

# Evolving human dimensions and the need for continuous health assessment of Indian rivers

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*River health assessment (RHA) protocols are the tools used globally that emphasize upon factors which contribute for ecological fitness of the river such as catchment health, floodplain health, channel health, flow health, quality health and biotic health indicators. Human intervention by constructions of dams, excess water abstraction, channel diversion and several other factors contribute to the depletion of diverse flora and fauna of a river. For the societal well being, it appears that RHA programmes associated with a culturally sensitive river such as River Ganga in India need a move beyond top-down technocratic approach towards one that creates inclusive spaces for collaboration and public participation. Moreover, there appears a need for continuous RHA of the river to bridge the gap between science and the sacred. Based on available literature we propose a community-based comprehensive RHA model which anchors on the premise that people's relationship with the river and human values are central to any effort towards restoration and sustainable river health management in India.*

**Keywords:** Ganga, human, river health assessment, sustainability, water.

RIVERS are main sources of fresh water that not only support human beings but are also home to a wide range of flora and fauna. Extensive human interventions are shifting the river system from healthy sustainable unit to an unsustainable one. Therefore, it is important to gain complete knowledge of the river-system dynamics and the factors influencing them. The concept of river health was first proposed under Clean Water Act (CWA) of the US wherein river health was considered as physical, chemical and biological integrity, referring to maintenance of natural ecosystem structure and function (Clean Water Act 1972, 33 US Code 1251). The health of a river depends on its ability to maintain its structure and function; to recover after disturbance; to support local biota (including human communities) and to maintain key processes such as sediment transport, nutrient cycling and energy exchange mimicking thereby an undisturbed ecosystem<sup>1</sup>.

The term 'River health' alone is, however, inherently ambiguous as it encompasses natural variations in form and function existing between all river systems<sup>2</sup>. The actual state of the river unless examined on certain well-defined parameters does not reflect essentially on the river health. Defining parameters to assess river health led to the emergence of the concept of River Health Assessment (RHA). For RHA, the logical reference point is

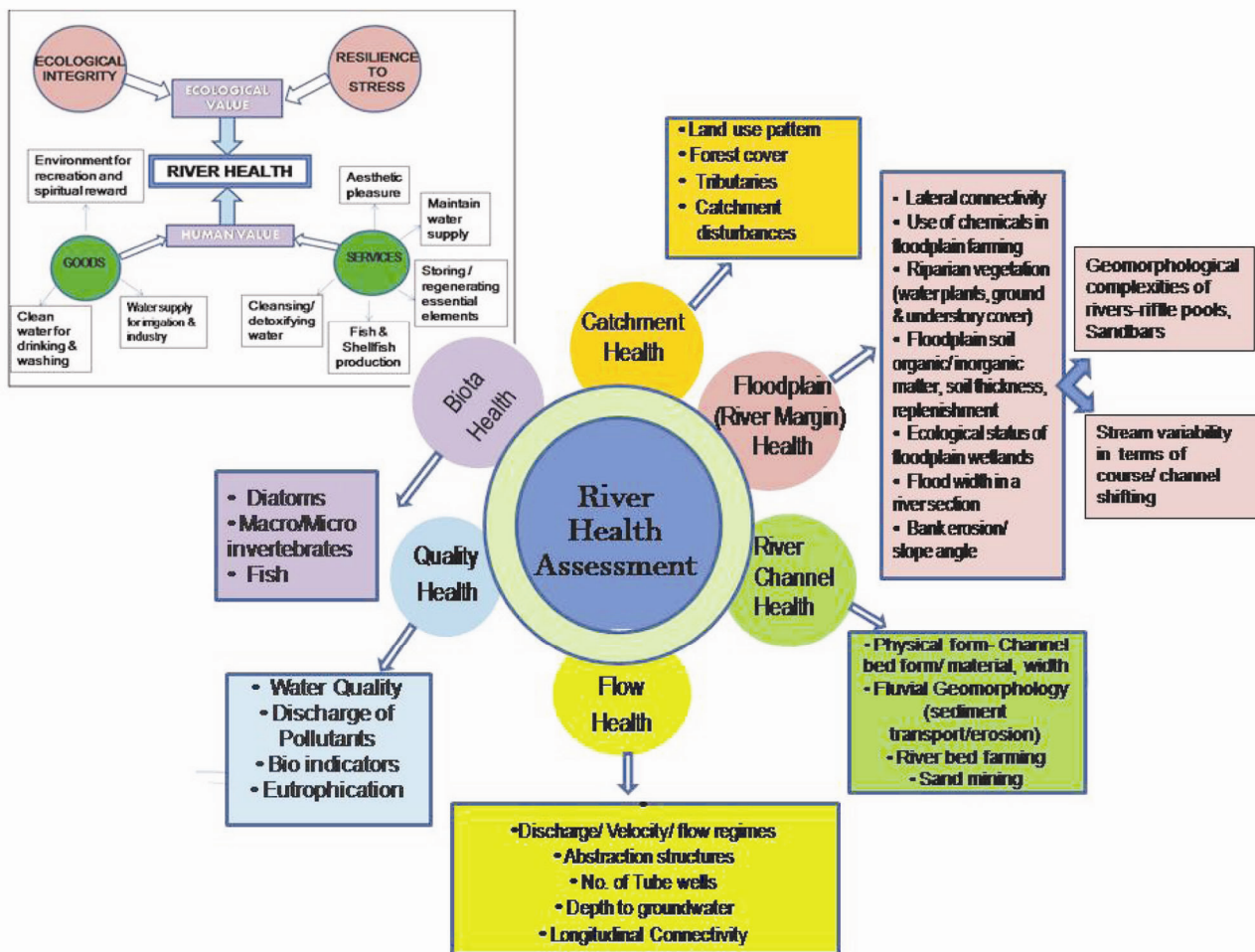
the biological status of the river in the absence of any human disturbance. The purpose of RHA is to identify rivers that are in poor health, identify its causes, help prioritize river restoration and management and evaluate the effectiveness of management actions<sup>1</sup>.

