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Assessment of water quality parameters using water quality index (WQI) of upper Ganga basin

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Abstract
The Upper Ganga Basin, a vital water resource for millions of people and a diverse ecosystem, faces significant challenges due to anthropogenic activities and natural processes affecting water quality. The aim of this study to evaluate the water quality of the Upper Ganga Basin using the Water Quality Index (WQI). By integrating multiple water quality parameters, the WQI provides a single, aggregated value that represents the overall health of the water body. Various water quality parameters data such as Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Water Temperature, Total Dissolved Solids (TDS) and Total Hardness (TH), were collected (from 1995 to 2020). These parameters were selected based on their significance to water quality and their impact on human health and aquatic life. Data were collected from five stations i.e., Uttarkashi, Bareilly, Kanpur, Prayagraj and Varanasi for this study. Each parameter was normalized against established water quality standards. The aggregated WQI values were then calculated, categorizing the water quality into different classes ranging from excellent to poor. This categorization aids in identifying pollution hotspots and assessing the suitability of the water for various uses such as drinking, agriculture, and recreation. The WQI values indicate areas of concern where water quality is significantly degraded, necessitating immediate remedial actions. Conversely, regions with high WQI values highlight zones where water quality management practices are effective. It was observed that poverty of water quality condition in various areas, represented by WQI. Kanpur shows a trend of predominantly poor water quality in the post monsoon season. The highest WQI recorded is 37 in 1995 and 2005, indicating fair quality. In the monsoon season, the highest WQI is 39 in 2005, showing fair quality, while many years, particularly 2000 to 2004, and 2008 to 2014, record poor water quality in compare to other stations.

Keywords: Water quality index (WQI), upper Ganga basin, water quality parameters, normalization and pollution assessment

1. Introduction
The largest river in India, the Ganges flows from Gangotri to the Bay of Bengal, covering a distance of around 2525 km. Its basin is approximately 861404 square km, and it delivers water essential for over 25 towns and hundreds of villages (Mehar *et al.*, 2014) [2]. Ganga due to the mixing of untreated sewage and organic matter. The water quality index of River Ganga changes from good to poor (Gani *et al.*, 2023) [3]. Water quality (WQ) is a helpful indicator for evaluating the characteristics of water with respect to human health and the consequences on natural quality. The surface water's low quality is a significant issue that harms ecosystems, human health, and plant and animal life throughout. As such, the analysis of water quality has emerged as a primary issue in environmental and water resource systems (Vanlandeghem *et al.*, 2012 & Espejo *et al.*, 2012) [4, 5]. A water quality index (WQI) is a single figure that expresses the water quality at a certain location and time using a collection of physicochemical water characteristics (Mohammadpour *et al.*, 2015) [6]. Horten was the first to introduce the idea of using WQI to show the gradation in water quality. The usage of WQIs streamlines the presentation of research findings pertaining to a body of water by condensing the cumulative impact of several water quality factors under analysis into a single unitless value. To evaluate the quality of natural waters, a number of water quality indices are used (Tyagi *et al.* 2013) [7].

As a result, the indices help with both temporal and spatial comparisons in addition to providing information about water quality. WQI is helpful for assessing water quality since it expresses water quality in terms of a single index value. Many methods, including statistical analyses of individual parameters and multi-stressor water quality indices, have been studied for the analysis of water quality (Venkatesharaju *et al.* 2010) [8]. A mathematical method that assesses the overall quality of the water is the water quality index. It makes it easier to comprehend the aquatic resources of water quality. Water quality of the Ganges River's has been the subject of multiple investigations that have been documented in the literature (Misra, 2011 & Rai *et al.*, 2010) [9, 10]. In this study, five sites along the Ganges River; Uttarkashi, Bareilly, Kanpur, Prayagraj, and Varanasi were assessed for water quality and spatial variation using Water Quality Index. The results of this study can help in planning strategies for lowering risks to human health and for reducing pollution in river water.

2. Materials and Methods

2.1 Study Area

Water quality parameters of the upper Ganga basin were analysed in the current study. The Ganga River originates in Uttarkashi, Uttarakhand, at Gangotri (Matta *et al.*, 2020) [11]. The Ganga basin is located between 22030'N and 31030'N in latitude and between 73030'E and 8900'E in longitude. The Ganga River is 2525 km long and has a surface area of 1999000 km^2. The Ganga River rises to a height of approximately 3892 metres at Uttarkashi, Uttarakhand (Gocic & Trajkovic, 2013) [12]. Topographical information of all selected stations of upper Ganga basin is presented in Table 1 and Fig. 1.

