CHAPTER 3

PROPOSED FRAMEWORK FOR RIVER HEALTH ASSESSMENT

3.1. Introduction

This chapter deals with the methodology adopted for a proposed framework of river health assessment in Indian conditions. Different sections of this chapter will discuss the rationale for choice of Indicator Groups and Parameters/Indices, the reference values of the selected Parameters/Indices, River Health Index, River Health Condition and its pictorial representation for the understanding of the general public. Phased intervention for River Health Improvement and a tentative program has also been discussed.

3.2. Methodology Adopted

River systems are normally managed by water resource managers. In past various water quality indices (WQI) have been developed from river water use perspectives. With development of biomonitoring programmes, understanding of the ecological health of river system have been successively evolved. Several indices such as River Pollution Index (RPI) (Liou et al., 2004), Overall Index of Pollution (OIP) (Sargaonkar and Deshpande, 2003), Ecological Quality Index (EQI)/ Ecological Health Index (EHI) (Joshi, 2013; Yadav et al., 2014; Yadav et al., 2015) using ecological parameters have been developed. With such developments, it appears that the idea of river health has evolved from the conceptual model to measurable stage. Moving ahead of the river health assessment studies done for Liao River (Taizi Sub-Catchment), China (Leigh et al., 2011) and presentation of river health conditions through a colored quality pentagon, the present study proposes to develop a River Health Index (RHI) and classify the river health condition as 'Acceptable' or 'Poor' for planned improvement and restoration. Apart from regular physico-chemical and nutrient parameters, biological indicators such as algae, macroinvertebrates and fish are proposed to be included for river health monitoring programs (Singh and Saxena 2018).

3.3. Proposed Framework for River Health Assessment

The proposed conceptual framework for assessing river health is on River Health Index (RHI) which is a number on 0-100 scale. The River Health Condition (RHC) is considered 'Acceptable' or 'Poor' based on RHI and is depicted through a colored circumscribed pentagon.

The indicator parameters have been put in five categories:

(1) Organo-Electrolytic-Bacterial (OEB)

(2) Nutrients (NT)

(3) Algae (A)

(4) Macroinvertebrates (MI) and

(5) Fish (F)

The Organo-Electrolytic-Bacterial (OEB) group, consists of 5 indicator parameters:

(i) Electrical Conductivity (EC)

(ii) Dissolved Oxygen (DO)

(iii) Biochemical Oxygen Demand (BOD)

(iv) Chemical Oxygen Demand (COD) and

(v) Fecal Coliform (FC)

The Nutrient (NT) group consists of 3 indicator parameters:

(i) Ammoniacal Nitrogen (NH_3-N)

(ii) Total Nitrogen (TN) and

(iii) Total Phosphorus (TP)

The Algal (A) group consists of 1 index Genus based Algal Palmer Pollution Index (APPI). The Macroinvertebrate (MI) group consists of 2 indices:

(i) Shannon Weiner Diversity Index (MSW)

(ii) Biological Monitoring Working Party (MBMWP) score

The Fish (F) indicator group consists of 2 indices:

