessment protocol called Mini-SASS app was developed in Southern Africa. It is an online platform where citizens can collect and upload data. | Graham *et al*., 2004 |
| 2006 | Ganga River System Biotic Score (GRSBioS) developed | Nesemann *et al.*, 2007 |
| 2010 | Hindu Kush-Himalayan biotic score (HKHbios) was developed for the Hindu Kush-Himalaya region that covers 5 countries (India, Bangladesh, Bhutan, Nepal and Pakistan). | Ofenböck *et al*., 2010 |
| 2011 | Biotic Indices were used in National Ecological Monitoring Programmes in Singapore | Clews *et al*., 2012 |
| 2017 | Biomonitoring Working Party Index was calibrated and validated for Neotropical rivers of Mexico | Ruiz-Picos *et al.*, 2017 |
| 2020 | Multimetric index for the Zio river basin in Togo, West Africa was developed | Tampo *et al.,* 2020 |

from all the possible habitats at the selected location. The hand-net is the most versatile collection device for deep as well as shallow water, hard as well as soft substrate, surface-dwelling as well as macrophytic roots inhabiting invertebrates. It consists of a handle and a frame that holds a net (mesh size 595-600 µm) in which invertebrates are collected. Handles are usually made of metal, wood or reinforced plastic and frames are usually constructed in metal (APHA, 2017).

Kick sampling (Fig. 2a) is the most suitable method for qualitative collection. The hand-net is placed firmly on the stream bed against the flow downstream of the operator's feet. The substratum is then kicked up with the foot and the released material is collected in the net. The net can be turned inside out to transfer the collected organisms onto the sieve of the same mesh size and then transferred into the sample container using forceps. Different habitats can be sampled by working across the river. This method allows the collection of some of the loosely attached organisms leaving the firmly attached ones, therefore, some of the stones should be picked up randomly and organisms should be collected using forceps (Fig. 2b). In deep-flowing and shallow water, with muddy or silty substratum, the handnet should be drawn through the surface layer of the substratum (Fig. 2c). The length of the handle is the determining factor for the limit of deep water sampling, 2 m is most often used but can be extended up to 4 m.The roots of the macrophytes also, provide appropriate habitat for benthic macro-invertebrates'colonization. To collect the organisms from the macrophytes,roots of macrophytes are disturbed by placing the hand net close to it (Fig. 2d). This facilitates the collection of loosely attached organisms. Some of the water plants are uprooted to collect firmly attached organisms with forceps (Fig. 2e) (Water quality guidelines, 2012).

**Preservation of Macro-Invertebrates**

The macro-invertebrates samples collected either quantitatively or qualitatively should be preserved, if, there is time lag between sample collection and taxonomic identification. Before preservation,the collected organisms should be fixed. Fixation stabilizes the tissue proteins of organisms to retain the characteristics for taxonomic identification. Organisms may be fixed in either 10% formalin or 70% ethanol. Organisms with calcareous shells or exoskeletons are preserved in 70% ethanol. Oligochaetes are first fixed in 5-10% formalin and then, preserved in 70-80% ethanol. Constriction of soft-bodied organisms can be avoided using relaxants (70% ethanol, 2% nicotine sulfate, propylene phenoxetol or 5-10% solutions of either chlorotone, chloral hydrate, or magnesium sulfate) during preservation to help in taxonomic identification (APHA, 2017).

**Processing of the sample to convert it into numeric index/ score**

Preserved benthic macro-invertebrates are washed with water to remove all the preservatives, fine sediment and any other unwanted material using a sieve (US Standard no. 30) and are segregated as per taxonomic orders and identified at the family, genus or species level. Identified organisms are classified as per their tolerance/ sensitivity to pollution to convert it into an index/ score.

