CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

This Chapter deals with the sampling, observations, analyses, results and discussion for the assessment of health of river Ganga studied during 2016-17 and 2017-18. The sections will focus on validation of the proposed framework of river health assessment and its application on river Ganga from Rishikesh to Patna. Phased intervention for River Health Improvement have also been presented and discussed.

4.2 Validation of the Proposed River Health Assessment Framework

The proposed River Health Assessment Framework was validated using observed data taken from river Ganga near Varanasi. The data was collected for two consecutive years (2016-17 and 2017-18) divided in four seasons each year.

4.2.1 Study Area and Sampling Locations for Validation

The Varanasi district lies in Uttar Pradesh (UP) state of India between 82° 56'E - 83° 03'E longitudes and 25° 14'N - 25° 23.5'N latitudes. The city of Varanasi is situated in the middle stretch of Ganga basin in the eastern part of Uttar Pradesh **(Fig 4.1)**. The samples of river water were collected for two years from Sep 2016 to May 2018 during four seasons: Post Monsoon (16 Sep-15 Nov), Winter (16 Nov-15 Jan), Spring (16 Jan-15 Mar) and Summer (16 Mar-15 May) from 5 locations along the ghats. The study area stretched from Saamne Ghat (upstream of confluence point of Assi Nala with Ganga) to confluence point of river Varuna with Ganga in the downstream side of the city. Starting from upstream the samples were collected from Saamne Ghat (V1), confluence

of (C/O) Assi Nala with Ganga (V2), Dashashwamedh Ghat (V3), Raaj Ghat (V4) and C/O Varuna with Ganga (V5) spread in a length of around 7 km.

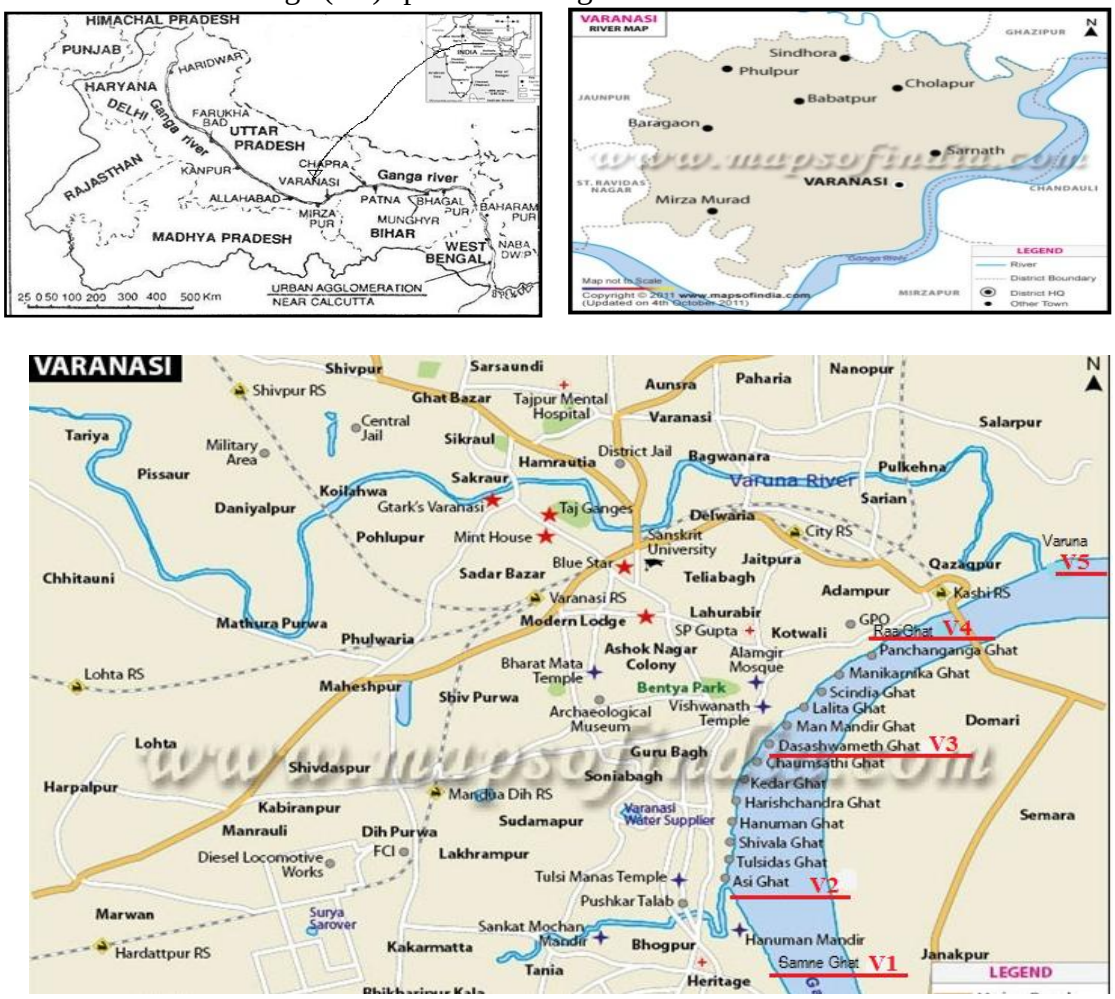


Fig 4.1: River Ganga near Varanasi and Sampling Locations

4.2.2 Sample Collection and Analyses

Samples for Organo-Electrolytic-Bacterial, Nutrient, Algae and Macroinvertebrate analyses were collected during Post Monsoon (16 Sep-15 Nov), Winter (16 Nov-15 Jan), Spring (16 Jan-15 Mar) and Summer (16 Mar-15 May) for two years 2016-17 and 2017-18. Three grab samples were collected during morning hours between 8.00 AM-11.00AM 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 360 (120 each for Organo-Electrolytic-Bacterial & Nutrient, Algae and Macroinvertebrate). 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 (Hanna Instrument), 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 (APHA, 2005).

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 macroinvertebrate samples were collected using standard D-frame dip net having 500 micron opening. Benthic macroinvertebrates were collected systematically from all available instream 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 macroinvertebrates were identified to the lowest possible taxonomic level using standard taxonomic literature such as APHA (2005), Gerber and Gabriel (2002)**,** Barbour et al. (1999), Merritt and Cummins (1996), Willium and Feltmate (1992), Pennak (1989), Durand and Leveque (1981), Tonapi (1980), Pennak (1978), Needham and Needham (1969).

4.2.3 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 (APHA, 2005). The Genus based Algal Palmer Pollution Index (APPI) was calculated using **Appendix. Table A.1** (Palmer, 1969; Nandan and Patel, 1986).

The Macroinvertebrate 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.

Macroinvertebrate Biological Monitoring Working Party (MBMWP) score was calculated based on presence of taxonomical class and families using **Appendix Table A.2** (De Zwart and Trivedi, 1994)**.**

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 (Das et al., 2013; Dwivedi et al., 2016).

The observed values of all the Parameters/ Indices of different Indicator Groups of four seasons for 2016-17 and 2017-18 are given in **Appendix Table A.3.** The algal genus and macroinvertebrate families observed at Varanasi in four seasons each during 2016-17 and 2017-18 are given in **Appendix Table A.4** and **A.5** respectively.

The observed values of individual Parameter/Index obtained from sample analyses are used to calculate the score of the Parameter/Index at particular location using **Table 3.2** (Chapter 3). 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 in **Table 4.1.** The variation of RHI as graphs and colored pictorial representation of River Health Condition (RHC) as quality pentagon & scores under various categories for four seasons during 2016-17 and 2017-18 at different locations is shown in **Fig 4.2** and **Fig 4.3**.

Table 4.1: Parameter/Index Score, Indicator Group Scores, RHI and RHC for River Ganga near Varanasi (India) (Sep 2016-May 2017 and Sep 2017- May 2018)

		OEB						NT				A		MI			F			RHI	RHC
		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)	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
2016-17		EC	DO	BOD	COD	FC	OEB	NH3-N	TN	TP	NT	APPI	A	MSW	MBMWP	MI	FS	FSW	F	RHI	RHC
Post Monsoon (16Sep-15Nov)	V1	4	4	3	4	3	72	4	3	3	67	3	60	1	3	40	4	3	70	60.3	Good
	V2	4	1	1	1	0	28	1	0	0	7	2	40	1	2	30	4	3	70	38.2	Critical
	V3	4	4	3	2	1	56	3	1	2	40	3	60	2	3	50	4	3	70	56.4	Stressed
	V4	4	4	2	2	1	52	2	1	1	27	3	60	1	3	40	4	3	70	51.3	Stressed
	V5	4	3	2	1	0	40	1	1	0	13	2	40	2	2	40	4	3	70	43.5	Over Stressed
Winter (16Nov-15Jan)	V1	5	4	3	4	3	76	4	2	3	60	3	60	2	3	50	4	3	70	62.4	Good
	V2	5	2	2	1	0	40	2	0	0	13	1	20	2	2	40	4	3	70	39.5	Critical
	V3	5	3	3	3	2	64	3	1	1	33	3	60	2	3	50	4	3	70	56.6	Stressed
	V4	5	3	3	3	1	60	2	1	0	20	3	60	2	2	40	4	3	70	51.5	Stressed
	V5	5	2	3	2	1	52	1	1	0	13	3	60	2	2	40	4	3	70	49.3	Over Stressed
Spring (16Jan-15Mar)	V1	5	4	4	2	3	72	4	3	4	73	3	60	2	3	50	4	3	70	63.8	Good
	V2	5	2	2	0	1	40	2	1	0	20	2	40	2	3	50	4	3	70	47.0	Over Stressed
	V3	5	4	3	2	2	64	4	3	1	53	3	60	2	3	50	4	3	70	59.6	Stressed
	V4	5	3	3	2	2	60	4	2	1	47	3	60	2	3	50	4	3	70	58.0	Stressed
	V5	5	3	2	1	1	48	4	2	0	40	3	60	2	2	40	4	3	70	52.7	Stressed
Summer (16Mar-15May)	V1	4	3	3	2	2	56	3	2	2	47	2	40	2	3	50	4	3	70	53.4	Stressed
	V2	3	0	1	0	0	16	0	0	0	0	1	20	1	2	30	4	3	70	31.4	Critical
	V3	4	3	2	2	2	52	2	2	1	33	2	40	2	3	50	4	3	70	50.8	Stressed
	V4	3	2	2	0	1	32	2	1	2	33	2	40	1	3	40	4	3	70	45.3	Over Stressed
	V5	3	1	1	0	0	20	1	1	1	20	1	20	2	2	40	4	3	70	37.5	Critical

2017-18		EC	DO	BOD	COD	FC	OEB	NH3-N	TN	TP	NT	APPI	A	MSW	MBMWP	MI	FS	FSW	F	RHI	RHC
Post Monsoon (16Sep-15Nov)	V1	4	4	3	4	3	72	4	2	2	53	3	60	2	3	50	4	3	70	60.8	Good
	V2	4	2	1	2	0	36	2	2	1	33	2	40	1	3	40	4	3	70	45.9	Over Stressed
	V3	4	4	3	3	2	64	3	2	2	47	3	60	2	3	50	4	3	70	58.6	Stressed
	V4	4	4	3	2	1	56	2	2	2	40	3	60	2	3	50	4	3	70	56.4	Stressed
	V5	4	3	2	1	1	44	2	1	1	27	2	40	2	3	50	4	3	70	48.6	Over Stressed
Winter (16Nov-15Jan)	V1	5	4	4	3	2	72	4	3	3	67	3	60	2	3	50	4	3	70	62.9	Good
	V2	5	2	2	1	1	44	4	2	1	47	2	40	2	2	40	4	3	70	49.1	Over Stressed
	V3	5	4	3	3	3	72	4	4	2	67	3	60	2	3	50	4	3	70	62.8	Good
	V4	5	3	3	3	2	64	4	3	1	53	3	60	1	3	40	4	3	70	57.1	Stressed
	V5	5	3	3	1	1	52	4	2	2	53	2	40	2	3	50	4	3	70	53.8	Stressed
Spring (16Jan-15Mar)	V1	5	4	4	2	3	72	4	4	4	80	3	60	2	3	50	4	3	70	64.8	Good
	V2	5	2	2	1	2	48	5	4	2	73	2	40	2	3	50	4	3	70	56.2	Stressed
	V3	5	4	3	2	3	68	5	4	3	80	3	60	2	3	50	4	3	70	64.2	Good
	V4	5	3	3	2	3	64	5	4	3	80	3	60	2	3	50	4	3	70	63.6	Good
	V5	5	3	3	1	2	56	4	2	2	53	2	40	2	3	50	4	3	70	54.4	Stressed
Summer (16Mar-15May)	V1	4	3	3	2	2	56	3	2	3	53	2	40	2	3	50	4	3	70	54.4	Stressed
	V2	3	0	1	0	0	16	1	1	1	20	0	0	2	2	40	4	3	70	32.9	Critical
	V3	4	3	2	2	2	52	2	2	2	40	2	40	2	3	50	4	3	70	51.8	Stressed
	V4	4	2	2	1	1	40	2	1	1	27	2	40	2	2	40	4	3	70	45.5	Over Stressed
	V5	2	1	1	0	1	20	2	1	1	27	1	20	2	2	40	4	3	70	38.5	Critical

From **Table 4.1,** it is observed that, based on RHI calculated through the proposed framework, health condition of river Ganga at Varanasi is found 'Acceptable' and under 'Good' category only at upstream location (V1) and this location also becomes 'Stressed' during summer season. All other locations are under 'Poor' river health category, varying from 'Stressed' to 'Critical' levels.