Table 1: The stations used in this study

S. No.	Stations	Altitude (m)	Latitude (N)	Longitude (E)
1.	Uttarkashi	1158	30.7299^o	78.4354^0
2.	Bareilly	268	28.3670^0	79.4304^0
3.	Kanpur	126	26.4499^0	80.3319^0
4.	Prayagraj	98	25.4358^0	81.8463^0
5.	Varanasi	81	25.3176^0	82.9739^0

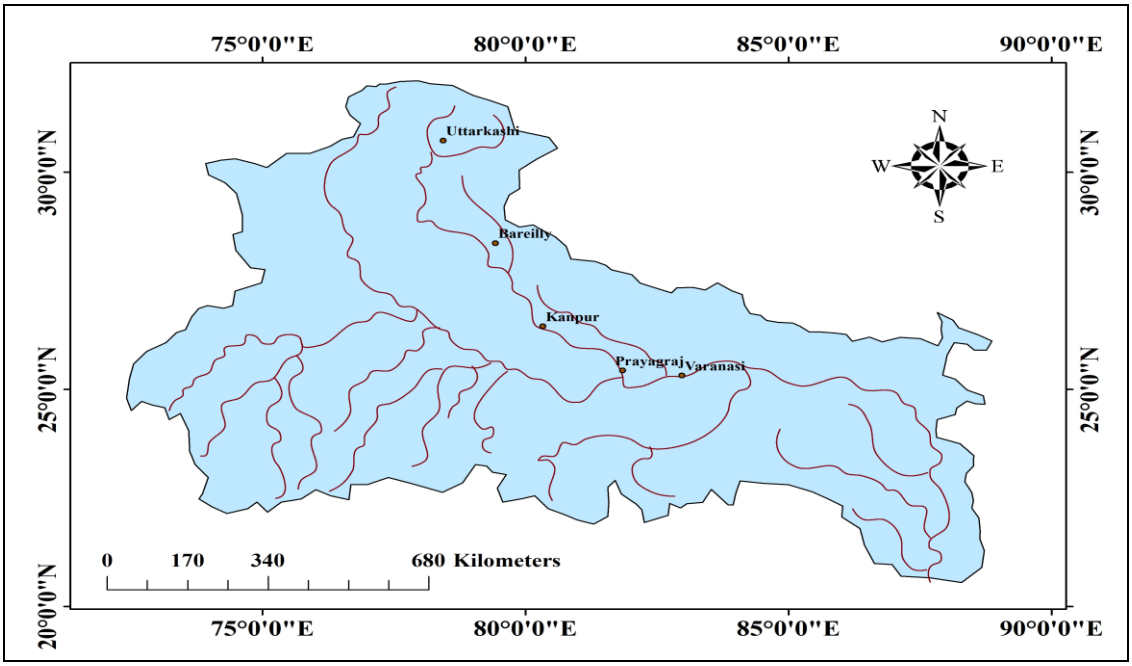

Fig 1: Representation of all stations of upper Ganga basin

2.2 Water Quality Data

For the purpose of analysing the WQI of upper Ganga basin, data were gathered from the Central Water Commission (CWC) during a period of 25 years (1995 to 2020) were obtained (Table 2). The study used data from five stations: Varanasi, Uttarkashi, Prayagraj, Bareilly, and Kanpur. The pre-whitening procedure eliminated auto correlation prior to data analysis. Here is a list of all the parameters:

Table 2: Water quality parameters selected for study

Physical parameters	Chemical parameters
Temperature	Dissolved Oxygen (DO)
Electrical Conductivity (EC)	pH
Total Dissolved Solids (TDS)	Total Hardness
	Sodium (Na)
	Potassium (K)
	Chlorine (Cl)
	Sulphate (SO_4)
	Bi-carbonate (HCO_3)

2.3 Water Quality Index (WQI)

An effective way to represent the relative weakness of water quality is to use the water quality index. By giving each physicochemical parameters, a weight (w_i) based on its relative importance in drinking water, the WQI was calculated (Kadam *et al.*, 2019) [13]. In the current study, the water quality index (WQI) was calculating using the calculator with the help of such parameters i.e. WT, TDS, DO and EC (Anon, 2024a) [1].