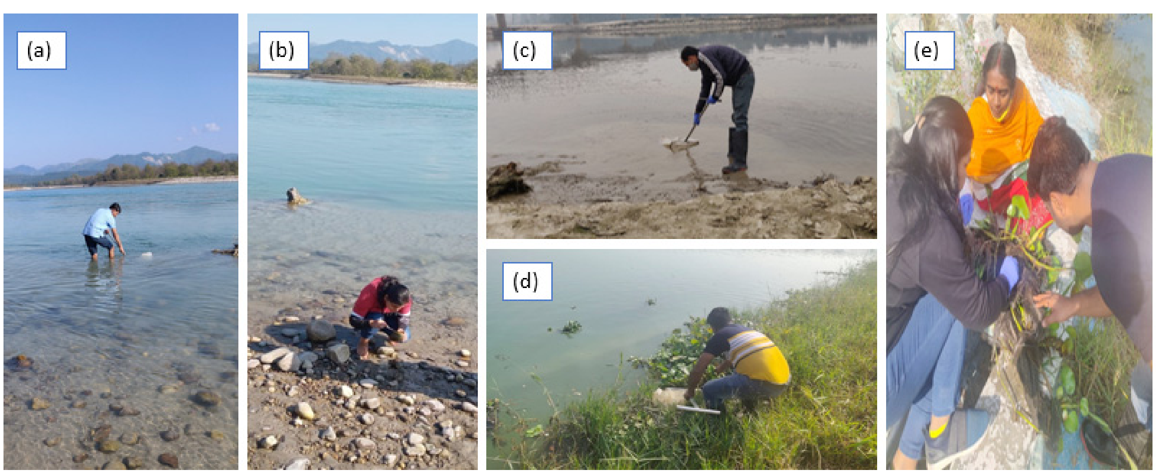



**Fig. 2.** Qualitative sample collection (a) Kick Sampling (b) from stones (c) shallow water with muddy substratum (d) roots of macrophytes (e) uprooted macrophytes

In water quality evaluation studies, the terms 'index' and 'score' are often used interchangeably but have different meanings. A biotic index is a numeric expression of the tolerance/ sensitivity of benthic community to stress. A score is a numeric expression of the ecological indicator status that can be used to calculate an index, which can be generated, e.g., an average of scores of several indicators. The principle of biotic indices is to assign different types of taxa to different levels of disturbance as per their sensitivity/ tolerance to the stress which causes the species replacement. Sensitive taxa may decrease or disappear and tolerance may increase or emerge (Moog *et al.*, 2018).

Several bio-indices/ scores have been developed worldwide to measure this species replacement quantitatively like Chandler biotic index, Trent biotic index, Biological Monitoring Working Party (BMWP) Score and Average Score Per Taxon (ASPT) etc. BMWP score was developed by the British Department of the Environment and recommended as a biological classification system for their national river pollution surveys (Hawkes, 1998) but was not limited to a single river catchment or geographical area. It classifies the inhabiting benthic macro-invertebrates families based on their sensitivity/ tolerance towards pollution on the scale of 1-10, where, 10 represents most sensitive to pollution and 01 represents least sensitive/ most tolerant towards pollution. The BMWP score suffers the limitation that its value increases with increase in sample size. On the other hand, ASPT equals the average of the sensitivity/ tolerance scores of all the observed benthic macro-invertebrates families and is thus independent of sample size unlike the BMWP score. BMWP and ASPT are the most preferred scores (Chapman *et al.*, 1996). The BMWP and ASPT methods identify the invertebrates at the family level. However, recently developed methods outside Europe are at higher taxonomic resolutions such as the genus and species levels (e.g., GRS-BIOS for Ganga River System (Nesemann *et al.,* 2007). Family-level identification is preferred in the bio-monitoring studies due to its simplicity compared to genus and species levels and precision in identification (Plafkin *et al.,* 1989).

**Translation of numerical data into biological water quality class**

The generated index/ score is translated into a specific biological water quality class that reflects the extent of alteration at that location in lotic ecosystems.

Water quality criterion is the numerical concentration or narrative statement recommended to support and maintain a designated best use of water. It is based on variables that characterize the quality of water. Water quality criteria are use-specific and are targeted to protect the most sensitive water use among a number of existing or planned uses within a catchment.

In bio-monitoring studies, the Biological Water Quality Criterion is defined as the measure of "biological integrity" of aquatic ecosystems to assess the cumulative impact of multiple sources and stressors (Enderlein *et al.* 1997). It is required to monitor alterations in the biological properties of water, assess the designated best use of water stretch and translate complex biological water quality data into easily understandable water quality status (Very Good, Good, Moderate, Poor and Severe) for effective communication with people.

## BIO-MONITORING STATUS IN THE WORLD

The biological water quality assessment in the World marked its real beginning during late 1840s, when German entomologist, Kolenati reported the absence of Trichoptera larvae from a stream due to the presence of factories upstream. This event took place in the history about four decades earlier than the coining of term 'ecology' itself by Ernst Haeckel. This was followed by quantum of research to quantify the level of pollution in the rivers and streams and consequently, various indices and scores were developed in different geographical parts of the world. A brief scenario of bio-monitoring in the world is presented in Table 2.

