Template

*for*

# River Health Assessment

*Submitted to*

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172 B Lodhi Road, New Delhi – 110003

By

Prof. Vinod Tare

**Professor and Project Investigator**

Environmental Engineering and Management Programme

Department of Civil Engineering

**INDIAN INSTITUTE OF TECHNOLOGY KANPUR**

**KANPUR-208016, INDIA**

# Template for River Health Assessment (RHA)

## 1.0 Introduction

Rivers and streams are among the most endangered ecosystems worldwide. Rivers have ecological, spiritual, aesthetic, social, cultural, and economic values, as well as intrinsic values that are not dependent on people's will. These values of rivers are based on their health. In India the rivers are over exploited for their functions and are under severe pressure due to various disruptive anthropogenic activities. Numerous stressors such as nutrient enrichment, presence of pollutants, sediment accumulation, erosion, alterations in stream hydrology and habitat are of concern for ecological integrity, sustainability and ecosystem health. For evaluation of the actual state and measure the rate of changes in the rivers and streams, the periodic assessment of its health is essential. This health assessment of rivers is the goal of the present program.

The concept of evaluating river health was perhaps formally initiated in Europe, America and Australia. Legally, the river health concept was most probably introduced through Clean Water Act (CWA) of the U.S. in 1972 for the first time. Currently, most countries in the world plan for a management approach to sustain the prime natural resources like rivers and streams. In some countries river health assessment is a routine requirement for river management. However, the river health concept and a national river health assessment system is absent in India. In this report, globally used indices which have been used for river health assessment are reviewed. Suitable assessment methods, recommended indicators/ variables and requirements for compilation of selected indices of river health assessment have been summarized here for further statistical analysis and cumulative assessment, and subsequent adoption for River Health Assessment (RHA) of Ram Ganga River.

RHA should ideally account for and involve all critical components of a riverine system including aquatic flora and fauna, water quality, habitat, hydrology, physical form of the channel and other geo-morphological features. However, it is impractical to include all the variables that make-up/constitute and/or influence these components. All of these components are affected by various anthropogenic activities and may also be interdependent. Monitoring of some of the crucial and/or critical indicators under these components is needed to provide holistic view of the health of river system. Thus, as a part of the river health assessment protocol development, variables/indicators generally considered under four major components are presented in Table 1.

There are two approaches to present the health status of a river drawing information on various components mentioned in Table 1. One approach is to arrive at integrated indices for various components and if possible an overall index that can reflect the river health. In the subsequent section of the report relevant variables and indices available in literature for various components are reviewed and summarized. Numerous indices have been used till date to determine river health. After selecting the preferred variables/indices, the 'Multimetric and Multivariate Approaches' to integrate the set of variables or matrices and to correlate the observed and expected conditions could be used.

**Table1: Components Along with their Indicators/Variables Considered for River Health Assessment**

| Component | Variables/Indicators |
|---|---|
| Hydrology | Flow and its relevant parameters |
| Geo-morphology | Bank, bed and floodplains condition, lateral and longitudinal connectivity |
| Water Quality | Physical, Chemical and Biological Parameters |
| Biotic Profile | Producers, Consumers, Decomposers |

The other approach is to present information in a comprehensive manner on various variables influencing and/or determining the status of various components. This kind of presentation is referred as report card on river health.

RHA either in the form of an index or a report card provides a periodic snapshot of the existing river health status. The advantages of RHA exercise and analysis may be stated as follows:

- ✓ Meaningful in deciding the portions of the river that need extensive attention.
- ✓ Helpful in tracking specific indicator status for any component at a fixed site.
- ✓ Handy in providing scientific information to the public.
- ✓ Guide river health management decisions.

## 2.0 Goals for Current Exercise

- ✓ Identification of the dominant, representative and independent indicators to make the index system comprehensive, objective, and that fully reflects the characteristics of river health.
- ✓ Set up a standardized method for river health assessment by including major indices covering all the components of the river (Hydrology, Geo-morphological, Water Quality and Biological).

## 3.0 Review of RHA Indices

The most important role for river experts is to identify and measure the indicators of river health. These indicators not only alert about possible upcoming disasters but are also useful in estimating the extent of disparity from its natural state. The river health indicators are categorized in three categories: *early warning*, *compliance* and *diagnostic*. Most of the biological and water quality indicators reviewed in this report are early warning and compliance indicators, respectively. In this section most of the indicators for all the components of the river (Hydrology, Geo-morphological, Water Quality and Biological) have been reviewed and reported. As not all of them meet the criteria for RHA, so in the next section our aim is to identify a small manageable subset of all the components.