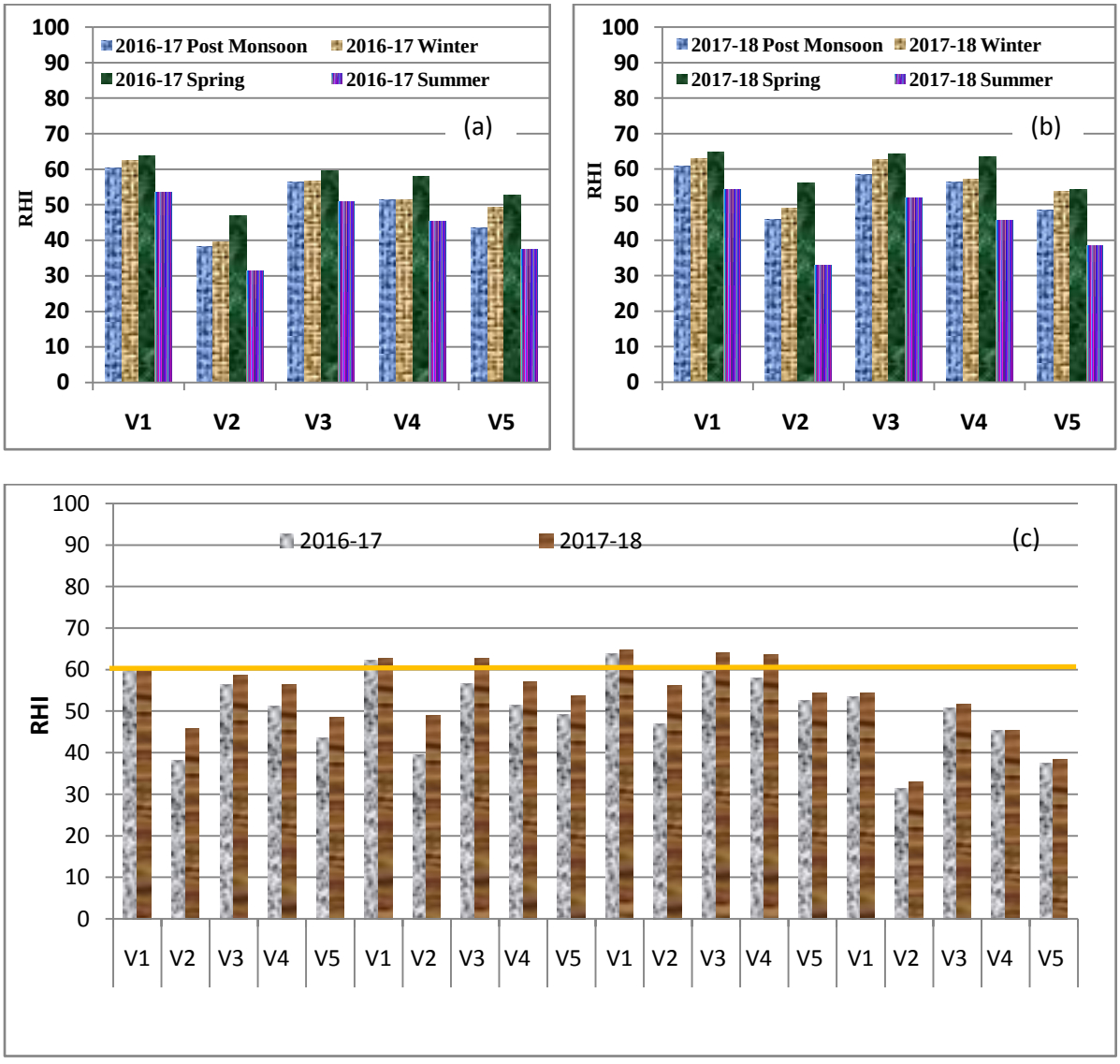


Fig 4.2: Variation of RHI at Different Locations of River Ganga near Varanasi for Four Seasons During 2016-17 and 2017-18

From **Fig 4.2**, 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 Post Monsoon months and Winter, and attains its best levels during Spring season (16Jan-15Mar). From the comparison of **Fig 4.2(a)** and **4.2(b)**, it is also observed that near Varanasi, the health of river Ganga at most of the ghats appears to have improved in 2017-18 with respect to 2016-17. A better river health during Spring season (16Jan-15Mar) could be due to many factors. Among OEB parameters, BOD and Fecal Coliform in riverine environment are at lowest levels during Spring season in comparison to other seasons. The OEB group score at V1 and V3 is 'Very Good' and 'Good' respectively during Spring season. All nutrient parameters decreased during Spring season which increases the NT score and all locations (except V5) 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 V1, V3 & V4 are in 'Stressed' range and V2 & V5 are in 'Critical' condition during Spring season. It is noted that locations V1, V3 and V4 shows presence of Flagilaria, Spirogyra, Staurastrum, etc genera of algae. Venkateswarlu and Reddy (1985) reported that abundance of green algal flora like Zygnema, Spirogira, Mougeotia, Euastrum, Staurastrum etc. indicate less polluted water. Among macroinvertebrates, presence of moderately sensitive species such as Baetidae, Culicidae, Dytiscidae, Elmidae, Hydrophilidae, Psychodidae families at locations V1, V3 and V4 indicate good quality of water near these points. Adakole (2001) also noted that the presence of Mayflies and Caddisflies 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 (16Mar-15May). Possibly because with the onset of summer, temperature starts rising and the 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 (Chadwick et al., 1986; Sprague et al., 1965). 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 (Connell, 1974; Huston, 1979). 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 (Gonza´lez-Oreja and SaizSalinas, 1998; Pearson and Rosenberg, 1978). 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 (Genter and Lehman, 2000; Biosson and Perrodin, 2006). This increase in pollution resistant species decreases the biotic indices score which lowers the RHI value, indicating deteriorating River Health Condition. At V2 (the confluence of Assi Nala with Ganga) and V5 (the confluence of Varuna with Ganga), large amounts of

sewage is added to river Ganga. The observed presence of algal genera such as Ankistrodesmus, Euglena, Navicula, Nitzschia, Oscillatoria, Scenedesmus etc. at these locations during the period is indicative of polluted water, as noted by Patrick (1965) and Palmer (1969) who concluded that Ankistrodesmus, Euglena, Navicula, Scenedesmus, Stigeoclonium, Oscillatoria, Chlamydomonas, and Nitzschia are highly pollution tolerant genera and found in organically polluted waters.

Pearsall (1932) 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. Rai et al. (2008), Das et al. (2007), Sanap (2007), Jafari and Gunale (2006), Goel et al. (1986), Gunale and Balakrishnan (1981) and Ratnasabapathy (1975) also suggested that the presence of these pollution tolerant species indicate polluted waters. At locations V2, V4 and V5 the repeated presence of macro invertebrates Oligochaeta (Tubificids, Tubifex) Chironomids (midge larvae) and Physidae, Muscidae indicate polluted water which is in accordance with the findings of Adakole (2001) who 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. The macroinvertebrate species which are pollution tolerant are expected to be more dominant in polluted water (Sallenave, 2015). Sharma et al. (2014) 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 4.3 a & b** that at upstream of Varanasi (V1), the health of river Ganga is in 'Good' condition. As it enters the city the first point is C/O of Assi Nala (V2) where large amount of sewage is being added to the river and the health condition varies at this point between 'Over Stressed' to 'Critical' 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 Dashashwamedh Ghat (V3) 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 spring and in 'Stressed' condition during summer. However, as it moves downstream to Raaj Ghat (V4) and C/O Varuna with Ganga (V5), 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 'Stressed' to 'Critical' condition at these points.

CPCB (2017) reported the Biological Water quality of river Ganga at Varanasi in moderate pollution range in the months of May 2017 and March 2018. The results of analyses in the present study are also reflective of similar conclusions, although with deeper diagnostic approach. Using the observational data for two years (Sept 2016-May 2018), the river health condition of Ganga near Varanasi may be categorized as 'Good' to 'Stressed' at upstream of Varanasi (V1) and near Dashaswamedhghat (V3), 'Stressed' to 'Overstressed' near Rajghat (V4) and 'Overstressed' to 'Critical' near the confluence of Assi Nala with Ganga (V2) and Varuna with Ganga (V5).

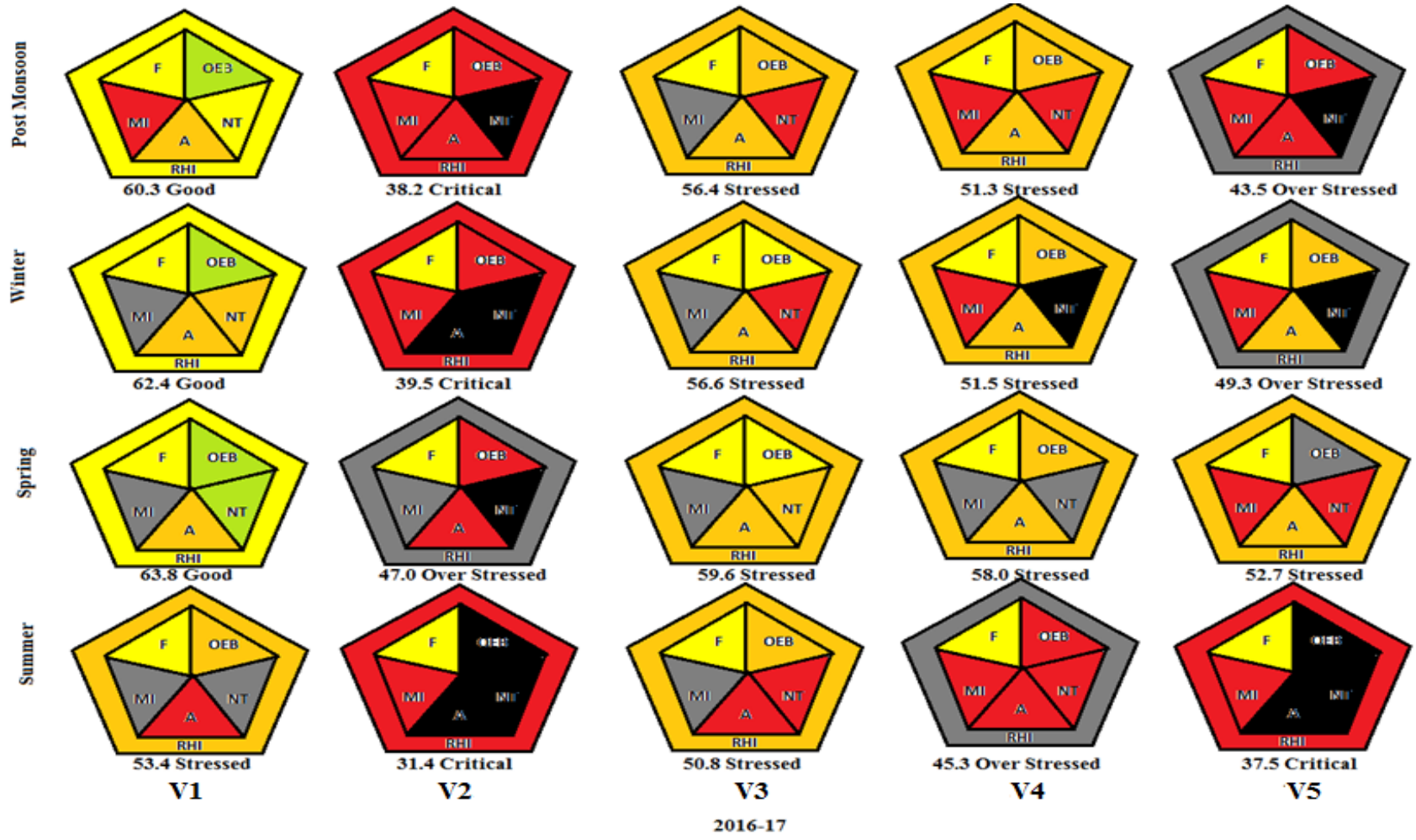


Fig 4.3 a: Pictorial Representation of Variations in Indicator Group Scores, River Health Index and River Health Conditions at five Locations of River Ganga near Varanasi for Four Seasons During 2016-17

