



ASSESSMENT OF WATER QUALITY INDEX OF RIVER GANGA, INDIA

Abhijat Arun Abhyankar

Associate Professor, NICMAR, Pune. Email- aabhyankar@nicmar.ac.in

Smita Sengupta

Research Scientist, CSE IIT Bombay. Email- smitasengupta55@gmail.com

Yogin Gajjar

Master Student, CEPT University. Email- yogin.bapsbvn@hotmail.com

Abstract

The present study aims at assessing the Water Quality Index (WQI) of Ganga river. The Holy 'Ganga' has social, economic and cultural importance in Indian history. The urbanization, disposal of untreated industrial and domestic sewage has resulted in degradation of water quality of Ganga river.

The eight water quality parameters namely, temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fecal Coliform, Total Coliform and Total Kjeldahl Nitrogen (TKN) were considered to compute water quality index using Unweighted Arithmetic Mean Model of the river Ganga across time and space.

Our findings highlight that the WQI was found better in upper Ganga compared to middle and lower Ganga. There was minimal effect of seasons on WQI. The Non-Industrial locations in Ganga were found to have better WQI than Industrial locations. There was significant change in WQI across states and districts spatially but no significant change in WQI across years (temporally).

1. Introduction

The Ganga river has significant environmental, economic, cultural, and social values in India. Originating from the Himalayas, the Ganga flows into the Bay of Bengal. Through the plains of north and east India, it traverses a course of around 2,500 km. The Ganga river basin accounts for about 26 percent of India's landmass. It makes up 30 percent of India's water resources and greater than 40 percent of its population. The Ganga is also revered as one of the sacred and holy rivers in India and is highly significant culturally and spiritually transcending the boundaries of the basin.

Despite this significant place, the amount of pollution threatens its biodiversity and environmental sustainability. The water quality of river Ganga has greatly deteriorated, especially during the dry seasons due to factors like urbanization, increased population in the

basin, industrial growth, and improper management. The primary sources of pollution are industrial wastewater and untreated sewage. This is primarily generated as around one-third of the sewage that is generated in the main stream towns and cities receives treatment before it is discharged in the river.

Improper collection and inadequate treatment of water and wastewater is the main reason of pollution in Ganga. The Industrial sector contributes to around 25% of the pollution in the Ganga. Additional factors like the frail capacity of the local water and wastewater utilities, regulating point source pollution, inadequate environmental monitoring also cause pollution. The non-point source pollution arising from agriculture and livestock and poor solid waste management also contribute to the problem. A decrease in the water flow during the dry season and extraction of water for irrigation also add up to the deteriorated water quality in the river's critical middle stretch. The main source of water pollution in Ganga is mainly due to Industrial Wastewater (ESMF, NGRBA), Agricultural Waste (ESMF, NGRBA), Municipal Solid Waste and non-point pollution. Areas like the various ghats, where people gather for religious bathing and rituals, cremation grounds, also aggravate the pollution load. The water quality is also affected by dumped carcasses. As these factors are linked to the social and cultural fabric, they must be addressed in an amenable and sensitive manner.

Clean water is necessary for several purposes for a healthy living (Mandalam *et al.*, 2009). Rivers are an important natural resource for human development but they are being polluted by industrial waste, disposal of sewage, and several other human activities. This adversely affects the water's physiochemical and microbiological quality. Deterioration of river water quality has led to its monitoring and evaluation of its production capacity (Mishra *et al.*, 2009). The present study assesses water quality of river basin by developing water quality Index. This approach is followed in the past by various researchers. Horton (1965) suggested that the various water quality data could be aggregated into an overall index. The WQI were developed by Brown *et al.* (1972). Water Quality Index of Warri River, Nigeria was determined by weighted mean index method (Egborge, A. M *et al.*, 1986). National Sanitation Foundation Water Quality Index was applied to Cazenovia creek, NY (Wills, M. and Irvine, K. N., 1996). Comparative assessment of various water quality indices was carried out for Mumbai coastal water (Gupta, A. K. *et al.*, 2003). Ground water quality of Tumkur Taluk of Karnataka state was assessed using WQI (Ramakrishnaiah, C. R. *et al.*, 2009). Water quality of Mahanadi and Atharabanki rivers and Taldanda Canal, Paradip, India was assessed using National Sanitation Foundation Water Quality Index (Samantray, P. *et al.*, 2009). WQI was used to assess water

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quality of water treatment plants and bore well (Chaturvedi, M. K. and Bassin, J. K., 2010). Water quality of the Titas river was evaluated by using NSF water quality index (Islam, S. *et al*, 2011).

The objective of the present study is to assess the water quality of the Ganga basin. Eight water quality parameters namely, temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fecal Coliform (FC), Total Coliform (TC) and Total Kjeldahl Nitrogen (TKN) were analyzed in laboratory. These water quality parameters were utilized for development of Q values and WQI. These water quality parameters selected in the present study represent physical, chemical, biological quality of water. These affect human health, flora and fauna considerably at unacceptable level.

2. Study Area

The river Ganga (about 2525 km long) is fed by runoff from a vast land area which is bound by the Himalayan snow peaks in the north, the peninsular highlands and the Vindhya range in the south. The river basin encompasses an area of more than one million square kilometers (1,186,000 sq. kms). This entire area is spread out over four countries, including, India, China, Nepal, and Bangladesh. The Ganga river basin is the largest river basin in India with an area of 861,404 sq. kms. within India. It covers approximately 25 percent of India's total geographical area. The Ganga river flows through the five states of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal. However, the extent of the entire Ganga basin is additionally spread over six states, which include Delhi, Himachal Pradesh, Haryana, Madhya Pradesh, Rajasthan, and Chattisgarh. Throughout the entire basin, the states of Uttar Pradesh and Uttarakhand together share the maximum area of 34%, followed by Madhya Pradesh, Bihar and Jharkhand.

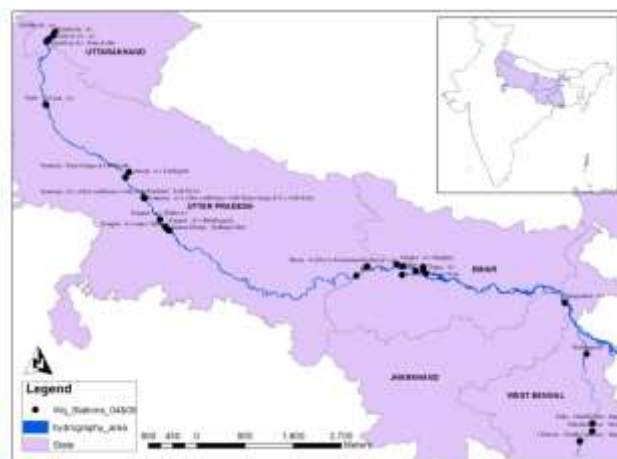


Figure 1. Ganga Basin

The Ganga rises in the Garhwal Himalaya (30° 55' N, 79° 7' E) as the Bhagirathi (ESMF, NGRBA). The traditional source of the Ganga is the ice cave of Gaumukh at the snout of the Gangotri glacier, at 3,892 meters above sea level. Cutting through the Himalayas, the river is joined by another head stream, the Alaknanda at Devprayag. The united stream of Bhagirathi and Alaknanda becomes and is known as the river Ganga.