### 3.1 *Biological indices*

The literature reveals that aquatic organisms such as microorganisms, algae, protozoans, rotifers, other macro-invertebrates and fishes can serve as bio-indicators to assess the current status of the rivers and streams. An ideal biological indicator should have the following properties**:** taxonomic soundness, cosmopolitan distribution, low mobility, well-known ecological characteristics, numerical abundance, suitability for lab experiments, high sensitivity to environmental stressors and high ability for quantification and standardization (Li *et al.*, 2010). The most frequently used bio-indicators are periphyton, benthic macro-invertebrates and fish (Kleynhans, 1984; Bell-Cross and Minshull, 1988;Skelton, 1993; Friedrich *et al*., 1996; Weeks *et al*., 1996; Russell and Rogers, 1998; Prygiel and Coste, 2000; Poulin et al., 2001). Various indices have been proposed till date using these indicator groups. The indices have their own merits and demerits. Some of the indices used in the literature and adopted in the bio-monitoring program globally are summarized in Table 1.

**Table 1: Assessment Index System for Determining the Biological Status of the River**

| Index | Principle | Pros and Cons | | References |
|---|---|---|---|---|
| Biological Diatom Index (IBD) | Based on Zelinka and Marvan (1961 index).<br>$ID = \sum_{i=1}^{n} Aj.Sj.Vj / \sum_{i=1}^{n} Aj.Vj$<br>Aj= Relative abundance of species j in the sample<br>Sj= The pollution sensitivity of the species<br>Vj= The indicator value of the species j<br>n= Number of species counted in the sample<br>This index is based on a list of 209 key species showing different pollution sensitivities. The pollution sensitivity, or "ecological profile", is determined through the species presence probability values along quality classes gradient (determined by analysis of a diatom community/ physico-chemical parameters relationship).<br>Index value ranging from 0 to 20, or classes 1 to 5, which correspond to water quality classes from eutrophy to oligotrophy. | Autoecological indices use the relative abundance of species in assemblages and their ecological preferences, sensitivities or tolerances to infer environmental conditions in an ecosystem. | IBD fails to correctly assess water quality in acidobiontic and brackish conditions.<br>Pollution sensitivity and tolerance of several key species used to calculate the index need to be improved. | Afnor (2000); Prygiel and Coste (2000); Poulin *et al*., (2001) |
| Specific Pollution Sensitivity Index (IPS) | Based on Zelinka and Marvan (1961 index).<br>$ID = \sum_{i=1}^{n} Aj.Sj.Vj / \sum_{i=1}^{n} Aj.Vj$<br>Aj= Relative abundance of species j in the sample<br>Sj= The pollution sensitivity of the species<br>Vj= The indicator value of the species j<br>n= Number of species counted in the sample | IPS was developed from a large database, involves large number of diatom taxa in the calculation and includes most of the species of the OMNIDIA | - | Coste in Cemagref, 1982 |

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| | Indicator taxa are divided into 5 classes according to their sensitivity to pollution and into 3 classes according to their indicative weight. All the taxa are used. | database. | | |
| Van Dam index | Ecological indicator values for pH, salinity, nitrogen uptake metabolism, oxygen, saprobity, trophic state and moisture could be assessed | - | - | Van Dam *et al*., 1994 |
| Benthic Chl-a Index | Periphyton chlorophyll a is measured as a density, in mass of benthic chlorophyll a per area of bed material from which the sample was obtained. The density (0 to >30 $mg/m^2$) corresponds to the trophic status (oligotrophy to eutrophy) of the stretch. | - | - | Biggs, 2000 |
| Simpson's Index | Diversity within the community was described using the Simpson's diversity index. It measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species) $$D = \frac{\sum n_i(n_i - 1)}{N(N-1)}$$ $n_i$ = the total number of organisms of each individual species N = the total number of organisms of all species The value of D ranges from 0 to 1. With this index, 0 represents infinite diversity and, 1, no diversity. That is, the bigger the value the lower the diversity. Some texts use derivations of the index, such as the inverse (1/D). | - | - | Krebs, 1994 |
| Shannon-Wiener Diversity Index | Index characterize diversity based on the number of species present (species richness) and the distribution of the number of organisms per species (species evenness). $$H' = -\sum_{i-1}^{k} ipi\,(\ln pi)$$ Pi = relative abundance; k = no. of taxa Evenness= H'/ $H_{max}$ $H_{max}$= log K | - | In an ecosystem different species make unequal contributions to diversity and that priority in conservation decisions should be given to species with unique genetic or morphological characteristics. | Gerritsen *et al*., 1998 |
| Taxa Richness | It indicates the health of the community through its' diversity, and increases with increasing habitat diversity, suitability, and water quality. TR equals the total number of taxa represented within the sample. | - | - | Plafkin *et al*., 1989 |
| ETO Index | The Ephemeroptera, Trichoptera, and Odonata (ETO) index represents the taxa richness of these groups. | - | - | Gerritsen *et al*., 1998 |