The following formula is used to determine the relative weight (W_i):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad \text{Eq}^n.1$$

Where-

W_i = relative weight

n = number of parameters.

For every parameter, a quality rating scale (qi) is computed using the subsequent equation:

$$q_i = (C_i/S_i) \times 100$$ Eqn.2

Where-
q_i = quality rating
C_i = chemical concentration/water sample (mg/l),
S_i = WHO drinking water quality standard (mg/l).
The sub-index of the i^{th} parameter is SI_i

$$SI_i = W_i \times q_i$$ Eqn.3

The water quality index (WQI) calculated by following formula:

$$WQI = \sum SI_i$$ Eqn.4

3. Results and Discussion

3.1 Temporal Assessment of the Water Quality using Water Quality Index (WQI)

A method for expressing the entire water quality of a particular water body in a single number is the Water Quality Index (WQI). This number is derived from multiple water quality parameters, making it easier to understand the overall state of the water in a simplified manner.

Table 3 represents the classification of water quality index. From the table red colour shows the poor water quality which range from 0 to 25. The range of fair water quality varies 26 to 50 denoted by orange colour. Yellow colour represents the average water quality which range 51 to 70. Light green and dark green show the good and excellent water quality which varies from 70 to 90 and 91 to 100 respectively.

Table 3: Classification of water quality index

WQI	0-25	Poor
	26-50	Fair
	51-70	Average
	71-90	Good
	91-100	Excellent

Table 4 presents the Water Quality Index (WQI) for Uttarkashi from 1995 to 2020. The WQI, on a scale of 0-100, categorizes water quality as poor (0-25), fair (26-50), average (51-70), good (71-90), and excellent (91-100). During the pre-monsoon season WQI is generally in the good range (71-90), with occasional dips into average (51-70). The highest WQI is 80 (1995), and the lowest is 66 (1998). In monsoon season WQI varies significantly, with some years showing excellent quality (87 in 1995) and others dropping to average (61 in 1998). Overall, it stays mostly good, with some fluctuations. Post-monsoon season WQI value is consistently good, with the highest value at 79 (1995). Several years, including 1997, 2006, 2019, and 2020, have a WQI of 67, indicating average quality.

Table 4: Water quality index at Uttarkashi

Water Quality Index (Uttarkashi)			
Year	**Pre Monsoon**	**Monsoon Season**	**Post Monsoon**
1995	80	87	79
1996	68	79	71
1997	71	68	67
1998	66	61	70
1999	74	76	72
2000	75	79	71
2001	73	70	71
2002	70	72	71
2003	71	71	70
2004	73	75	72
2005	72	73	71
2006	70	70	67
2007	76	72	75
2008	69	76	77
2009	76	80	77
2010	68	72	73
2011	67	73	71
2012	74	72	68
2013	69	71	74
2014	74	72	70
2015	70	72	72
2016	69	73	73
2017	69	73	73
2018	71	69	72
2019	70	69	67
2020	69	72	67

Table 5 highlights the variability in Water Quality Index (WQI) for Bareilly from 1995 to 2020 across different seasons. During pre-monsoon season the WQI fluctuates, peaking at 47 in 2004 (fair quality), but frequently dips below 25, indicating poor quality, especially in 2005, 2006, 2009, 2013, 2014, 2015, and 2020. In monsoon season WQI values mostly fall in the poor to fair range, with a high of 43 in 2012. Years like 2005, 2006, 2007, 2008, 2009, 2013, 2014, 2015, and 2020 show values below 25. Post-monsoon season shows the widest range in WQI, peaking at 51 in 1998 (average quality). Poor quality is noted in 2002, 2006, 2007, 2013, 2014, 2015, and 2020, with values below 25. Some fair quality years include 2003 and 2011 with mid-30s values. Overall, the data indicates persistent challenges with poor water quality in Bareilly.