For long, RHA studies focused only upon water quality indices encompassing physicochemical properties of water. This approach suffered serious drawbacks as it only identified situations wherein biotic communities were at risk, but did not provide any information about the actual damage to biota, the streams affected with multiple pollutants, habitat disturbances and hydrological alterations<sup>3</sup>. These drawbacks, therefore, led to a shift towards direct monitoring of river health using indices which included aquatic biotic conditions or bio-assessment. The first instance of bio-assessment reported in 20th century in Europe<sup>4,5</sup> included biological species or group of species (bioindicator), wherein function, population, or status of these bioindicators determined environmental integrity<sup>3</sup>.

Physicochemical methods or bio-assessment carried out individually or in combination are insufficient for a complete RHA. Assessment of channel health, catchment condition, floodplain health, hydrological and geomorphological aspects is also required for a comprehensive RHA worldwide<sup>6-12</sup>. The three major indices namely, Ecological Quality Index (includes Water Quality Index), River Population Index and Overall Pollution Index are generally assessed to set minimum targets, which if not met, are indicative of the need for some management action<sup>2,13,14</sup>.

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**Figure 1.** Overview of river health components used globally for assessment of river health. The inset shows the proposed model by Meyer<sup>15</sup>.

Literature review indicates the RHA model by Meyer<sup>15</sup> and reported by Boulton<sup>16</sup> to be the first model proposed for RHA, illustrated in inset in Figure 1.

The model suggests a proper balance between the ecological and human values as the key factor in maintaining river health, wherein the ecological values are derived from ecological integrity and a resilience to stress whereas the human values are governed by goods and services<sup>15</sup>. Man is the principal user of rivers and an ‘unhealthy’ river may not be fit for use<sup>17</sup>. Uses of river for navigation, drinking water, irrigation water, effluent, disposal and recreation, inappropriate land use as well as in-stream practices bear high social and economic values. The transformation of rivers from its pristine state to a disturbed state indicates the changing perception of human values towards rivers and their uses. Mangold emphasized RHA to be a people-driven process requiring team effort from individuals<sup>18</sup>. The development of ecosystem health study has led researchers to recognize that it is important to consider river health in the background of society, economy and culture. RHA as a community

driven process essentially must include human dimensions, communication, liaison, promotion, quality control, information management, reporting and management activities as its key components<sup>1,16,18</sup>.

Therefore, participatory river protection and rehabilitation, together with local awareness at community level may act as a ‘multiplier’ of contributions from higher levels of government<sup>19</sup> for suitable river conservation measures.

### RHA studies at the global level

RHA has drawn the attention of scientists and governments throughout the world initiating several RHA projects worldwide (Table 1).

The countries where RHA gathered importance include Australia, China, European Union, USA and South Africa. These countries developed separate indicators to assess river health under similar but broader canopy.

Development of each RHA protocol by a country was done with its own set of objectives. Studies conducted in

**Table 1.** River health assessment protocols of projects in practice world wide for river management. A list of indicator within each protocol is included for each project

Country/Project	Thematic indicators and sub-indicators	Reference
Australia/FARWH 2010	<ol style="list-style-type: none"> <li>1. Catchment Disturbance Infrastructure, Land cover change, Land use</li> <li>2. Hydrological Changes Flow stress ranking: Low/High flow, Proportion of zero flow, Monthly variation, Seasonal period</li> <li>3. Water Quality Total nitrogen, Turbidity, Salinity, Diel temperature, Total phosphorus, Diel dissolved oxygen</li> <li>4. Physical Form Longitudinal connectivity: Major/minor dams, Gauging stations, Road-rail crossings Erosion: Erosion extent, Bank stabilization, Artificial channel</li> <li>5. Fringing Zone Extent of fringing zone: Fringing vegetation width, Fringing vegetation length Nativeness</li> <li>6. Aquatic Biota Macroinvertebrates: WA Spring Channel Model, O/E (AUSRIVAS) Fish and crayfish: Expectedness, Nativeness</li> </ol>	11
China/ACEDP 2011	<ol style="list-style-type: none"> <li>1. Hydrology Regulation of flow pattern and volume by dam, Flow volume change</li> <li>2. Physical form and Sediment transport processes Sand/gravel extraction, Gold mining, Channelization, Channel diversion, Lateral barriers (levees, dykes, embankments), Longitudinal barriers (weirs, dams, culverts), Reduced/Accelerated catchment sediment supply, Low mobility/homogeneity of channel, Accelerated mobility of channel (bank erosion, channel migration)</li> <li>3. Water quality Sewerage outfall, Industrial effluents, Irrigation return flow, Direct channel disturbance (stock/sand and gravel extraction), Land use practices (non-point source pollution, salinization)</li> <li>4. Sediment chemistry Sediment contamination</li> <li>5. Aquatic and Riparian life Spread of exotic species, Over-fishing, Low fish diversity/abundance, Poor extent and quality of riparian/wetland vegetation</li> </ol>	7
European Union/ STAR 2006	<ol style="list-style-type: none"> <li>1. Land use practices in the catchment area Degree of urbanization, agriculture and silviculture, Natural vegetation</li> <li>2. River channel and habitats Floodplain cultivation, Coarse woody debris, Stream bottoms and stream margins, Spawning habitats for the natural fish population, Migration barriers</li> <li>3. Riparian vegetation and floodplain Natural riparian vegetation, Lateral connectivity between the stream and its floodplain, Riparian buffer zone</li> <li>4. Hydrologic conditions and regulation Natural hydrograph and discharge regime, Upstream impoundments, reservoirs, weirs and reservoirs retaining sediment, Hydrological alterations</li> <li>5. Physical and chemical conditions Nutrient input, Eutrophication, Acidification, Salinity</li> <li>6. Biological conditions Indigenous biota, Fish farming</li> </ol>	6
USA/WSA, 2004	<ol style="list-style-type: none"> <li>1. Water Chemistry Acid base status, Trophic condition (nutrient enrichment), Chemical Stressors (metals, toxicants)</li> <li>2. Physical Habitat Thalweg Profile, Woody Debris Tally, Channel and Riparian Characterization, Channel Constraint, Debris, Torrents, and major floods, Discharge</li> <li>3. Benthic Macroinvertebrate Assemblage Pool/Glide/Riffle/Rapid habitat</li> </ol>	12, EPA841- B-04-004

*(Contd)*

## GENERAL ARTICLES

**Table 1.** (Contd)

Country/Project	Thematic indicators and sub-indicators	Reference
South Africa/ Pangani River Basin Flow Assessment, 2007	<ol style="list-style-type: none"> <li>1. Water quantity/discharge</li> <li>2. Water quality ( in stream and riparian)</li> <li>3. Index of Habitat Integrity (IHI) In Stream: Water abstraction, Flow modification, Bed modification, Channel modification, Extent of inundation, Presence of exotic macrophytes, Presence of exotic fauna, Solid waste disposal Riparian: Water abstraction, Flow modification, Channel modification, Extent of inundation, Decrease of indigenous vegetation from the riparian zone, Exotic vegetation encroachment, Bank erosion</li> <li>4. Invertebrates</li> <li>5. Fish</li> <li>6. Riparian vegetation</li> </ol>	21, 22
India/Aquatic Insects for Bio-monitoring Freshwater Ecosystems A Methodology Manual, River Fish Monitoring Programme, Development of River Health Index (RHI) through local stakeholder Participation and Action Planning, Living Rivers	<ol style="list-style-type: none"> <li>1. Land Use</li> <li>2. Riparian Vegetation/animals</li> <li>3. Agriculture Practices</li> <li>4. Forest cover</li> <li>5. Sand Mining</li> <li>6. Construction in floodplain</li> <li>7. In stream features: Reach length, Stream width/depth, Sampling reach area, Velocity, Canopy Cover, Stream Morphological Types, Channelization, Dams</li> <li>8. Drains/river tributaries</li> <li>9. Quality and Quantity of Groundwater</li> <li>10. Ranney wells</li> <li>11. Water quality</li> <li>12. Bottom substrate</li> <li>13. Fish population</li> <li>14. Aquatic insects</li> </ol>	3, 9, 10, 31

Australia aimed at rapid biological assessment to develop policies, strategies and regulatory measures as a means for assessing: (a) levels of attainment against established environmental quality objectives; (b) progress towards meeting defined targets for improved environmental quality; (c) potential risks to aquatic ecosystems from the impacts of human activities; and (d) the environmental condition or health of aquatic ecosystems<sup>20</sup>. A national assessment of the condition of wadeable streams and rivers in the U.S. however, had the objectives to (i) estimate the current status of selected indicators on the condition of the Nation's streams and tributaries on a regional basis with known statistical confidence, and (ii) seek associations between selected indicators of natural and anthropogenic stresses to assess the condition of wadeable streams and rivers<sup>12</sup>. The seven river commissions of China carried out studies to standardize a river health criterion that suited their own river basin with the objectives to support priorities recognized by the Chinese government, to improve water quality and river health of Gui, Pearl, Lio and Yellow river basins<sup>7</sup>.

Protocols developed by a country for its two rivers also did not have the same objectives as the protocol developed for each river were region specific. For example, the South Africa National River Health Programme<sup>21</sup> involved the use of biomonitoring tools to determine the ecological condition of South Africa's freshwater ecosystems by promoting standardized and continuous monitor-

ing and for providing reports on river health. However, the South African River Assessment Scheme aimed at establishing a capacity building research framework for promotion of biodiversity in tropical South Africa<sup>22</sup>. The latter protocol is presently being utilized for developing new RHA protocol for Indian rivers.

### General protocol for RHA

In general, the basic protocol for major RHA projects worldwide (Table 1) score the deviation of present river conditions with respect to the reference sites (pristine, sites unaffected by human influence). The information for the reference sites is gathered from (i) natural and ecological history, (ii) GIS data and (iii) expert opinion. Different RHA indicators are assessed using individual parameter index identified for the purpose. These indices are then integrated to generate the Overall Index of Pollution (OIP) using mathematical equations<sup>23</sup>. The OIP when compared with standard concentration levels ascertains pollution level of the river.

The six thematic components used commonly as indicators for RHA include catchment health, floodplain health, river channel health, flow health, quality health and biotic health (Figure 1). These indicators are assessed by scoring on a 10 point scale, such that the overall score for each index varies between a minimum 0 and a maximum 50. These individual indices thus obtained are integrated to obtain an

integrated index. Based upon the integrated index, the decision is made about the river condition attributed as very poor, poor, adequate, good or excellent.

Assessment of catchment health (CH) includes sub-indicators such as land use change and physical characteristics of the catchment for planning and controlling water quality and connectivity. The CH indicator helps to evaluate impact of human activities which disturb physical form and channel dynamics of the catchment area of the river.

Flood plain health (FPH) includes sub-indicators such as use of chemicals in floodplain farming, lateral connectivity, mining, canopy cover, bank stability/erosion, bank shape/slope, bank width/height, exotic vegetation, invasive species, average run-off, status and impact of solid waste or chemical compounds if any on the river bed or bank. FPH provides information about the changes and the impact due to flood dynamics.

River channel health (RCH) sub-indicators include channel width, longitudinal connectivity (dams and weirs), condition of macro-invertebrate communities in the vicinity of dams and weirs, characterization of physical form, its fluvial geomorphology (sediment transport/erosion/subsidence/mining/slumping, sediment nourishment and bed stabilization) and various practices which affect the shape of the river channels and floodplains. The RCH indicator also provides information regarding the ecology and biotic condition of the river.

The indicators for flow health (FH) of a river include flow regimes, water extraction structures (tube wells and water pumps, canals, settlements, city and town settlements and pipelines, mines, impoundment, industries, cultivated lands, etc.) and water barriers (weirs, dams) as sub-indicators. A disturbance in water gradient reduces the flow of water in rivers. The FH evaluates the impact of barriers, water extraction and exploitation on the natural flow (volume and velocity) of the river.

River water quality health (QH) is measured with water quality index (WQI) at the background<sup>24</sup>. To analyse water quality index, the statistical analyses of individual water quality parameters as well as bioindicators are assessed<sup>21,25</sup>. Bio-assessment techniques measure river health by assessing ecological values through direct measurement of the system. This, however, has to be substantiated with biotic health assessment of rivers.

Biotic health (BH) is measured by calculating ecological quality index (EQI) which is evaluated through Carlson trophic state index (CTSI) and Simpson's diversity index (SDI)<sup>26</sup>. It includes indicators such as the aquatic organisms present in rivers that are continuously affected by the changing conditions of the river, the population of flora and fauna, their habitats, linkages between the river and its catchment, the dynamics of water flow and the transport and transformation of nutrients. The information provided by these indicators (diatoms, macros, micros and fish) is summarized to produce either a single

number (an index), or a series of numbers (indices) describing ecosystem state<sup>21</sup>.

An indicator for RHA for a country can be measured as an individual indicator whereas the same can also be part of a cumulative indicator for another country (Table 1). For example, Australia considered 'hydrological changes' and 'physical form' as separate indicators whereas USA considered the two under one indicator, i.e. 'physical habitat'. Similarly, few indicators like water quality, discharge volume, riparian vegetation, macro-invertebrate and fish population make a common set of indicators in most of the RHA projects, irrespective of the country. However, there are certain indicators which are exclusive to specific countries only. The Thalweg profile and solid waste disposal (Table 1) are considered as indicators for RHA by USA and South Africa respectively. However, these parameters were not considered as assessment parameters by any other country which indicates that no single RHA protocol is employed for assessing a river health at global level. Therefore, there is a need of country/river specific indicators for an RHA in a given geographical region.

### RHA in India

In the Indian context, rivers are the prime source for sustaining life of the large population of the country. Not much work has been done related to a holistic framework of RHA encompassing the six major components, viz. catchment, floodplain, river channel, flow health, water quality health and biotic health. Except for assessing the health of Yamuna river at Jalalpur (Allahabad) under 'Yamuna Jiye Abhiyan'<sup>9</sup> most of the RHA work in India focused only on water quality index.

Studies on Swan river in Himachal Pradesh using water quality indices<sup>13</sup>, ecological health of Chambal river<sup>2</sup>, water quality assessment of river Godavari<sup>27</sup> and Ninglad stream and Kosi river using benthic micro-invertebrates<sup>28,29</sup>, are some of the few reports of RHA from India. A recent report on water quality assessment of Chenab River in India during low flow season evaluated WQI for three intended uses of water (irrigation, drinking and aquatic life) and reported that overall WQI ranking of river Chenab was poor and unsafe for drinking whereas the water quality was marginal for both irrigation and aquatic life<sup>30</sup>. Apart from these, RHA in India has also been conducted for water quality parameters involving bioindicators like aquatic insects<sup>3</sup> and fishes<sup>31</sup> (Table 1). RHA of the country's most vital resource river Ganga has also been carried out with a piecemeal approach using physicochemical parameters like water quality alone, heavy metal contamination and/or microbial contamination only<sup>32-36</sup> or considering population of any one city at a time overlooking the impact of the overall pollution in the entire Ganga river basin<sup>37</sup>. Sporadic studies on fishes of Ganga<sup>38-40</sup>, its bottom sediments microflora<sup>41</sup>,

geomorphology<sup>42–44</sup> and few reports on adverse impact of construction of dams and barrages on the Ganga<sup>45–50</sup> are also reported.

### River Ganga: what more is needed to assess her health?

River Ganga forms the largest river basin in India. Passing through the states, it covers 26% of the country's landmass and supports 43% of its population<sup>37</sup>. The length of the main channel is some 2,525 km, from high Himalayas to sea level. The waters of the Ganga carry one of the highest sediment loads anywhere in the world, with a mean annual total of 1.6 billion tonnes, compared to 0.4 billion tonnes for the Amazon<sup>51</sup>. Ganga is joined by well known tributaries like Ramganga, Gomti, Kali, Yamuna, Kosi, Son, Gandak and Ghaghra which forms a formidable current stretch between Rishikesh in Uttarakhand and Malda in West Bengal<sup>51</sup>. The Ganga supports rich fauna and flora, including the endangered river dolphin (*Platanista gangetica gangetica*) and at least nine other species of aquatic mammals. The mighty river passes through industrially developed areas harbouring several small scale industrial units located on the banks. There are some 30 cities, 70 towns and thousands of villages along the banks of the Ganga<sup>52</sup>.

Underpinning these concerns is the gap associated with the absence of clear, accurate picture of Ganga river condition. Although in 1986, the federal government of India launched the Ganga Action Plan I (GAP I) with the primary objective of cleaning the river<sup>37</sup>, this programme included only few aspects of RHA protocol, viz. control of non-point pollution from agricultural runoff, human defecation, cattle wallowing and throwing of unburnt and half burnt bodies into the river, conservation of the biotic diversity of the river to augment its productivity and rehabilitation of soft-shelled turtles for pollution abatement of river. In 1993, the second phase (GAP-II) programme was continued, but included work on four tributaries of the river – Yamuna, Gomti, Damodar and Mahanadi<sup>37</sup>. Further, a study by Das and Tamminga<sup>52</sup> reports that the two GAPs had limited impact due to little public participation. Thereafter in 2011, the Indian government launched another clean-up programme – the National Ganga River Basin Project – with support from the World Bank. The reports of this programme emphasize the relationship between pollution control programmes and stakeholders' participation to be crucial for any effort to clean the Ganga, restore its waterfront, and catalyse broader regeneration in the Ganga River basin.

### Discussion

Anthropogenic activities, rapid urbanization, change of land use patterns, extensive use of water for irrigation,

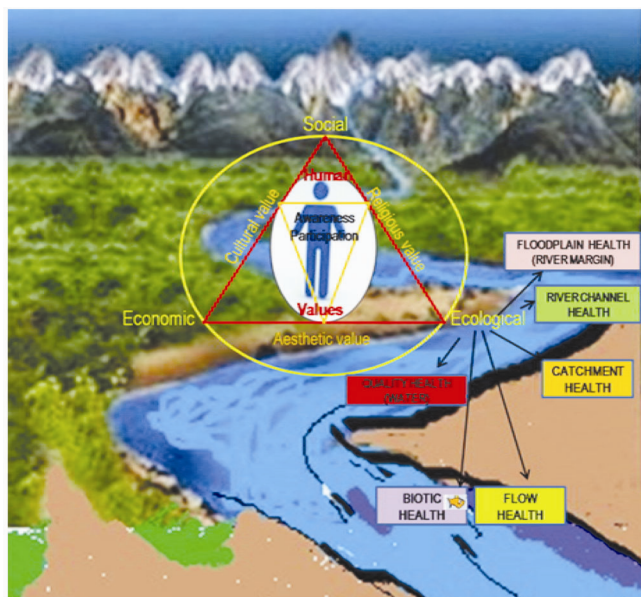
excessive water abstraction, channel diversion and construction of dams here led to some drastic effects like channel migration, increasing flood vulnerabilities, reduction of flow, extinction of its diverse flora and fauna as well as degradation of water quality. These growing concerns about River Ganga advocate proper scientific health assessment of this vital source of water in India. A comprehensive RHA protocol needs to be developed for Ganga based on standard bio-assessment protocol of RIVPACS<sup>53</sup> and the other RHA projects being carried out worldwide (Table 1).

Within RIVPACS, the selection of reference sites, adequate number and density of reference sites, high flow variability, seasonal and inter-annual variability of micro-invertebrate communities in River Ganga may be studied. The latter further will involve explicit studies pertaining to aquatic invertebrate fauna using South African scoring system (SASS) for biological indices<sup>54</sup>, fisheries employing fish assemblage integrity Index (FAII)<sup>55</sup>, riparian vegetation using riparian vegetation index (RVI)<sup>53</sup>, diatoms, phytoplankton through biomass measurements, microorganisms, aquatic macrophytes and process-oriented measure of river health by community metabolism measurements.

Reports on reforming water management in the global era of climate change<sup>56</sup> suggest that traditional knowledge residing with the communities inhabiting the river banks could be put to use for proper river management which remains undocumented and dormant. This knowledge could bring forth more insights into RHA process. The water from River Ganga is drawn for agriculture, industry and cities, but what is returned to the river instead is only waste<sup>37</sup>. Rivers have always been part of our culture with human settlements located adjacent to rivers for transport, fishing, farming and recreation. Any civilization known so far has begun at the banks of a river. For this reason, the interdependency of human community and river health cannot be overlooked while making sincere efforts for river restoration. To conserve the health of Ganga in the cities that witness its flow, proper measures for combating local pollution problems is necessary. This requires that any river health assessment programmes associated with a culturally sensitive context like Ganga river need a move beyond top-down technocratic approach towards one that creates inclusive spaces for collaboration and public participation to help bridge the gap between science and the sacred.

Considering all the above, we suggest a more comprehensive yet abridged model for RHA of a river with socio-cultural connects like that of River Ganga in India (Figure 2).

The approach of the proposed model anchors on the premise that people's relationship with the Ganga is central to any effort to restore the river's health. The key features of proposed RHA model for a culturally sensitive river is explained below.



**Figure 2.** An abridged RHA model for rivers with socio-cultural connect as River Ganga in India.

1. Sustenance of a healthy river is possible only when there exists a good balance between social, economic and ecological factors. These, therefore form the apices of the proposed model. Each of them can be measured using specific thematic indicators.
2. Human values are key to anthropogenic activities which when altered disturb the balance between the sustenance apices.
3. Human values are considered as central to the proposed model comprising of cultural, aesthetic and religious values as important indices that must be measured.
4. The model presumes that a balance between these three major human values can maintain socio-economic and ecological health of the river.
5. This demands participatory river management involving all stakeholders, their participation and awareness for establishing river health without compromising on their livelihood, social wellbeing, culture, tradition and environment.
6. Stakeholders' participation in the management and restoration of river may be by capacity building, judicious use of water resource (agriculture, drinking, recreation, transport, industries) or limited use of aquatic biodiversity (fishes, turtles, dolphins and others) or by creating awareness about the disturbance caused due to human activities on the river health.

## Conclusion

Human activities are constantly degrading the health of rivers which is a major concern for those dependent upon

river. However, a comprehensive study towards proper assessment of the health of an important lifeline, river Ganga, is still lacking in India. Models of RHA developed so far essentially capture the ecological aspects of channel health, floodplain health, catchment health, biota and water quality, to assess, manage and restore aquatic ecosystems, while neglecting the human activity that largely contributes towards river pollution and health. The involvement of every human being with the river is qualitatively different. The existing RHA models when posed in the framework of society and sustenance appear incomplete. Use of river as a resource in the environment – society interactions in all parts of the world is the key to understanding the river and its ecosystem in the true sense. Moreover, with the priority of goods and servicing global environment, the important human sensitivities for the river health often remain unaddressed. Therefore, the community based holistic yet simplified RHA-model proposed herein for a culturally connected river (Ganga) seems promising for assessment of the river health, and maintenance of good water quality supporting greater biodiversity in rivers. The model includes human values, awareness and participation as important parameters for an effective RHA. The model appears useful for providing a deeper understanding and future projections about the health of a river in the near future. All these are universally recognized as vital elements of social wellbeing possible only with the involvement of locals and stakeholders' participation, so as to preserve river Ganga, its ecological and environmental sustainability thus making it 'live' forever.

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. All the authors have contributed equally to the work.

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