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| EPT Index | EPT index is calculated based on the relative abundances in the sample of the orders Ephemeroptera, Plecoptera and Trichoptera, in comparison to the total number of individuals in the sample. The higher relative abundance of those taxa in the sample represents the higher water quality at the site. | - | - | Plafkin *et al*., 1989; Carrera & Fierro 2001; Resh & Jackson 1993; Rosenberg & Resh 1993 |
| EPT/C | The abundance of EPT and Chironomidae indicates the balance of the community, since EPT are considered to be more sensitive and Chironomidae less sensitive to environmental stress. A community considered to be in good biotic condition will display an even distribution among these four groups, while communities with the disproportionately high numbers of Chironomidae may indicate environmental stress. | - | - | Plafkin *et al*., 1989 |
| Oligochaete Index | In the index the relative abundance of oligochaetes to all other benthic organisms is used as an index of pollution.<br>OI= (Number of tubificids/ Number of all organisms)×100 | - | Dependent on the presence and dominance of *Tubifex* and necessitates the enumeration of all organisms collected. | Wright and Todd (1933) |
| BMWP | It is a scale from 1 (grossly polluted) to 10 (very clean) along which the sensitivity of various insect and other macro-invertebrate families, with the highest scores assigned to species most sensitive to organic pollution.<br><br>Values greater than 100 are associated with clean streams, while the scores of heavily polluted streams are less than 10. | Based on the family richness.<br><br>Assessment can be on the basis of identification at family level. | Numerous times naturally species rich sites have higher scores than naturally poor sites even if the water quality is the same. Assessment value sometimes differs between stream types. | Friedrich *et al*., 1996 |
| ASPT | It is an adapted version of the BMWP index. It is calculated as the ratio of the score obtained in the BMWP index to the number of scored families in the sample.<br>A high ASPT score is considered indicative of the clean site containing large numbers of high scoring taxa. | Index of organic pollution and does not depend on family richness. | - | Friedrich *et al*., 1996; Mackie, 2001; Armitage et al., 1983; Wright et al., 2000 |
| HFBI | HFBI index scores organisms based on the saprobiotic system, in a fashion inverse to that of the BMWP. Scores are calculated as follows:<br>HFBI = ΣnVT/N<br>VT = tolerance value of each family, n = the number of individuals in each family, and N = the total number of individuals.<br>The tolerance value ranges from 0 to 10 | Estimate the degree of saprobity and possibly trophism of a benthic population. | The need for keys to species; influence of stream current and temperature, seasonal changes, and impact of habitat variables are some of the problems that need to be | Hilsenhoff (1982); |