Table 5: Water quality index at Bareilly

Water Quality Index (Bareilly)			
Year	**Pre Monsoon**	**Monsoon Season**	**Post Monsoon**
1995	41	40	42
1996	40	38	42
1997	41	37	40
1998	23	41	51
1999	43	41	40
2000	39	41	39
2001	43	41	40
2002	39	38	21
2003	42	41	44
2004	47	32	40
2005	13	23	31
2006	15	24	16
2007	21	21	21
2008	19	22	39
2009	13	14	33
2010	26	36	37
2011	29	37	28
2012	23	43	34
2013	5	17	11
2014	11	13	13
2015	11	16	17
2016	32	35	40
2017	33	36	32
2018	36	39	42
2019	35	31	31
2020	12	31	14

Table 6 shows the Water Quality Index (WQI) for Kanpur from 1995 to 2020, revealing variability across pre-monsoon, monsoon, and post-monsoon seasons. In pre-monsoon season WQI values are mostly poor to fair, peaking at 40 in 1996 and 1997. Many years, especially 2000, 2001, 2002, 2004, and 2008-2014, have poor quality with values between 19 and 25. Monsoon season displays similar trends with WQI in the poor to fair range, peaking at 39 in 1995 and 2005. Poor quality years include 2000-2004, 2008-2014, and 2018-2020, often below 25. During Post-monsoon WQI values vary but remain largely poor to fair, peaking at 37 in 1995 and 2005. Poor quality is noted in 1997, 2000-2004, 2008-2014, and 2018-2020, with values below 25. Kanpur consistently faces low to fair water quality across all seasons.

Table 6: Water quality index at Kanpur

Water Quality Index (Kanpur)			
Year	**Pre Monsoon**	**Monsoon Season**	**Post Monsoon**
1995	39	39	37
1996	40	38	35
1997	40	35	20
1998	39	37	35
1999	39	36	36
2000	21	23	23
2001	21	21	21
2002	22	22	21
2003	25	22	23
2004	22	22	21
2005	38	39	37
2006	39	37	34
2007	36	37	35
2008	19	18	20
2009	19	18	18
2010	21	17	19
2011	40	38	33
2012	20	19	17
2013	19	19	17
2014	20	19	20
2015	37	37	33
2016	36	35	34
2017	20	26	23
2018	24	26	31
2019	32	26	32
2020	36	25	18

Table 7 shows the Water Quality Index (WQI) for Prayagraj. During the pre-monsoon season, the WQI generally falls within the fair range, with some years exhibiting average water quality. The highest WQI recorded is 59 in 1998, indicating average water quality. However, the years 2015-2019 show poor water quality, with the lowest value being 20 in 2016. The overall trend suggests that pre-monsoon water quality has generally been fair to poor in recent years. In the monsoon season, the WQI values show a consistent pattern of fair water quality, with occasional drops into the poor category. The highest value recorded is 40 in 2003 and 2004, indicating fair quality. However, there are notable years with poor water quality, such as 2001 with a WQI of 20, and 2015-2017, where values drop to as low as 19. This indicates that monsoon seasons often do not significantly improve water quality in Prayagraj. The post-monsoon season exhibits a similar pattern to the other seasons, with WQI values largely in the fair range. The highest values are 39 in 2004 and 2005, showing fair water quality.

Table 7: Water quality index at Prayagraj

Water Quality Index (Prayagraj)			
Year	**Pre Monsoon**	**Monsoon Season**	**Post Monsoon**
1995	47	37	36
1996	37	37	37
1997	40	36	35
1998	59	38	38
1999	37	38	35
2000	57	37	37
2001	41	20	38
2002	47	36	37
2003	37	40	37
2004	38	40	39
2005	38	37	39
2006	38	39	37
2007	39	37	34
2008	36	34	36
2009	37	34	36
2010	35	36	36
2011	35	33	35
2012	42	36	33
2013	39	37	33
2014	38	35	33
2015	27	19	22
2016	20	19	19
2017	22	20	20
2018	24	26	20
2019	24	24	31
2020	35	38	30

Table 8 shows the Water Quality Index (WQI) for Varanasi from 1995 to 2020, highlighting significant seasonal variations. In pre-monsoon season WQI generally falls within the fair category, peaking at 49 in 1998. Poor quality is noted in 1999, 2000, 2001, 2005, and 2006, with a low of 23. During the monsoon season ranges from fair to poor, with a high of 46 in 1995 and 1998. Poor quality years include 2006 and 2020, with values as low as 21 and 22. The post-monsoon season mostly shows fair quality, peaking at 47 in 1998 and 2007. Poor quality is observed in 2000, 2005, 2006, 2010, 2019, and 2020, with values as low as 20. Varanasi shows variability in water quality across seasons, trending towards fair quality but with frequent fluctuations.