## BIO-MONITORING STATUS IN THE INDIA

In India, bio-monitoring began during 1980s, in collaboration with the Netherlands Government in its International Cooperation program on 'The Environment' with India. A brief scenario of bio-monitoring in the India is presented in Table 3.

## DISCUSSION

Presently, both the academicians and researchers are reporting the biological water quality of selected stretches of rivers in India, like Sharma *et al.* (2013) on river Kunda (Madhya Pradesh); Santhosh *et al.* (2014) on river Meenachil (Kerala); Bhadrecha *et al.* (2016) on river Mahisagar (Gujarat); Ganguly *et al.* (2018) on river Mahanadi (Odisha); Agrawal *et al.*

**Table 3.** Bio-monitoring status in India

| Year | Events | Reference |
|---|---|---|
| 1986 | The biological water quality monitoring began at Central Pollution Control Board (CPCB), Delhi in collaboration with the Directorate General for International Cooperation of the Netherlands Government in its International Cooperation program on "The Environment" with India | Zwart and Trivedy, 1995 |
| 1988-1991 | Bio-monitoring methodology was developed in a pilot study on the Yamuna River | |
| 1993-1994 | The developed methodology was validated and tested for sustainability in other river systems *viz.,* Tungabhadra (Karnataka) and Chaliyar (Kerala). The British BMWP Score was tested with modifications on River Yamuna in India by Andrews of the Thames Water Authority and found suitable on Indian rivers. The composition of the BMWP Score Chart (Table 1) was adopted for Indian rivers | |
| 1999 | The Biological Water Quality Criteria (BWQC) using a combination of Average Score Per Taxon (ASPT) /Saprobic Score and Sequential Comparison Index was derived and the concept of bio-mapping of Indian rivers was introduced. | Parivesh Newsletter, 1999 |
| 2007 | A methodology manual for bio-monitoring of fresh water ecosystems was developed using BMWP-ASPT Score method as developed by Zwart and Trivedi (1995) but proposed the comparison of results of impacted site with the reference (undisturbed) site. | Subramanian and Sivaramakrishnan, 2007 |
| 2014 | The biological condition of river Dikhow in Assam and evaluated water quality using Family Biotic Index was assessed. | Dutta *et al.,* 2014 |
| 2017 | The quality of rivers Karo and Koina was evaluated using Macro-invertebrate Water Quality Index. | Pachu *et al.,* 2017 |
| 2017 | The protocol for bio-monitoring and modified BMWP Score chart based on the observations on river Ganga and its tributaries was developed | CPCB, 2017 |
| 2021 | The health of river Jatinga was evaluated using $BMWP^{THAI}$ and $ASPT^{THAI}$ method. . | Chakravarty and Gupta, 2021 |
| 2021 | The BWQC was revised based on ASPT Score. | CPCB, 2021 |
| 2022 | Water quality of river Beas in mid Himalayan Zone, India was evaluated using Ephemeroptera Plecoptera Trichoptera (EPT) Index. | Jindal *et al.,* 2022 |

(2019) on river Ganga in Uttarakhand stretch and Goel *et al.* (2021) on river Ganga in Patna stretch (Bihar) but proper coordination and harmony among all the stakeholders is required to fill the research gap on available information from origin to confluence of the lotic water resources. More comprehensive information is available for the river Ganga where biological water quality is being evaluated since 2014 at the Central Pollution Control Board, Delhi in coordination with concerned State Pollution Control Boards.

In India, 311 polluted stretches in 279 rivers across the country have been identified by Central Pollution Control Board, Delhi based on Chemical Water Quality Criteria (CPCB, 2022) and action plans are being implemented by various stakeholders for improvement. But, it is important to integrate bio-monitoring with chemical water quality evaluation in view of growing concern to assess the environmental health of these polluted river stretches as well as other water bodies. This would measure accurately the efficacy of implemented action plants for term-long pollution control in the polluted river stretches.

There is urgent need to create bio-monitoring network by setting the representative bio-monitoring stations covering all the bio-geographical zones in the country and generation of biological water quality database through uniform methodologies/ guidelines. This could be achieved by having a bio-monitoring specific policy framework under regulatory regime. This would measure the cumulative impact of all the pollutants and habitat alterations of lotic ecosystems and may bring harmony and coordination for the bio-monitoring study in the country. Inventory of biological water quality of rivers and streams is also imperative in view of global climate change responsible for the extinction of many species and is expected to magnify in the future.