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| | and decreases when water quality increases. | | addressed to make the index more functional. | |
| Community Loss Index | The Community Loss Index (CLI) measures the loss of benthic taxa in a study site with respect to a reference site. Values range from 0 to "infinity" and increase as the degree ofdissimilarity between the sites increases. It provides the information regarding the variation occurs under natural conditions.<br>Community loss= D-A/E<br>A: No. of Taxa common to both sites<br>D: Total Taxa present in reference site<br>E: Total Taxa present in study site | - | - | Plafkin *et al.*, 1989 |
| Index of Biological Integrity | IBI includes a series of metrics to evaluate fish assemblages and the scores quantify deviations from reference conditions. | - | Various aspects of fish assemblages and the metricscores quantify deviations from reference conditions.<br><br>Very large investment in equipment (special equipment being designedfor unique situations), financial resources and in a sufficientlylarge and trained workforce. | Karr, 1981; Hughes & Oberdorff, 1999 |
| Fish Assemblage Integrity Index (FAII) | FAII basis:<br>The relative intolerance of the indigenous fish species expected to occur in every segment is estimated. Intolerance in the context refers to the degree to which a species is able to withstand changes in the environmental conditions under which it occurs.<br><br>Four components will taken into account in estimation of the intolerance of fish species, viz., habitat preference and specialization, food preference and specialization, requirement for flowing water during different life stages and association with habitats with unmodified water quality. | - | Experimental information on the intolerance of various fish species is, however, largely lacking and the assessment of the degree to which species are tolerant or intolerant usually has to be based on field observations. | Crass (1964); Gaigher (1969); Pienaar (1978); Kleynhans (1984); Bell-Cross and Minshull (1988); Skelton (1993); Russell and Rogers (1998); Weeks et al. (1996) |

## 3.2 *Hydrological/ Hydraulics indices*

In the process of RHA, Hydraulics/Hydrological indices are considered as the key component. Few Hydrological Indices, used in various studies are reviewed in this part of document. Hydrological indicators are accepted as one of the controlling variable of the health of biota in streams. Most of the indices describe the hydrological condition of any river based on a -outcome of the FSR (Flow Stress Ranking). Hydrological/Hydraulics indices can be calculated using Monthly/Daily flow data for any river. Flow and it's seasonal variation shows the hydrological condition of any river. Most frequently used hydrological indices are HD index, IFD index, Shannon diversity index for velocity, RVA index, Hydrology condition index and IFH index (Richter,1997; Kangand Kazama, 2013; NSW Office of Water, August, 2012; Gippel *et al*., 2012; Taylor, 2013). The details of the indices reviewed under Hydrological/ Hydraulics component with its principles and merits and demerits are summarized briefly in Table 2.

**Table 2: Assessment index system for determining the Hydrological/ Hydraulics status of the river**

| Index | Principle/ Indicators | Pros and Cons | | Reference |
|---|---|---|---|---|
| **FSR**<br><br>Flow Stress Ranking | **(1) Mean Annual Flow (A):** Based on difference in un-impacted and Current mean annual flow<br>**(2)Seasonal amplitude (SA):** The seasonal amplitude index compares the difference in magnitude between the high and low flows within each year under current and un-impacted conditions.<br>**(3) Seasonal Period (SP):** The timing of periods of flooding and low flows has an important influence on how floodplain and riverine ecosystems respond (SKM, 2005), and this index provides a measure of the shift in the timing of the maximum flow month and the minimum flow month under both un-impacted and current conditions.<br>**(4) Low Flow Magnitude:** Altering the magnitude of low flows changes the availability of instream habitat, which can lead to a long term reduction in the viability of populations of flora and fauna (SKM, 2005). The index measures the change in low flow magnitude under current and un-impacted conditions. comparison based on 90% exceedance flow<br>**(5) High Flow Magnitude:** High flow make changes in physical form of river. This index measures the change in high flows under current and un-impacted conditions.<br><br>**Other indicator:-** Flow Duration Curve | Can be calculated based on modeled monthly flow data. | Sometimes it gives negative values for a river in that case one can consider it as Zero.<br><br>Depend on Modeled monthly data so natural variation in flow can be rarely incorporated. | SKM (2005) |

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| **HD Index** | Indicator for Hydrology and water resources<br><br>**Flow Variation Degree (FD)**<br><br>Indicator for Ecological requirements<br><br>**Satisfaction level of Ecological Flow (EF)** | Incorporate flow requirement for river ecology | 1. Modeled reference monthly data for FD<br><br>2. Long term historical data for EF | Gippel, 2011 |
| **IFD**<br><br>Index of Flow Deviation | 1. IFD was developed to measure flow alteration based on comparison with pre-regulated monthly flow data.<br><br>2. Comparison with reference site (within test river)<br><br>3. Natural range of variation (e.g. ±1 standard deviation from the mean, or $25^{th}$ to $75^{th}$ percentile range) in hydrological parameters.<br><br>**Indicators:**<br><br>1. High Flow Volume (HFV)<br><br>2. Low Flow Volume (LFV)<br><br>3. Highest Monthly Flow (HMF)<br><br>4. Lowest Monthly Flow (LMF)<br><br>5. Persistently Higher Flow (PHF)<br><br>6. Persistently Lower Flow (PLF)<br><br>7. Persistently Very Low (PVL)<br><br>8. Seasonality Flow Shift (SFS) | IFD highlights impact of flow regulation and also highlights years of naturally lower than usual flow (Natural Deviation in flow) | Uses monthly flow only which is coarse from the ecological point of view | |
| Shannon diversity index for velocity | | Kangand Kazama (2014) | | |
| **RVA**<br><br>Range of Variability Approach | Assessing hydrological alteration based on the differences in stream flow regime characteristics between two defined time periods at a given stream gauge.<br><br>1. Magnitude of monthly discharge condition<br><br>2. Magnitude and duration of annual extreme discharge condition<br><br>3. Timing of annual extreme discharge condition | Taylor (2013) | | |