Table 8: Water quality index at Varanasi

Water Quality Index (Varanasi)			
Year	**Pre Monsoon**	**Monsoon Season**	**Post Monsoon**
1995	39	46	40
1996	43	38	39
1997	42	44	43
1998	49	46	47
1999	23	39	38
2000	23	23	24
2001	23	23	39
2002	41	45	40
2003	41	41	40
2004	42	41	41
2005	25	40	24
2006	25	21	21
2007	36	39	47
2008	36	46	46
2009	45	45	45
2010	35	35	22
2011	38	40	36
2012	40	41	33
2013	39	38	36
2014	39	38	36
2015	39	37	34
2016	36	33	36
2017	38	42	38
2018	48	41	45
2019	35	22	32
2020	46	22	20

3.2 Spatial Assessment of the Water Quality using Water Quality Index (WQI)

Fig.2 illustrates the Water Quality Index (WQI) during the pre-monsoon season from 1995 to 2020 across five cities: Uttarkashi, Bareilly, Kanpur, Prayagraj, and Varanasi. Uttarkashi consistently shows higher WQI values compared to the other cities, indicating relatively better water quality over the years. Conversely, Bareilly and Kanpur exhibit more fluctuations, with some years showing notably low WQI, particularly around the early 2000s and mid-2010s. Prayagraj and Varanasi also demonstrate variability, with Prayagraj experiencing a peak in 1998 and another high in the early 2000s. Varanasi's water quality shows an upward trend in the late 2010s. Overall, the data indicates significant inter-annual and inter-city variations in water quality, highlighting the need for targeted water management and policy interventions.