(i) Family level Fish Species Richness Index (FS) and

(ii) Fish Shannon Weiner Diversity Index (FSW) **(Fig 3.1)**

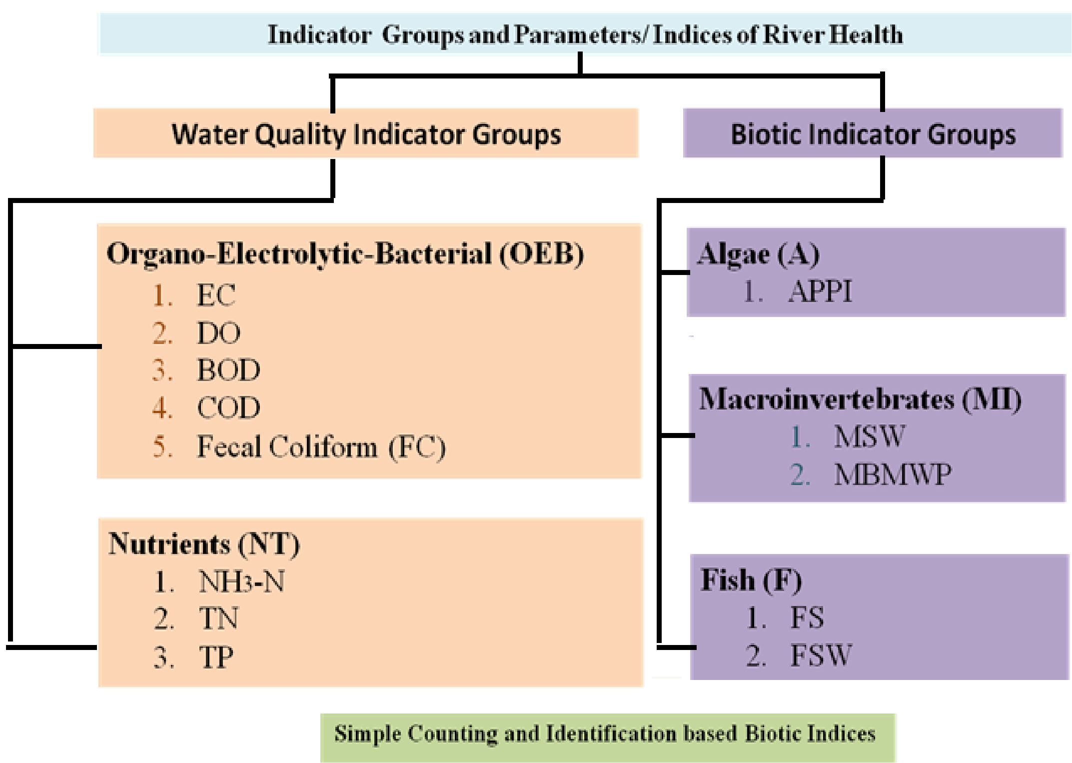


Fig 3.1: Indicator Groups and Parameters/Indices Included in Each Group for River Health Assessment

In order to simplify the process of calculating RHI, identification and counting based simple indices which could be performed by non experts also for algae, macroinvertebrate and fish have been used to reflect biotic species environment in river.

3.4. Rationale for Choice of Indicator Groups and Parameters/Indices

Indicators are important key components in river health assessments. Indicators reflect the condition of river health. A suite of indicators are used to characterize different features such as water quality, plants, macroinvertebrates and fish of the riverine system in most river health assessment programs around the world (Bond et al., 2012). The most crucial step in river health assessment is the selection of appropriate indicators that are sensitive to disturbances, threats, or management actions (Bond et al., 2012). The human disturbances are readily and easily measured and reflected by different indicators (Gipple et al., 2017). The successful and well-documented river health monitoring programs advocate and support the use of multiple indicators of river system that represent different aspects such as physical, chemical and biological (Flotemersch et al., 2006; Bunn et al., 2010). The water quality indicators include physico-chemical parameters such as electrical conductivity, oxygen demand and nutrients (Gipple, 2010).

According to Designated Best Use (DBU) concept developed by the Central Pollution Control (India), for Zoning and Classification of Indian Rivers, Estuaries and Coastal Waters (CPCB, ADSORBS/3/1978/-79), the inland surface waters were grouped into five categories (A to E) based on eight primary water quality criteria (**Table 2.1**). It was classified in such a way that the water quality requirement becomes progressively lower from A to E. The water quality of any one of the five categories also satisfies the requirements of categories lower than the chosen one. An area or stretch of a river may be subjected to a number of uses. The area or the stretch is designated by that particular use which demands the highest/purest water quality, defining its Designated-best-use.

3.4.1. Water Quality Indicator Groups

In rivers there exists a complex interaction between the physical and biochemical cycles. The stresses induced by anthropogenic activities, such as addition of chemicals into the surface water bodies, may adversely affect aquatic plants and animal species present which is dependent on both abiotic and biotic conditions of the river. To protect aquatic life present in rivers the water quality criteria may take into account the physico-chemical parameters which define a water quality that protects and maintains aquatic life in all its forms and life stages. The water quality parameters of concern are dissolved oxygen as at low concentrations it may cause fish kills, as well as phosphates, ammonium and nitrate because if released into riverine system in excessive amounts may change community structure (Ute et al., 1997).