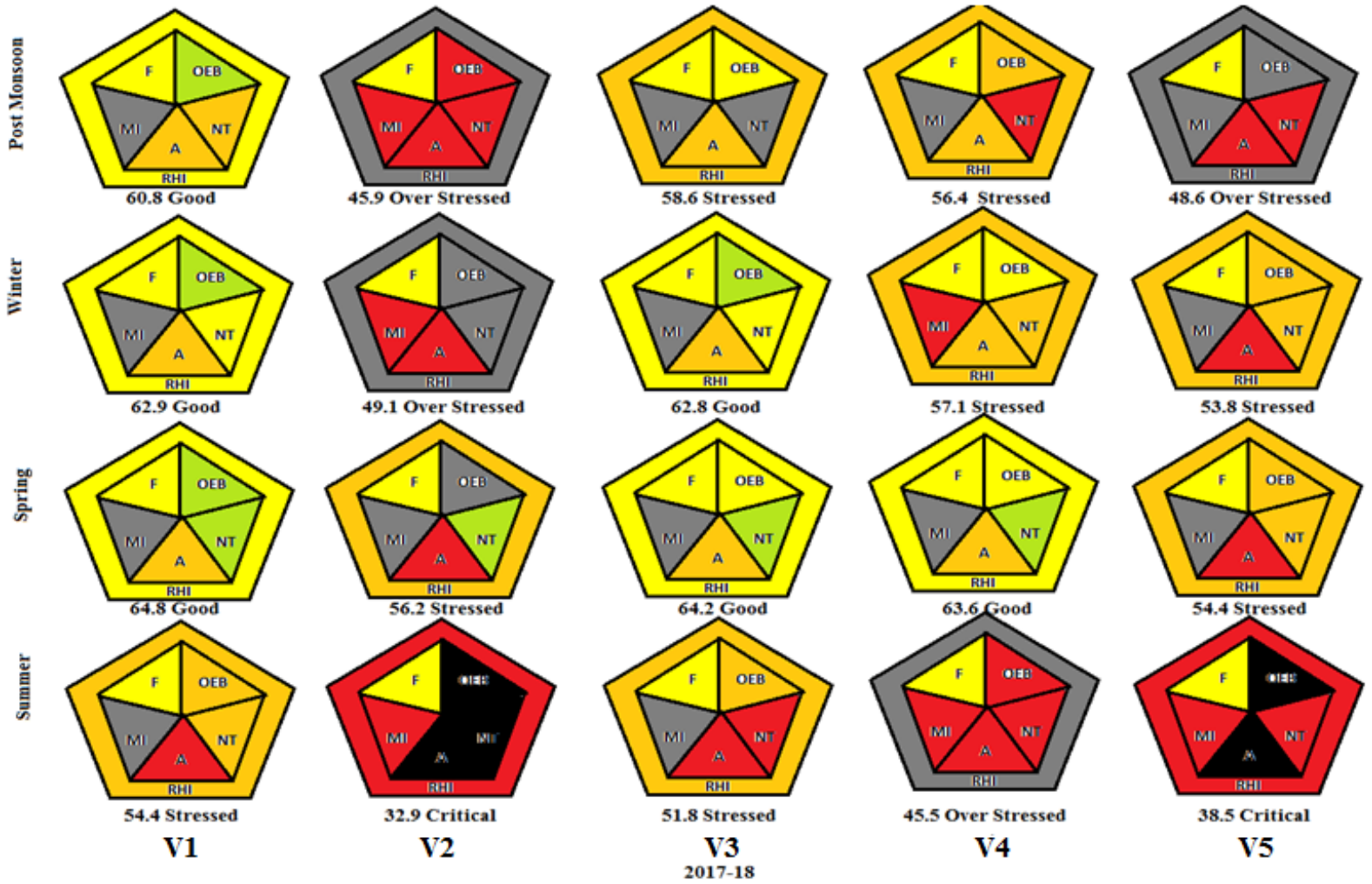


Fig 4.3 b: Pictorial Representation of Variations in Indicator Group Scores, River Health Index and River Health Conditions at five Locations of River Ganga near Varanasi for Four Seasons During 2017-18

4.3 Application of the Proposed River Health Assessment Framework on River Ganga from Rishikesh to Patna

The applicability of the proposed River Health Assessment Framework was checked by applying it on river Ganga from Rishikesh to Patna. The data was collected for four seasons from Sept 2017 to May 2018.

4.3.1 The River Stretch and Sampling Plan

The framework was applied on river Ganga near six cities namely Rishikesh, Haridwar, Kanpur, Allahabad (Prayagraaj), Varanasi and Patna (**Fig 4.4)**. Rishikesh in Uttarakhand lies around 30° 5'N and 78° 16'E. Haridwar which also is in Uttarakhand and lies around 29° 56'N and 78° 9'E. Kanpur is one of the largest city in the state of Uttar Pradesh, lying around 26° 26'N and 80° 19'E. Allahabad (Prayagraaj) is also in Uttar Pradesh and lies around 25° 22'N and 81° 52'E. Varanasi is one of the holy cities of Uttar Pradesh and lies between 82° 56'E - 83° 03'E and 25° 14'N - 25° 23.5'N and Patna, the capital and largest city of the state of Bihar is located around 25.6°N, 85.1°E on the southern bank of the river Ganga in Eastern India.

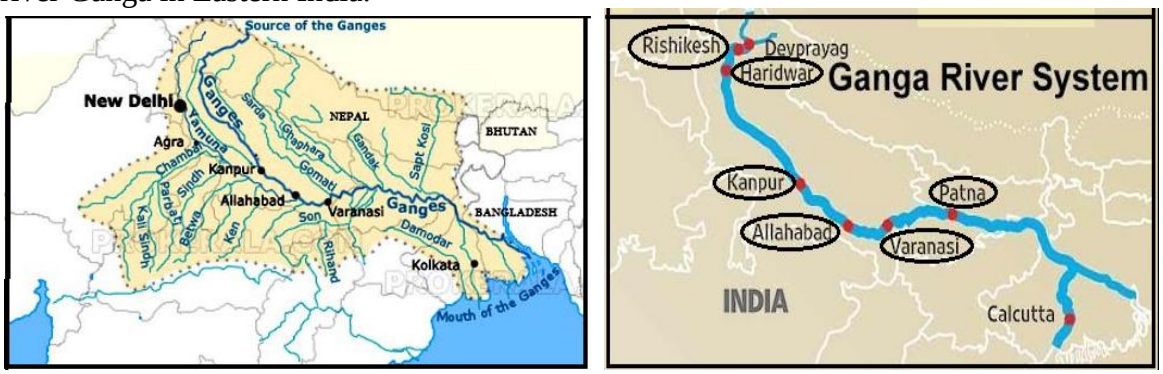


Fig 4.4: River Ganga and Location of 6 Selected Cities/Towns

For our study purposes, representative samples of river water were collected from Sep 2017 to May 2018 during four seasons: Post Monsoon (16Sep-15Nov), Winter (16Nov-15Jan), Spring (16Jan-15Mar) and Summer (16Mar-15May) from 2 sites in Rishikesh and 3 sites each in Haridwar, Kanpur, Allahabad (Prayagraaj) & Patna and 5 sites in Varanasi along the ghats of river Ganga. The cities and the sampling locations are given in **Table 4.2**.

Table 4.2: Cities and Sampling Locations on River Ganga from Rishikesh to Patna

S. No.	Cities	Sampling Locations	
1	Rishikesh (2 Locations)	(1) U/S Lakshman Jhula	R1
		(2) Triveni Ghat	R2
2	Haridwar (3 Locations)	(3) U/S Bhim Gauda Dam	H1
		(4) Har Ki Paudi	H2
		(5) Ravidas Ghat	H3
3	Kanpur (3 Locations)	(6) U/S Ganga Barrage	K1
		(7) Sarsaiya Ghat	K2
		(8) Duedi Ghat	K3
4	Allahabad (Prayagraaj) (3 Locations)	(9) Dashashwamedh Ghat, Daraganj	A1
		(10) Sangam	A2
		(11) Chattnag Ghat	A3
5	Varanasi (5 Locations)	(12) Saamne Ghat	V1
		(13) C/O Assi Nala with Ganga	V2
		(14) Dashashwamedh Ghat	V3
		(15) Raaj Ghat	V4
		(16) C/O Varuna with Ganga	V5
6	Patna (3 Locations)	(17) Digha Bridge	P1
		(18) Kali Ghat	P2
		(19) Kangan Ghat	P3

4.3.2 Sample Collection and Analyses

Samples for Organo-Electrolytic-Bacterial, Nutrient, Algae and Macroinvertebrate parameter analyses were collected from all 19 sites for Post Monsoon (16Sep-15Nov), Winter (16Nov-15Jan), Spring (16Jan-15Mar) and Summer (16Mar-15May) during 2017-18.

The observed value of all the Parameters/ Indices of different Indicator Groups for four seasons is given in **Appendix Table A.6.** The algal genus and macroinvertebrate families observed for four seasons during 2017-18 are given in **Appendix Table A.7** and **Table A.8** respectively. The Parameter/Index score, Indicator Group score, RHI and RHC is given in **Table 4.3.**

Fig 4.5 shows the variation of RHI for all the four seasons during 2017-18 at different locations on river Ganga from Rishikesh to Patna. The **Fig 4.6 a-d** shows the graphical and colored pictorial representation of Indicator Group score, RHI and RHC as quality pentagon & scores under various categories for four seasons (**Fig 4.6a-d)** during 2017-18 at different locations.

Table 4.3: Parameter/Index Score, Indicator Group Scores, RHI and RHC from Rishikesh to Patna (2017-18)

(a) Post Monsoon (16 Sep 2017-15 Nov 2017)

	OEB						NT				A		MI			F			RHI	RHC
Sampling Sites	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)	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 Color Code
	EC	DO	BOD	COD	FC	OEB	NH3-N	TN	TP	NT	APPI	A	MSW	MBMWP	MI	FS	FSW	F	RHI	RHC Color
R1	5	5	5	5	4	96	5	4	2	73	4	80	2	3	50	4	4	80	73.9	Very Good
R2	5	5	4	5	4	92	4	3	1	53	3	60	2	3	50	4	4	80	66.3	Good
H1	5	5	3	5	4	88	4	4	4	80	3	60	2	2	40	4	3	70	64.7	Good
H2	5	5	3	5	4	88	4	3	4	73	3	60	2	2	40	4	3	70	63.7	Good
H3	5	4	3	5	4	84	4	3	4	73	3	60	2	2	40	4	3	70	63.1	Good
K1	5	4	3	1	3	64	2	2	2	40	2	40	2	2	40	4	4	80	53.6	Stressed
K2	5	2	2	0	1	40	2	2	0	27	1	20	2	2	40	4	4	80	44.0	Over Stressed
K3	5	3	2	0	2	48	2	1	0	20	2	40	2	2	40	4	4	80	48.2	Over Stressed
A1	4	4	4	2	3	68	2	2	1	33	2	40	2	2	40	4	4	80	53.2	Stressed
A2	4	4	3	2	2	60	2	2	3	47	2	40	2	3	50	4	4	80	56.5	Stressed
A3	4	3	3	2	1	52	2	1	2	33	2	40	2	3	50	4	4	80	53.3	Stressed
V1	4	4	3	4	3	72	4	2	2	53	3	60	2	3	50	4	3	70	60.8	Good
V2	4	2	1	2	0	36	2	2	1	33	2	40	1	3	40	4	3	70	45.9	Over Stressed
V3	4	4	3	3	2	64	3	2	2	47	3	60	2	3	50	4	3	70	58.6	Stressed
V4	4	4	3	2	1	56	2	2	2	40	3	60	2	3	50	4	3	70	56.4	Stressed
V5	4	3	2	1	1	44	2	1	1	27	2	40	2	3	50	4	3	70	48.6	Over Stressed
P1	5	4	3	3	3	72	4	3	3	67	3	60	2	2	40	4	3	70	60.3	Good
P2	4	2	1	1	2	40	3	2	0	33	2	40	2	2	40	4	3	70	46.5	Over Stressed
P3	5	3	2	1	3	56	3	2	2	47	3	60	2	2	40	4	3	70	54.9	Stressed

(b) Winter (16 Nov 2017-15 Jan 2018)