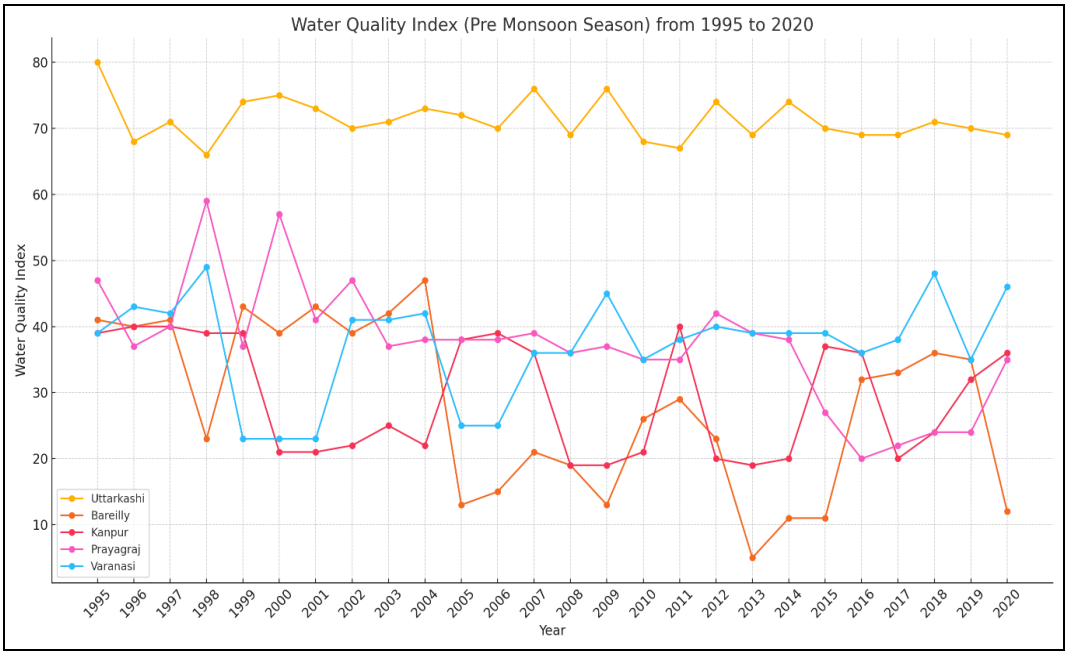

Fig 2: Spatial water quality index in pre monsoon season

Fig.3 shows the Water Quality Index (WQI) during the monsoon season from 1995 to 2020 across five cities: Uttarkashi, Bareilly, Kanpur, Prayagraj, and Varanasi. Uttarkashi stands out with consistently higher WQI values, indicating better water quality compared to the other cities, despite a noticeable decline from 1995 to 1996. Bareilly and Kanpur exhibit more volatile trends, with frequent fluctuations and some years showing significantly low WQI values, especially around the late 1990s and mid-2000s. The water quality of Prayagraj shows a slight improvement after 2000 but remains inconsistent. Varanasi demonstrates a relatively stable trend with moderate variations throughout the years. Overall, the data highlights substantial variability in water quality among these cities, underscoring the need for focused and adaptive water management strategies to address the seasonal and regional challenges.

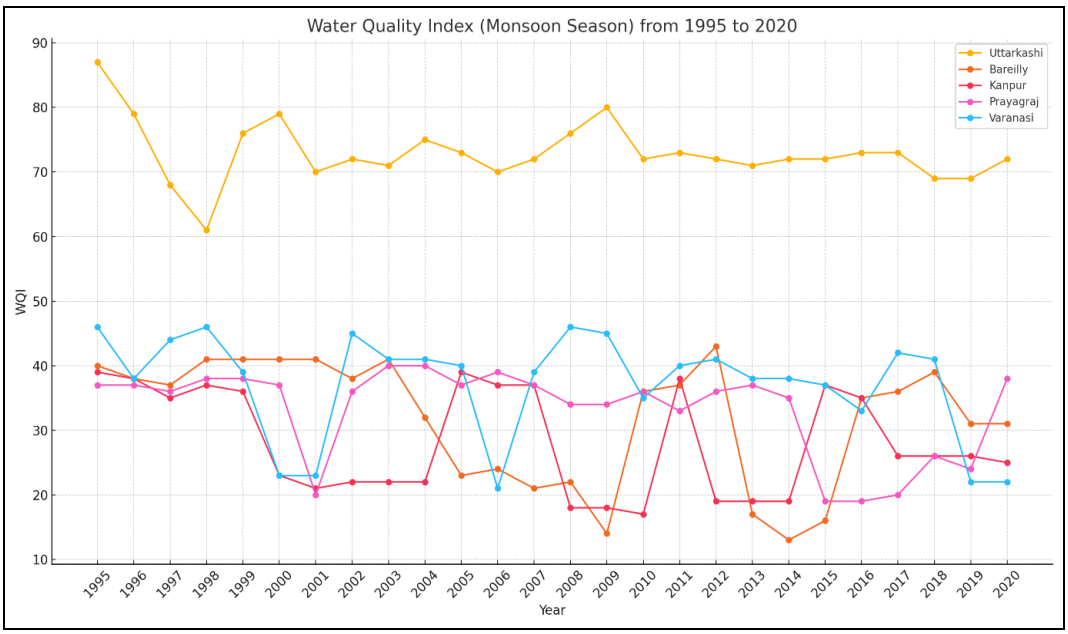

Fig 3: Spatial water quality index in monsoon season

Fig.4 depicts the Water Quality Index (WQI) during the post-monsoon season from 1995 to 2020 for five cities: Uttarkashi, Bareilly, Kanpur, Prayagraj, and Varanasi. Uttarkashi consistently shows the highest WQI values, reflecting better water quality across the years, although there is a slight decline from the mid-1990s to the early 2000s. Bareilly and Kanpur display significant fluctuations in their WQI values, indicating variable water quality, with some years showing notably low indices, especially around the late 1990s and mid-2000s. Prayagraj and Varanasi also show considerable variability, with Prayagraj experiencing a decline in the early 2000s and then stabilizing, while Varanasi demonstrates periodic peaks and troughs throughout the years. Overall, the graph highlights the diverse trends in water quality across these cities, emphasizing the importance of localized water management strategies to address the distinct challenges faced by each region during the post-monsoon season.