After flowing around 250 kilometers from its source, the Ganga pierces through the Himalayas at Sukhi (near Rishikesh), and turns southwest wards for another 30 km. Here, it finally descends into the vast Indo-Gangetic plain at Haridwar (elevation 283 meter). At this point, the river swells into a mighty stream of 750 meters width.

Ganga river water is widely used for domestic and industrial purposes in towns and villages located on its course. The river water is also majorly used for irrigation. At Haridwar, where the Ganga opens to the Gangetic plains, a barrage diverts a large quantity of its waters into the Upper Ganga Canal, to provide water for irrigation. At Bijnore, another barrage diverts water into Madhya Ganga Canal only during the months of monsoon. At Narora, water diverts into the Lower Ganga Canal. The Ganga cannot receive any major tributary until the Ramganga joins at Kannauj adding some 17.79 billion cum/annum of water. At Allahabad (1020 km from the source), the river Yamuna joins the on the right. Yamuna actually contributes more water (57.24 billion cum/annum) than the main river itself, and significantly augments the flow volume of the Ganga.

After Allahabad, several major tributaries join the Ganga at more frequent intervals. After Rajmahal, the Ganga reaches the head of its delta at Farrakka, in West Bengal. Along with the flow volume, the water quality and sediment load also fluctuate as per the composition of the contributing stream.

The Ganga then bifurcates into the Padma and the original channel of the Ganga, called Bhagirathi, below Farrakka. As a result, the Bhagirathi is considered as the main Ganga in West Bengal. The Padma, carrying the majority of Ganga's flow, later turns southwestwards into Bangladesh. The Bhagirathi (Ganga) winds southwards down the deltaic plains of West Bengal. Bhagirathi empties into the Bay of Bengal under the name of Hugli. Right from Gaumukh, the source of Ganga to its mouth at Sagar Island in Bay of Bengal, Indians daily dips in the Holy Ganga water, especially at places of pilgrimage like Rishikesh, Haridwar, Garhmukteshwar, Kannauj, Allahabad, Mirzapur and Varanasi.

3. Methodology

The overall methodology involves data collection followed by data cleaning and structuring, data analysis, development of Q graphs with best fitting curve method, unweighted arithmetic mean model and hypothesis testing.

3.1 Data Collection

Total of 111 different Sampling Stations were distributed across four different states from the year 1987 to 2010 (According to Census of India 2001, river Ganga flows through five states. In this study we have selected states according to Census of India 1991). Monthly water quality parameters data was not available for all stations spatially and temporally. The water samples were collected and analyzed for eight water quality parameters every month and across years at these predefined stations/locations using the standard method procedures (Lenore, S. C. *et al.*, 1989). We selected the year 2004 and 2009 for further analysis as these two years had maximum data points with chemical analysis. We found that for the year 2004 and 2009, 34 stations across four states had information about all the eight water quality parameters. Out of 34 stations, 6 stations were in Uttarakhand, 11 stations in Uttar Pradesh, 11 in Bihar and 6 in West Bengal state. The station Rajmahal is considered in state Bihar in the present study (The states redistribution after 2001 this station comes under Jharkhand state). Further we have distributed Ganga in upper, middle and lower Ganga region. We designated Uttarakhand state to upper Ganga, UP state to middle Ganga and Bihar and West Bengal state to lower Ganga based on spatial locations. The sampling location map of Ganga basin is shown in Figure 1. The latitude and longitude of these water sample stations is given in Table 1. Table 2 reports the chemical analysis results of eight water quality parameters for station Kannauj u/s Fategarh only for the year 2004 and 2009. We prepared the final maps in ArcGIS ArcMap 10.

Table 1. Latitude and Longitude of water sample locations/stations in the river Ganga

Station No.	Location	Sub Location	State	Latitude	Longitude
1	Rishikesh	u/s	Uttarakhand	30.12416944	78.31674722
2	Rishikesh	d/s	Uttarakhand	30.04805833	78.27317533
3	Haridwar d/s	u/s	Uttarakhand	29.97875556	78.19052778
4	Haridwar d/s	Hari-Ki-Puri	Uttarakhand	29.95648333	78.17103889
5	Haridwar d/s	Lalta Rao	Uttarakhand	29.94746667	78.16173889
6	Haridwar d/s	Dam Kothi	Uttarakhand	29.94216389	78.15635278

7	Kannauj	u/s Fategarh	Uttar Pradesh	27.39913889	79.62755556
8	Kannauj	Ram Ganga at Fategarh	Uttar Pradesh	27.49811111	79.69599722
9	Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)	Uttar Pradesh	27.01588611	79.97926667
10	Kannauj	Kali River	Uttar Pradesh	27.02088889	79.97436111
11	Kannauj	d/s (After Confluence with Kali)	Uttar Pradesh	27.01138333	79.98612222
12	Kanpur	u/s (Bithoor)	Uttar Pradesh	26.61380833	80.27518056
13	Kanpur	d/s (Shuklaganj)	Uttar Pradesh	26.47380556	80.37561111
14	Kanpur	d/s Jane Village	Uttar Pradesh	26.40578333	80.451
15	Jajmau Bridge	Bathing Ghat	Uttar Pradesh	26.429	80.41319444
16	Garh	u/s	Uttar Pradesh	28.76795556	78.14042222
17	Garh	d/s	Uttar Pradesh	28.75740278	78.14652778
18	Buxar	u/s	Bihar	25.56364167	83.94472222
19	Buxar	d/s	Bihar	25.72989444	84.13955
20	Buxar	d/s (River Karamanasha)	Bihar	25.73246667	84.14008333
21	Patna	u/s	Bihar	25.64828611	85.05118056
22	Patna	d/s	Bihar	25.59889167	85.24377222
23	Rajmahal	d/s	Bihar	25.05750556	87.83943333
24	Koelwar	River Sone	Bihar	25.577225	84.79964167
25	Chapra	u/s Ghaghra	Bihar	25.77825278	84.69818611
26	Chapra	d/s Chapra	Bihar	25.73546111	84.81149167
27	Hajipur	d/s (River Gandak)	Bihar	25.68144444	85.19343889
28	Hajipur	u/s (River Gandak)	Bihar	25.72090556	85.18613333
29	Berhampore	Middle	West Bengal	24.10055	88.24425278
30	Palta	Middle	West Bengal	22.80161944	88.35533611
31	Palta	Impact	West Bengal	22.80048056	88.35726389

32	Dakshineswar	Middle	West Bengal	22.65516667	88.35396667
33	Uluberia	Middle	West Bengal	22.46818611	88.11979167
34	Uluberia	Impact	West Bengal	22.46905556	88.11669722