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| | 4. Frequency and duration of high and low flow pulse<br><br>5. Rate/ Frequency of hydrograph changes | | |
| **Hydrology Condition Index** | The index combines the five indicators below and reflects the relative ecological importance of high and low flow events, changes in flow variability and seasonality, and the annual flow volume:<br><br>1. High-flow events indicator - A measure of change in the size of high flow events relative to Reference condition.<br><br>2. Low- and zero-flow events indicator - An integrated measure of change in the size of lowflows and the duration of zero flow periods relative to Reference condition.<br><br>3. Flow variability indicator - A measure of change in the variability of flows relative to Reference condition.<br><br>4. Flow seasonality indicator - A measure of change in the seasonal pattern of flows relative to Reference condition.<br><br>5. Gross annual flow volume indicator - An integrated measure of changes in mean and median annual flow volumes relative to Reference condition. | River Condition Index in New South Wales (NSW Office of Water, August 2012) | |
| **IFH**<br><br>Index for Flow Health | **Indicators:**<br><br>1. High Flow (HF)<br><br>2. Low Flow (LF)<br><br>3. Highest Monthly (HM)<br><br>4. Lowest Monthly (LM)<br><br>5. Persistently Higher (PH)<br><br>6. Persistently Lower (PL)<br><br>7. Persistently Very Low (PVL)<br><br>8. Seasonality Flow Shift (SFS)<br><br>9. Flood Flow Interval (FFI) | 1. Each of the indicator has an explicit link to ecosystem health, in particular those aspects related to the key ecological assets. | Gippel *et al*.(2012) |

### 3.3 *Fluvial Geomorphology indices*

Fluvial Geomorphological indices shows the condition/status of the geomorphological processes *i.e.*, bank and bed erosion, interaction of sediment and flowing water with organic factors (growing and dead vegetation) which decides the shape of river channel and floodplain. Geomorphological processes are the major contributors for maintaining the suitable habitat conditions for biota. Geomorphological processes like erosion and sediment supply/transport determine various physical form of river which gives rise to range of river types. Geomorphological indices can - be calculated based on the data collected by field study or desktop study. Most frequently used indices for geomorphology are Geomorphological driver assessment index, Index of stream geomorphology, Stream bank stability index and Physical form stressor index (Preez and Rowntree, 2006; Taylor, 2013; Rowntree and Wadeson, 2000; Heeren *et al*., 2012 ). GM Index for river Ramganga would be calculated - on the basis of data availability. A new index for Ramganga Rivermight also be taken into consideration based on the Geomorphological indicators like bed slope, lateral and longitudinal connectivity, bank stability, riffle-pool sequence, channel shifting, channelsinuosity etc. A list of the indices reviewed for RHA is presented in Table 3.

**Table 3: Assessment of Index System for Determining the Fluvial Geomorphology Status of the River**

| Index | Principle/ Indicators | Reference |
|---|---|---|
| **Geomorphological Driver Assessment Index (GAI)** | 1. System connectivity<br>2. Sediment balance<br>3. Resistance of the channel to change<br>4. The channel morphology | Assessment of Geomorphological reference condition (Preez and Rowntree, 2006) |
| | 1. Channel complexity<br>2. Substrate<br>3. Riparian cover | (Taylor, 2013) |
| **Index of Stream Geomorphology** | 1. Channel classification<br>2. Channel condition assessment | South African River Health Programme<br>(Rowntree and Wadeson, 2000) |
| **Streambank Stability Index** | 1. Channel Stability Index(CSI)<br>2. Oklahoma Ozark Streambank Erosion Potential Index (OSEPI) | (Heeren *et al*., 2012) |
| **Physical Form Stressor Index** | 1. Free-flow interruption sub-indicator (FFI)<br>2. Sediment transport interruption sub-indicator (STI)<br>3. Longitudinal-continuity barrier sub-indicator (LoCB)<br>4. Lateral-continuity barrier sub-indicator (LaCB)<br>5. Bed disturbance sub-indicator (BD)<br>6. Bank stabilization sub-indicator (BS) | |

