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Towards developing a river health index

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A R T I C L E I N F O

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A B S T R A C T

A number of physical, chemical and biological water quality parameters are measured to understand quality conditions of a riverine environment. Various aggregation techniques have been used to reflect the combined effect of the existing or proposed quality levels. Water Quality Index (WQI) has been developed primarily for fresh water environments. Organic pollutants are not considered in many WQIs because analyses of organics are rather expensive. In general, fecal coliform and total coliform counts are measured to reflect biological contamination of water. With growing consensus on considering rivers as ecological entity, rather than merely a source of water for human consumptions, the emphasis is changing from water quality index (WQI) to River Health Index (RHI). As benthic macroinvertebrate species are differentially sensitive to many biotic and abiotic factors in river environment, macroinvertebrate community structure has commonly been used as indicator of stream water condition. A number of river health assessment methodologies have been proposed in past and several indices such as Ecological Health Index (EHI), Ecological Quality Index (EQI), Overall Index of Pollution (OIP) and River Pollution Index (RPI) have been developed using water quality variables and aquatic species for evaluating the ecological health of river systems. This paper attempts to review and summarize some of these indices with particular emphasis on measurable parameters included in such formulations. The analyses suggest that with sufficient scientific experience and understanding in this area, it is possible to define a River Health Index (RHI) by including algae, macroinvertebrates and fish species as measurable parameters along with routine physico-chemical characteristics of river water. One such formulation on RHI has been proposed by the authors in this paper. The novelty of the proposed formulation include simple calculations and presentation of RHI value on 0–100 scale. The biological indices used in ACEDP (2011) requires biological expertise which is not normally available with water resource managers. Hence species identification and counting based simple biotic indices have been proposed so that it can be easily done by non experts also. River Health Level (RHL) can be categorized as 'critical' or 'excellent' based on RHI value < =20 or > 80. Thus RHI values can be used to identify the healthy or unhealthy stretches of the river. RHI can serve as scientific tool to assess the current status, need and effectiveness of any intervention required to improve the condition of the river. Application of this RHI formulation on main stream of river Ganga (India) is under study.

1. Introduction

In India, the concept of Designated Best Use (DBU) based on certain primary water quality criteria has been followed since 1978. According to this, out of several beneficial options, a water source is put to the use which demands highest quality is termed as "DBU". Accordingly, the water body is designated under five different classes (Table 1). The objective of DBU concept is aimed at restoring and/or maintaining natural water bodies or their parts to such a quality as needed for their best uses.

In DBU approach, Total Coliform (TC) organisms count has been included as biological indicator of water quality. Under revised criteria for classification of inland water bodies, monitoring parameters were grouped under three categories: Simple Parameters, Regular Monitoring Parameters and Special Parameters. Observations for presence of fish and insects were included as ecological parameter in the first category and Fecal Coliform (FC) count (as MPN/100 ml) and Bioassay Tests for Zebra fish were added in the Regular Monitoring Parameters. Inland water quality was classed as: A-Excellent, B-Desirable and C- Acceptable and limits were suggested for each class (CPCB, 2002). Thus, there seems an inherent desire to describe river water quality in more holistic way. A significant paradigm shift has been made in Ganga River Basin Management Plan (GRBMP) under consideration for Government of India, where the wholesomeness of River Ganga has been considered as including four perspectives: i. Aviral Dhara (Continuous flow), ii. Nirmal Dhara (Unpolluted flow), iii.

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Table 1
Designated Best Use (DBU) of Inland Waters.
Source: CPCB, ADSORBS/3: 1978–1979, Scheme for Zoning and Classification of Indian Rivers: Estuaries and Coastal Waters, and CPCB, ADSORBS/32: 1999–2000, 'Water Quality Status of Yamuna River, Assessment and Development of River Basin', CPCB Report.

S.N.	Designated Best Use (DBU)	Class of Water	Primary Water Quality Criteria
1.	Drinking Water Source without conventional treatment but after disinfection	A	1.Total Coliform (TC) Organism (MPN/100 ml) ≤ 50 2. pH: 6.5–8.5 3. Dissolved Oxygen (DO) ≥ 6 mg/l 4. Biochemical Oxygen Demand (BOD) (5 days at 20 °C) ≤ 2 mg/l
2.	Outdoor bathing (Organized)	B	1. Total Coliform (TC) Organism (MPN/100 ml) ≤ 500 2. pH: 6.5–8.5 3. Dissolved Oxygen (DO) ≥ 5 mg/l 4. Biochemical Oxygen Demand (BOD) (5 days at 20 °C) ≤ 3 mg/l
3.	Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms (TC) Organism (MPN/100 ml) ≤ 5000 2. pH: 6–9 3. Dissolved Oxygen (DO) ≥ 4 mg/l 4. Biochemical Oxygen Demand (BOD) (5 days at 20 °C) ≤ 3 mg/l
4.	Propagation of wild life and fisheries, recreation and aesthetic	D	1. pH: 6.5–8.5 2. Dissolved Oxygen (DO) ≥ 4 mg/l 3. Free Ammonia (as N) ≤ 1.2 mg/l
5.	Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH: 6.0–8.5 2. Electrical Conductivity (EC) (25 °C) ≤ .2250 μmhos/cm 3. Sodium Absorption Ratio (SAR) ≤ 26 4. Boron ≤ 2 mg/l