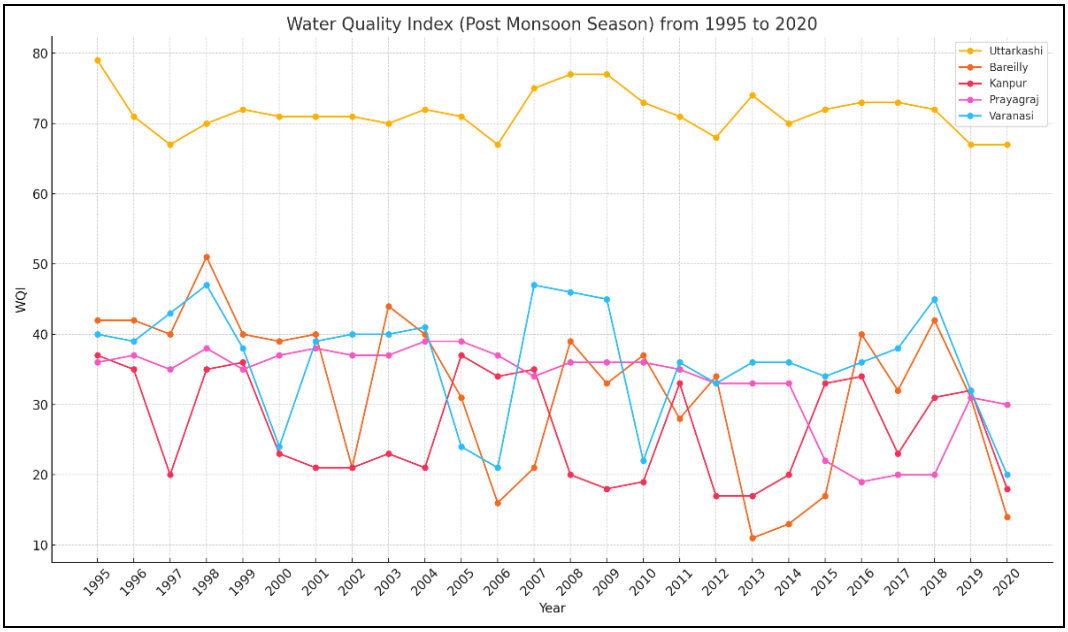

Fig 4: Spatial water quality index in post monsoon season

The finding in Misra (2011) [9] and Rai *et al.* (2010) [10] are addressed with the same result of Water Quality Index (WQI). In the current study Kanpur Prayagraj and Varanasi identify the poor to fair water quality whereas, Uttarkashi shows the average to good quality of water. Similar observation also reported by Mohammadpour *et al.* (2015) [6]. Tyagi *et al.* (2013) [7] conducted a study for water quality assessment in terms of water quality index. In that study they analyzed Several countries have utilized aggregated water quality data to develop water quality indices. Efforts have been made to evaluate the criteria for Water Quality Indices (WQI) concerning the suitability of drinking water sources. Additionally, the current article emphasizes the need for creating a new, globally accepted Water Quality Index in a simplified format that can be widely used and accurately reflect water quality.

4. Conclusions

To identify the change in water quality, the present study examined water quality data of the upper Ganga basin over 25 years (from 1995 to 2020). It can be concluded that human-caused pollution in the Ganga River poses a major threat to the ecology. Continuous deterioration of water quality in the Ganga River will affect various sectors such as municipal and agricultural water supplies. When choosing certain parameters to test frequently to regularly assess the state of water quality, WQI of the parameters related to water quality can be helpful. This will facilitate regulatory agencies' ability to implement control measures and offer warnings when water quality begins to decline. Compared to all stations, the water quality index shows very low water quality in Kanpur. Some conclusions found in this study are as follows:

1. WQI reveals that water quality is decreasing over time.
2. The water quality of the Ganga River is found to be lowest in Kanpur due to pollution from the industrial area, which contaminates the river and decreases its quality.
3. Analysis of the Water Quality Index (WQI) shows that the water quality in Uttarkashi is generally good because it is located in the upper reaches of the Himalayas, where the primary water source is glacial melt and there is less industrial and human waste.
4. The water quality in Bareilly varies between average and fair.
5. The lowest quality of water in the Ganga River is found in Kanpur, Prayagraj, and Varanasi due to a combination of anthropogenic activities and environmental factors such as industrial pollution, domestic sewage, solid waste disposal, and religious and cultural activities.

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