Sampling Sites	OEB						NT				A		MI			F			RHI	RHC
	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)	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 Color Code
	EC	DO	BOD	COD	FC	OEB	NH3-N	TN	TP	NT	APPI	A	MSW	MBMWP	MI	FS	FSW	F	RHI	RHC Color
R1	5	5	4	4	4	88	4	4	5	87	4	80	2	4	60	4	4	80	77.2	Very Good
R2	5	5	4	4	4	88	4	3	5	80	3	60	2	3	50	4	4	80	69.7	Good
H1	5	5	4	4	4	88	4	5	5	93	4	80	2	2	40	4	3	70	70.7	Very Good
H2	5	5	3	4	4	84	4	3	4	73	3	60	2	3	50	4	3	70	65.6	Good
H3	5	5	3	3	4	80	4	3	3	67	4	80	2	2	40	4	3	70	65.5	Good
K1	5	3	3	2	2	60	3	1	4	53	2	40	2	3	50	4	4	80	57.5	Stressed
K2	5	3	2	1	2	52	3	0	2	33	2	40	2	2	40	4	4	80	50.8	Stressed
K3	5	3	3	2	1	56	4	0	3	47	2	40	2	2	40	4	4	80	53.4	Stressed
A1	5	4	4	3	1	68	2	2	4	53	3	60	2	3	50	4	4	80	62.7	Good
A2	5	4	4	3	0	64	4	2	4	67	2	40	2	2	40	4	4	80	57.6	Stressed
A3	5	4	3	3	0	60	3	1	4	53	2	40	2	2	40	4	4	80	55.0	Stressed
V1	5	4	4	3	2	72	4	3	3	67	3	60	2	3	50	4	3	70	62.8	Good
V2	5	2	2	1	1	44	4	2	1	47	2	40	2	2	40	4	3	70	49.1	Over Stressed
V3	5	4	3	3	3	72	4	4	2	67	3	60	2	3	50	4	3	70	62.8	Good
V4	5	3	3	3	2	64	4	3	1	53	3	60	1	3	40	4	3	70	57.1	Stressed
V5	5	3	3	1	1	52	4	2	2	53	2	40	2	3	50	4	3	70	53.8	Stressed
P1	5	4	4	3	3	76	4	4	4	80	2	40	2	3	50	4	3	70	61.4	Good
P2	5	3	4	2	2	64	4	1	3	53	2	40	2	2	40	4	3	70	53.1	Stressed
P3	5	4	4	4	2	76	5	2	3	67	3	60	2	2	40	4	3	70	60.9	Good

(c) Spring (16 Jan 2018-15 Mar 2018)

	OEB						NT				A		MI			F			RHI	RHC
Sampling Sites	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)	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 Color Code
	EC	DO	BOD	COD	FC		NH3-N	TN	TP		APPI		MSW	MBMWP		FS	FSW		RHI	RHC Color
R1	5	5	4	5	4	92	4	5	5	93	5	100	2	4	60	4	4	80	82.8	Excellent
R2	5	5	4	5	4	92	4	4	4	80	3	60	2	3	50	4	4	80	70.3	Very Good
H1	5	5	3	4	4	84	4	4	5	87	4	80	2	3	50	4	3	70	71.6	Very Good
H2	5	5	3	4	4	84	4	3	4	73	3	60	2	3	50	4	3	70	65.6	Good
H3	5	5	3	2	3	72	4	3	4	73	4	80	2	3	50	4	3	70	67.8	Good
K1	5	3	3	2	2	60	4	2	3	60	2	40	2	3	50	4	4	80	58.5	Stressed
K2	5	2	2	0	2	44	3	1	2	40	2	40	2	3	50	4	4	80	53.1	Stressed
K3	5	3	2	1	2	52	2	1	2	33	3	60	2	3	50	4	4	80	57.3	Stressed
A1	5	3	4	3	3	72	4	2	4	67	3	60	2	3	50	4	4	80	65.3	Good
A2	5	4	3	2	2	64	4	3	4	73	2	40	2	3	50	4	4	80	61.1	Good
A3	5	3	3	1	2	56	4	2	4	67	2	40	2	2	40	4	4	80	56.4	Stressed
V1	5	4	4	2	3	72	4	4	4	80	3	60	2	3	50	4	3	70	64.8	Good
V2	5	2	2	1	2	48	5	4	2	73	2	40	2	3	50	4	3	70	56.2	Stressed
V3	5	4	3	2	3	68	5	4	3	80	3	60	2	3	50	4	3	70	64.2	Good
V4	5	3	3	2	3	64	5	4	3	80	3	60	2	3	50	4	3	70	63.6	Good
V5	5	3	3	1	2	56	4	2	2	53	2	40	2	3	50	4	3	70	54.4	Stressed
P1	5	4	4	3	3	76	4	3	3	67	3	60	2	3	50	4	3	70	63.4	Good
P2	4	3	3	2	1	52	4	3	3	67	2	40	2	3	50	4	3	70	55.8	Stressed
P3	5	4	3	2	2	64	4	2	4	67	3	60	2	3	50	4	3	70	61.6	Good

(d) Summer (16 Mar 2018-15 May 2018)

	OEB						NT				A		MI			F			RHI	RHC
Sampling Sites	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)	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 Color Code
	EC	DO	BOD	COD	FC		NH3-N	TN	TP		APPI		MSW	MBMWP		FS	FSW		RHI	RHC Color
R1	5	5	4	4	4	88	5	3	5	87	4	80	2	2	40	4	4	80	72.2	Very Good
R2	5	4	4	4	4	84	3	1	5	60	3	60	2	2	40	4	4	80	63.6	Good
H1	5	4	4	4	4	84	4	3	5	80	2	40	2	2	40	4	3	70	60.1	Good
H2	5	5	3	3	3	76	4	3	5	80	2	40	2	3	50	4	3	70	61.4	Good
H3	5	5	3	4	2	76	4	3	5	80	2	40	2	2	40	4	3	70	58.9	Stressed
K1	3	2	3	1	2	44	4	3	1	53	1	20	2	2	40	4	4	80	48.6	Over Stressed
K2	2	1	2	0	0	20	3	0	0	20	0	0	2	2	40	4	4	80	36	Critical
K3	2	1	2	0	1	24	4	1	1	40	0	0	2	2	40	4	4	80	39.6	Critical
A1	4	3	2	1	3	52	3	2	2	47	2	40	2	2	40	4	4	80	52.8	Stressed
A2	3	3	3	1	3	52	2	1	3	40	2	40	2	2	40	4	4	80	51.8	Stressed
A3	3	3	2	0	2	40	0	0	2	13	2	40	2	2	40	4	4	80	46	Over Stressed
V1	4	3	3	2	2	56	3	2	3	53	2	40	2	3	50	4	3	70	54.4	Stressed
V2	3	0	1	0	0	16	1	1	1	20	0	0	2	2	40	4	3	70	32.9	Critical
V3	4	3	2	2	2	52	2	2	2	40	2	40	2	3	50	4	3	70	51.8	Stressed
V4	4	2	2	1	1	40	2	1	1	27	2	40	2	2	40	4	3	70	45.5	Over Stressed
V5	2	1	1	0	1	20	2	1	1	27	1	20	2	2	40	4	3	70	38.5	Critical
P1	4	3	3	2	3	60	3	3	3	60	2	40	2	2	40	4	3	70	53.5	Stressed
P2	2	1	1	0	1	20	3	2	0	33	1	20	2	2	40	4	3	70	39.5	Critical
P3	3	2	2	2	2	44	4	2	1	47	2	40	2	2	40	4	3	70	49.1	Over Stressed

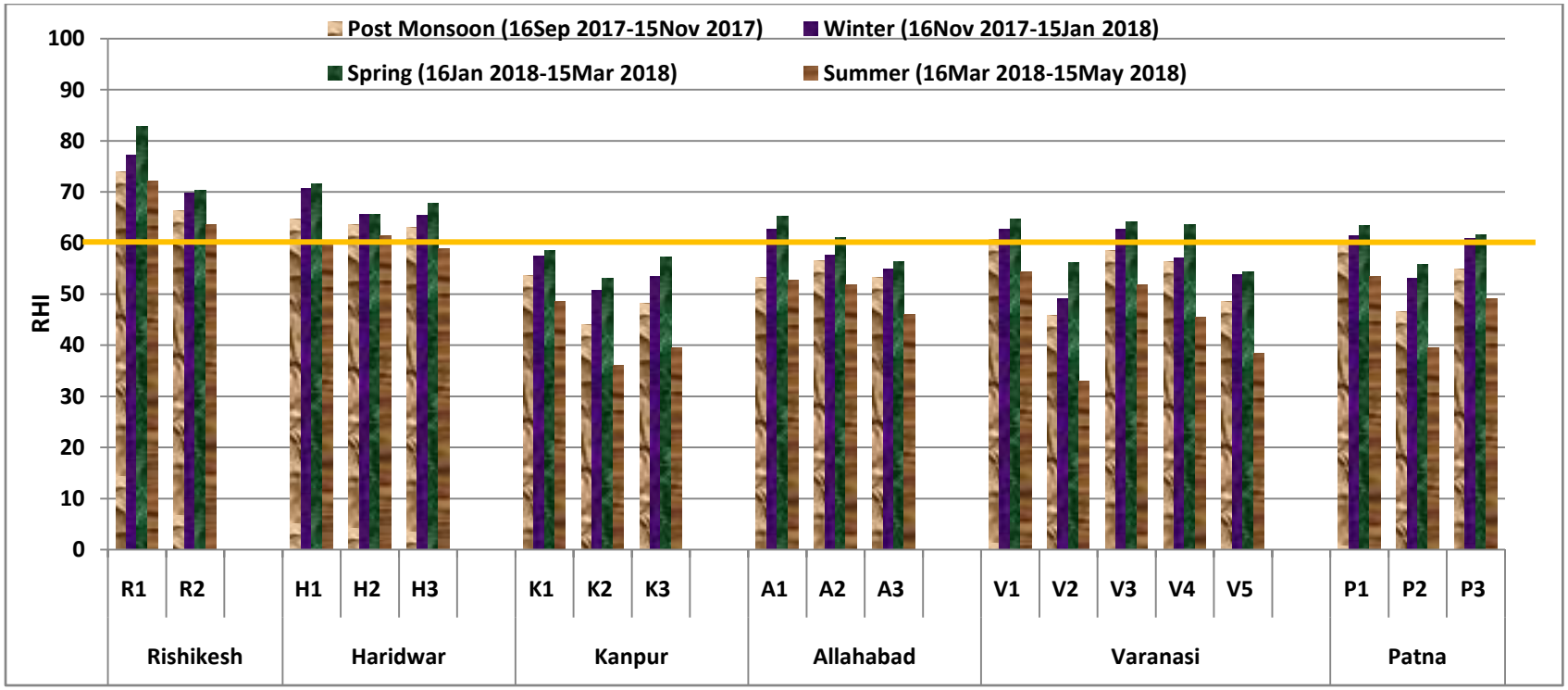


Fig 4.5: Variation of RHI for Four Seasons at Different Locations on River Ganga from Rishikesh to Patna (2017-18)

R1 U/S Lakshman Jhula	H1 U/S Bhim Gauda Dam	K1 U/S Ganga Barrage	A1 Dashashwamedh Ghat	V1 Saamne Ghat	P1 Digha Bridge
R2 Triveni Ghat	H2 Har Ki Paudi	K2 Sarsaiya Ghat	A2 Sangam	V2 C/O Assi Nala	P2 Kali Ghat
	H3 Ravidas Ghat	K3 Duedi Ghat	A3 Chattnag Ghat	V3 Dashashwamedh Ghat	P3 Kangan Ghat
				V4 Raaj Ghat	
				V5 C/O Varuna	

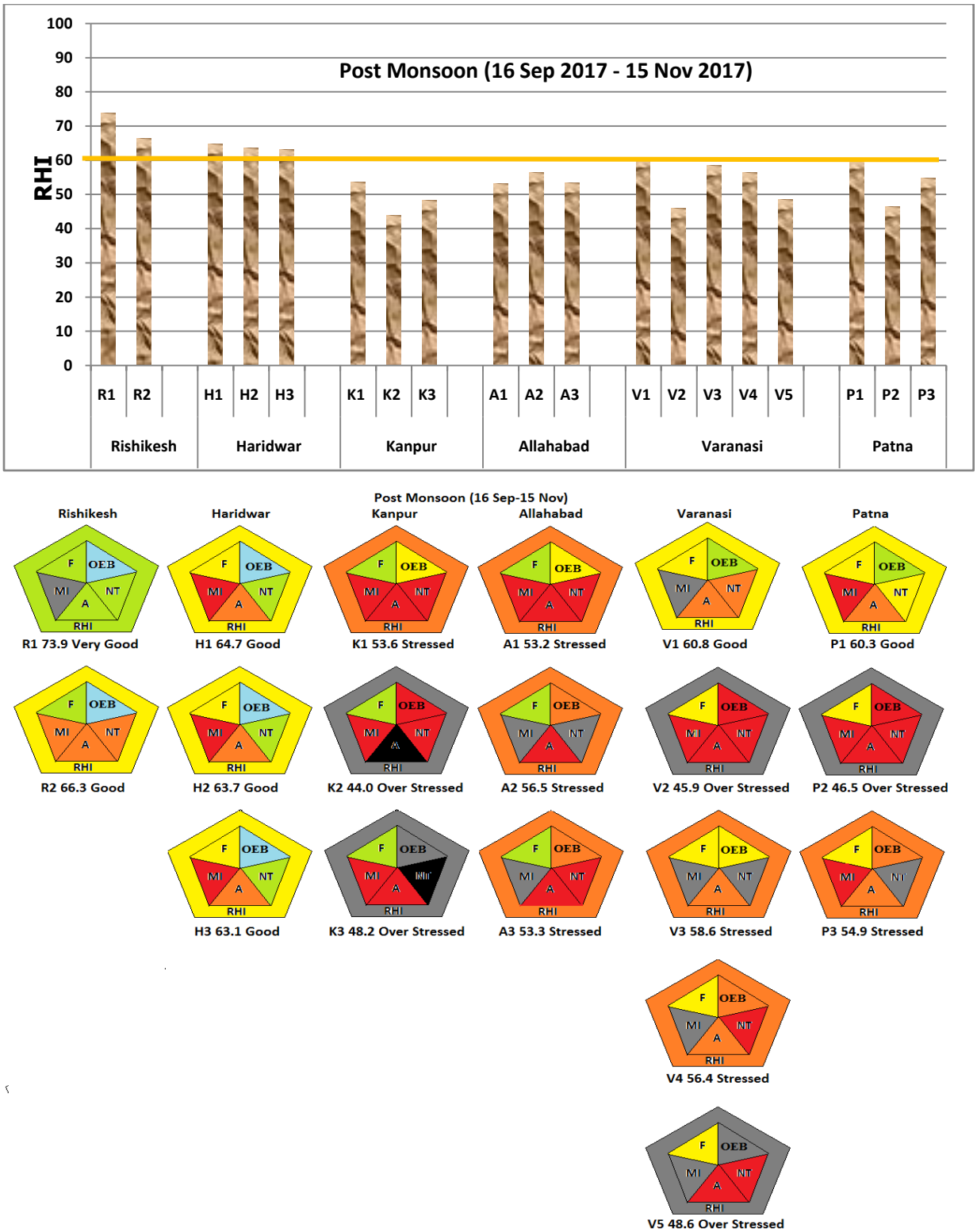


Fig 4.6 a: Graphical and Pictorial Representation of Health of River Ganga from Rishikesh to Patna during Post Monsoon Season (2017)

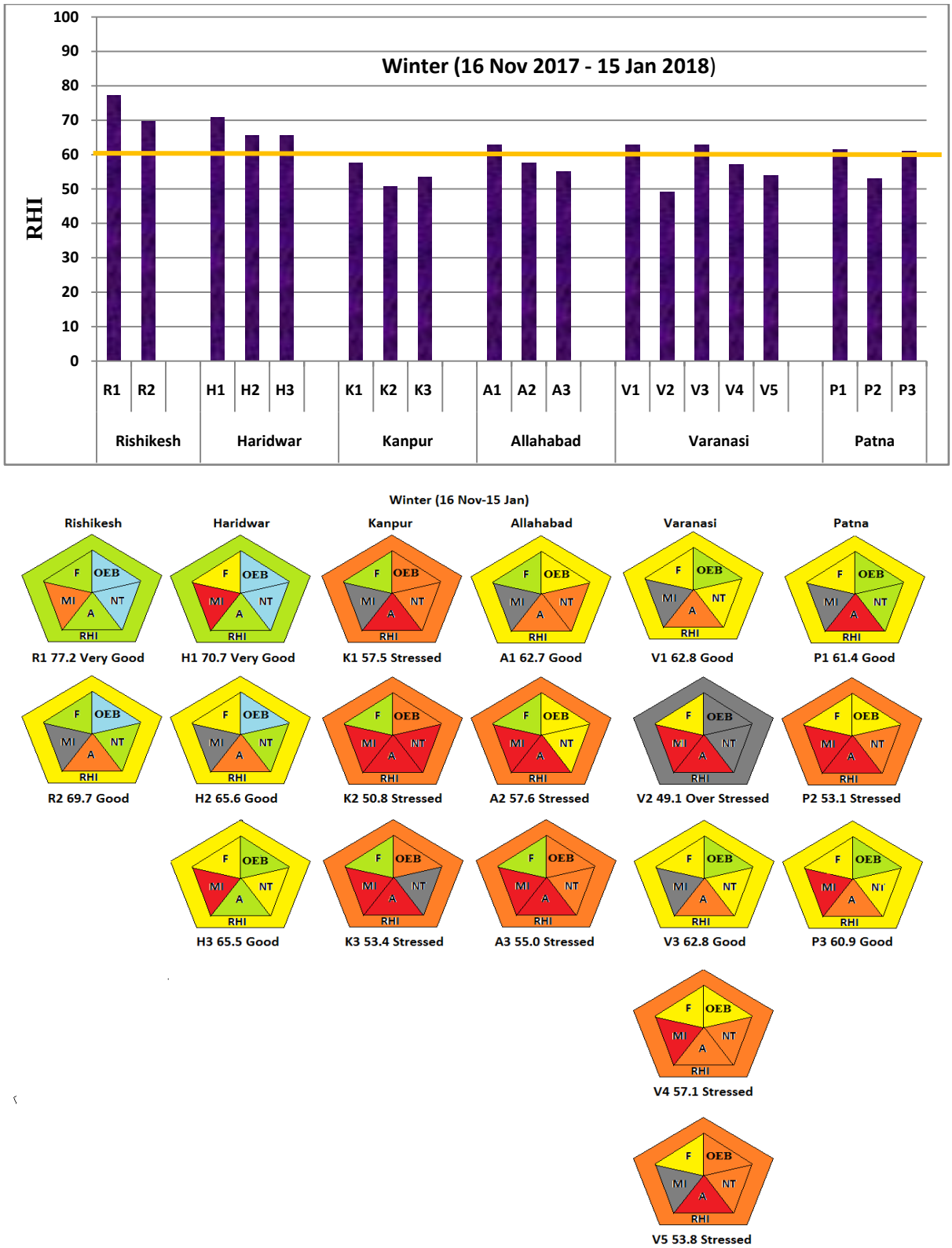
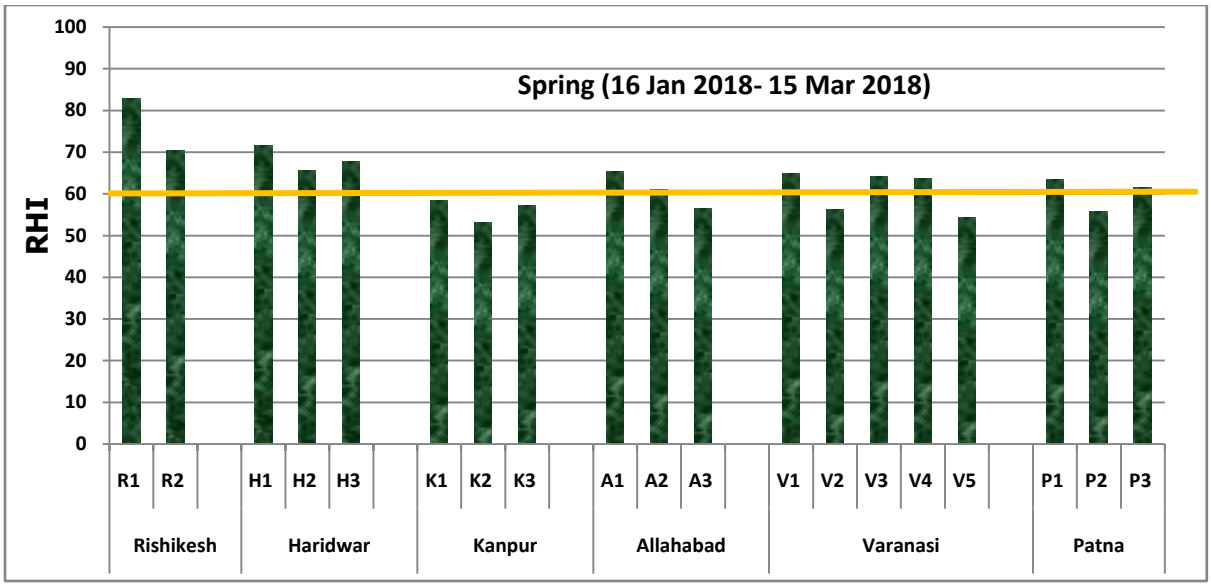


Fig 4.6 b: Graphical and Pictorial Representation of Health of River Ganga from Rishikesh to Patna during Winter Season (2017-2018)



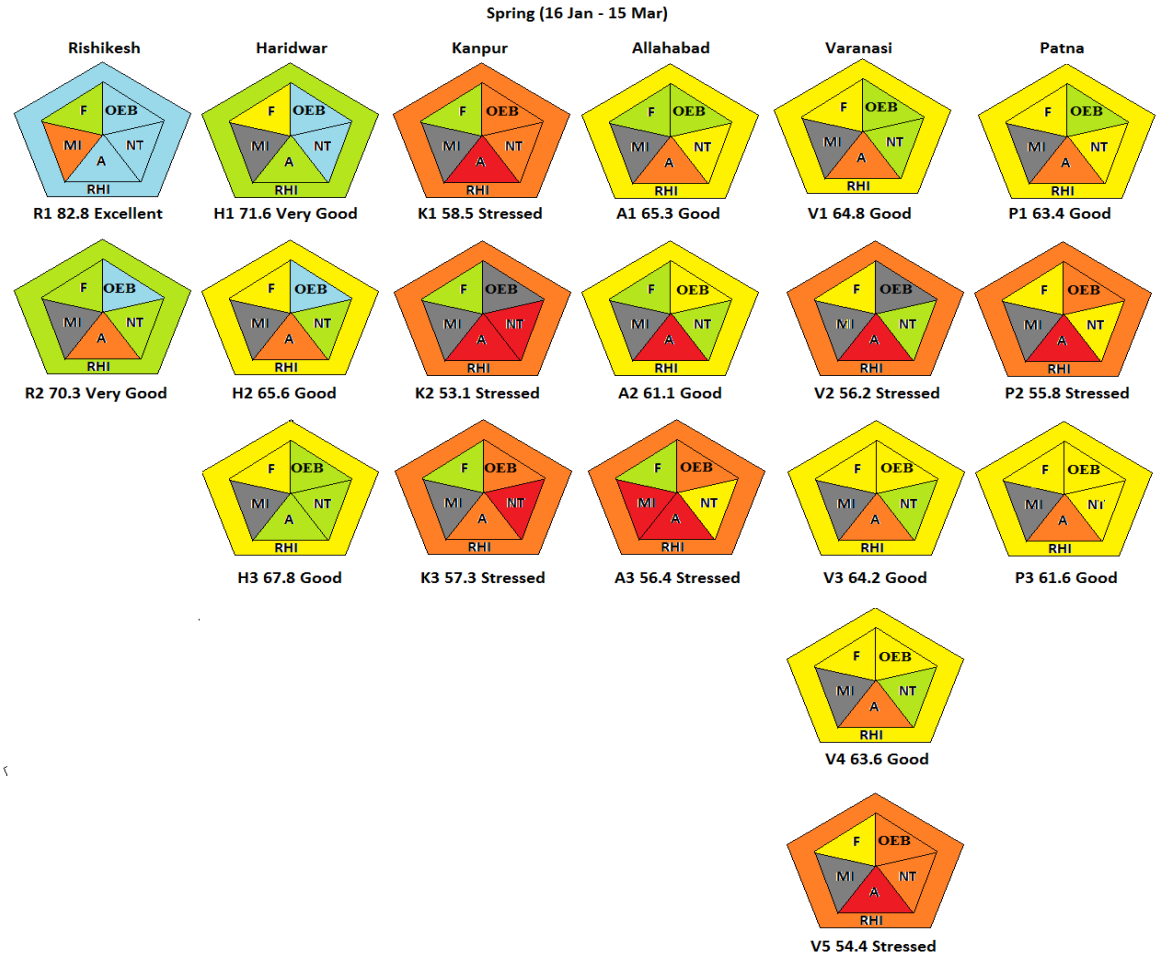


Fig 4.6 c: Graphical and Pictorial Representation of Health of River Ganga from Rishikesh to Patna during Spring Season (2018)