## CONCLUSION

Bio-monitoring using benthic macro-invertebrates is a powerful tool to assess both the ecosystem health and term-long impact of pollutants on the lotic water resources. In the wake of depleting aquatic resources, it is an absolute necessity to monitor and record the changes in the lotic ecosystems and the impact of environmental conditions and pollutants on the inhabiting biota. Adoption of uniform methodologies/ guidelines and policy framework under regulatory regime is expected to strengthen the country to have a regular biological water quality network for lotic ecosystems with harmony and coordination. A good bio-monitoring system may help the environmentalists and policy makers in sustainable management of both the aquatic resources and the inhabiting biodiversity.

**Conflicts of Interest**

The authors declare no competing interests.

## ACKNOWLEDGMENT

Not applicable.

## REFERENCES

Agrawal, S., Sharma, J. and Goel, A. 2019. Bioassessment of river Ganga in Uttarakhand stretch (India) using benthic macro-invertebrates as bioindicator. *Appl. Biol. Res.* 21(3): 235-244. http://dx.doi.org/10.5958/0974-4517.2019.00030.2

APHA. 2017. Benthic macro-invertebrates. Part 10500. p. 10-67 to 10-81.In: Rice, E.W., Baird, R.B., Eaton, A.D. andClesceri, L.S. (Eds.). *Standard Methods for the Examination of Water and Waste Water.* American Public Health Association, Washington, USA.

Bhadrecha, M.H., Khatri, N. and Tyagi, S. 2016. Rapid integrated water quality evaluation of Mahisagarriver using benthic macroinvertebrates. *Environ. Monit. Assess.* 188: 254. https://doi.org/10.1007/s10661-016-5256-9

Bolinches, A., De Stefano, L. and Paredes-Arquiola, J. 2020. Designing river water quality policy interventions with scarce data: case of the Middle Tagus Basin, Spain. *Hydrol. Sci. J.* 65(6). https://doi.org/10.1080/02626667.2019.1708915

Cairns, J. Jr., Albough, D.W., Susey, F. and Charry, M.D. 1968. The sequential comparison index- a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. *J. Water Poll. Contrl. Fed.* 40: 1607-1613.

Chakravarty, T. and Gupta, S. 2021. Monitoring of river health using aquatic insects: A study on Jatinga River, North East India. *Aqua. Res.* 4 (4): 363-375. https://doi.org/10.3153/AR21031

Chapman, D., Jackson, J. and Krebs F. 1996. Biological monitoring. In:Bartram, J. and Balance, R., (Eds.).*Water quality monitoring- A practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. United Nations Environment Program and the World Health Organization. https://apps.who.int/iris/handle/10665/41851

Clews, E., Lin, Y. and Eikaas, H. 2012. Biomonitoring of Singapore's Freshwater Ecosystems; Citygreen #5. A Centre for Urban Greenery and Ecology Publication. p. 29.

CPCB, An introduction to aquatic bio-monitoring using macro-invertebrates. Published by: PR Division, Central Pollution Control Board, Delhi (India), https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMTM0NV8xNjM4NTM1 MzczX21lZGlhcGhvdG80MzIzLnBkZg

CPCB, 2017. Benthic macro-invertebrates of River Ganga. Published by: PR Division, Central Pollution Control Board, Delhi (India), https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvNzk3XzE1NDc3MjU2 MzFfbWVka WFwaG90bzE5MzcucGRm

CPCB, 2022. Polluted river stretches for restoration of water quality. Central Pollution Control Board, Delhi (India). Available online at:https://cpcb.nic.in/openpdffile.php?id=TGF0ZXN0RmlsZS8zNjJfMTY3Mjk4ODA3MI9tZWRpYXBob3RvMjkxOS5wZGY=#:~:text=To%20give%20a%20brief%20 overview,to% 20311%20in%20year%202022.

De Pauw, N. and Vanhoren, G. 1983. Method for biological quality assessment of watercourses in Belgium. *Hydrobiologia.* 100: 153-168. https://doi.org/10.1007/BF00027428

Dickens, C.W.S. and Graham, P.M. 2002. The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers. *Afr. J. Aquat. Sci.* 27: 1-10. https://doi.org/10.2989/16085914.2002.9626569

Dutta, B., Baruah, D. and Biswas, S.P. 2014. Biomonitoring of benthic macroinvertebrates of the tail race of Dikhowriver, Assam, India*. Int. J. Fisheries Aquatic Stud.* 1(6): 72-81. https://www.fisheriesjournal.com/archives/2014/vol1issue6/PartB/151.pdf

E C (European Commission) Directive, 2000/60/EC of the European Parliament and of the Council– Establishing a framework for Community action in the field of water policy. 2000. *Off. J.* 327: 1-73.