Table 2. Water Quality Parameter data for station Kannauj u/s Fategarh

Month	Water Quality Parameter Data							
	Temperature	pH	Dissolved Oxygen	Biological Oxygen Demand	Chemical Oxygen Demand	Fecal Coliform	Total Coliform	Total Kjeldahl Nitrogen
Year 2004								
January	13	8.4	9.8	2.2	16	300	1600	2.3
February	20.5	8.1	10	2	16	4	1100	1.5
March	19	8.2	6.8	1.6	16.6	70	170	1.8
April	26.5	8.3	5.8	1	11.3	110	3000	4.5
May	29	8.5	6.8	2.4	14.8	80	300	5.8
June	28	8.2	7.2	2.1	17.1	5	1300	4.4
July	29	8.3	6	1.6	15.5	270	3000	5.1
August	29	8.2	6.8	0.4	16	220	5	5.6
September	30	8.4	6.8	0.8	15	5	2400	2.21
October	29.5	8.2	7	1.1	8	130	800	3.2
November	21	8.4	8.8	0.6	8	170	230	2.6
December	18.5	8.4	9	1.4	15	4	110	2.8
Year 2009								
January	14	8.4	10	1.4	14	80	300	1.3
February	18	8.4	9.4	1.6	16	140	1300	1.74
March	21	8.35	7.8	0.8	14	4	270	2.36
April	21	8.32	7.4	1.4	16	80	130	2.48
May	25	8.35	7.2	1.3	16	4	270	1.98
June	27	8.29	6.6	2	15	4	5	1.89
July	27	8.22	7.8	2.2	15	80	220	1.95
August	29	8.09	5.8	1.2	15	80	2.6	1.82
September	27	8.15	7.2	2	7	4	80	1.64
October	28	8.45	6.4	1.2	11	80	5	2.94
November	25	8.49	8.4	1.5	14	4	170	3.14
December	19	8.63	9.2	1.2	8	80	300	2.25

3.2 Data Analysis

The present section covers in detail spatio-temporal analysis of water quality parameters, development of Q graphs with best fit curve method, unweighted Arithmetic mean model and hypothesis testing.

3.2.1 Spatio-Temporal study of Water Quality Parameters

We analyzed water quality parameter across months and years. Figure 2 depicts water quality parameters for all the stations for January months of 2004 and 2009. Similar exercise was performed for other months and details are discussed below.

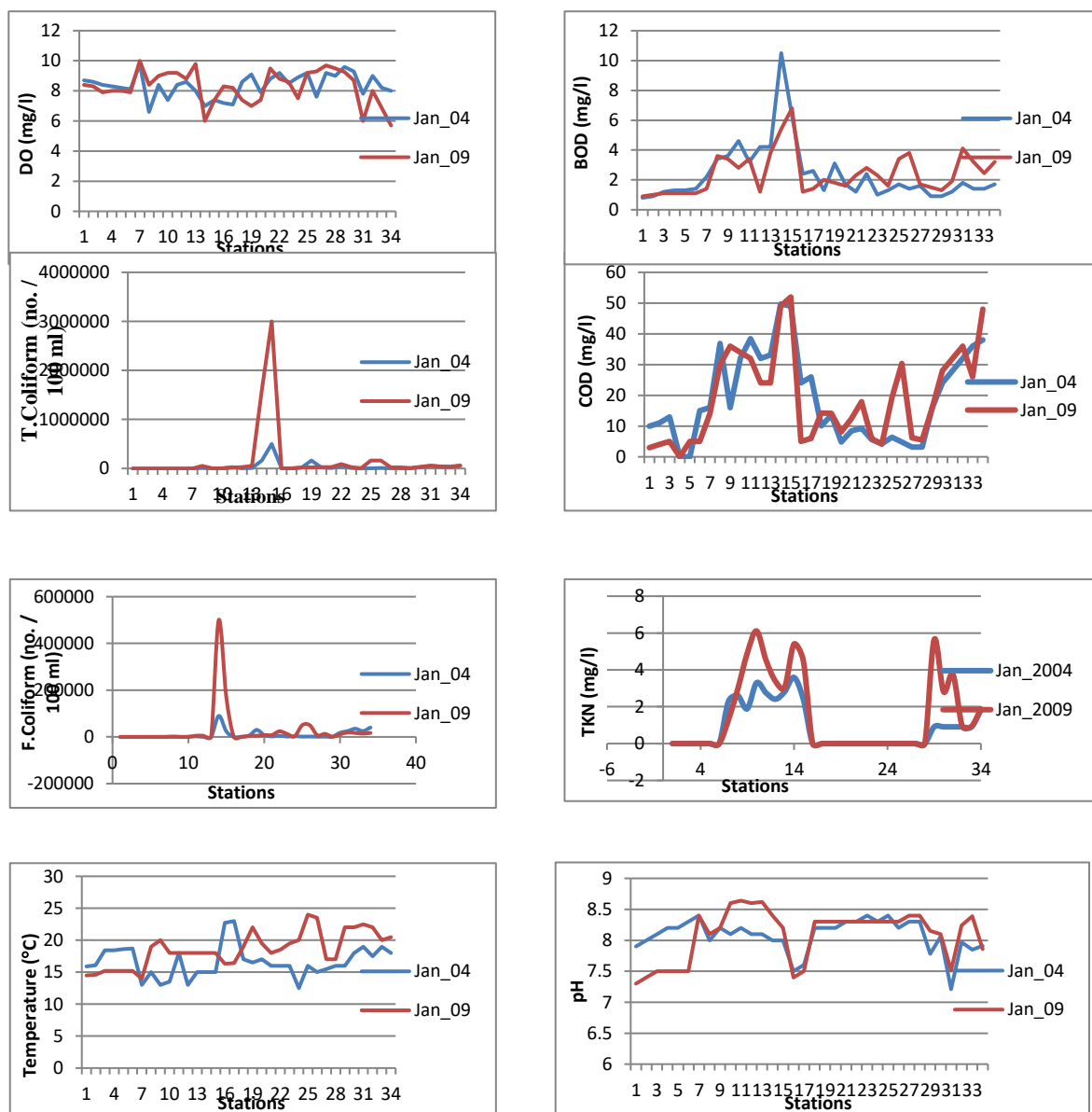


Figure 2. Water Quality Parameters for different station for January month of 2004 and 2009

Table 3 shows the range of water quality parameters across season and years for 2004 and 2009

Table 3. Water quality parameter ranges for all the stations across years for 2004 and 2009

No.	Parameter	Minimum	Maximum
1	Temperature	12.5	35.5
2	pH	7	9.71
3	Dissoved Oxygen	1.6	12.7
4	Biological Oxygen Demand	0.4	24
5	Chemical Oxygen Demand	0	96
6	Fecal Coliform	2.6	900000
7	Total Coliform	2.6	9000000
8	Total Kjeldahl Nitrogen	0	20.12

- Temperature

For March 2004 and 2009, all stations except the Station 7 of Uttar Pradesh shows lower values of temperature in 2009 compared to 2004 temperature. One station of Uttarakhand shows higher temperature in March 2009 compared to March 2004; remaining all stations shows the almost similar values.