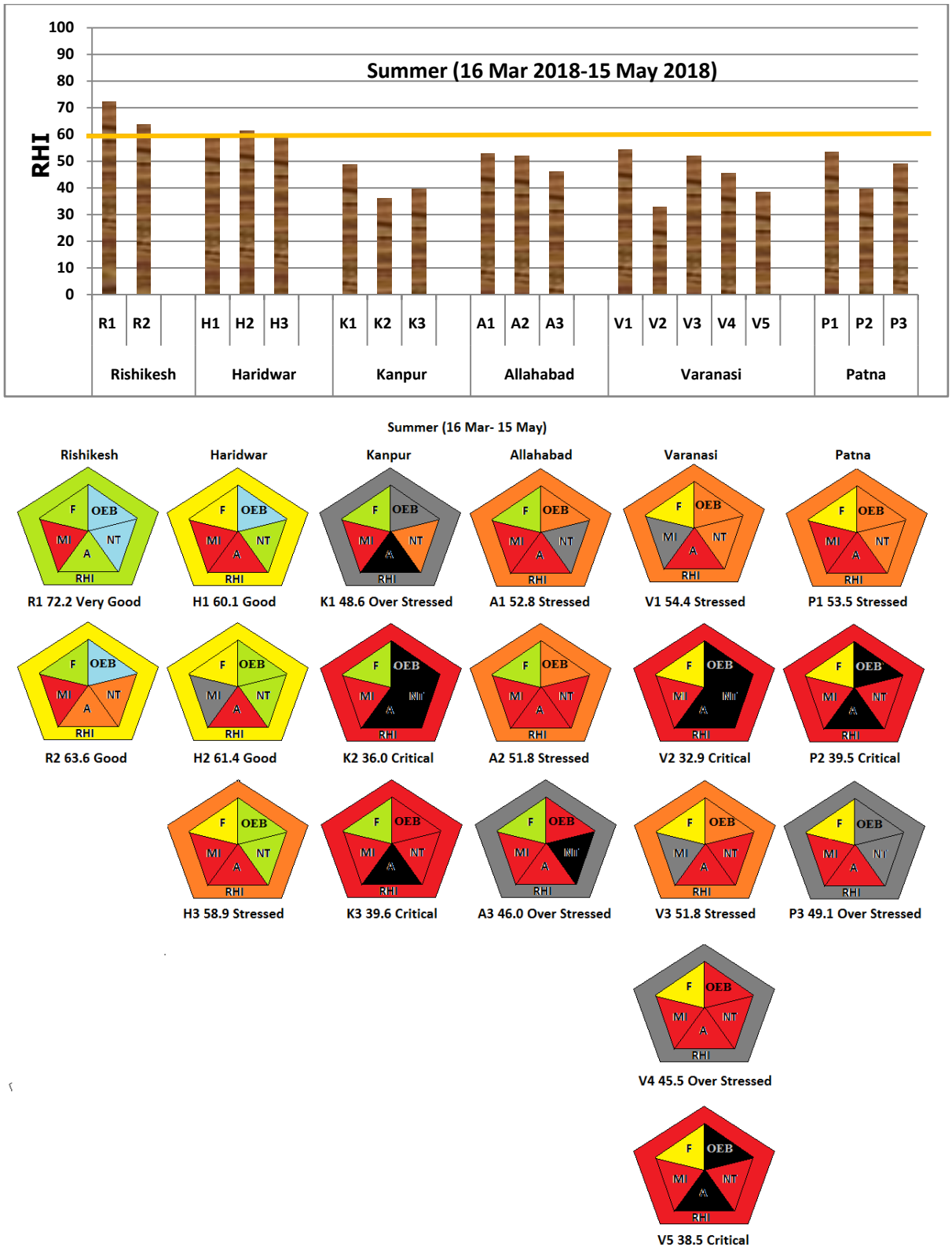


Fig 4.6 d: Graphical and Pictorial Representation of Health of River Ganga from Rishikesh to Patna during Summer Season (2018)

From **Fig 4.5** it is clear that the health of River Ganga at Rishikesh and Haridwar is in 'Acceptable' category (i.e., RHI >60) throughout the year except for Summer in Haridwar. The river health on all sites at Kanpur, Chatnaag Ghat (A3) of Allahabad, C/O Assi Nala (V2) & C/O Varuna (V5) of Varanasi and Kali Ghat (P2) at Patna is in 'Poor' category (RHI ≤60) throughout the year. The river health is found better in Spring season as compared to other seasons at all locations along its flow.

The **Fig 4.6** gives an indication of the critical indicator groups. The health of river Ganga at Rishikesh varies between 'Excellent' to 'Good'. During Summer season TN at Triveni Ghat (R2) is the critical parameter. In Post Monsoon season Total Phosphorus (TP) concentration increases near Lakshman Jhula (R1) and Triveni Ghat (R2) of Rishikesh.

At Haridwar, the health of river Ganga is between 'Very Good' and 'Stressed' conditions. Fecal Coliform (FC) at Ravidas Ghat (H3) is the critical parameter during Summer season.

As we move downstream along river Ganga, the health of river Ganga at Kanpur varies between 'Stressed' and 'Critical'. COD, FC, TN and TP are found as critical parameters at all locations throughout the year. During Spring and Summer, DO decreases, BOD and NH_3-N increases at Sarsaiya Ghat (K2) and Duedi Ghat (K3). The COD and TN are beyond the 'Critical' value at Sarsaiya Ghat (K2) and Duedi Ghat (K3) at most of the times. It is pertinent to note that at Kannauj U/S of Kanpur, river Ramganga joins the river Ganga, and large amount of industrial wastewater is added at this confluence point. This amount is more than that carried by Ganga itself. Hence, river Ramganga appears to be the major source of pollution for Ganga U/S of Kanpur at Kannauj (CPCB, 2013; WWF-India, 2019).

As river Ganga reaches Allahabad (Prayagraaj), it's health condition appears a little improved. The health of river Ganga at Allahabad (Prayagraaj) varies between 'Good' to 'Over Stressed'. Critical parameters are COD, FC and TN throughout the year, but during Summer season, NH_3-N also becomes critical at Sangam (A2) and Chattnag Ghat (A3).

At upstream of Varanasi the health of river Ganga is 'Good' in general and COD, TN and TP are critical parameters. The C/O Assi Nala with Ganga (V2) add large amount of sewage to the river Ganga and as a result BOD, COD, FC, NH_3-N, TN and TP are found critical parameters at this point. At Raaj Ghat (V4) and C/O Varuna with Ganga (V5), the critical parameters are COD, FC, TN and TP, largely due to addition of waste water from under drain at Raaj Ghat and contaminated water from river Varuna to river Ganga. Overall the river health varies between 'Good' to 'Critical' condition round the year.

The health of river Ganga at upstream of Patna is in 'Good' condition during all the seasons except Summer when it is under 'Stressed' condition. At Kali Ghat (P2) and Kangan Ghat (P3) BOD, COD, FC, TN, TP are the critical parameters during Summer and Post Monsoon seasons, but during Winter and Spring, COD, FC and TN are observed to be critical. The river health varies between 'Good' to 'Critical' condition throughout the year.

Thus it is observed that the application of proposed framework of River Health Assessment reasonably reflects the internal stresses of water quality conditions and resultant biotic indicators of aquatic environment. Group Indicator Score and River Health Index based colored representation of River Health Condition appears very useful for public masses as well as scientific community and policy makers for improvement/or health restoration programs.

4.4 Summary

4.4.1 Validation of Proposed Framework for River Health Assessment Using Observations Near Five Locations of River Ganga at Varanasi

1. Based on RHI calculated through the proposed framework, the health condition of river Ganga at Varanasi is found 'Acceptable' and under 'Good' category only in upstream near Saamne Ghat (V1), but this location also becomes 'Stressed' during Summer season. All other locations are under 'Poor' river health category, varying from 'Stressed' to 'Critical' conditions.
2. The analyses indicate that health of river Ganga near Varanasi is improving with time. Based on RHI, the river health is found to be better in 2017-18 as compared to 2016-17.
3. The river health is found at its best level during Spring season and unstable during Post Monsoon period at most of the locations in Varanasi.
4. At C/O Assi Nala and Varuna, with river Ganga, River Health Index (RHI) is reduced severely and River Health Condition (RHC) becomes 'Over Stressed' which is evidenced by the presence of pollution tolerant biotic species on these sites.
5. There are clear stretches of river near outfall points of river Assi and Varuna in river Ganga which are nutrient rich and organically polluted, causing 'Poor' health of river and showing disturbed balance of biotic species.
6. The health of river Ganga near Varanasi is at its best level during Spring (January – March) period.

7. During Summer season, near Varanasi 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 'Very Good' category (except near C/O Varuna with Ganga).

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 Spring season the Algal group scores at all sites are in 'Stressed' range (except near C/O Assi and Varuna which are in 'Critical' condition). Increase in biotic scores improves RHI. Higher RHI indicates a better river health condition. At C/O Assi & Varuna with Ganga, large amounts of sewage is added to river Ganga. 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. Near C/O Assi & Varuna and Raaj Ghat, the repeated presence of macroinvertebrates Oligochaeta (Tubificids, Tubifex) Chironomids (midge larvae) and Physidae, Muscidae indicate polluted water. Overall, River Health Condition is found to be the worst during Summer Season.

4.4.2 Application of River Health Assessment Framework on River Ganga from Rishikesh to Patna (2017-18)

The River Health Assessment Framework was applied on river Ganga in its stretch from Rishikesh to Patna covering six cities. In spatial terms, the river health was found to be generally **'Acceptable'** near Rishikesh, and Haridwar and started deteriorating as it moved downstream. The health was in **'Poor'** category near Kanpur, Allahabad (Prayagraaj), Varanasi and Patna, during the study period.

Some of the important observations are:

1. During post monsoon season, at upstream of all the cities (except Patna) the critical parameters are TN and TP. The increased concentration of TN and TP at the upstream of all the cities may possibly be due to surface runoff from the agricultural fields.
2. At Kanpur the river health varies between 'Stressed' to 'Critical' conditions. COD, FC, NH_3-N, TN, and TP are critical parameters throughout the year.
3. As river Ganga reaches Allahabad (Prayagraaj), its health is observed to be under 'Good' to 'Over Stressed' condition. Thus there seems to be some improvement possibly due to self purification during travel from Kanpur to Allahabad (Prayagraaj). The critical parameters at Allahabad are COD, FC and TN throughout the year but during summer NH_3-N also becomes critical parameter near Sangam (A2) and Chattnag Ghat (A3).
4. In Varanasi at C/O of Assi Nala (V2), Raaj Ghat(V4) and C/O Varuna (V5) the critical parameters are COD, FC, TN and TP. Two additional parameters one each from OEB and NT such as BOD and NH_3-N are also critical during summer season.

5. At Patna COD, FC and TN are critical parameters at Kali Ghat (P2) and Kangan Ghat (P3) throughout the year. The BOD and TP also become critical at Kali Ghat (P2) and Kangan Ghat (P3) during summer season.

At clean/less polluted locations such as upstream of Rishikesh and Haridwar, sensitive or moderately sensitive algae and macroinvertebrate community were found to be present. At polluted sites of river Ganga near Kanpur such as Sarsaiya Ghat (K2) and Duedi Ghat (K3) and Chatnaag Ghat (A3) near Allahabad (Prayagraaj), pollution resistant species of algae and macroinvertebrate were observed. Somewhat clean locations such as upstream of Ganga Barrage (K1) at Kanpur and Dashashwamedh Ghat Daraganj (A1) and Sangam (A2) at Allahabad (Prayagraaj) showed presence of sensitive or moderately sensitive biotic species.

Thus the observations of water quality parameters and biotic indicators on river Ganga and River Health Assessment done through application of the proposed Framework using Indicator Group Score and River Health Index appears to demarcate the stretches of different River Health Conditions along the stretch and the reasons for such variations can be scientifically explained.

4.5 Phased Intervention for River Health Improvement

For river health improvement, indicators representing Organo-Electrolytic-Bacteriological (OEB) and/ or Nutrients (NT) qualities are considered to be the causative parameters and biotic indicators as resultant conditions. As the pollution load and concentrations of OEB and NT parameters decrease, the population and diversity of the

sensitive species of clean water is expected to increase, resulting in improvement of biotic indices and ultimately the RHI.

Near Rishikesh region of river Ganga, nitrogenous species are observed to be critical and affecting the river health more adversely. Hence, controlling such pollutants reaching to river may be the focus of planned river health improvement initiatives. At Haridwar, the observations indicate that river health is adversely affected due to Fecal Coliform. Hence due attention has to be paid for all the possible measures to control Fecal Coliform reaching to the river. Any discharge of treated or untreated waste water must ensure Fecal Coliform reduction using appropriate methods.

Near Kanpur, observations and analyses indicate that the river is heavily inflicted with high COD, FC, TN and TP even in the upstream (U/S) of the city. This suggests that heavy load of pollution is entering the river Ganga before city of Kanpur. It seems possible that such pollution loads may be reaching to river Ganga from river Ramganga and Kali which meet the main stem of Ganga near Kannauj. Hence, it seems essential to work on quality and health restoration of river Ramganga and Kali before their confluence with Ganga to improve health of main stem of river Ganga. In order to achieve 'Good' river health condition of Ganga near Kanpur, special focus needs to be directed to effectively reduce COD, FC and TP reaching to the river in U/S, including confluence points of river Ramganga and Kali to the city stretch of Kanpur. High level of COD in river water reflects industrial sources of pollution.

Before the river Ganga enters the city of Allahabad (Prayagraaj), the river appears already heavily loaded with BOD, COD, TN and TP which result in 'Stressed' condition of river health. Possibly, it may be due to untreated or partially treated waste water reaching to

river Ganga near Fatehpur town in the upstream of Allahabad (Prayagraaj). In order to regain the health of river Ganga at Allahabad (Prayagraaj) in 'Good' condition, it appears imperative to control and effectively reduce all sources of pollution contributing to BOD, COD, TN and TP.

Upstream of the city of Varanasi, the health of river Ganga is found under 'Stressed' condition and pollution load in terms of COD, FC and TN are on the higher side. Hence, any step or process which reduces COD, FC and TN between Allahabad and Varanasi section of river Ganga is likely to positively contribute to river health improvement before entering Varanasi. At Varanasi, the confluence of river Assi with Ganga, Raaj Ghat and confluence of Varuna with Ganga are major points of pollution. All efforts need to be directed to restore the river Assi and improve its quality of water before confluence. Serious attempts appears essential to control pollution reaching to the river Ganga near Raaj Ghat and improve the water quality of river Varuna before its confluence.

At upstream of Patna, the river health is in 'Stressed' condition. The COD is exceptionally high in river water. Between Digha Bridge and Kali Ghat, EC, DO, BOD, COD, FC, TN and TP are in high concentrations and all measures must be taken to control the sources of pollution to reduce these pollutants. Such steps are likely to improve the health of river Ganga near Patna.

To improve the health of river Ganga at different cities, the improvement works can be carried out in phases. The critical parameters at all the 6 cities as identified based on the representative data collected during Sep 2017 to May 2018 have been taken as background and the effect of the suggested improvements have been worked out. The improvement plan

may be made to bring down the concentration of the pollutants reaching the river Ganga in two phases to achieve levels as given in **Table 4.4.**

Table 4.4: Phased Intervention for Ganga River Health Improvement from Rishikesh to Patna

City	OEB & NT parameters of concern	Current Status (March-May 2018)	Improvement Stages	
			Phase I (3 Years)	Phase II (2 Years)
		Concentration	Concentration	Concentration
Rishikesh	BOD (mg/l)	3.5-3.9	≤3	To be maintained ≤ 3
	COD (mg/l)	35-38	≤ 30	To be maintained ≤ 30
	FC (MPN/100 ml)	780-850	≤ 500	To be maintained ≤ 500
	NH_3-N (mg/l)	0.14-0.90	≤ 0.30	To be maintained ≤ 0.30
	TN (mg/l)	0.95-1.87	0.50-0.80	≤ 0.50
Haridwar	BOD (mg/l)	4.0-4.4	≤3	To be maintained ≤ 3
	COD (mg/l)	40-42	≤ 30	To be maintained ≤ 30
	FC (MPN/100 ml)	1000-1600	500-1000	≤ 500
	NH_3-N (mg/l)	0.32-0.42	≤ 0.30	To be maintained ≤ 0.30
	TN (mg/l)	0.97-1.14	0.50-0.80	≤ 0.50
Kanpur	EC (µmhos/cm)	800-1200	400-750	≤ 400
	DO (mg/l)	3.5-4.9	5-6	6-7
	BOD (mg/l)	4.5-5.9	3.0-4.0	≤ 3
	COD (mg/l)	68-120	40-50	≤ 30
	FC (MPN/100 ml)	1600-3000	1000-1500	≤ 500
	NH_3-N (mg/l)	0.32-0.90	0.30-0.60	≤ 0.30
	TN (mg/l)	0.95-2.10	0.80-1.20	≤ 0.50
	TP (mg/l)	0.26-0.33	0.15-0.20	≤ 0.10
Allahabad	EC (µmhos/cm)	480-820	≤ 400	To be maintained ≤ 400
	DO (mg/l)	5.4-5.9	6-7	≥ 7
	BOD (mg/l)	4.5-5.8	3.0-4.0	≤ 3
	COD (mg/l)	80-120	40-50	≤ 30
	FC (MPN/100 ml)	1200-2000	500-1000	≤ 500
	NH_3-N (mg/l)	0.90-1.90	0.60-0.90	≤ 0.30
	TN (mg/l)	1.35-2.36	0.80-1.20	≤ 0.50
	TP (mg/l)	0.16-0.25	0.10-0.15	≤ 0.10
Varanasi	EC (µmhos/cm)	420-1100	≤ 400	To be maintained ≤ 400
	DO (mg/l)	2.9-5.9	6-7	≥ 7
	BOD (mg/l)	4.4-6.9	3.0-4.0	≤ 3
	COD (mg/l)	50-110	40-50	≤ 30
	FC (MPN/100 ml)	1600-3300	1000-1500	≤ 500
	NH_3-N (mg/l)	0.89-1.50	0.30-0.60	≤ 0.30
	TN (mg/l)	1.35-2.00	0.80-1.20	≤ 0.50
	TP (mg/l)	0.16-0.29	0.10-0.15	≤ 0.10
Patna	EC (µmhos/cm)	500-1100	≤ 400	To be maintained ≤ 400
	DO (mg/l)	3.9-5.2	6-7	≥ 7
	BOD (mg/l)	4.3-6.8	3.0-4.0	≤ 3
	COD (mg/l)	55-85	40-50	≤ 30
	FC (MPN/100 ml)	1300-2200	1000-1500	≤ 500
	NH_3-N (mg/l)	0.35-0.90	0.30-0.60	≤ 0.30
	TN (mg/l)	1.20-1.39	0.50-0.80	≤ 0.50
	TP (mg/l)	0.15-0.26	0.10-0.15	≤ 0.10

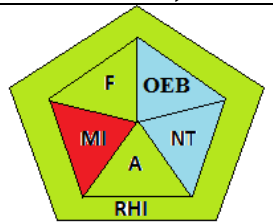
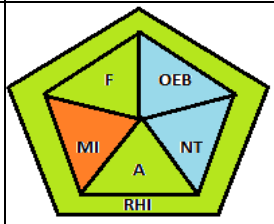
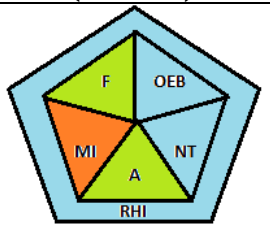
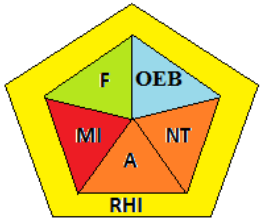
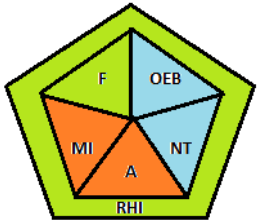
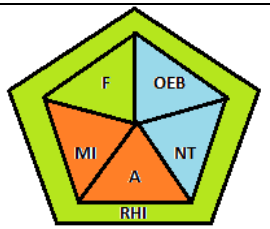
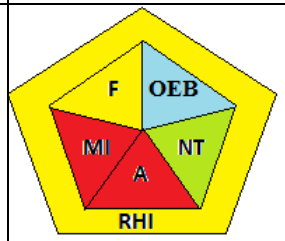
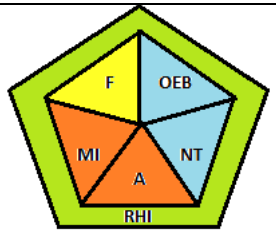
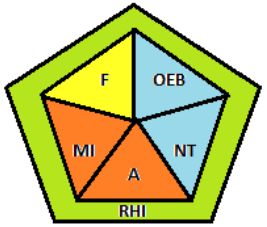
The Phased intervention plan has been designed in such a way that the entire stretch of river Ganga from Rishikesh to Patna attains atleast a 'Good' River Health Condition under 'Acceptable' category. The river near cities of Rishikesh and Haridwar may attain higher River Health Condition ('Very Good') in Phase I only and in Phase II the same has to be maintained. For river near Kanpur, Allahabad, Varanasi and Patna as the causes of 'Poor' River Health Condition are serious and varied, a two-phased program appears more reasonable. The analyses indicate that with suitable interventions to achieve the Target concentrations of critical indicator parameters in the first phase, it is possible to attain 'Good' River Health Condition under 'Acceptable' category, and it will improve to 'Very Good' River Health Condition in Phase II period **(Table 4.5).**

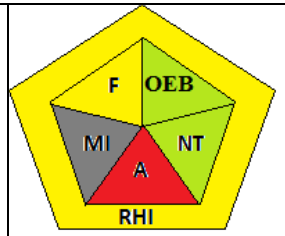
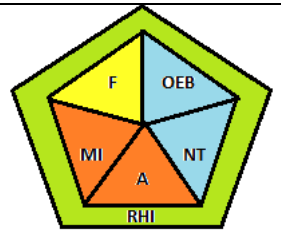
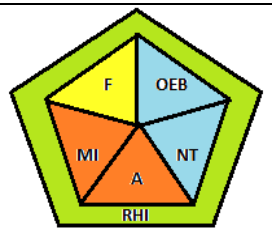
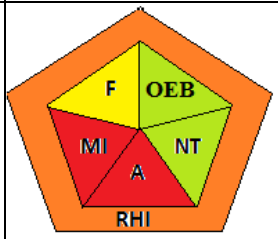
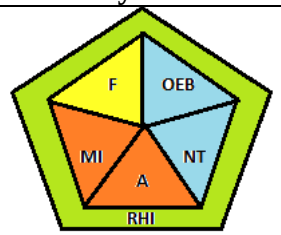
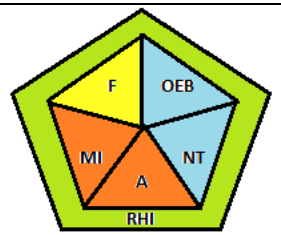
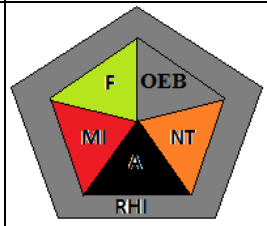
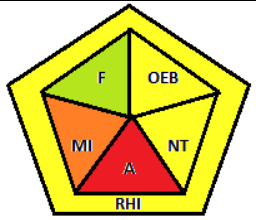
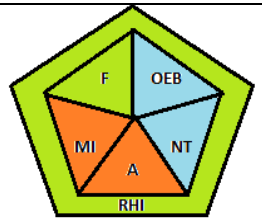
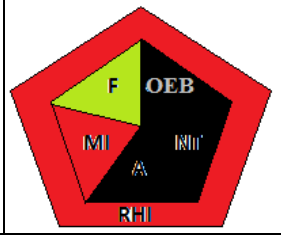
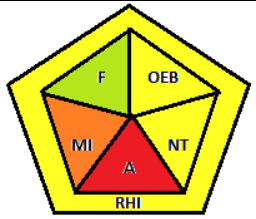
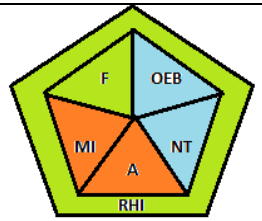
The colored pictorial representation of current status (Summer 2018) and the improvement in River Health Condition with phased interventions are shown in **Table 4.6.**

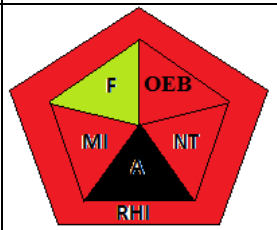
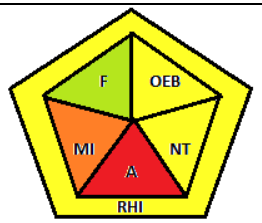
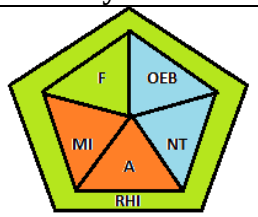
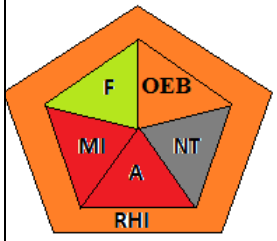
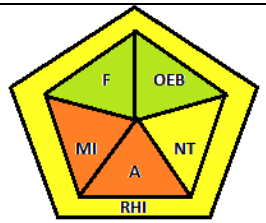
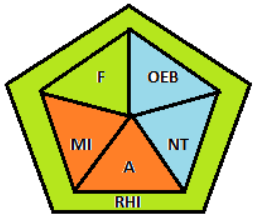
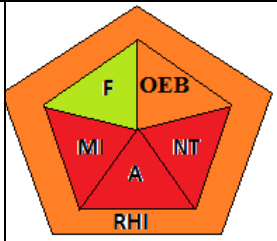
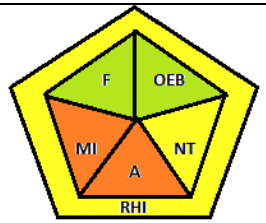
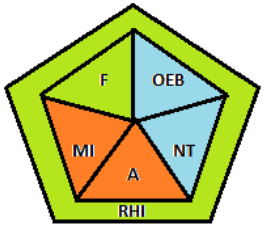
Table 4.5: Current Status and Likely Improvement in Health of River Ganga from Rishikesh to Patna