Water quality criteria have been established using water quality variables such as pH, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and nutrients. In countries like India where rivers are affected by severe organic pollution, such criteria guide decision makers to establish control strategies to decrease the potential for oxygen depletion and the resultant low BOD and COD levels. Many rivers in the world suffer from pollution by organic matter, so in order to control water pollution the parameters related to oxygen demand and nutrients (DO, BOD, COD, NH_3- N) should be given priority (Meybeck et al., 1989).

The natural processes and human disturbances both affect the physical and chemical characteristics of surface water. The quality of water may also act as a stressor on aquatic biota present in river (Leigh et al., 2012). Aquatic biota can tolerate the water quality outside the preferred range for brief periods of time. However, water quality outside the tolerable range will cause a decline in river health. Organo-Electrolytic-Bacterial (OEB) and Nutrient (NT) group are key components of riverine system. The parameters included in OEB (EC, DO, BOD, COD, FC) and NT (NH_3-N, TN, TP) group depends on natural and anthropogenic factors. Potential sources of pollution include agricultural activities, domestic and industrial waste waters. The diffuse sources may include activities such as runoff from agricultural fields, clearing of land, erosion of soil, urban runoff, construction and development activities, septic waste and general waste disposal, atmospheric deposition etc. Agricultural activities contribute pollution to surface water bodies in the form of nutrients, sediment, herbicides and pesticides. The livestock and urban septics add fecal wastes to the rivers (Leigh et al., 2012). These OEB and NT indicators are included in river health Index because they relate to the assets and values of the surface water system and the objectives of monitoring programs, such as the provision of safe drinking water or the protection of aquatic biota from highly toxic contaminants (Leigh et al., 2012). The likely sources of pollution within the catchment can be easily identified by the concentration of nutrients and pollutants present in the water. EC, DO, BOD and COD have been used successfully in other river monitoring programs also to give a general indication of water quality. Pathogens are significant from human health perspective. Fecal Coliforms are added to surface waters from discharge of untreated domestic wastewater, fecal wastes from livestock and urban septics, surface runoff from areas of open defecation etc. In India, presence of Fecal Coliform has been reported in the entire length of river Ganga (CPCB, 2013) and hence is considered a critical parameter. Therefore, it is considered as one of the key parameters of OEB indicator group affecting river health.

Certain chemicals such as nitrogen, phosphorus and carbon at elevated concentrations have detrimental effects on aquatic organisms and can cause excessive algal growth and the loss of oxygen from the water body. NH_4 can be directly toxic to aquatic biota, so it is recommended that NH_4, along with TN and TP, be considered for inclusion in an assessment program (Leigh et al., 2012). Total Phosphorus (TP) is preferred because dissolved concentration can vary substantially through time due to natural ecosystem processes. Thus in Nutrient group the parameters considered are NH_3-N, TN and TP.

3.4.2. Biotic Indicator Groups

Algae presence in rivers reflect natural factors such as geology, soil, climate, hydraulic conditions, and nutrient concentration. Algae are useful biotic indicator as they are present in abundance in most of the surface water bodies, are easy to sample, respond rapidly to changed conditions, and their tolerance to environmental conditions is known for many species due to the cosmopolitan distribution of many taxa (Whitton et al., 1991). The composition of algae communities is widely used as an indicator to assess river health. Algae are popular indicator in Europe, where numerous indicators have been developed that reflect changes in community composition with declining water quality (Torrisi et al., 2010; Żelazna-Wieczorek and Ziulkiewicz, 2009; Griffith et al., 2005; Johnson et al., 2005). Specific Pollution Sensitivity Index (Indice de

Polluosensibilité Spécifique, or IPS). (IPS; Coste in CEMAGREPH 1982) is based on the tolerance of different taxa to water quality deterioration. The sensitivity of the metrics is well established, but high level of taxonomic expertise is required to identify specimens, and considerable amount of lab work to process samples. In the present study, simple identification based pollution tolerant index, such as Genus based Algal Palmer Pollution Index (APPI) have been used. Algae were identified to the genus level according to classification manuals given by Hu and Wei (2006), Zhu and Chen (2000) and Zhang and Huang (1991).