Comparison of April 2004 and 2009, temperature data shows the state Uttarakhand and Uttar Pradesh shows corresponding 2004 values lower then 2009. The other stations show similar values. Comparison of May 2004 and 2009 temperature data shows states of Uttarakhand, Uttar Pradesh and Bihar have lower values in 2009 corresponding to 2004. The other state West Bengal shows almost similar temperature values for both years.

For November 2004 and 2009, temperature values for state Uttarakhand state were lower for year 2009 than 2004. Temperature values of state Uttar Pradesh were higher in year 2009 compared to 2004 (except for two stations-16 and 17). Temperature values in 2009 were higher than 2004 for state West Bengal. For Bihar state there is no trend observed for year 2004 and 2009. Comparing temperature values of December 2004 and 2009, temperature values for Uttarakhand state of 2009 were lower than of 2004. Temperature values of Bihar and West Bengal states showed lower temperature values during 2009 compared to 2004.

- pH

West Bengal state the average pH data for the year 2004 higher than 2009. For all remaining states average pH data of 2004 was lower than 2009.

- Dissolved Oxygen

In general, Station 14 : Kanpur-d/s (Jane village) and Station 15 : Jajmau Bridge-Bathing Ghat shows low DO values compared to other stations for year 2004 and 2009.

- Biological Oxygen Demand (BOD)

In general, Station 14 : Kanpur-d/s (Jane village) and Station 15 : Jajmau Bridge-Bathing Ghat shows high BOD values compared to other stations for year 2004 and 2009.

- Chemical Oxygen Demand (COD)

In general, Station 14 : Kanpur-d/s (Jane village), Station 15 : Jajmau Bridge-Bathing Ghat, Station 31 : Palta-Impact, Station 34 : Uluberia-Impact shows high COD values compared to other stations for year 2004 and 2009.

- Total Coliform (T. Coliform)

For Station 15 : Jajmau Bridge-Bathing Ghat the T. Coliform values are high for the year 2004 and 2009 compared to other stations.

- Fecal Coliform (F.Coliform)

For Station 14 : Kanpur d/s (Jane village) and Station 15 : Jajmau Bridge-Bathing Ghat the F. Coliform values are high for year 2004 and 2009 compared to other stations.

- Total Kjeldahl Nitrogen (TKN)

The stations of Uttar Pradesh and West Bengal shows the detectable TKN values. The other two states Uttarakhand and Bihar reported undetectable TKN values.

3.2.2 Q-Graphs and Fitting Curve Line Method

The Q graphs normalises all the different water quality of different units of measurement to a common standard representable quality unit. This would lead us in calculation of overall/average water quality score. In general, various standard and scales are used for water quality parameters. It is not possible to perform any analysis using the water quality parameters values as they are monitored in different units and large variation in water quality parameter values is observed. Hence it necessary to normalize of the data.

The Q graphs shows water quality parameter values on its X axis and water quality index values on Y axis. Figure 3 depicts Q value graphs for 8 different water quality parameters and corresponding best fit curve equation. The Q graphs were generated based on literature information and expert opinion approach. The final Q graphs depicted in Figure 3 are average of literature information and expert approach exercise followed during the course of this study. For determination of Q value for unknown water quality parameter, its Q graph and best fit curve equation was used. The water quality parameter values was inserted into the best fit equation to obtain corresponding Q value. The out of range water quality parameter value was

assigned Q value of 2. The monthly variation of Q-value for 8 different water quality parameters and for station Kannauj u/s Fategarh of Uttar Pradesh state is given in Table 4.

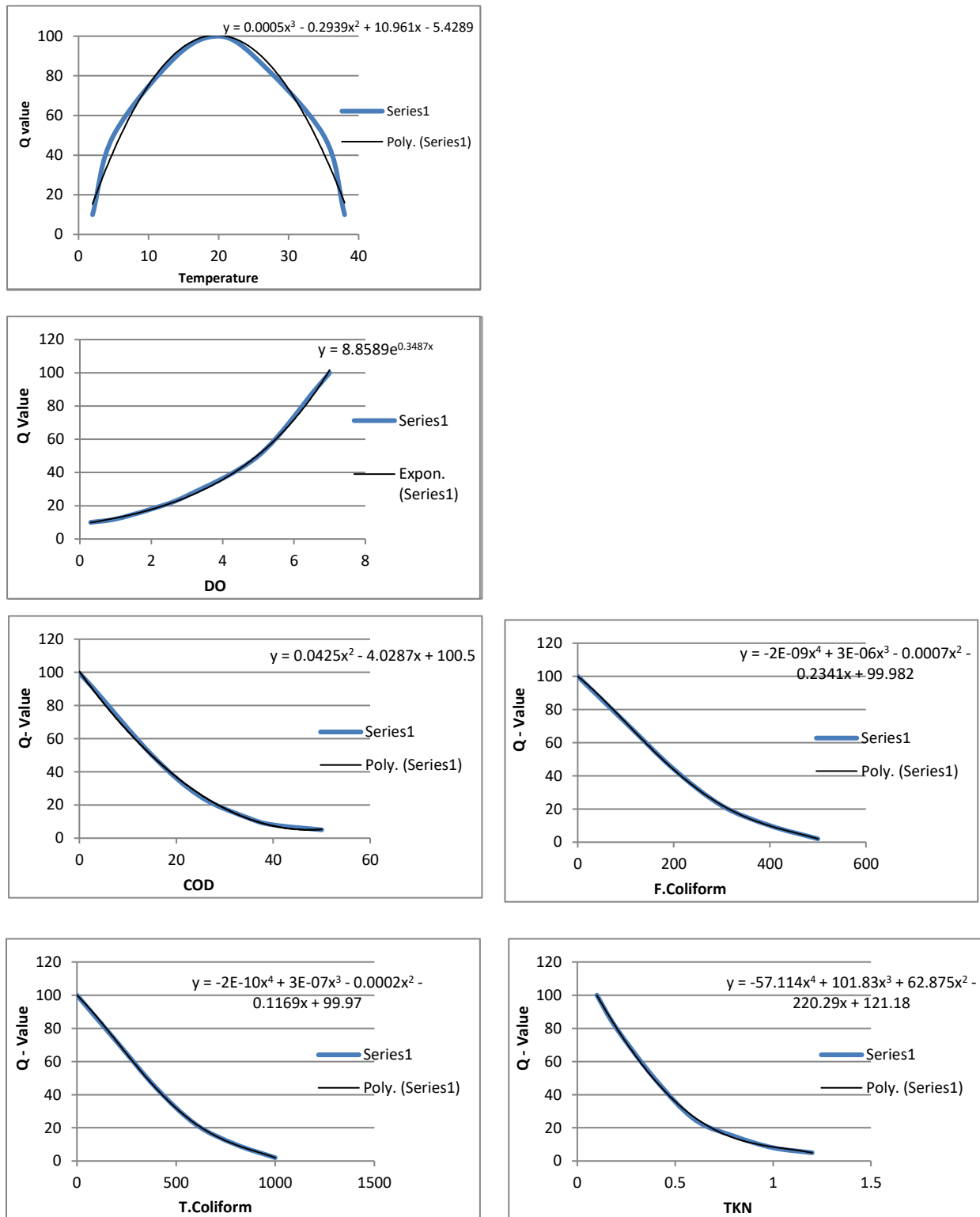


Figure 3. Q graph for 8 different water quality parameters

Table 4. Normalized Q value for different parameter for station Kannauj u/s Fategarh

Month	Normalized Q Value							
	Temp - eratur e	pH	Dissolve d Oxygen	Bio- chemical Oxygen Demand	Chemic al Oxygen Deman d	Fecal Colifor m	Total Colifor m	Total Kjeldah l Nitroge n
2004								
January	87.54	81.94	100.00	78.41	46.80	29.78	2.00	2.00
February	96.12	86.65	100.00	80.18	46.80	99.04	2.00	2.00
March	97.04	85.20	92.16	83.82	45.21	83.60	80.25	2.00
April	79.25	83.63	65.34	89.54	60.35	74.24	2.00	2.00
May	66.00	80.13	92.16	76.67	50.09	81.26	65.17	2.00
June	71.74	85.20	100.00	79.29	43.90	98.81	2.00	2.00
July	66.00	83.63	69.99	83.82	48.16	36.80	2.00	2.00
August	66.00	85.20	92.16	95.57	46.80	48.50	99.39	2.00
Septemb er	59.67	81.94	92.16	91.51	49.53	98.81	2.00	2.00
October	62.91	85.20	98.73	88.56	70.96	69.56	7.17	2.00
Novemb er	95.52	81.94	100.00	93.52	70.96	60.20	73.29	2.00
Decemb er	97.05	81.94	100.00	85.69	49.53	99.04	87.21	2.00
2009								
January	90.58	81.94	100.00	85.69	52.34	81.26	65.17	2.00
February	96.92	81.94	100.00	83.82	46.80	67.22	2.00	2.00
March	95.52	82.80	100.00	91.51	52.34	99.04	68.65	2.00
April	95.52	83.30	100.00	85.69	46.80	81.26	84.89	2.00
May	85.45	82.80	100.00	86.64	46.80	99.04	68.65	2.00
June	76.90	83.79	86.04	80.18	49.53	99.04	99.39	2.00
July	76.90	84.90	100.00	78.41	49.53	81.26	74.45	2.00
August	66.00	86.79	65.34	87.60	49.53	81.26	99.67	2.00
Septemb er	76.90	85.94	100.00	80.18	74.36	99.04	90.69	2.00
October	71.74	81.05	80.32	87.60	61.27	81.26	99.39	2.00
Novemb er	85.45	80.32	100.00	84.75	52.34	99.04	80.25	2.00
Decemb er	97.04	77.59	100.00	87.60	70.96	81.26	65.17	2.00

3.2.3 Calculation of WQI using Unweighted Arithmetic Mean Model

Unweighted Arithmetic Mean Model was used for developing water quality index of Ganga river. This was originally proposed by Horton, thereafter called as the arithmetic water quality index. Many researcher, have used this index in their research work, which is basically the summation of Q value of each water quality parameter followed by averaging leading to final WQI and is represented mathematically as:

$$WQI_{UA} = (1/n) \cdot \sum_{i=1}^n Q_i$$

Where, n is the number of variables and q_i is the quality rating of the i th parameter.

Figure 4 shows temporal variation in WQI using Unweighted Arithmetic Water Quality model for Station Kannauj u/s Fategarh for 2004 and 2009. The WQI values of 2009 are higher during March to October and almost same for remaining months.

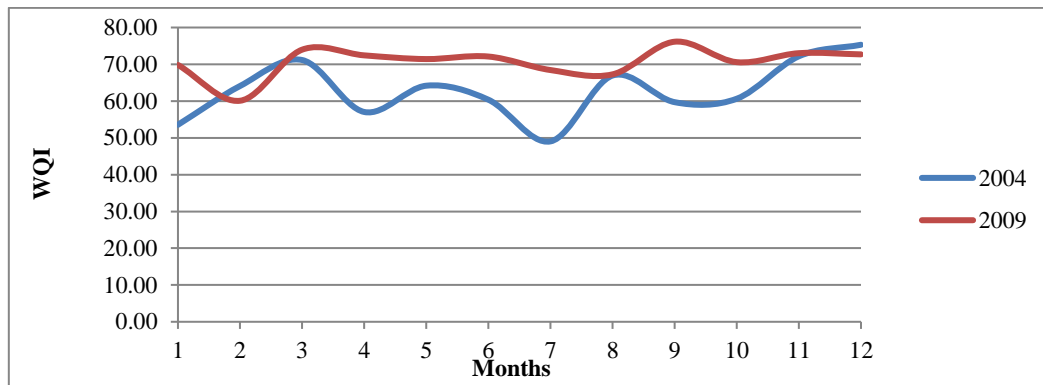


Figure 4. Temporal Graph of Unweighted Arithmetic Water Quality Index for Station Kannauj u/s Fategarh

3.2.4 Hypothesis

The following null hypothesis were framed in the present study and are given below:

- There is no difference in actual water quality parameters across months as well as across years
- There is no difference in WQI across states and district (spatial)
- There is no difference in WQI in the Upper, Middle and Lower regions of the Ganga river
- There is no difference in WQI of industrial and non-industrial stations across states
- There is no difference in WQI across the seasons (temporal)

4. Result and Discussion

4.1 Hypothesis 1: There is no difference in water quality parameter data across months, seasons and years temporally

The temperature plots for different stations for month May and December for 2004 and 2009 is shown in Figure 5 and 6 respectively. It is observed that the temperature values for all stations of May and December in 2009 lower than 2004. Similar temperature patterns were observed for other months.

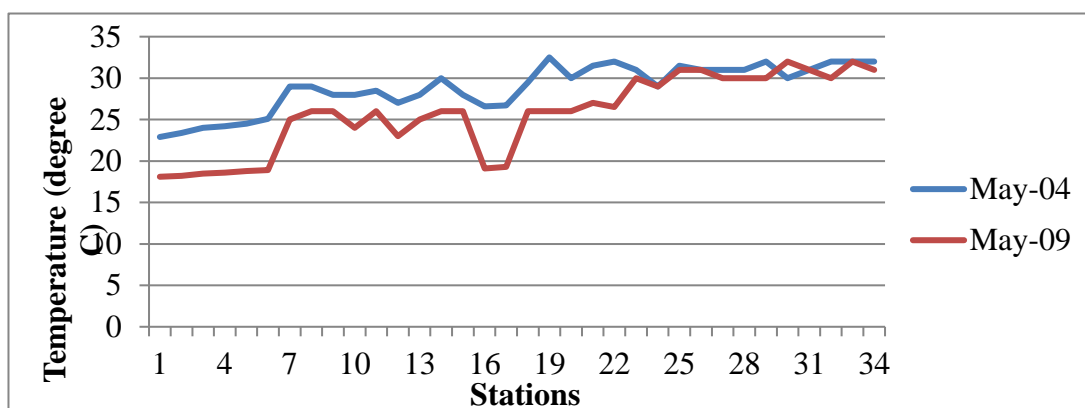


Figure 5. Temperature data for all stations across May month of 2004 and 2009

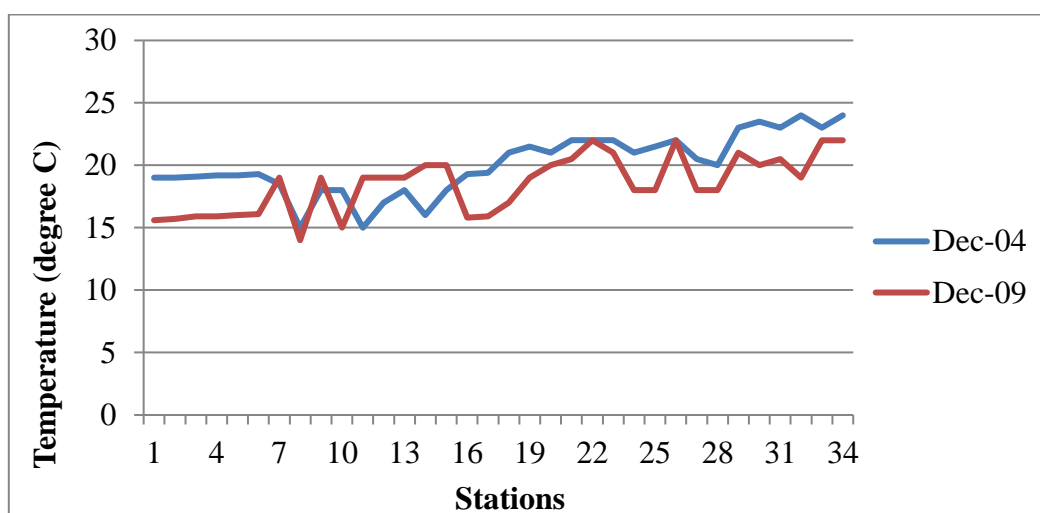


Figure 6. Temperature data for all stations across December month of 2004 and 2009

This shows that there is a change in temperature parameter across month, season and year. Similar observations were observed for other water quality parameters.

4.2 Hypothesis 2: There is no spatial difference in WQI across the states and districts

Table 5 gives average WQI across states for year 2004 and 2009

Table 5. Average WQI across states for year 2004 and 2009

Location	Sub-Location	State	WQI across States	
			Average 2004	Average 2009
Rishikesh	u/s	Uttarakhand	87.33	88.95
Rishikesh	d/s	Uttarakhand		
Haridwar d/s	u/s	Uttarakhand		
Haridwar d/s	Hari-Ki-Puri	Uttarakhand		
Haridwar d/s	Lalta Rao	Uttarakhand		

Haridwar d/s	Dam Kothi	Uttarakhand		
Kannauj	u/s Fategarh	Uttar Pradesh		
Kannauj	Ram Ganga at Fategarh	Uttar Pradesh		
Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)	Uttar Pradesh		
Kannauj	Kali River	Uttar Pradesh		
Kannauj	d/s (After Confluence with Kali)	Uttar Pradesh		
Kanpur	u/s (Bithoor)	Uttar Pradesh	53.43	53.89
Kanpur	d/s (Shuklaganj)	Uttar Pradesh		
Kanpur	d/s Jane Village	Uttar Pradesh		
Jajmau Bridge	Bathing Ghat	Uttar Pradesh		
Garh	u/s	Uttar Pradesh		
Garh	d/s	Uttar Pradesh		
Buxar	u/s	Bihar		
Buxar	d/s	Bihar		
Buxar	d/s (River Karamanasha)	Bihar		
Patna	u/s	Bihar		
Patna	d/s	Bihar		
Rajmahal	d/s	Bihar	62.42	60.79
Koelwar	River Sone	Bihar		
Chapra	u/s Ghaghra	Bihar		
Chapra	d/s Chapra	Bihar		
Hajipur	d/s (River Gandak)	Bihar		
Hajipur	u/s (River Gandak)	Bihar		
Berhampore	Middle	West Bengal		
Palta	Middle	West Bengal		
Palta	Impact	West Bengal		
Dakshineswar	Middle	West Bengal	43.13	42.38
Uluberia	Middle	West Bengal		
Uluberia	Impact	West Bengal		

Table 6 gives average WQI across district for year 2004 and 2009

Table 6. Average WQI across districts for year 2004 and 2009

Location	Sub-Location	Districts	WQI across Districts	
			Average 2004	Average 2009
Rishikesh	u/s	Tehri Garhwal	91.65	91.17
Rishikesh	d/s	Dehradun	88.71	89.23
Haridwar d/s	u/s	Dehradun		
Haridwar d/s	Hari-Ki-Puri	Haridwar	84.96	88.01
Haridwar d/s	Lalta Rao	Haridwar		
Haridwar d/s	Dam Kothi	Haridwar		
Kannauj	u/s Fategarh	Farukhabad	62.85	70.67
Kannauj	Ram Ganga at Fategarh	Shahjahanpur	44.93	46.92
Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)	Kannauj	52.77	46.83
Kannauj	Kali River	Kannauj		
Kannauj	d/s (After Confluence with Kali)	Kannauj		
Kanpur	u/s (Bithoor)	Kanpur Nagar	40.90	39.65
Kanpur	d/s Jane Village	Kanpur Nagar		
Jajmau Bridge	Bathing Ghat	Kanpur Nagar		
Kanpur	d/s (Shuklaganj)	Unnao	51.35	42.80
Garh	u/s	Jyotiba Phule Nagar	74.98	87.57
Garh	d/s	Ghaziabad	72.60	85.41
Buxar	u/s	Ballia	61.64	59.76
Buxar	d/s	Ballia		
Buxar	d/s (River Karamanasha)	Ballia		
Patna	u/s	Patna	62.16	60.67
Patna	d/s	Patna		
Koelwar	River Sone	Patna		
Rajmahal	d/s	Sahibganj	63.23	62.28
Chapra	u/s Ghaghra	Saran	62.92	61.48
Hajipur	d/s (River Gandak)	Saran		
Chapra	d/s Chapra	Bhojpur	62.43	58.93
Hajipur	u/s (River Gandak)	Vaishali	63.75	63.29
Berhampore	Middle	Murshidabad	48.76	48.48
Palta	Middle	Hugli	44.92	44.88
Palta	Impact	North Twenty Four Parganas	44.23	40.40
Dakshineswar	Middle	North Twenty Four Parganas		
Uluberia	Middle	Haora	40.33	40.07
Uluberia	Impact	Haora		

We conclude from table 5 and 6 that there is a significant change of WQI across the states and the districts. But there is no significant change across year.

4.3 Hypothesis 3: There is no difference in WQI in the Upper, Middle and Lower regions of the Ganga river

Figure 7 depicts the upper, middle and lower stations in Ganga. Table 7 gives average WQI across regions for year 2004 and 2009.

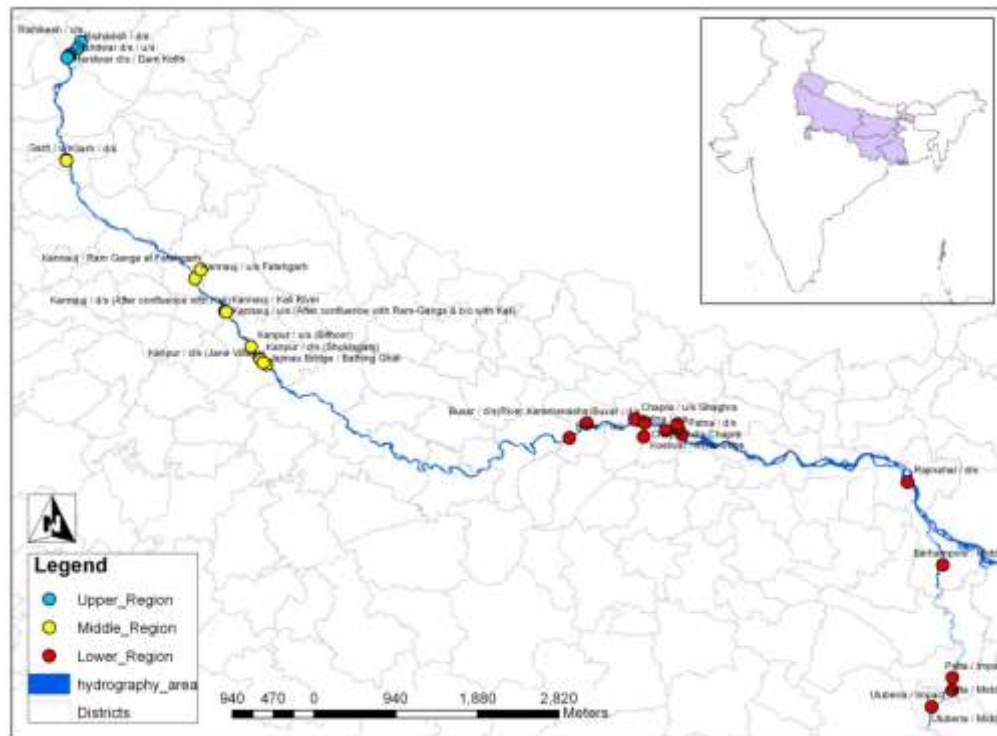


Figure 7. Upper, Middle and Lower regions of the River Ganga

Table 7. Average WQI across regions for year 2004 and 2009

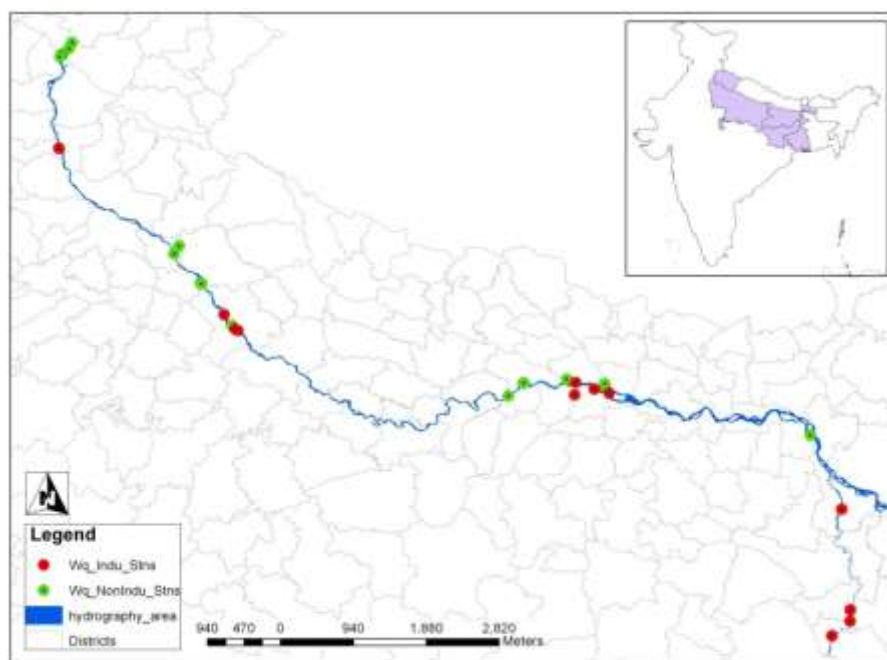
Location	Sub-Location	Region	WQI across Regions	
			Average 2004	Average 2009
Rishikesh	u/s	Upper	87.32	88.94
Rishikesh	d/s			
Haridwar d/s	u/s			
Haridwar d/s	Hari-Ki-Puri			
Haridwar d/s	Lalta Rao			
Haridwar d/s	Dam Kothi	Middle	53.43	53.89
Kannauj	u/s Fategarh			
Kannauj	Ram Ganga at Fategarh			
Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)			
Kannauj	Kali River	Lower	53.43	53.89

Kannauj	d/s (After Confluence with Kali)			
Kanpur	u/s (Bithoor)			
Kanpur	d/s (Shuklaganj)			
Kanpur	d/s Jane Village			
Jajmau Bridge	Bathing Ghat			
Garh	u/s			
Garh	d/s			
Buxar	u/s			
Buxar	d/s			
Buxar	d/s (River Karamanasha)			
Patna	u/s			
Patna	d/s			
Rajmahal	d/s			
Koelwar	River Sone			
Chapra	u/s Ghaghra			
Chapra	d/s Chapra	Lower	55.61	54.29
Hajipur	d/s (River Gandak)			
Hajipur	u/s (River Gandak)			
Berhampore	Middle			
Palta	Middle			
Palta	Impact			
Dakshineswar	Middle			
Uluberia	Middle			
Uluberia	Impact			

We conclude from table 7 that there is a significant change in WQI across the three region of Ganga *i.e.* Upper, Middle and Lower region. High WQI was observed in the Upper region in Uttarakhand State. Ganga originates from this state with good water quality. As the Ganga river passes through various states the water quality degrades.

4.4 Hypothesis 4: There is no difference in WQI of industrial and non-industrial stations across states

Figure 8 depicts classified Industrial and Non-Industrial stations and Table 8 gives average WQI of Industrial and Non-Industrial Zones for year 2004 and 2009.