Geological Entity, and iv. Ecological Entity (GRBMP, 2015). Considering river as ecological entity, an overall picture of the ecological health of the river can be evaluated by using physico-chemical and biological parameters. Under such larger vision, inclusion of chlorophyll-a/algae, benthic macroinvertebrates and fish as biological parameters appears imperative for complete assessment of river condition. A River Health Index (RHI) may, then be developed as scientific tool, to assess the current status, need and effectiveness of any intervention required to improve the condition of the river.

2. Physico-chemical parameters based approach of water quality assessment

The concept of indexing water quality with a numerical value based on physical, chemical and biological parameters was initially developed by National Sanitation Foundation (NSF) of United States. Horton (1965), Prati et al. (1971), Brown et al. (1972), Harkins (1974) etc. are the early workers towards development of Water Quality Index (WQI). Ott (1978) summarized various approaches of formulating environmental indices.

The National Sanitation Foundation Water Quality Index (NSFWQI) used Delphi method to select water quality parameters and their weightage. Dissolved Oxygen (DO), Fecal Coliform (FC), pH, Biological Oxygen Demand (BOD), Temperature Change, Total Phosphate (TP), Nitrate (NO_3^-), Turbidity and Total Solids (TS) were the nine parameters considered for the purpose. Weighted geometric mean function was used in NSFWQI.

$$\text{Water Quality Index} = \prod_{i=1}^{n} SI_i^{W_i}$$

where, SIi = Sub-index of each parameters, Wi = Weighting factor, n = Number of sub-indices.

Weighting factor (Wi) given to various parameters on 0–1 scale was as follows: DO: 0.17, FC: 0.16, pH: 0.11, BOD: 0.11, Temp. Change: 0.10, TP: 0.10, Nitrates: 0.10, Turbidity: 0.08, TS: 0.07. The index curves to determine the quality parameter (Q) in the NSFWQI model is shown in Fig. 1.

Oregon Water Quality Index (OWQI), developed by Oregon Department of Environmental Quality (ODEQ) in late 1970s also used Delphi method. Weighted arithmetic mean function was used in OWQI.

$$WQI = \sum_{i=1}^{n} SI_i W_i$$

where, SIi = Sub-index of each parameters, Wi = Weighting factor, n = Number of sub-indices.

The earlier OWQI was discontinued in 1983 on account of enormous resources required for calculating and reporting the results, but with advancement in computing facilities, enhanced facilities of data display and visualization, an updated version came in 1995 by refining the original sub indice, adding two more subindices for temperature and phosphorus and improving the aggregation calculation. Temperature, DO, BOD, pH ($NH_4^+ + NO_3^-$)-Nitrogen, TP, TS and FC are the eight parameters used in formulating OWQI. Similarly Florida Stream Water Quality Index (FWQI) used eight parameters: Turbidity, TS, DO, BOD, COD, Total Organic Carbon (TOC), Nutrients (phosphorus and nitrogen) and Bacteria (total and fecal coliform).

Bhargava (1983a) divided the multitude of parameters in four groups: the first: bacterial quality in drinking water: Coliform organisms; the second: heavy metals and toxicants; the third: parameters that affect physical effects, such as odour, colour and turbidity; and the fourth: organic and inorganic, such as sulphate, chloride etc. The simplified model for WQI is given by:

$$WQI = \prod_{i=1}^{n} fi(Pi)^{1/n}$$

where, n = number of relevant variables, fi(Pi) = function of sensitivity of the ith variable including the effect of weighting of the ith variable.

This WQI gives a number in the range 0–100, where 0 represents extremely polluted water and 100 represent unpolluted conditions. This WQI was applied to the stretches of river Ganga and Yamuna in India to identify the pollution status (Bhargava, 1983b, 1983c).

Smith (1987, 1990) developed WQI which is a hybrid approach of using Delphi method and statistical technique. Delphi method is used for selection of parameters for each of four classes of uses, development of subindices and assigning weightage. Final index score was calculated using minimum operator technique:

$$Imin = \Sigma \min (Isub1, Isub2, \ldots\ldots Isubn)$$

where, Imin equals the lowest sub index value.

In 1995, the Canadian Ministry of Environment developed British Columbia Water Quality Index (BCWQI) for water quality evaluation. BCWQI makes possible the classification on the basis of all existing measureable parameters.

Following equation is used to calculate final index value: