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Research Article

River Health Assessment of Paisuni River, Chitrakoot

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Abstract—River health refers to the overall condition of a river ecosystem, encompassing its physical, chemical, and biological characteristics. The health of a river can be influenced by various factors such as water quality, flow regime, habitat condition and the presence of pollutants or invasive species. It is concluded that all three seasons the Algal group scores at all sites are in Stressed range (except Sati Anusuiya which are in excellent condition). Increase in biotic scores improves RHI. Higher RHI indicates a better river health condition. At Ram Ghat large amounts of sewage is added to river Paisuni. Decreased DO & increase in BOD & FC reduces OEB Group Score, which decreases sensitive biotic species and there is increase in pollution resistant species. Pollution resistant species decrease biotic indices score which lowers RHI value, indicating deteriorating RHC.

Keywords— River Health Index, River Health Condition, Pictorial representation, Circumscribed pentagon

1. Introduction

River ecosystems encompass the full diversity of rivers, streams, and creeks, as well as riparian areas and groundwater systems that are linked to them. River ecosystems [1] provide important ecological services, have substantial cultural heritage and scientific values, and support a rich diversity of plant and animal life. They also support a variety of human uses such as fisheries and recreation. The study of river health has become an important part of ecosystem health research, and the stresses on the structure and function of ecosystems from human activities have been recognized around the world.

From an economic point of view, water resources are composite assets that provide a variety of goods and services for consumptive and productive activities of human being [2,3]. Water is an essential resource for the existence of both human and other species on the earth [4]. In recent years, the concept of environmental flow (E-flow) has received increasing awareness; common understanding has come to recognize the importance of preserving some amount of water in a river to maintain the health of a river ecosystem [5-9].

However, the problems of water scarcity and deteriorating water quality, due to rapid socioeconomic development [2,10] and climate change [11], have become more serious around the world, resulting in an increase in water demand for socioeconomic sectors and reduction in E-flow. The survey results of the United Nations Environment Programme (UNEP) on 25 rivers reveal that water quality of the major rivers in the world is poor and deteriorated, and water quantity in the rivers is decreasing [12]. It is estimated that, in 2025, five billion out of the world's 7.9 billion people will be living in areas where it will be difficult or even impossible to meet basic water demand for drinking, cooking, and sanitation [4,13].

The river health concept was first proposed in the 1972 Clean Water Act by the USEPA which means maintain the chemical, physical, and biological integrity. Whereas integrity refers to a condition in which the natural structure and function of ecosystems is maintained [14]. To give a general sense of understanding, river ecologists embrace the term of river health as an analogous to human health [1,15] and it was defined through different perspectives within the natural ecosystem [16-18] with further understanding of the social, economic and cultural characteristics of river, it has been expanded and included socio-economic, policy, and managerial perspectives [19,20].

In some countries river health assessment is a routine requirement for river management. 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, the river health assessment protocol development, variables/indicators considered under four major components are presented in Table-1.1**.**

Health of the Paisuni River

The Paisuni River, flowing through Madhya Pradesh and Uttar Pradesh, is an essential water resource for agriculture, biodiversity, and local communities. This report examines the river's health from 2000 to 2024, focusing on water quality, pollution levels, biodiversity, and human impacts. Despite facing significant environmental challenges, recent efforts in conservation and sustainable management practices have shown positive trends in restoring the river's health.

The Paisuni River, originating from the Vindhya Range in Madhya Pradesh and flowing through Uttar Pradesh, is vital for the region's ecological balance and economic activities.

During the decade (2000-2010), the river's water quality was moderately good but exhibited seasonal fluctuations. Parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were generally within acceptable limits but showed signs of stress during dry seasons. The main pollution sources included agricultural runoff, untreated sewage, and small-scale industrial discharges. The river supported a diverse range of aquatic species, including fish, amphibians, and invertebrates. Riparian zones were rich in flora and fauna. Natural habitats were relatively intact, though pressures from human activities were beginning to emerge. Pollution levels were moderate but increasing. Key pollutants included agricultural chemicals, sewage, and industrial waste. Monitoring was sporadic, and enforcement of environmental regulations was weak. Agriculture was the dominant land use, with significant water extraction for irrigation and runoff from fields affecting water quality. Growing urban areas began to encroach on the river, leading to habitat loss and increased waste discharge.

In decade 2011-2020 the water quality declined noticeably, with increased levels of BOD and COD indicating higher organic pollution. Elevated nitrate and phosphate levels from intensified agricultural activities were also recorded. Several significant pollution events were reported, particularly near urban centers and industrial areas, linked to inadequate waste management infrastructure. There was a noticeable decline in biodiversity, particularly in fish populations, due to habitat degradation and increased pollution. The introduction of invasive species further stressed the native aquatic life. Pollution levels rose significantly, impacting water quality and biodiversity. Urbanization and industrialization were major contributors. The government initiated several programs to monitor and reduce pollution, but implementation was inconsistent. Industrial activities increased, adding to the pollution load and altering the river's flow regimes. There was limited awareness and involvement of local communities in river conservation efforts.

Recent years (2021-2024) have seen improvements in water quality due to the implementation of sewage treatment plants and stricter pollution controls. However, episodic pollution events still occur, particularly during the monsoon season when agricultural runoff is high. Conservation programs aimed at habitat restoration and reintroducing native species showed early signs of success, with some recovery in fish populations and riparian vegetation. Stricter regulations and improved waste management practices helped reduce pollution levels. Community-led initiatives also played a role in enhancing river health. Advanced technologies for pollution monitoring and control were deployed, providing better data and response capabilities. Increased community engagement and awareness programs helped in better managing and conserving the river. Adoption of sustainable agricultural and industrial practices contributed to improving the river's health.

The present work is an attempt to interpret and understand the above frame work of river health assessment for Paisuni River Chitrakoot taking water quality and biotic indicators together into consideration [21]. The framework calculates River Health Index (RHI) based on five indicator group scores, using a total of thirteen parameters/indices. Organo-Electrolytic-Bacterial(OEB) group has five parameters (BOD, COD, DO, Electrical Conductivity and Fecal Coliform values), Nutrients (NT) group consists of three monitoring characteristics: NH_3-N,Total-Nitrogen and Total Phosphorus measurements. In addition, algae, macro invertebrates and fishes are represented using five indices suitable for their groups. River Health Condition (RHC) has been classified as Acceptable (Excellent, Very Good, Good) and Poor (Stressed, Overstressed, Critical and Sick/Dead) based on RHI.

2. Materials and Methods

Proposed framework (model) for river health assessment:

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 bio-monitoring programmes, understanding of the ecological health of river system have been successively evolved. Several indices such as River Pollution Index [22] (RPI), Overall Index of Pollution [23] (OIP), Ecological Quality Index (EQI)/ Ecological Health Index[24-26] (EHI) 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[27] (Taizi Sub-Catchment), China 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[28].

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.

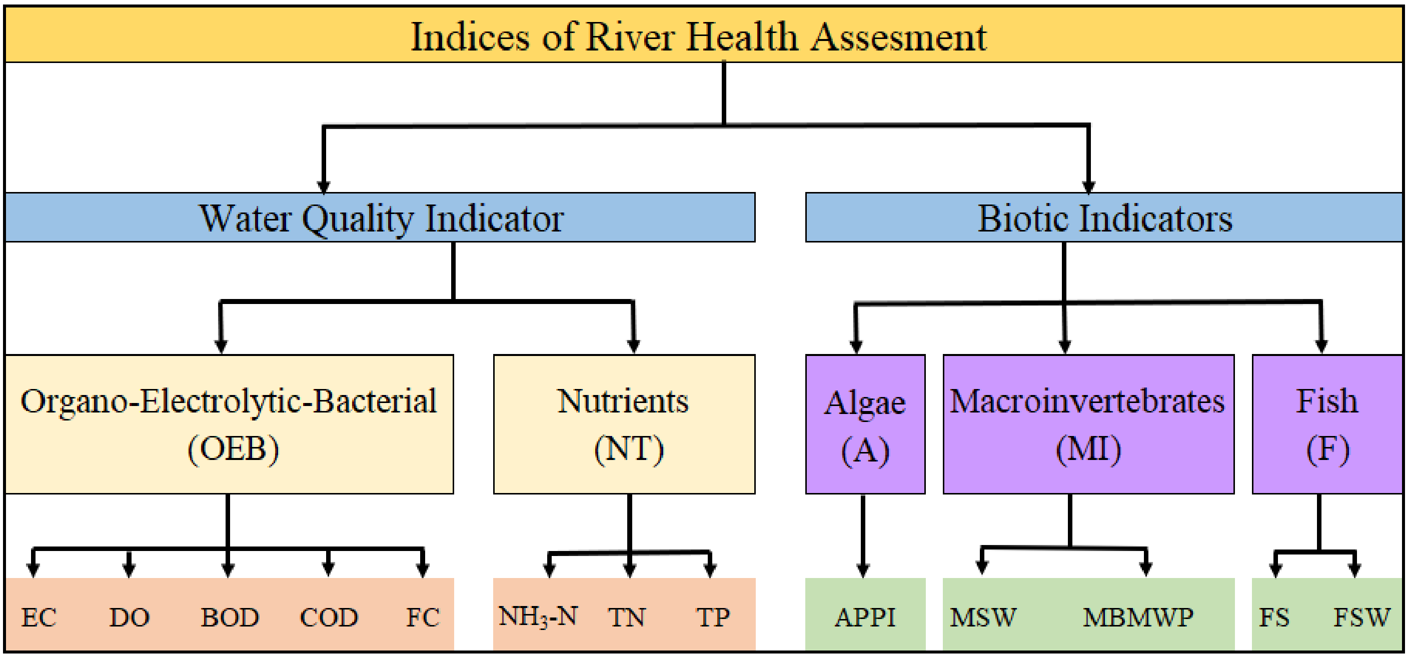


Fig 1.1 : Indicator Groups and Parameters/Indices Included in Each Group for River Health Assesment

The indicator parameters have been put in five categories (Fig 1.1):
(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:
(1) Electrical Conductivity (EC)
(2) Dissolved Oxygen (DO)
(3) Biochemical Oxygen Demand (BOD)
(4) Chemical Oxygen Demand (COD) and
(5) Fecal Coliform (FC)

The Nutrient (NT) group consists of 3 indicator parameters:
(1) Ammoniacal Nitrogen (NH_3-N)
(2) Total Nitrogen (TN) and
(3) 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:
(1) Shannon Weiner Diversity Index (MSW)
(2) Biological Monitoring Working Party (MBMWP) score
The Fish (F) indicator group consists of 2 indices:
(1) Family level Fish Species Richness Index (FS) and
(2) Fish Shannon Weiner Diversity Index (FSW)

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.

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 [29]. 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.

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**.** 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 Equation-

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

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[21,27].

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 Equation-

River Health Index (RHI) = [(OEB x w1) + (NT x w2) + (A x w3) + (MI x w4) + (F x w5)]

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 w1, w2, w3, w4 & w5 are weightage given to respective groups(Table-1.2).

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 (Table-1.3) 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.

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 includes 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.

The river health is pictorially represented by a circumscribed pentagon in which colour of each side represents one indicator group score of water quality in the river environment and the colour of the circumscribing pentagon represents the river health condition (RHC) based on overall River Health Index (RHI) for the site(Fig.-1.2).

Fig.-1.2. Circumscribed pentagon for the RHC and RHI

Validation of the Proposed River Health Assessment Framework:-

This article deals with the sampling, observations, analyses, results and discussion for the assessment of health of river Paisuni studied during 2022-23 and 2023-24. The sections will focus on validation of the proposed framework of river health assessment and its application on river Paisuni from Sphatik Shila to Karwi.

The proposed River Health Assessment Framework was validated using observed data taken from river Paisuni at Sati Anusuiya. The data was collected for two consecutive years (2022-23 and 2023-24) divided in three seasons each year.

Sampling Locations for Validation:-

The samples of river water were collected for two years from Nov. 2022 to May 2024 during three seasons: winter (Nov-Feb), summer (Mar-Jun) and rainy (Jul-Oct) from eight locations along the Paisuni river Ghats. The study are stretched from Sati Anusuiya, M.P. to Karwi, U.P., starting from upstream the samples were collected from Sati Anusuiya (S1), Sphatic Shila (S2), Arogyadham (S3), Janki Kund (S4), Pramodvan (S5), Ram Ghat (S6), Bhude Hanuman (S7) and Karwi (S8) spread in a length of around 35 km.

Sample Collection and Analyses:-
Samples for Organo-Electrolytic-Bacterial, Nutrient, Algae and Macro-invertebrate analyses were collected during Winter (Nov-Feb), Summer (Mar-Jun) and Rainy (Jul- Oct) for two years 2022-23 and 2023-24. Three grab samples were collected during morning hours between 8.00 AM-11.00 AM from each location and mixed to form a compound sample for that location once every month and results were grouped in seasons. The total number of samples analyzed is 192. Parameters such as Electrical Conductivity (EC), Dissolved Oxygen (DO), temperature, and pH were recorded on the site using multi parameter instruments. Others including 5-Day Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) by closed Reflux Titrimetric Method, Fecal Coliform (FC) by Multiple Tube Fermentation Technique and Nutrient parameters, such as Ammonia-Nitrogen (NH_3-N) by Titrimetric Method, Total Nitrogen (TN) and Total Phosphorous (TP) by Stannous Chloride Method were tested in the laboratory as per the Standard Methods [30].

The samples for algae analyses were collected in bottles and preserved in 4% formaline solution and transported to the laboratory for identification using the microscope. The macro-invertebrate samples were collected using standard D-frame dipnet having 500 micron opening. Benthic macro-invertebrates were collected systematically from all available in stream habitats by kicking the substrate and jabbing with a D-frame dip net. The samples were preserved in 4% formaline solution and transported to the laboratory for further examination. In the laboratory, the samples were rinsed thoroughly with pure water to remove the preservative. Collected samples were examined and counted using the hand lens and microscope. The macro-invertebrates were identified to the lowest possible taxonomic level using standard taxonomic literature [30-39].

Observations and Data Analyses:-
The value of all the parameters for Ogano-Electrolytic-Bacterial and Nutrient group is obtained by conducting experiments in the laboratory as per the standard methods [30]. The Genus based Algal Palmer Pollution Index [40,41] (APPI) was calculated using Table-1.4.

The Macro-invertebrate Shannon Weiner Diversity Index (MSW) was calculated as follow:

$$MSW = -\Sigma pi. \ln pi$$

Where pi = Si/N, Si = No. of individual of particular Species, N = Total number of individuals of all species in the sample.

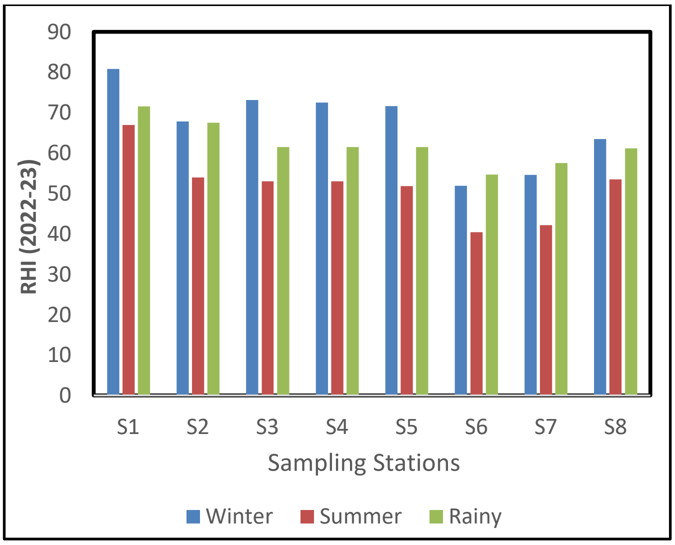
Macro-invertebrate Biological Monitoring Working Party [42] (MBMWP) score was calculated based on presence of taxonomical class and families using Table-1.5.

The two fish indices i.e. Fish Species Index (FS) and Shannon Weiner Diversity Index (FSW) were calculated based on species count and process suggested in the available literature[43,44].

The 'Target Value' and 'Critical Value' for the indicators were obtained from available literature as given in Table-1.6. The values of individual parameter/indices obtained from sample analysis are used to calculate the score of the parameter/index at a particular location. For making the score calculation more precise, the full range between 'Target value' and 'Critical value' has been divided into five zones on a 0-5 scale, as given in Table-1.7. According to this, if at a particular site, the observed value of an indicator is better than or equal to the target value, the site would have an indicator score 5 and if the observed value is less than the critical value, the indicator score would be 0.

3. Results & Discussion

The observed values of all the Physicochemical Parameters, algal genus and macro-invertebrate families in three seasons each during 2022-23 and 2023-24 are described in earlier article. The Parameter/Index Score on 0-5 scale, Indicator Group Score and RHI on 0-100 scale along with RHC in color coded form are given inTable-1.8 and Table-1.9.The variation of RHI as graphs and colored pictorial representation of River Health Condition (RHC) as quality pentagon & scores under various categories for three seasons during 2022-23 and 2023-24 at different locations is shown in Fig.-1.3 & Fig.-1.4and Fig.-1.5& Fig.-1.6.



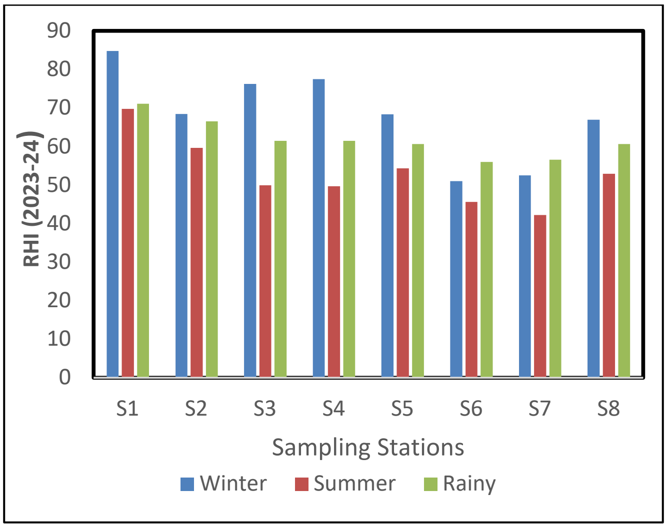


Fig.-1.3. Variations of River Health Index (RHI) for River Paisuni at different Season & locations during 2022-23 & 2023-24

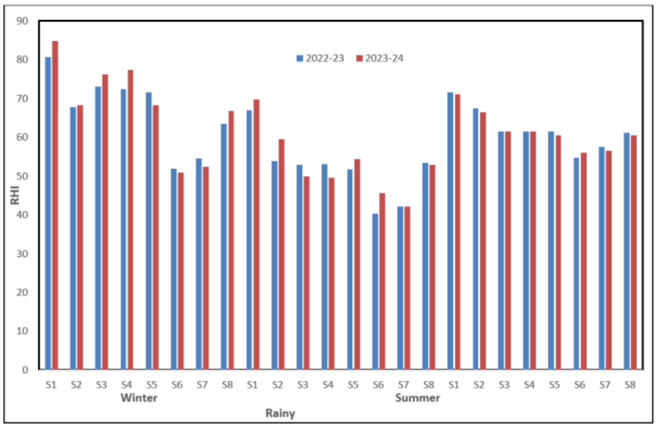


Fig.-1.4. Variations of River Health Index (RHI) for River Paisuni at different locations during 2022-23 & 2023-24

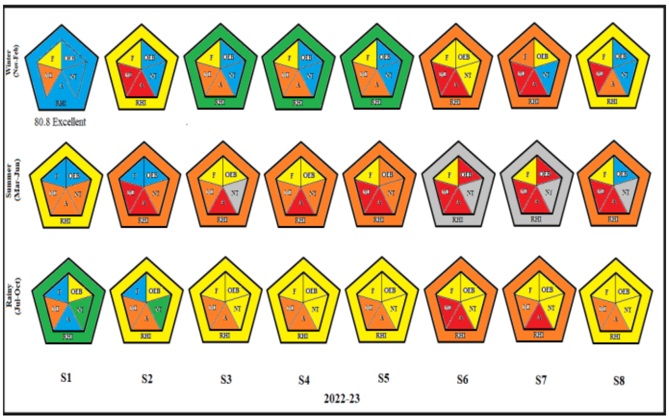


Fig.-1.5. Pictorial representation for River Paisuni at different locations (2022-23)

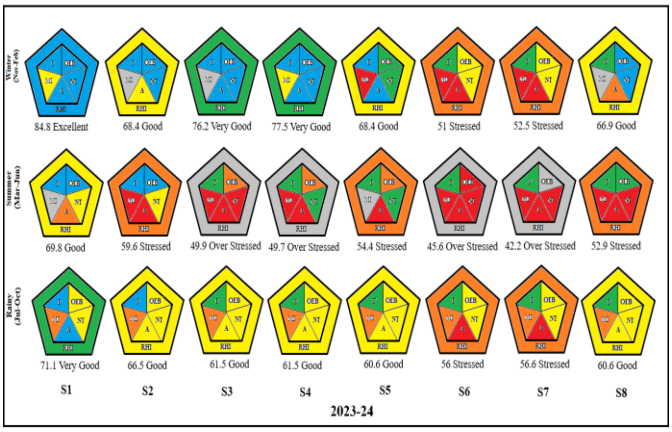


Fig.-1.6. Pictorial representation for River Paisuni at different locations (2023-24)

The observed values of all the Parameters/Indices of different Indicator Groups of three seasons for 2022-23 and 2023-24 are given in Table-1.8 and Table-1.9respectively. From Table-1.8 and Table-1.9, it is observed that, based on RHI calculated through the proposed framework, health condition of river Paisuni at Sati Anusuiya, Sphatic Shila, Arogydgam, Janki Kund and Pramodvan is found Acceptable and under Excellent, Very Good and Good category. At downstream location (S6 and S7) becomes Over Stressed and Stressed during summer season. Ram Ghat and Bude Hanuman locations are under Poor river health category, varying from Stressed to Over Stressed levels.

From Fig.-1.3 & Fig.-1.4, based on River Health Index (RHI) values, it appears that river health is at its lowest (worst) levels during summer season. It relatively improves during Rainy and attains its best levels during winter season.

From the comparison of Fig.-1.3 & Fig.-1.4, it is also observed that the health of river Paisuni at most of the ghats appears to have deteriorated in 2023-24 with respect to 2022-23. A better river health during winter season could be due to many factors. Among OEB parameters, BOD and Fecal Coliform in riverine environment are at lowest levels during winter season in comparison to other seasons. The OEB group score at S1, S2, S3 and S4 is Very Good and Good respectively during winter season. All nutrient parameters decreased during winter season which increases the NT score and all locations (except S6) are in 'Very Good' category.

As water quality improves with respect to OEB and NT parameters, there is an increase in the population and diversity of biotic indicators. The population of pollution sensitive species increase, which increases the scores of biotic indices. The algal group scores at S3, S4 & S5 are in Stressed range and S6 & S7 are in Over Stressed condition during summer season. It is noted that locations S3, S4 and S5 shows presence of Flagilaria, Spirogyra, Staurastrum, etc genera of algae. Venkateswarlu and Reddy [45] reported that abundance of green algal flora like Zygnema, Spirogira, Mougeotia, Euastrum, Staurastrumetc. indicate less polluted water. Among macro-invertebrates, presence of moderately sensitive species such as Baetidae, Culicidae, Dytiscidae, Elmidae, Hydrophilidae, Psychodidae families at locations S2, S3 and

S4 indicate good quality of water near these points. Adakole [46] also noted that the presence of May flies and Caddis flies reflects clean water. Thus the resultant increase in biotic scores improves the River Health Index (RHI). A higher RHI indicate a better River Health Condition (RHC).

The water quality and river health is found at its lowest levels during summer (Mar-June), possibly because with the onset of summer, temperature starts rising and DO in river water starts decreasing due to enhanced microbial activities for organic decomposition. The decreased DO, and increase in BOD and Fecal Coliform reduces the OEB group score during summer season. Due to low dilution and increased pollution the nutrient concentration also increases. These reduced water quality conditions affects the aquatic biota present. When the pollution starts increasing in a river, a reduction in abundance or shift in community composition from sensitive taxon to tolerant taxon is expected. However there are two theories which describe the fluctuating state of pollution and compositions of biotic species in streams. According to one theory species diversity remains highest at the intermediate levels of disturbance and as the pollution rises there is decrease in species diversity due to stress. The other theory postulates that species richness, abundance, and biomass initially reduces with increasing pollution and then it rises again as pollutant tolerant species increase with increasing pollution. Due to low level of DO, reduced discharge and increased concentration of pollutants, sensitive biotic species decrease and there is increase in the number of pollution resistant species [47,48].

This increase in pollution resistant species decreases the biotic indices score which lowers the RHI value, indicating deteriorating River Health Condition. At S6 (Ram Ghat) and S7 (Bude Hanuman), large amounts of sewage is added to river Paisuni. The observed presence of algal genera such as Ankistrodesmus, Euglena, Navicula, Nitzschia, Oscillatoria, Scenedesmus etc. at theselocations during the period is indicative of polluted water, as noted by Patrick [49] and Palmer [40] who concluded that Ankistrodesmus, Euglena, Navicula, Scenedesmus, Stigeoclonium, Oscillatoria, Chlamydomonas, and Nitzschia are highly pollution tolerantgenera and found in organically polluted waters.

Pearsall [50] was the first to establish a correlation between blue-green algae and organic pollution tolerant species of diatoms such as Anabaena, Chlorella, Closterium, Cosmarium, Eudorina, Melosira, Navicula, Pandorina, Scenedesmus, Spirulina. Some Researchers [51-57] also suggested that the presence of these pollution tolerant species indicate polluted waters. At locations S6, S7 and S8 the repeated presence of macro invertebrates Oligochaeta (Tubificids, Tubifex) Chironomids (midgelarvae) and Physidae, Muscidae indicate polluted water which is in accordance with the findings of Adakole[46] reported that certain tubificids (especially *Tubifex tubifex* and *Lumnodrilus hoffmeisteri)* or midge larva of the genus *Chrironomis*or *Eristalis*larvae or class Oligocheata can reflect low DO levels and high organic concentration in the area. Themacro-invertebrate species which are pollution tolerant are expected to be more dominant in polluted water [58]. Sharma etal. [59] gave the order of disappearance of organisms due to continuous increase in pollution as Plecoptera (stoneflies): Ephemeroptera (mayflies, damsel flies etc): Trichoptera (caddis flies): *Gammarus* (freshwater shrimp): *Asellus* (water hog louse): Chironomidae (‘blood worms’): Oligochaeta (tubificid worms).

It is evident from Fig.-1.5 & Fig.-1.6that at upstream of Paisuni river (S1 to S4), the health of river is in Excellent, Very Good and Good condition. As it enters the city the point is Bharat Ghat where large amount of sewage is being added to the river and the health condition varies at this point between Stressed to Over Stressed during various seasons of the year. In OEB group category, DO decreases and there is increase in the BOD, COD and Fecal Coliform. In Nutrient group there is increase in NH_3-N, TN and TP concentration.

At Arogydham, Janki Kund and Pramodvan (S3, S4 & S5) both OEB and NT group parameters seem to have improved possibly due to self purification, or some physico-chemical reactions, and the health comes in the ‘Good’ category during winter and rainy and in Stressed condition during summer. However, as it moves downstream to Ram Ghat (S6) and Bude Hanuman (S7), the concentration of COD and Fecal Coliform, parameters of OEB group and TN and TP parameters of NT group increase. Consequently, the river health again comes under Over Stressed to Stressed condition at these points.
Using the observational data for two years (Nov. 2022-Oct. 2024), the river health condition of Paisuni river may be categorized as Excellent at Sati Anusuiya, Very Good and Good at Sphatic Shila, Arogyadham, Janki Kund and Pramodvan. The river health condition is Overstressed and stressed at Ram Ghat, Bude Hanuman and Moderate at Karwi (S8).

4. Validation of Proposed Framework

Validation of proposed framework for river health assessment using observations in eight locations of river paisuni, Chitrakoot are-

1. Based on RHI calculated through the proposed framework, the health condition of river Paisuni is found Acceptable and under Excellent, Very Good and Good category in upstream Sati Anusuiya, Sphatic Shila, Arogya Dham and Pramodvan (S1-S4), but all eight location also becomes Stressed and Over Stressed during Summer season accept Sati Anusuiya (S1). All other locations are under Poor river health category, varying from Over Stressed to Stressed conditions.
2. The analyses indicate that health of river Paisuni is decreasing day by day with time. Based on RHI, the river health is found to be better in 2022-23 as compared to 2023-24.
3. The river health is found at its best level during winter season and unstable during rainy period at most of the locations in Chitrakoot.
4. Ram Ghat, Bude Hanuman and Karwi, River Health

Index (RHI) is reduced severely and River Health Condition (RHC) becomes Over Stressed/Stressed which is evidenced by the presence of pollution tolerant biotic species on these sites.

5. The health of river Paisuni is at its best level during winter (Nov.- Feb.) period.
6. During summer season, near Sati Anusuiya to Janki Kund among OEB parameters, BOD and Fecal Coliform are relatively low in riverine environment as compared to other seasons. Also, the decreased nutrient concentrations increase the NT score at all locations and the RHC is under Good and Stressed category.

As water quality improves with respect to OEB and NT parameters, there is an increase in the population and diversity of biotic indicators. The population of pollution sensitive species increase, which increases the scores of biotic indices. During all three seasons the Algal group scores at all sites are in Stressed range (except Sati Anusuiya which are in excellent condition). Increase in biotic scores improves RHI. Higher RHI indicates a better river health condition. At Ram Ghat large amounts of sewage is added to river Paisuni. Decreased DO & increase in BOD & FC reduces OEB Group Score, which decreases sensitive biotic species and there is increase in pollution resistant species. Pollution resistant species decrease biotic indices score which lowers RHI value, indicating deteriorating RHC. The presence of algal genera such as Ankistrodesmus, Euglena, Navicula, Nitzschia Oscillatoria, Scenedesmus, etc. at these locations during the study period is indicative of polluted water.

5. Conclusion

River health is an indicator of the harmony between human and water resources. Therefore, river health assessment is an important tool for human to develop, utilize, and manage the river in a sustainable way. In the present study, an attempt has been made to studies of Paisuni river health.

It is observed that at upstream of Paisuni river (S1 to S4), the health of river is in Excellent, Very Good and Good condition. As it enters the city the point is Bharat Ghat where large amount of sewage is being added to the river and the health condition varies at this point between Stressed to Over Stressed during various seasons of the year. In OEB group category, DO decreases and there is increase in the BOD, COD and Fecal Coliform. In Nutrient group there is increase in NH_3-N, TN and TP concentration.

At Arogydham, Janki Kund and Pramodvan (S3, S4 & S5) both OEB and NT group parameters seem to have improved possibly due to self-purification, or some physico-chemical reactions, and the health comes in the ‘Good’ category during winter and rainy and in Stressed condition during summer. However, as it moves downstream to Ram Ghat (S6) and Bude Hanuman (S7), the concentration of COD and Fecal Coliform, parameters of OEB group and TN and TP parameters of NT group increase. Consequently, the river health again comes under Over Stressed to Stressed condition at these points.

Finally, the observational data of two years (Nov. 2022-Oct. 2024), the river health condition of Paisuni river may be categorized as Excellent at Sati Anusuiya, Very Good and Good at Sphatic Shila, Arogyadham, Janki Kund and Pramodvan. The river health condition is Overstressed and stressed at Ram Ghat, Bude Hanuman and Moderate at Karwi (S8).

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Conflict of Interest
Authors declare that they do not have any conflict of interest.

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Table-1.1. 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

Table-1.2. Weightage of different indicator groups

SN	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(M1)	MSW, MBMWP	2	W_4	0.25
5	Fish Score (F)		2	W_5	0.25
	Total		13	-	1.00

Table-1.3. River Health Condition (RHC) based on Indicator Group Score and River Health Index (RHI)

River Health	Indicator Group Score/RHI Score	RHC	Colour Code
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

Table-1.4. Genus based Algal Palmer Pollution Index (APPI)

Genus	Pollution Index	Genus	Pollution Index
Anacystis	1	*Micractinium*	1
Ankistrodesmus	2	*Navicular*	3
Chlamylomonas	4	*Nitzschia*	3
Chlorella	3	*Oscillatoria*	5
Closterium	1	*Pandorina*	1
Cyclotella	1	*Phacus*	2
Euglena	5	*Phormidium*	1
Gomphonema	1	*Scenedesmus*	4
Lepocinclis	1	*Stigeoclonium*	2
Melosira	1	*Synedra*	2
Anabaena	1		

Table-1.5. Biological Monitoring Working Party (BMWP) Score

Taxonomical Class	Taxonomical Families	BMWP Score
Ephemeroptera	Heptogeniidae, Leptophlebiidae, Ephemerellidae, Ephemeridae, Potoaminthidae, Siphonuridae	10
Plecoptera	Leuctridae, Capniidae, Perlodidae, Perlidae, Taeniopterygidae	
Hemiptera	Aphlocheiridae	
Trichoptera	Leptoceridae, Goeridae, Lepidostomatidae, Brachycentridae, Sericostomatidae	
Odonata	Lestidae, Gomphidae, Cordulegasteridae, Aeschnidae, Corduliidae, Libellulidae, Plathycnemididae	8
Trichoptera	Psychomyiidae, Philopotomidae	7
Ephemeroptera	Caenidae	
Plecoptera	Nemouridae	
Trichoptera	Rhyacophilidae, Polycentropodidae, Limnephilidae	
Mollusea	Ancylidae, Hydrobiidae, Netitidae, Viviparidae, Thiaridae, Bithynidae, Unionidae	6
Trichoptera	Hydroptilidae	
Crustacea	Palaemonidae, Atydae, Gammaridae	
Polychaeta	Nereidae, Nephthyidae	
Odonata	Coenagriidae, Agriidae	
Hemiptera	Mesovelidae, Hydromeridae, Gerridae, Nepidae, Naucoridae, Notonectidae, Pleidae, Corixidae, Veliidae, Hebridae, Belestomatidae	5
Coleoptera	Haliplidae, Hygrobidae, Dytiscidae, Gyrinidae, Hydrophilidae, Noteridae, Helodidae, Dryopidae, ELminthidae, Psephenidae	

Trichoptera	Hydropsychidae	
Diptera	Tripulidae, Culicidae, Blephroceridae, Simulidae	
Planaria	Planariidae, Dendroceolidae	4
Ephemerooptera	Baetidae	
Megaloptera	Sialidae	
Hirudinea	Piscicodidae	
Mollusea	Lymnacidae, Planorbidae, Sphaeridae	3
Hirudinea	Glossiphonidae, Hirudidae, Erpobdellidae	
Planaria	Dugesiidae	
Crustacea	Asselidae	
Diptera	Chironomidae, Syrphidae	2
Oligochaeta	All Families	1

Table-1.6. Target and Critical value for parameters/indices in a river environment

SN	Indicator Group	Parameter/Indices	Target Value	Critical Value
1	**Organo-Electrolytic-Bacterial (OEB)**	EC (μmhos/cm)	≤ 400	> 1500
		DO (mg/l)	≥ 7	< 3
		BOD (mg/l)	≤ 3	> 8
		COD (mg/l)	≤ 30	> 80
		FC (MPN/100ml)	≤ 500	> 2500
2	**Nutrients (NT)**	NH_3-N (mg/l)	≤ 0.3	> 1.5
		TN (mg/l)	≤ 0.5	> 2
		TP (mg/l)	≤ 0.1	> 0.3
3	**Algae (A)**	Genus APPI	≤ 10	> 20
4	**Macroinvertebrate (M1)**	MSW	> 3.5	0
		MBMWP (Saprobic)	> 7	0
5	**Fish (F)**	Family Level Fish species Richness Index (FS)	≥ 75	0
		FSW	> 3.5	0

Table-1.7. Score of Parameters/indices on a 0-5 Scale.

Indicator Group		Parameter/ Indices	Score					
			0	**1**	**2**	**3**	**4**	**5**
1	**Organo-Electrolytic-Bacterial (OEB)**	EC (µmhos/cm)	>1500	1250-1500	1000-1250	750-1000	400-750	≤400
		DO (mg/l)	>3	3-4	4-5	5-6	6-7	≥ 7
		BOD (mg/l)	>8	6.5-8	5.0-6.5	4.0-5.0	3.0-4.0	≤ 3
		COD (mg/l)	>80	65-80	50-65	40-50	30-40	≤ 30
		FC(MPN/100ml)	>2500	2000-2500	1500-2000	1000-1500	500-1000	≤ 500
2	**Nutrients (NT)**	NH_3-N (mg/l)	>1.5	1.2-1.5	0.9-1.2	0.6-0.9	0.3-0.6	≤ 0.3
		TN (mg/l)	>2	1.6-2.0	1.2-1.6	0.8-1.2	0.5-0.8	≤ 0.5
		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)**	APPI(Genus)	>20	18-20	15-17	13-14	11-12	≤ 10
4	**Macroinvertebrate (MI)**	MSW	0	0-1.0	1.0-2.0	2.0-3.0	3.0-3.5	> 3.5
		MBMWP (Saprobic)	0	0-2.0	2.0-4.0	4.0-5.5	5.5-7.0	> 7
5	**Fish (F)**	FS (Species)	0	1-15	15-35	35-55	55-75	≥ 75
		FSW	0	0-0.75	0.75-1.5	1.5-2.5	2.5-3.5	> 3.5

Table-1.8. The Parameter/Index Score, Indicator Group Scores, RHI & RHC (2022-23)

		OEB						**NT**				**A**	
2022-23	**Sampling Stations**	**Parameter/Index Score (0-5)**					**Indicator Group Score (0-100)**	**Parameter/Index Score (0-5)**			**Indicator Group Score (0-100)**	**Parameter/ Index Score (0-5)**	**Indicator Group Score (0-100)**
		EC	**DO**	**BOD**	**COD**	**FC**	**OEB**	**NH_3-N**	**TN**	**TP**	**NT**	**APPI**	**A**
Winter (Nov-Feb)	**S1**	4	5	5	5	5	96	5	4	4	86	4	80
	S2	4	5	5	5	5	96	5	4	4	86	2	40
	S3	4	5	4	5	4	88	5	4	4	86	3	60
	S4	4	5	3	5	4	84	5	4	4	86	3	60
	S5	4	4	4	5	4	84	5	3	4	80	3	60
	S6	4	4	0	5	2	60	4	3	3	66	2	40
	S7	4	4	1	5	2	64	4	4	4	80	2	40
	S8	4	5	3	5	4	80	5	4	3	80	3	60

Summer (Mar-Jun)	**S1**	5	5	5	1	4	80	4	4	0	53	3	60
	S2	5	5	5	1	4	80	4	4	0	53	1	20
	S3	5	3	5	1	1	60	3	3	0	40	2	40
	S4	5	3	5	2	1	64	4	4	0	53	2	40
	S5	4	3	4	2	1	56	4	4	0	53	2	40
	S6	4	3	0	2	0	36	3	3	0	40	1	20
	S7	5	3	1	2	1	48	3	3	0	40	1	20
	S8	5	5	4	2	4	80	3	3	0	40	2	40
Rainy (july-Oct)	**S1**	4	5	0	4	3	64	3	4	4	73	4	80
	S2	4	5	0	4	3	64	3	4	4	73	3	60
	S3	4	5	0	4	3	64	3	4	3	66	3	60
	S4	4	5	0	4	3	64	3	4	3	66	3	60
	S5	4	5	0	4	3	64	3	3	4	66	3	60
	S6	4	5	0	4	4	68	3	3	3	60	2	40
	S7	4	5	0	4	3	64	3	3	4	66	2	40
	S8	4	5	1	4	3	68	3	3	3	60	3	60

Cont……..Table-1.8. The Parameter/Index Score, Indicator Group Scores, RHI & RHC (2022-23)