Figure 8: Industrial and Non-Industrial Stations across Ganga river**Table 8. Average WQI across Industrial and Non-Industrial stations for year 2004 and 2009**

Location	Sub-Location	State	Industrial/Non-Industrial	WQI across I/ N	
				Average 2004	Average 2009
Kannauj	u/s Fategarh	Uttar Pradesh	Non-Industrial		
Kannauj	Ram Ganga at Fategarh	Uttar Pradesh	Non-Industrial		
Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)	Uttar Pradesh	Non-Industrial		
Kannauj	Kali River	Uttar Pradesh	Non-Industrial	56.06	55.49
Kannauj	d/s (After Confluence with Kali)	Uttar Pradesh	Non-Industrial		
Kanpur	d/s (Shuklaganj)	Uttar Pradesh	Non-Industrial		
Garh	u/s	Uttar Pradesh	Non-Industrial		
Kanpur	u/s (Bithoor)	Uttar Pradesh	Industrial		
Kanpur	d/s Jane Village	Uttar Pradesh	Industrial	48.82	51.09
Jajmau Bridge	Bathing Ghat	Uttar Pradesh	Industrial		

Garh	d/s	Uttar Pradesh	Industrial	62.53	61.11
Buxar	u/s	Bihar	Non-Industrial		
Buxar	d/s	Bihar	Non-Industrial		
Buxar	d/s (River Karamanasha)	Bihar	Non-Industrial		
Rajmahal	d/s	Bihar	Non-Industrial		
Chapra	u/s Ghaghra	Bihar	Non-Industrial	62.22	60.23
Hajipur	d/s (River Gandak)	Bihar	Non-Industrial		
Hajipur	u/s (River Gandak)	Bihar	Non-Industrial		
Patna	u/s	Bihar	Industrial		
Patna	d/s	Bihar	Industrial		
Koelwar	River Sone	Bihar	Industrial		
Chapra	d/s Chapra	Bihar	Industrial		

We conclude from Table 8 that there is a difference in WQI of Non Industrial and Industrial stations within each state. Uttarakhand state had all Non-Industrial stations whereas West Bengal state had all Industrial stations. Hence we couldn't compare WQI of Industrial vs. Non Industrial for these two states. Uttar Pradesh and Bihar states had both Industrial and Non-Industrial stations. Hence comparison of WQI was possible for these two states. It is observed that many polluting industries like steel, cement, power plants and textiles around Uttar Pradesh and Bihar states degrading the river water quality. This is the main reason for decrease in WQI.

4.5 Hypothesis 5: There is no change in WQI across seasons

Table 9 depicts average WQI across seasons for year 2004 and 2009

Table 9. Average WQI across seasons for year 2004 and 2009

Location	Sub-Location	State	WQI across Seasons					
			Winter		Summer		Monsoon	
			2004	2009	2004	2009	2004	2009
Rishikesh	u/s	Uttarakhand						
Rishikesh	d/s	Uttarakhand						
Haridwar	u/s	Uttarakhand	87.8	91.3	86.7	90.5	87.2	86.0
d/s			2	7	8	3	6	5
Haridwar	Hari-Ki-Puri	Uttarakhand						
d/s								
Haridwar	Lalta Rao	Uttarakhand						
d/s								

Haridwar d/s	Dam Kothi	Uttarakhan d					
Kannauj	u/s Fategarh	Uttar Pradesh					
Kannauj	Ram Ganga at Fategarh	Uttar Pradesh					
Kannauj	u/s (After Confluence with Ram-Ganga and b/c with Kali)	Uttar Pradesh					
Kannauj	Kali River	Uttar Pradesh					
Kannauj	d/s (After Confluence with Kali)	Uttar Pradesh					
Kanpur	u/s (Bithoor)	Uttar Pradesh	56.4 7	58.0 8	49.3 5	50.8 0	53.4 5
Kanpur	d/s (Shuklaganj)	Uttar Pradesh					52.4 0
Kanpur	d/s Jane Village	Uttar Pradesh					
Jajmau Bridge	Bathing Ghat	Uttar Pradesh					
Garh	u/s	Uttar Pradesh					
Garh	d/s	Uttar Pradesh					
Buxar	u/s	Bihar					
Buxar	d/s	Bihar					
Buxar	d/s (River Karamanasha)	Bihar					
Patna	u/s	Bihar					
Patna	d/s	Bihar					
Rajmahal	d/s	Bihar	67.0 6	63.3 5	60.2 9	60.0 9	59.9 9
Koelwar	River Sone	Bihar					57.5 7
Chapra	u/s Ghaghra	Bihar					
Chapra	d/s Chapra	Bihar					
Hajipur	d/s (River Gandak)	Bihar					
Hajipur	u/s (River Gandak)	Bihar					
Berhampor e	Middle	West Bengal					
Palta	Middle	West Bengal					
Palta	Impact	West Bengal					
Dakshinesw ar	Middle	West Bengal	48.2 8	46.8 5	40.0 8	40.1 2	40.8 4
Uluberia	Middle	West Bengal					40.1 6
Uluberia	Impact	West Bengal					

We conclude from table 9 that there is no difference in WQI across seasons as well as across years at state level. This means that the effect of dilution on WQI across seasons is minimal.

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5 Conclusions and Future Work

The present study used Unweighted Arithmetic Mean model for assessing water quality of Ganga basin. The present study formulated various hypothesis and validated preconceived premise using Unweighted Arithmetic mean model. The Unweighted Arithmetic Mean model discussed in the present study is one of the simplest models reported in the literature. The results were simple, self explanatory and quantitative in nature and mostly on pre-conceived theory. It was reported using this study that seasonal effect is minimal on water quality but literature reports the other way. Also, it observed that water quality decreases downstream. This was found to be mostly true except in the case of Uttar Pradesh and Bihar states. The Bihar state was found to have better water quality than Uttar Pradesh. The main reason is flow of fresh water from Ghaghara, largest tributary to river Ganga. This Ghaghara flows into the river Ganga most of the year resulting in overall improvement in the water quality of Ganga in Bihar state. Further downstream, the WQI decrease on expected lines. We observe that water quality parameters namely, Total Coliform, Fecal Coliform, TKN, COD, BOD are mostly out of standard range. This Ganga river water is unfit for any purpose/activity in present condition (bathing, industrial and irrigation).

The indexing approach enables large amount of water quality data to a single index value. Further, we can determine the potential water use after determining the index score. The water quality index analysis results in a single number resulting from complex water quality data. The advantage of the single number is understandable to general public and authorities. WQI can be used as a rapid tool for assessment of water quality. This can be used as a decision making tool for water quality assessment and management. The shortcoming of this analysis includes masking of individual water quality parameter importance and non consideration of other important water quality parameters. This can be overcome by subjecting each parameter to importance factor (not considered in the present study) which may overcome the present limitation of Unweighted Arithmetic Mean model. It is evident from above study that monitoring of river Ganga is necessary for proper management.

The future work involves development and comparison of water quality Indexes, spatial and temporal depiction of water quality index across the river Ganga using spatial interpolation techniques. Attempt can be made to develop the linkage between climate change and urban sprawl around the river Ganga. Also, there is an immediate need to develop Qualitative and Quantitative Environmental Management Plan for Ganga basin. This will help significantly reduce pollution load in Ganga basin. A specific study is required to understanding flow of

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tributaries across seasons, its pollution load on Ganga basin. This will help prioritize immediate remedial option available for improving water quality.

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