Enderlein, U.S, Enderlein, R.E. and Williams, W.P. 1997. Water Quality Requirements. In: Helmer, R. andHespanhol, I. (Eds.).*Water Pollution Control - A Guide to the Use of Water Quality Management Principles.* United Nations Environment Programme, the Water Supply & Sanitation Collaborative Council and the World Health

Organization WHO/UNEP. https://apps.who.int/iris/handle/10665/41967

Ganguly, I., Patnaik, L. andNayak, S. 2018. Macroinvertebrates and its impact in assessing water quality of riverine system: A case study of Mahanadi river, Cuttack, India. *J. Appl. Nat. Sci.* 10(3): 958-963. https://doi.org/10.31018/jans.v10i3.1817

Goel, A., Sharma, J. and Durgapal, N.C. 2021. Assessment of biological water quality of river Ganga in Patna (India) using benthic macro-invertebrates. *Appl. Biological Res.* 23(2): 136-146. DOI: 10.5958/0974-4517.2021.00019.7

Graham, P.M., Dickens, C.W. and Taylor, R.J. 2004. miniSASS—A novel technique for community participation in river health monitoring and management. *Afr. J. Aquat. Sci.*29: 25-35. https://doi.org/10.2989/16085910409503789

Hawkes, H. A. 1998. Origin and development of the biological monitoring working party score system. *Water Res*. 32(3): 964-968. https://doi.org/10.1016/S0043-1354(97)00275-3.

Hellawell, J. M. 1977. Biological surveillance and water quality monitoring. P. 69-88. In:Alabaster, J. S. (Ed.). *Biological Monitoring of Inland Fisheries.* Appl. Sci. Publ. London, United Kingdom.

Holt, E.A. and Miller, S.W. 2011. Bio indicators: Using organisms to measure environmental impacts. *Nature Education Knowledge.* 3(10): 8.

ISO-BMWP. 1979. Assessment of the Biological Quality of Rivers by a Macroinvertebrate Score. ISO/TC147/SC5/WG6/N5, International Standards Organization, Geneva, Switzerland.

Jindal, R., Chawla, C., Singh, D., Soshta, A. and Kaur, S. 2022. Bio-monitoring and water quality evaluation of river Beas in Mid-Himalayan zone, India. *Curr. Appl. Sci. Technol.* 22(5). doi: 10.55003/cast.2022.05.22.002

Kolkwitz, R. and Marsson, M. 1908.[Translated 1967]. Ecology of plant saprobia, p. 47-52. In:Keup, L.E., Ingram, W.M. andMacKenthum K.M. (Eds.). *Biology of Water Pollution.*Federal Water Pollution Control Administration, Washington, DC.

Li, Li., Zheng, B. and Liu, L. 2010. Biomonitoring and bioindicators used for river ecosystems: Definitions, approaches and trends. *Procedia Environ Sci.* 2: 1510-1524. https://doi.org/10.1016/j.proenv.2010.10.164

Marsh, G.A. and Fairbridge, R.W. 1999. Lentic and lotic ecosystems. In: *Environmental Geology, Encyclopedia of Earth Science*, Springer, Dordrecht. https://doi.org/10.1007/1-4020-4494-1_204

Moog, O., Schmutz, S. and Schwarzinger, I. 2018. p. 371-390. Biomonitoring and Bioassessment. In: Schmutz, S. and Sendzimir, J. (Eds.). *Riverine Ecosystem Management. Science for Governing Towards a Sustainable Future. Aquatic Ecol. Ser.* 8. https://doi.org/10.1007/978-3-319-73250-3

Nesemann, H., Sharma, S., Sharma, G., Khanal, S.N., Pradhan, B., Shah, D.N. and Tachamo, R.D. 2007. *Aquatic Invertebrates of the Ganga River System (Mollusca, Annelida and Crustacea) 1.* Chandi Media Pvt. Ltd., Kathmandu, Nepal.