Macroinvertebrates are the most popular choice around the globe for use as indicator in river health assessment (Gordon et al., 2004). In Europe out of more than one hundred different bioassessment methods in use, two thirds of them are based on macroinvertebrates (Rosenberg and Resh, 1993; Verdonschot et al., 2000). Macroinvertebrates are found in most habitats, they are easy to collect due to limited mobility and well established sampling techniques. They are sensitive to changes in both water quality and habitats (Hellawell, 1986; Gippel and Speed, 2010). The macroinvertebrate community structure respond to almost all the stressors, due to this characteristic the macroinvertebrates are the most broadly applicable group as indicator (ANZECC and ARMCANZ, 2000 d). Macroinvertebrates are generally not affected by altered river flows (Harris, 1995).

Fish populations and communities are sensitive to water quality and habitat deterioration. They can respond actively to changes in water quality (ANZECC and ARMCANZ, 2000 d; Chessman and Jones, 2001) and are considered popular bioindicators of riverine health. As fish are much valued by the wider community and are highly visible, fish monitoring usually has strong community interest and approval (Gordon et al., 2004). Fish are relatively easy to sample and identify. In the field, they tend to integrate effects of lower trophic levels, thus integrated environmental health is reflected by fish assemblage structure (Barbour et al., 1999). They are long-lived and can integrate the effects of long-term changes in stream health (Simon and Lyons, 1995). Hence globally fish is considered as one of the biotic indicator of river health.

3.5. Setting Reference Values of Parameters and Indices

In order to report on the status or condition of River Health, it is important to set Critical or Target values (referred to here as 'reference values') for each selected Parameter/Index that reflect different status or condition of the river. It is necessary to differentiate between 'Good' (acceptable) and 'Bad' (unacceptable) condition of the river (Bond et al., 2012). The process of setting Target and Critical values for parameters /indices can be guided by scientific knowledge and may evolve over time and may vary from place to place. Different interest groups such as water managers, industry, farmers etc. may have different opinion about what is acceptable. Thus, the final reference value may require an iterative process which may involve negotiation and assessment of different objectives of the program.

The approach to use the values of the 'reference sites' or 'pristine condition' i.e., the site or catchment which is undisturbed by human activity is common, but rarely used in practice. In practice, these sites will not exist for many rivers (Bond et al., 2012; Leigh et al., 2012). The other alternatives for setting reference values include:

(i) The best attainable condition, i.e., the condition to be expected if best management practices were in use, for a given river;

(ii) Use of established criteria or standards of water quality;

(iii) Use of standards required for designated use (drinking, swimming, fishing, agriculture);

(iv) Using Expert opinion or local knowledge;

(v) Using historical or modeled data (prior to a particular disturbance); and

(vi) Use of the data from similar systems elsewhere in good condition.

In the present framework, the 'Target' and 'Critical' values are set using:

- the criteria used for DBU of Inland waters in India as per CPCB 2002.
- the data from similar systems elsewhere in good condition.
- the established criteria or standards of water quality.
- the data from available literature.

The 'Target' and 'Critical' value used for Parameters/Indices under different Indicator Groups are given in **Table 3.1**.

Table 3.1: Target and Critical Values for Parameters/ Indices

	Indicator Group	Indicator Parameter	Target value	Critical value	Source/ References
1	Organo-Electrolytic-Bacterial (OEB)	i. EC (µmhos/cm)	≤400	> 1500	EHMP (2010) Anon. (2000);
		ii. DO (mg/l)	≥7	<3	UNECE (1994)
		iii. BOD (mg/l)	≤3	>8	CPCB (2015), (Existing); CPCB (2002)
		iv. COD (mg/l)	≤30	>80	Assumed (Currently no limit is available)
		v. FC (MPN/100 ml)	≤500	>2500	CPCB (2015) (Existing)
2	Nutrients (NT)	i.NH3-N (mg/l)	≤0.3	>1.5	CPCB (2002); MEP (2008)
		ii. TN (mg/l)	≤0.5	>2	Anon. (2000); MEP (2008)
		iii. TP (mg/l)	≤0.1	>0.3	CPCB (2002)
3	Algae (A)	i. Genus APPI	≤10	>20	Palmer (1969)
4	Macroinvertebrate (MI)	i. MSW	>3.5	0	Kerkhoff (2010)
		ii. MBMWP (Saprobic)	>7	0	CPCB (2015)
5	Fish (F)	i. Family Level Fish Species Richness Index (FS)	≥15 R, ≥30 H ≥60 K, A ≥ 75 V, P	0 0 0 0	Das et al. (2013)
		ii. FSW	>2.5 R, H >3.5 K, A, V, P	0 0	Das et al. (2013)