*Geo-morphological Index can be driven based on the Indices proposed by the FGM group i.e., Bed Slope, Lateral and Longitudinal Connectivity, Bank Stability, Riffle-Pool sequence, Channel Shifting, Chanel Sinuosity etc.*

### 3.4 *Water Quality indices*

Water quality is a key attribute of aquatic ecosystem health. The characteristics of the physical and chemical attributes of river water quality are a response of both natural processes, and human disturbances. Poor water quality can be a cause of decline in the ecological health of river. Water quality is also highly variable with time like hydrology. Most frequently used indices for WQI are EPI WATQI, Horton's WQI, CCME WQI, BC WQI, Index of River Water Quality (Tanja *et al*., 2012; CCME, 2001; BC water Quality Guidelines, 2001; Liou et al., 2004). A new multiplicative WQI would be proposed for Ramganga based on the measured parameters. A list of some WQI used in the literature is presented in Table 4.

**Table 4: Assessment of Index System for Determining the Water Quality Status of the River**

| Parameters | Principle/ Indicators | Reference |
|---|---|---|
| **EPI (Environmental Performance Index) WATQI** | 1. DO<br>2. Electrical conductivity<br>3. pH<br>4. Total Phosphorus<br>5. Total Nitrogen | Tanja *et al.* (2012) |
| **Horton's WQI** | 1. DO<br>2. pH<br>3. Coliforms<br>4. Specific Conductivity<br>5. Alkalinity<br>6. Chloride etc. | |
| **CCME** (Canadian Council of Ministers of the Environmental Quality)**WQI** | CCMEWQI = $100 - (\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732})$<br>(Scope)$F_1$= $\frac{Number\ of\ Failed\ Variables}{Total\ Number\ of\ Variables} \times 100$<br>$F_1$ = Number of variables whose objective are not met<br>(Frequency)$F_2$ = $\frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Variables} \times 100$<br>$F_2$ = Frequenct by which the objective are not met<br>(Amplitude) $F_3$= $\frac{nse}{0.01nse+0.01}$<br>$F_3$= the ammount by which the objective are not met<br>Where nse = $\frac{\sum_{i=1}^{n} excursion_i}{Number\ of\ test}$ | Also known as the water quality index for freshwater Life (CCME, 2001) |
| **BC (British Columbia)WQI** | BCWQI = $100 - (\frac{\sqrt{F_1^2+F_2^2+(F_3/3)^2}}{1.453}$<br>$F_1$, $F_2$, $F_3$ are same as CCMEWQI | BC water Quality Guidelines, 2001 |
| **Index of River** | 1. Faecal Coliform<br>2. DO | Liou *et al*. (2004) |

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| **Water Quality** | 3. BOD<br>4. Ammonical Nitrogen<br>5. Suspended Solids<br>6. Turbidity<br>7. pH<br>8. Toxicity | |

## 4.0 Proposed Indices and Data Required to Achieve the Goals

For RHA excersise some selected indices have been proposed for all the components of river health.

### 4.1 *Proposed Biological indices*

In biodiversity component, indices have been selected at every trophic level as all the trophic levels are equally important for the process of River Health Assessment. Some key indicators at each level are selected and its sub-indices are taken into account to assess the overall biological health. Diatoms at producers level and invertebrates and fishes at consumer level are selected as the representative indicators of their respective groups/trophic levels. The selected sub-indices for these indicators are mentioned as follows.

*Proposed indices for biodiversity:*

*Diatoms: Specific Pollution Sensitivity Index (IPS)/ Van Dam Index*
*Invertebrates: Biological Monitoring Working Party Index (BMWP)*
*Fish: Fish Assemblage Integrity Index (FAII)*

### 4.2 *Proposed Hydrological/ Hydraulics indices*

Recommended Index for this study is Flow health (FH) (Gippel *et al*., 2012). Flow Health is based on the concept of comparing hydrological attributes of a river in a reporting/test year with the distributions of the values of the attributes under reference conditions. Reference condition is based on the period when a particular hydrology station of any river was not impacted or less impacted, and is specific for each hydrological stations or reaches. Monthly flow data for reference period and test period are required to calculate the Flow Health Index value for any river.

