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Temporal and spatial analysis of water quality parameters of upper Ganga basin

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Abstract
The availability of water resources for ensuring the life and health of both individuals and ecosystems depends in large part on rivers. As a result, maintaining and managing river water quality is a crucial factor. The presence of impurities and the characteristics of water indicates the quality of water. The quality of water is affected by industrial, agricultural and urban wastes. Polluted water is not good for human health and agricultural purposes. It causes many diseases and reduces the productivity of crops. Different quality of water is required for agriculture, household and drinking purpose. Various water quality parameters data like Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Temperature, Total Dissolved Solids (TDS) and Total Hardness, were collected (from 1985 to 2020) and analysed to find the trend in upper Ganga basin using Mann-Kendal test. Primary data of five stations i.e., Uttarkashi, Bareilly, Kanpur, Prayagraj and Varanasi were used for this study. Among the parameters studied hardness and TDS represent the positive trend and DO represent the negative trend, which indicate that the quality of water deteriorates. It was observed that poverty of water quality condition in various areas, represented by trend analysis, which is affected by higher variations in the magnitude.

Keywords: Water quality parameters, trend analysis, Mann Kendal test, Sen's slope

1. Introduction
Water is the foundation of life and finite resource of water for agriculture, industry, drinking purpose and households (Othman *et al.*, 2012) [6]. In view of population growth and economic development, India is facing a major problem of scarcity of natural resources, especially water. Most of fresh water resources around the world are getting polluted and reducing the flexibility of water (Gholizadeh *et al.*, 2016) [1]. Due to rising water demands from agriculture, industry and hydroelectricity production as well as continued pollution and these shown the negative effects on the water (Othman *et al.*, 2012) [6]. Living beings is dependent on water and is present in many forms in nature such as sea, river, lake, etc (Gholizadeh *et al.*, 2016) [1].
These are many too rivers are better sources of water which helps humans and animals to survive and do agriculture (Postel *et al.*, 2012) [11]. Ganga is one of them whose water is used for agriculture, industrial, drinking and domestic purposes. Pollution is the main cause of the Ganga River to decline water quality that is increasing day by day, as a result of that the quality of water of the Ganga River has become very poor. During the travel in North Indian River plain Ganga waterway passes through the industrial city of Kanpur, the industrial ranges in Kanpur are arranged with the middle of populated region along river bank (Shukla *et al.*, 2021) [10]. Ganga receives household sewage, industrial and chemical pollutants (Khatoon *et al.*, 2013) [15]. The water quality of the Ganga River is declining day by day due to industrial effluents and human activities, which are constructed on its bank. Therefore, it is important to monitor and replicate the water quality parameters of Ganga River (Grode and Jadhav, 2013) [3].
An important environmental diagnosis of a given river basin is provided by trends analysis of water quality data, which enables assessments of how the water body responds over a period of several years, qualitatively, to the rise in anthropogenic interventions.

Trend analysis show the water quality variable's measured value has increased or decreased during the time period (Naddafi *et al.*, 2007) [5]. The time series of monthly and annual values of water quality parameters are statistically examined for trend analysis in this study, the assessment of magnitude in change in water quality in these stations is conducted.

2. Materials and Methods

2.1. Study Area

In the current study, the water quality parameters of the upper Ganga basin were analysed. Ganga river originates from Gangotri in Uttarkashi of Uttarakhand (Matta *et al.*, 2020) [12]. The latitude and longitude of Ganga basin lies between $73^0$30'E to $89^0$0'E and $22^0$30'N to $31^0$30'N. The length of the Ganga River is 2525 kilometres, and the surface area of basin is 1999000 km^2. The elevation of the Ganga river at Uttarkashi of Uttarakhand is about 3892 meters (Gocic & Trajkovic, 2013) [2]. Geographical information of five 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	Latitude (N)	Longitude (E)	Elevation (m)
1.	Uttarkashi	30.7299°	78.4354^0	1158
2.	Bareilly	28.3670^0	79.4304^0	268
3.	Kanpur	26.4499^0	80.3319^0	126
4.	Prayagraj	25.4358^0	81.8463^0	98
5.	Varanasi	25.3176^0	82.9739^0	81