Ofenböck, T., Moog, O., Sharma, S. and Korte, T. 2010. Development of the HKHbios: A new biotic score to assess the river quality in the Hindu Kush-Himalaya. *Hydrobiologia*. 651: 39-58. https://doi.org/10.1007/s10750-010-0289-5

Pachu, A.V., Kumar, S., Mohan, V. and Kunhikannan, C. 2017. Aquatic macroinvertebrate based preliminary biomonitoring of the Karo and Koina rivers of saranda region in West Singhbhum District, Jharkhand, India. *The Indian Forester*. 143(12): 1303-1311. DOI: 10.36808/if/2017/v143i12/120392

Parivesh Newsletter: Bio-mapping of rivers, 5(iv). 1999. Central Pollution Control Board, Delhi. (India) http://www.cpcbenvis.nic.in/cpcb_newsletter/bio%20mapping%20of%20river.pdf

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: Benthic macro-invertebrates and fish. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C. EPA 440-4-89-001.

Ruiz-Picos, R.A., Kohlmann, B., Sedeño-Díaz, J.E. and López-López, E. 2017. Assessing ecological impairments in Neotropical rivers of Mexico: calibration and validation of the Biomonitoring Working Party Index. *Int. J. Environ. Sci. Technol.* 14: 1835-1852. https://doi.org/10.1007/s13762-017-1299-x

Santhosh, S., Mohan, K., Dhanesh, N.R., Sobha, V. and Akolkar, P. 2014. Biomonitoring status and contribution to the knowledge of benthic macro invertebrates for river Meenachil, Southern Kerala, India: A First case approach. *International J. Advanced Res. Biol. Sci.* 1(6): 218-225. https://ijarbs.com/pdfcopy/sept2014/ijarbs30.pdf

Selvanayagam, M. and Abril, R. 2016. Use of benthic macro invertebrates as a biological indicator in assessing water quality of river Puyo, Pastaza Ecuador. *Am. J. Life Sci*. 4(1) : 1-12. Doi: 10.11648/j.ajls.20160401.11

Sharma, S., Dubey, S. and Chaurasia, R. 2013. Aquatic benthic macro-invertebrate diversity of Kunda river district Khargone (M.P.) India. *Glob. J. Biol. Agriculture Health Sci.* 2(4): 203-204. https://www.walshmedicalmedia.com/open-access/aquatic-benthic-macroinvertebrate-diversity-of-kunda-river-district-khargone-mp-india.pdf

Sládecek, V. 1973. System of water quality from the biological point of view. *Arch. Hydrobiol. Beih. Ergebnisse. Limnol.* 7: 1-218.

Srivastava, V.K. 2007. River ecology in India: Present status and future research strategy for management and conservation. *Proc. Indian Natl. Sci. Academy*. 73(4): 255-269.

Subramanian, K.A. and Sivaramakrishnan, K.G. 2007. Aquatic insects for bio-monitoring freshwater ecosystems- a methodology manual. Asoka Trust for Research in Ecology and Environment (ATREE), Bangalore, India. http://wgbis.ces.iisc.ac.in/energy/water/paper/cistup_TR1/Biomonitoring_manual.pdf

Tampo, L., Lazar, J.M., Kaboré, I.,Oueda, A., Akpataku, K.V., Djaneye-Boundjou, G.D., Bawa, L.M., Lazar, G. and Guenda, W.A. 2020. Multimetric index for assessment of aquatic ecosystem health based on macroinvertebrates for the Zio river basin in Togo. *Limnologica*. 83. https://doi.org/10.1016/j.limno.2020.125783

U.S. Environmental Protection Agency (U.S. EPA). 1987. Surface water monitoring: A framework for change. U.S. Environmental Protection Agency, Office of Water, Office of Policy Planning and Evaluation, Washington, D.C.

Verneaux, J. and Tuffery, G. 1967. Unemethodezoologiquepratique de determination de la qualitebiologique des eauxcourantes. Indices Biotiques. *Ann. Univ. Besancon. Biol. Anim.* 3: 79-90.

Water quality-Guidelines for the selection of sampling methods and devices for benthic macro-invertebrates in fresh waters. BS EN ISO 10870: 2012.

Woodiwiss, F.S. 1964. The biological system of stream classification used by the Trent River board. *Chem. Ind.* 443-447.

Zwart, D.D. and Trivedi, R.C. 1995. Manual on Integrated Water Quality Evaluation. RIVM Project Report No. 802023 & DGIS Project No. 754192 IN/92/021, RIVM, Bilthoven, The Netherlands.