### 4.3 *Proposed Fluvial Geomorphology indices*

The parameters suggested by FGM group for Fluvial Geomorphology index (FGI) are listed in Table 5

**Table 5: Parameters for FG Index**

| Parameter | Measure | Details | Remarks |
|---|---|---|---|
| Occupancy | R1 = $\frac{AFLw + AFRw}{Vw}$ | Find centre line of the channel belt (i.e., union of in-channel features, including water). Draw perpendicular lines at equally spaced (e.g., 5km apart) points along centre line. Measure width of active floodplain (channel belt margin to active floodplain margin) along the perpendiculars. Measure the left (AFLw) and the right (AFRw) floodplains separately. | Measures landscape scale equilibrium of the river system. A value close to 1 would indicate that the channel belt and its floodplains fully occupying the lateral accommodation space. A small value (say, > 0.5) would indicate an under-fit system. |
| Floodplain Development | R2 = $\frac{Cbw}{Sw}$ | Use the same perpendicular lines.Measure width of the channel belt(Cbw) and the width from the leftactive floodplain margin to rightactive floodplain margin (Sw). | Low values might indicate flood prone / avulsive system. Moderate values(say, around 0.5) should indicate astable system with good lateralconnectivity. High values shouldindicate incised/embanked or partlyabandoned system. |
| Bar density | R3 = $\frac{\sum Ba}{\sum Ca}$ | Use "reach polygons" to clip inchannel features. Compute total areaof all in-channel bar features (Ba) andtotal area of all in-channel, channelfeatures (Ca). Repeat for all reaches. | High values indicate high sediment-water discharge ratio. Very high valueswill indicate degeneration of river.Moderate values good for biota as itwould indicate the presence of amplesubstrate for biological activities. |
| Flow line sinuosity | R4a = $\frac{Arc\ Length}{Straight\ Length}$ (Primary channel) | Sinuosity of primary channel centreline. The values for multi-channel andsingle-channel reaches are to be treated separately. | Complexity of water flow. A high value would indicate better support forbiological activity. A very high value in multi-channel reach might reflectimbalance in sediment-water ratio. |
| Channel belt Sinuosity | $R4a = \frac{Arc\ Length}{Straight\ Length}$ (Channel Belt) | Sinuosity of channel belt centre line. The values for multi-channel andsingle-channel reaches are to be treated separately. | In single-channel reach higher valuesmight indicate rising base level.In multi-channel reach a high valuewould indicate structural controls. |
| Vallry Sinuosity | $R4v = \frac{Arc\ Length}{Straight\ Length}$ | Sinuosity of valley centre line. | Higher sinuosity would indicatestructural control. |
| Bar Complexity | $R6a = \frac{Bar\ Perimeter}{Bar\ Area}$ | Average of the perimeter area ratio of all kind of bars | Measures complexity of the barmargins. Higher values are good forbiota |
| Width to Depth (w/d) Ratio | Bankfull Width / Maximum Depth | Ratio of Bankfull width andMaximum depth of the same crosssection | Indicates channel shape, reflectschannel stability and percentage ofmuddy sediments in channel perimeterand |

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| | | | banks; positively related todischarge and sediment loads; Low tomoderate w/d ratios favor turbulenceand oxygenation; increased w/d ratioresults in less canopy cover |

## 4.4 *Proposed Water Quality indices*

Water quality index can be calculated based on the parameters like DO, BOD, TKN, Metal toxicity, pH, Fecal Coliform, etc. Based on the information received from the Biodiversity group an index for water quality is to be calculated.

## 4.5 *Data required from various groups to achieve the goal of RHA*

RHA group would likely to propose the river health assessment in two different ways. One in the form of Overall Health Index of river Ramganga on the basis of cumulative assesment of the values obtained by all the four broadly selected components and its indicator sub-indices. The other in the form of Report Card considering various comopnents that makes the health of the river. As discussed in the previous QPR meetings, biodiversity/Hydrology/Hydraulics experts agreed with the selected indices and they also agreed to provide the necessory information for successful assessment of the river health. Some of the desired information to compile the overall index has been delivered by the respected groups, but still some information is fragmentory and expected to be delivered at the earliest to prepare the report on RHA. The brief details of information recieved/awaited are indicated in Table 6.