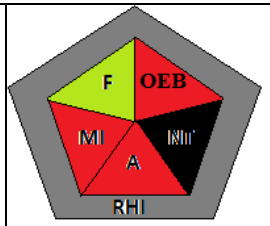
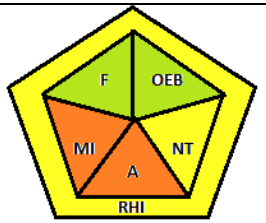
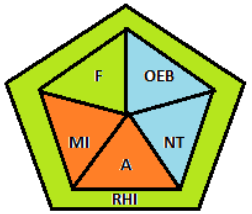
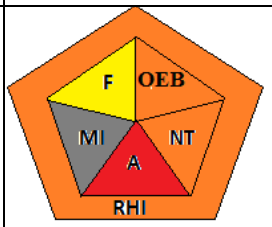
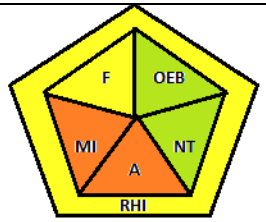
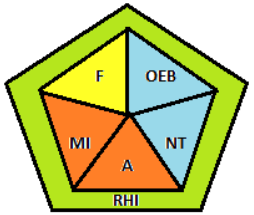
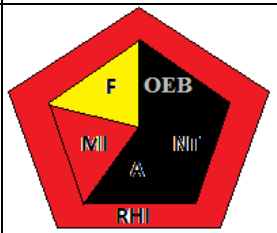
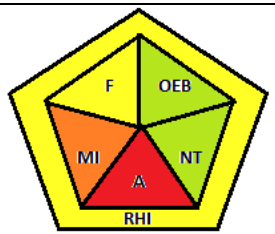
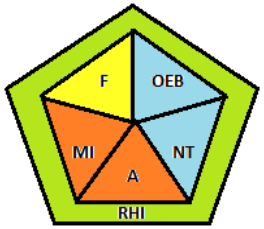
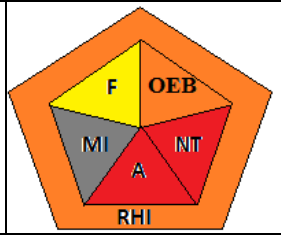
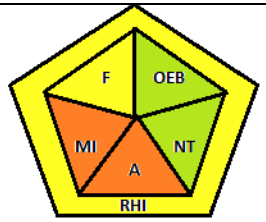
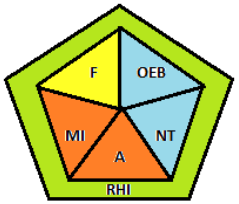
	Cities	Locations		Current Status (16 Mar -15 May 2018)		Likely Improvement Stages			
						Phase I (3 Years)		Phase II (2 Years)	
				RHI	RHC	RHI	RHC	RHI	RHC
1	Rishikesh	U/S Lakshman Jhula	R1	72.2	Very Good	80.0	Very Good	81.0	Excellent
		Triveni Ghat	R2	63.6	Good	75.4	Very Good	77.0	Very Good
2	Haridwar	U/S Bhim Gauda Dam	H1	60.1	Good	72.3	Very Good	74.5	Very Good
		Har Ki Paudi	H2	61.4	Good	72.9	Very Good	74.5	Very Good
		Ravidas Ghat	H3	58.9	Stressed	72.9	Very Good	74.5	Very Good
3	Kanpur	U/S Ganga Barrage	K1	48.6	Over Stressed	63.2	Good	76.4	Very Good
		Sarsaiya Ghat	K2	36.0	Critical	63.2	Good	76.4	Very Good
		Duedi Ghat	K3	39.6	Critical	63.2	Good	76.4	Very Good
4	Allahabad (Prayagraaj)	Dashashwamedh Ghat	A1	52.8	Stressed	69.0	Good	77.0	Very Good
		Sangam	A2	51.8	Stressed	69.0	Good	77.0	Very Good
		Chattnag Ghat	A3	46.0	Over Stressed	69.0	Good	77.0	Very Good
5	Varanasi	Saamne Ghat	V1	54.4	Stressed	66.9	Good	74.5	Very Good
		C/O Assi Nala with Ganga	V2	32.9	Critical	62.9	Good	74.5	Very Good
		Dashashwamedh Ghat	V3	51.8	Stressed	66.9	Good	74.5	Very Good
		Raaj Ghat	V4	45.5	Over Stressed	66.9	Good	74.5	Very Good
		C/O Varuna with Ganga	V5	38.5	Critical	62.9	Good	74.5	Very Good
6	Patna	Digha Bridge	P1	53.5	Stressed	67.9	Good	74.5	Very Good
		Kali Ghat	P2	39.5	Critical	63.9	Good	74.5	Very Good
		Kangan Ghat	P3	49.1	Over Stressed	67.9	Good	74.5	Very Good

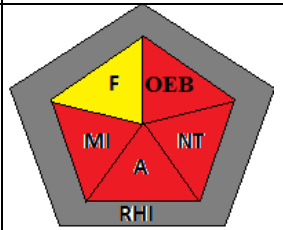
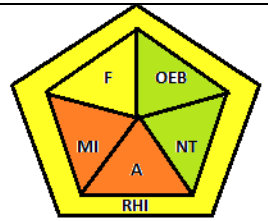
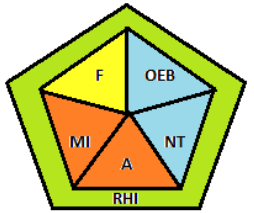
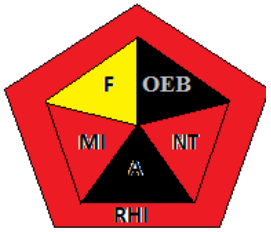
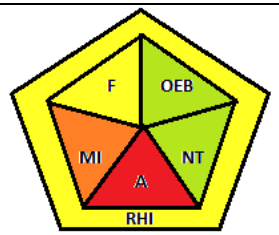
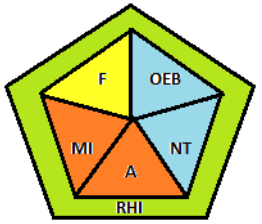
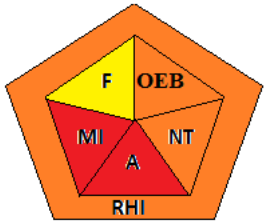
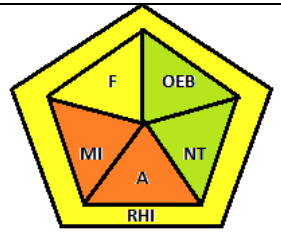
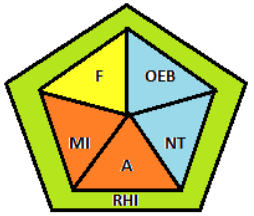
Table 4.6: Colored Pictorial Representation of Likely Improvement in Health of River Ganga from Rishikesh to Patna

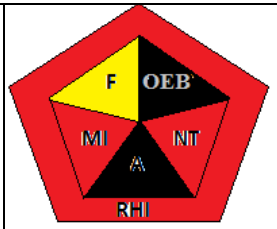
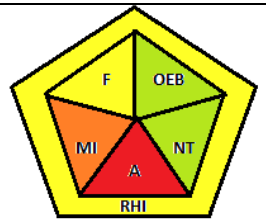
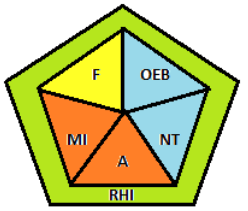
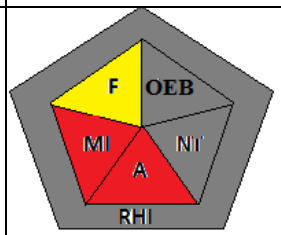
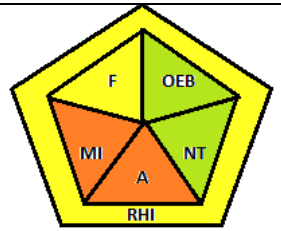
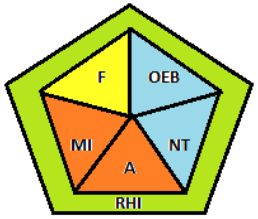
	Cities	Locations		Current Status (16 Mar -15 May 2018)	Likely Improvement Stages	
					Phase I (3 Years)	Phase II (2 Years)
1	Rishikesh	U/S Lakshman Jhula	R1 RHI RHC	 72.2 Very Good	 80.0 Very Good	 81.0 Excellent
		Triveni Ghat	R2 RHI RHC	 63.6 Good	 75.4 Very Good	 77.0 Very Good
2	Haridwar	U/S Bhim Gauda Dam	H1 RHI RHC	 60.1 Good	 72.3 Very Good	 74.5 Very Good

		Har Ki Paudi	**H2** **RHI** **RHC**	 **61.4** **Good**	 **72.9** **Very Good**	 **74.5** **Very Good**
		Ravidas Ghat	**H3** **RHI** **RHC**	 **58.9** **Stressed**	 **72.9** **Very Good**	 **74.5** **Very Good**
3	Kanpur	U/S Ganga Barrage	**K1** **RHI** **RHC**	 **48.6** **Over Stressed**	 **63.2** **Good**	 **76.4** **Very Good**
		Sarsaiya Ghat	**K2**			

			RHI **RHC**	**36.0** **Critical**	**63.2** **Good**	**76.4** **Very Good**
		Duedi Ghat	**K3** **RHI** **RHC**	 **39.6** **Critical**	 **63.2** **Good**	 **76.4** **Very Good**
4	Allahabad (Prayagraaj)	Dashashwamedh Ghat	**A1** **RHI** **RHC**	 **52.8** **Stressed**	 **69.0** **Good**	 **77.0** **Very Good**
		Sangam	**A2** **RHI** **RHC**	 **51.8** **Stressed**	 **69.0** **Good**	 **77.0** **Very Good**

		Chattnag Ghat	**A3** **RHI** **RHC**	 **46.0** **Over Stressed**	 **69.0** **Good**	 **77.0** **Very Good**
5	Varanasi	Saamne Ghat	**V1** **RHI** **RHC**	 **54.4** **Stressed**	 **66.9** **Good**	 **74.5** **Very Good**
		C/O Assi Nala with Ganga	**V2** **RHI** **RHC**	 **32.9** **Critical**	 **62.9** **Good**	 **74.5** **Very Good**
		Dashashwamedh Ghat	**V3**			

			RHI **RHC**	**51.8** **Stressed**	**66.9** **Good**	**74.5** **Very Good**
		Raaj Ghat	**V4**			
			RHI **RHC**	**45.5** **Over Stressed**	**66.9** **Good**	**74.5** **Very Good**
		C/O Varuna with Ganga	**V5**			
			RHI **RHC**	**38.5** **Critical**	**62.9** **Good**	**74.5** **Very Good**
6	Patna	Digha Bridge	**P1**			
			RHI **RHC**	**53.5** **Stressed**	**67.9** **Good**	**74.5** **Very Good**

		Kali Ghat	**P2** **RHI** **RHC**	 **39.5** **Critical**	 **63.9** **Good**	 **74.5** **Very Good**
		Kangan Ghat	**P3** **RHI** **RHC**	 **49.1** **Over Stressed**	 **67.9** **Good**	 **74.5** **Very Good**

Excellent Very Good Good Stressed Over Stressed Critical Sick/Dead

Thus the present study shows that for River Health Assessment, an Indicator Group based approach for River Health Index (RHI) calculation gives insights for identification of critical parameters, which helps in strategic planning for improvement and restoration. A colored pictorial representation of River Health Condition (RHC) based on Indicator Groups Scores and overall RHI makes it simpler for the scientific community to diagnose the cause(s) of 'Poor' River Health and suggest corrective steps for river health improvement/restoration. The novelty of the proposed framework include simple calculations, presentation of RHI value on 0 -100 scale and colored pictorial presentation of RHC for common people. RHI values can be used to identify the 'Acceptable' and 'Poor' stretches of river. RHI<60 has been considered as 'Poor' category of River Health indicating need of engineered intervention to improve. This framework may be used as a scientific tool to assess the river health and may be instrumental to the policy makers to carry out the River Health Improvement/Restoration programs.