2022-23	**Sampling Stations**	**MI**			**F**			**RHI**	**RHC**
		Parameter/ Index Score(0-5)		**Indicator Group Score (0-100)**	**Parameter/ Index Score (0-5)**		**Indicator Group Score (0-100)**	**River Health Index (0-100)**	**River Health Condition**
		MSW	**MBMWP**	**MI**	**FS**	**FSW**	**F**	**RHI**	**RHC**
Winter (Nov-Feb)	**S1**	2	4	60	5	4	90	80.8	Excellent
	S2	1	3	40	5	4	90	67.8	Good
	S3	2	3	50	5	4	90	73.1	V. Good
	S4	2	3	50	5	4	90	72.5	V. Good
	S5	2	3	50	5	4	90	71.6	V. Good
	S6	1	2	30	4	3	70	51.9	Stressed
	S7	1	2	30	4	3	70	54.6	Stressed
	S8	2	2	40	4	3	70	63.5	Good
Summer (Mar-Jun)	**S1**	2	3	50	5	4	90	66.9	Good
	S2	1	2	30	5	4	90	53.9	Stressed
	S3	2	3	50	4	3	70	53.0	Stressed
	S4	1	2	40	4	3	70	53.1	Stressed
	S5	1	2	40	4	3	70	51.9	Stressed
	S6	2	2	30	4	3	70	40.4	Over Stressed
	S7	2	2	30	4	3	70	42.2	Over Stressed
	S8	2	2	40	4	3	70	53.5	Stressed
Rainy (July-Oct)	**S1**	2	3	50	5	4	90	71.6	V. Good
	S2	2	3	50	5	4	90	67.6	Good
	S3	2	3	50	4	3	70	61.5	Good
	S4	2	3	50	4	3	70	61.5	Good
	S5	2	3	50	4	3	70	61.5	Good
	S6	2	2	40	4	3	70	54.7	Stressed
	S7	2	3	50	4	3	70	57.5	Stressed
	S8	2	3	50	4	3	70	61.2	Good

Table-1.9. The Parameter/Index Score, Indicator Group Scores, RHI & RHC (2023-24)

2023-24	**Sampling Stations**	**OEB**						**NT**				**A**	
		Parameter/Index Score (0-5)					**Indicator Group Score (0-100)**	**Parameter/Index Score (0-5)**			**Indicator Group Score (0-100)**	**Parameter/ Index Score (0-5)**	**Indicator Group Score (0-100)**
		EC	**DO**	**BOD**	**COD**	**FC**	**OEB**	**NH_3-N**	**TN**	**TP**	**NT**	**APPI**	**A**
Winter (Nov-Feb)	**S1**	4	5	5	5	5	96	5	4	4	86	5	100
	S2	4	5	5	5	5	96	5	4	3	80	3	60
	S3	4	5	4	5	4	88	5	4	3	80	4	80
	S4	4	5	2	5	4	80	5	4	3	80	4	80

	S5	4	4	2	5	4	76	5	3	3	73	4	80
	S6	4	4	0	5	2	60	4	3	2	60	2	40
	S7	4	4	1	5	2	64	4	3	3	66	2	40
	S8	4	4	3	5	4	80	5	4	4	86	3	60
Summer (Mar-Jun)	**S1**	5	5	5	4	4	92	4	5	0	60	3	60
	S2	5	2	5	5	4	84	4	5	0	60	1	20
	S3	5	2	1	5	1	56	3	3	0	40	2	40
	S4	5	2	3	5	1	64	4	3	0	47	2	40
	S5	4	1	3	5	1	56	4	4	0	53	2	40
	S6	5	2	0	3	1	44	3	3	0	40	2	40
	S7	4	3	0	4	1	48	3	3	0	40	1	20
	S8	4	3	3	5	4	76	3	3	0	40	2	40
Rainy (Jul-Oct)	**S1**	4	5	0	5	3	68	3	4	3	66	4	80
	S2	4	5	0	4	3	64	3	4	3	66	3	60
	S3	4	5	0	4	3	64	3	4	3	66	3	60
	S4	4	5	0	4	3	64	3	4	3	66	3	60
	S5	4	5	0	4	3	64	3	3	3	60	3	60
	S6	4	5	0	4	2	60	3	3	3	60	2	40
	S7	4	5	0	4	3	64	3	3	3	60	2	40
	S8	4	5	0	4	3	64	3	3	3	60	3	60

Cont…..Table-1.9. The Parameter/Index Score, Indicator Group Scores, RHI & RHC (2023-24)

2023-24	Sampling Stations	MI			F			RHI	RHC
		Parameter/ Index Score (0-5)		Indicator Group Score (0-100)	Parameter/ Index Score (0-5)		Indicator Group Score (0-100)	River Health Index (0-100)	River Health Condition
		MSW	MBMWP	MI	FS	FSW	F	RHI	RHC
Winter (Nov-Feb)	**S1**	2	4	60	5	4	90	84.8	Excellent
	S2	1	2	30	5	4	90	68.4	Good
	S3	2	3	50	5	4	90	76.2	V. Good
	S4	2	4	60	5	4	90	77.5	V. Good
	S5	1	2	30	5	4	90	68.4	Good
	S6	1	2	30	4	3	70	51.0	Stressed
	S7	1	2	30	4	3	70	52.5	Stressed
	S8	2	3	50	4	3	70	66.9	Good
Summer (Mar-Jun)	**S1**	2	3	50	5	4	90	69.8	Good
	S2	1	2	30	5	4	90	59.6	Stressed
	S3	2	2	40	4	3	70	49.9	Over Stressed
	S4	1	2	30	4	3	70	49.7	Over Stressed
	S5	2	3	50	4	3	70	54.4	Stressed
	S6	1	2	30	4	3	70	45.6	Over Stressed
	S7	1	2	30	4	3	70	42.2	Over Stressed
	S8	2	2	40	4	3	70	52.9	Stressed
Rainy (Jul-Oct)	**S1**	2	3	50	5	4	90	71.1	V. Good
	S2	2	3	50	5	4	90	66.5	Good
	S3	2	3	50	4	3	70	61.5	Good
	S4	2	3	50	4	3	70	61.5	Good
	S5	2	3	50	4	3	70	60.6	Good
	S6	2	3	50	4	3	70	56.0	Stressed
	S7	2	3	50	4	3	70	56.6	Stressed
	S8	2	3	50	4	3	70	60.6	Good