**Table 6: List of the Selected Indices with the Information Needed to Make a Comprehensive RHA Index or River Health Report Card**

| S. No. | | Component | Selected index | Required information | Information received | Information awaited |
|---|---|---|---|---|---|---|
| 1. | Biodiversity indices | Diatoms | Specific Pollution Sensitivity Index/ Van Dam Index | • Abundance and distribution<br>• Van Dam index values for every stretch | | √ |
| 2. | Biodiversity indices | Invertebrates | Biological Monitoring Working Party Index | • Abundance and distribution | √ | |
| 3. | Biodiversity indices | Fish | Fish Assemblage Integrity Index (FAII)<br><br>Observed values | • Intolerance values of the selected fishes<br>• Percentage of fish with evident disease, parasite load and frequency of affected fish<br>• Frequency of occurrence | √ | |
| | Biodiversity indices | | Reference values | • Intolerance values of the selected fishes<br>• Percentage of fish with evident disease, parasite load and frequency of affected fish<br>Frequency of occurrence | | √ |
| 4. | HH index | Hydrology | FHI | • Monthly/Daily Flow Data (Observed /Simulated)<br>• Reference value for FHI | | √ |
| 5. | | Fluvial Geomorphology | As suggested by FGM group | • Indices values at all selected sites<br>• Rank wise comparison of all suggested indices | | √ |

## 5.0 Information Required to Adopt the "Multimetric and Multivariate Approaches" for RHA

For calculating the RHI, it is required to finalize the indices and assign them a relative weightage using rankwise comparision. All expert members are urged to share there views in the format given in Table 7.

**Table 7: First Level of Feedback**

| Components | Arrangement According to Importance/Priority | Pairwise Comparision | | | | | Criteria for Assigning Weightage/ Rankwise Comparision | Remarks if any |
|---|---|---|---|---|---|---|---|---|
| **Hydrology** | | | | | | | | |
| **Water Quality** | | | | | | | | |
| **Biodiversity** | | | | | | | | |
| **Geo-morphology** | | | | | | | | |

Illustrative Example:

| Components | Arrangement According to Importance/Priority | Pairwise Comparision | | | | | Criteria for Assigning Weightage/ Rankwise Comparision | Remarks if any |
|---|---|---|---|---|---|---|---|---|
| **Hydrology** | Biodiversity | 1 | | | | | | |
| **Water Quality** | Hydrology | 0.8 | | 1 | | | | |
| **Biodiversity** | Water quality | | | 0.9 | | 1 | | |
| **Geo-morphology** | Geomorphology | | | | | 0.6 | | |

The information provided by various groups as above will then be used to create preference matrix as given in Table 8, and then subsequently weightages as given in Table 9. This exercise will be done by the RHA group and the individual groups are not expected to do this exercise.

**Table 8: Preference Matrix Derived Based on Information Provided in Table 7**

| | Biodiversity | Hydrology | Water Quality | Geomorphology |
|---|---|---|---|---|
| **Biodiversity** | 1 | 2 | 4 | 5 |
| **Hydrology** | 0.5 | 1 | 3 | 4 |
| **Water Quality** | 0.25 | 0.33 | 1 | 2 |
| **Geomorphology** | 0.2 | 0.25 | 0.50 | 1 |
| **Sum** | **1.95** | **3.583333** | **8.5** | **12** |

**Table 9: Final Weightages Computed Based on Preference Matrix Given in Table 8**

| | Biodiversity | Hydrology | Water Quality | Geomorphology | $4^{th}$ root | Final Weightages |
|---|---|---|---|---|---|---|
| **Biodiversity** | 0.513 | 0.558 | 0.471 | 0.417 | 0.487 | **0.492** |
| **Hydrology** | 0.256 | 0.279 | 0.353 | 0.333 | 0.303 | **0.306** |
| **Water Quality** | 0.128 | 0.093 | 0.118 | 0.167 | 0.124 | **0.125** |
| **Geomorphology** | 0.103 | 0.070 | 0.059 | 0.083 | 0.077 | **0.078** |
| | | | | | **0.9903** | 1 |

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