where R=Rishikesh, H= Haridwar, K= Kanpur, A= Allahabad, V= Varanasi, P= Patna

Table 3.2: Score of Parameters/ Indices on 0-5 Scale

	Indicator Group	Parameter/ Index	Score					
			0	1	2	3	4	5
1	Organo-Electrolytic-Bacterial (OEB)	i. EC (μmhos/cm)	>1500	1250-1500	1000-1250	750-1000	400-750	≤400
		ii. DO (mg/l)	<3	3-4	4-5	5-6	6-7	≥7
		iii. BOD (mg/l)	>8	6.5-8	5.0-6.5	4.0-5.0	3.0-4.0	≤3
		iv. COD (mg/l)	>80	65-80	50-65	40-50	30-40	≤30
		v. FC (MPN/100 ml)	>2500	2000-2500	1500-2000	1000-1500	500-1000	≤500
2	Nutrients (NT)	i.NH3-N (mg/l)	>1.5	1.2-1.5	0.9-1.2	0.6-0.9	0.3-0.6	≤0.3
		ii. TN (mg/l)	>2	1.6-2.0	1.2-1.6	0.8-1.2	0.5-0.8	≤0.5
		iii. TP (mg/l)	>0.3	0.25-0.3	0.2-0.25	0.15-0.2	0.1-0.15	≤0.1
3	Algae (A)	i. APPI (Genus)	>20	18-20	15-17	13-14	11-12	≤10
4	Macroinvertebrate (MI)	i. MSW	0	0-1.0	1.0-2.0	2.0-3.0	3.0-3.5	>3.5
		ii. MBMWP (Saprobic)	0	0-2.0	2.0-4.0	4.0-5.5	5.5-7.0	>7
5	Fish (F)	i. FS (Species)						
		R	0	1-3	3-7	7-11	11-15	≥15
		H	0	1-6	6-14	14-22	22-30	≥30
		K, A	0	1-15	15-30	30-45	45-60	≥60
		V, P	0	1-15	15-35	35-55	55-75	≥75
		ii. FSW						
		R, H	0	0-0.5	0.5-1.0	1.0-1.75	1.75-2.5	>2.5
		K, A, V, P	0	0-0.75	0.75-1.5	1.5-2.5	2.5-3.5	>3.5

where R=Rishikesh, H= Haridwar, K= Kanpur, A= Allahabad, V= Varanasi, P= Patna

3.6. Scoring and Aggregating Parameter/Indices Observed Values

For making the score calculation more precise, the full range of 'Target' and 'Critical' values have been divided in five zones with a score value on 0-5 scale (**Table 3.2)**. According to this, the observed value of Parameter/Index would score between 5 (Target value or better) and 0 (Critical value or lower) depending upon the range in which it falls.

The score of the Parameters/Indices within the group are averaged to obtain the Indicator Group Score. The Indicator Group Score is calculated by aggregating the Parameters/ Indices score of each group using **Eqn 3.1.**

Indicator Group Score =

[∑scores of parameters or indices/ (5 x no. of parameters or indices in the group)] x 100

……….**Eqn. (3.1)**

3.7 River Health Index

River Health Index (RHI) calculation is based on Indicator Groups score. The OEB and NT group indicators are normally affected by short term fluctuations, whereas biotic indicators such as algae, macroinvertebrates and fish are long term integrators of river health. Therefore the biotic indicators should contribute more heavily towards an overall RHI. With similar reasoning, Macroinvertebrates and Fish indicators are weighted more heavily than Algal indicators as they are longer lived than algae (Leigh et al., 2012). The weigthage assigned to different Indicator Groups is given in **Table 3.3.**