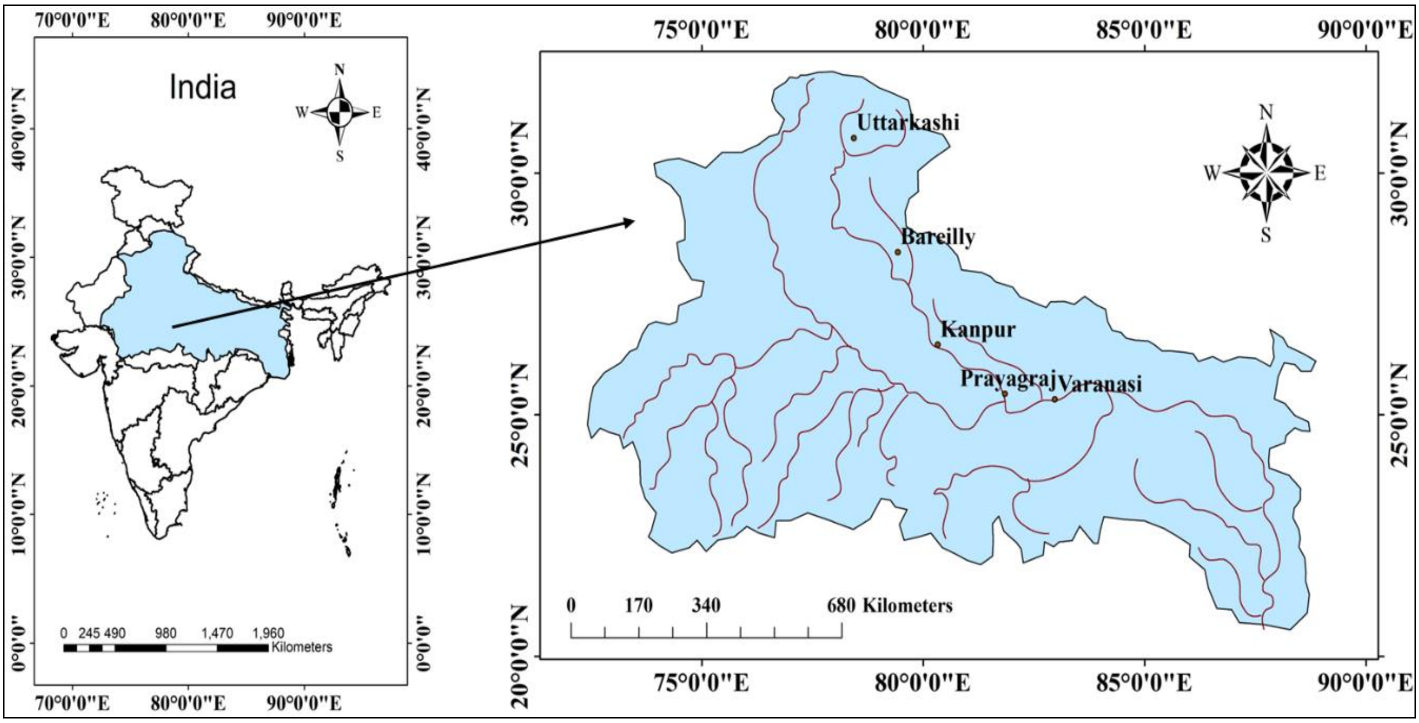


Fig 1: Geographical representation of upper Ganga basin

2.2 Water Quality Data

Water quality data collected from Central Water Commission (CWC) for 35 years (1985 to 2020) were analysed for study of trend of data of upper Ganga basin (Table 2). Primary data of five stations i.e., Uttarkashi, Bareilly, Kanpur, Prayagraj and Varanasi were used for this study. Auto correlation removed by pre-whitening method before analysing the data. All Parameters are mentioned here:

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

2.3 Methodology of Trend Analysis

The trend analysis approach was used to evaluate temporal changes. It is made up of several graphical, parametric, and non-parametric statistical methods that are separated into exploratory and confirmatory data analysis. Trend analysis was done using the Mann Kendall Test. Trend analysis helps us identify whether a water quality variable's measured values have increased or decreased during the time period.

2.3.1 Mann Kendall Test

The most popular technique for identifying trend in a time series is the non-parametric Mann Kendall test proposed by Mann (1945) [7]. Mann Kendall statistics is determined by the following equations-

$$\mathrm{sign}(x_i - x_j) = \begin{cases} -1 \text{ for } (x_i - xj) < 0 \\ 0 \text{ for } (x_i - x_j) = 0 \\ 1 \text{ for } (x_i - x_j) > 0 \end{cases} \qquad \ldots 1$$

where;
x = data set
i = 1,2,3…n term
j = i+1

For calculating the sum of all sign formula will be used-

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=i+1}^{n} \mathrm{sign}(x_i - x_j) \qquad \ldots 2$$

The following formula used to calculate the variance-

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} tp(tp-1)(2tp+5)}{18} \quad ...3$$

Where;
Var(s) = variance of sum
n = total number
tp = number of terms whose equal value

For estimating the trend Z value will be calculate by following formula-

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{s+1}{\sqrt{var(S)}} & \text{if } S < 0 \end{cases} \quad ...4$$

Where;
Z = Mann-Kendall statistics

Positive Z value shows the increasing trend and negative Z value show the negative trend.