Table 3.3: Weightage of Indicator Groups

	Indicator Group	**Parameters/ Indices**	**No. of Parameters/ Indices**	**Weight factor**	**Weight factor given in the present study**
1	Organo-Electrolytic-Bacterial (OEB)	EC, DO, BOD, COD, FC	5	w_1	0.15
2	Nutrient Score (NT)	NH_3-N, TN, TP	3	w_2	0.15
3	Algae Score (A)	APPI	1	w_3	0.20
4	Macroinvertebrate Score (MI)	MSW, MBMWP	2	w_4	0.25
5	Fish Score (F)	FS, FSW	2	w_5	0.25
	Total		**13**		**1.00**

These Indicator group scores of Organo-Electrolytic-Bacterial (OEB), Nutrient (NT), Algae (A), Macroinvertebrate (MI) and Fish (F) with their respective weigthage are used to calculate the River Health Index (RHI) using the relation given by **Eqn. 3.2.**

River Health Index (RHI) = $[(OEB \times w_1) + (NT \times w_2) + (A \times w_3) + (MI \times w_4) + (F \times w_5)]$

……….**Eqn. (3.2)**

where, OEB = Organo-Electrolytic-Bacterial indicator group score, NT = Nutrient indicator group score, A= Algal indicator group score, MI = Macroinvertebrate indicator group score, and F= Fish indicator group score and w_1, w_2, w_3, w_4 & w_5 are weightage given to respective groups.

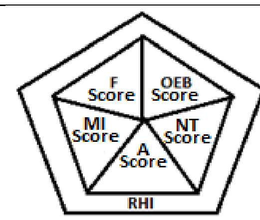
3.8. Assessing River Health Condition (RHC) and Communicating Results

Based on the value of River Health Index (RHI) the River Health Condition (RHC) has been classified as 'Acceptable' (RHI >60) and 'Poor' (RHI ≤60). The 'Acceptable' condition is further divided into 'Excellent' (RHI>80), 'Very Good' (RHI=70-80), 'Good'

(RHI= 60-70), and ‘Poor’ condition is divided into ‘Stressed’ (RHI= 50-60), ‘Overstressed’ (RHI= 40-50), ‘Critical’ (RHI= 20-40) and ‘Sick/Dead’ (RHI ≤20).

A color code is given for visual representation of Indicator Group Score, River Health Index (RHI) and River Health Condition (RHC). The River Health is pictorially represented by a circumscribed pentagon in which color of each sector represent one Indicator Group Score in river environment and the color of the circumscribing pentagon represents the overall River Health Condition (RHC) based on integrative River Health Index (RHI) for the site, as shown in **Table 3.4**.

Table 3.4: Color Code and Pictorial Presentation for Indicator Group Scores, River Health Index (RHI) and River Health Condition (RHC)

River Health Category	Indicator Group Score / RHI	RHC	Color Code	Color	Pictorial Presentation
Acceptable	>80	Excellent	Blue		
	70-80	Very Good	Green		
	60-70	Good	Yellow		
Poor	50-60	Stressed	Orange		
	40-50	Over Stressed	Grey		
	20-40	Critical	Red		
	≤20	Sick/Dead	Black		

The Indicator Group Score based approach of River Health Index (RHI) calculation gives insights for identification of critical parameters and strategic plan preparation for restoration. The colored representation of state of water quality based on indicators groups scores of riverine system and overall river health condition (based on RHI) makes it simpler to the scientific community for diagnostic and corrective purposes. The novelty of the proposed formulation include simple calculations and presentation of RHI value on 0 -100 scale. RHI values can be used to identify the healthy or unhealthy stretches of river. RHI < 60 may be considered as ‘Poor’ indicating need of scientific intervention to improve the river health. This framework may be used as a tool to assess the Health of river and may be instrumental to the policy makers to carry out the River Health Improvement/ Restoration programs.