2.3.2 Sen' slope Estimator
A non-parametric technique known as Sen's slope estimator can be used to measure the magnitude of trend in a time series. Sen's estimator proposed by Sen (1968), can be determined by following-

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1, 2, \ldots\ldots, N \quad ...5$$

Where;
x_j = data values at time j
x_k= data values at time k (j>k)
Ti = the Sen's estimator of slope.

2.3.3 Change point detection
The Pettitt (1979) technique is a non-parametric change detection method designed to determine the most likely year when the pattern of a recorded climatic time series changed. It is capable of identifying changes in both the mean of the time series and the year when these changes first became evident in the series. The test statistics that are nonparametric for this test, U_t can be explained as follows-

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \text{sign}(x_t - x_j) \quad ...6$$

$$\text{sign}(x_t - x_y) = \begin{cases} 1 \text{ for} \ldots\ldots\ldots \text{if} > 0 \\ 0 \text{ for} \ldots\ldots\ldots \text{if} = 0 \\ 1 \text{ for} \ldots\ldots\ldots \text{if} < 0 \end{cases} \quad ...7$$

The confidence level (ρ) and test statistic K for the sample length (n) can be explained as follows-

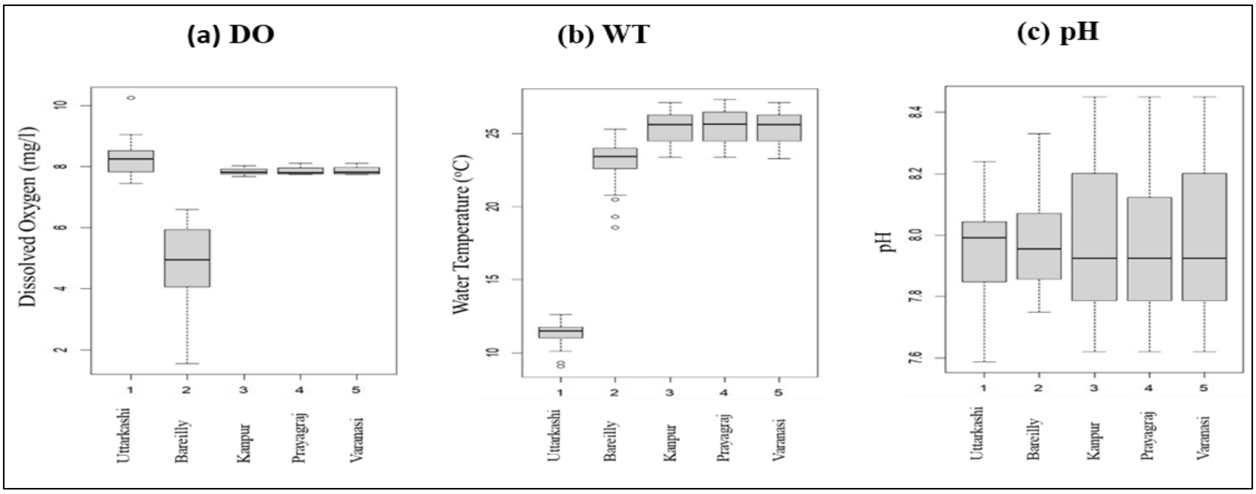
$$K = \max(U_t) \quad ...8$$

$$\rho = \exp\left[\frac{-K}{n^2 + n^3}\right] \quad ...9$$

The null hypothesis is rejected when the value of ρ is less than the designated confidence level. The definition of the approximate significance probability (p) for a change-point is as follows-

$$P = 1 - \rho \quad ...10$$

3. Results and Discussion
3.1. Boxplot graph of water quality parameters for annual data
Figure 2 presents a box plot representation of annual water quality parameters, summarizing the data with minimum, first quartile, median, third quartile, and maximum values (excluding outliers) (Spitzer *et al.*, 2014) [13]. The bold horizontal line within the box indicates the median, while the lower and upper edges represent the first and third quartiles, respectively. Dotted lines extend to the first and last 25% of the data, excluding outliers. Bareilly exhibits very low DO levels, whereas Kanpur, Prayagraj, and Varanasi show higher DO levels, with Uttarkashi having the highest (Fig. 2a). Water temperatures in Kanpur, Prayagraj, and Varanasi are higher than in Bareilly, while Uttarkashi shows very low temperatures (Fig. 2b). Uttarkashi's water pH ranges from 7.6 to 8.2, indicating an alkaline nature, similar to Bareilly. Kanpur has a higher pH compared to Prayagraj and Varanasi (Fig. 2c). EC is lowest in Uttarkashi, higher in Bareilly, and highest in Kanpur, Prayagraj, and Varanasi (Fig. 2d). TDS values peak in Prayagraj and are lowest in Uttarkashi, with other stations ranging from 600 to 1300 mg/l (Fig. 2e). Kanpur shows the highest water hardness, while Uttarkashi has the lowest (Fig. 2f).



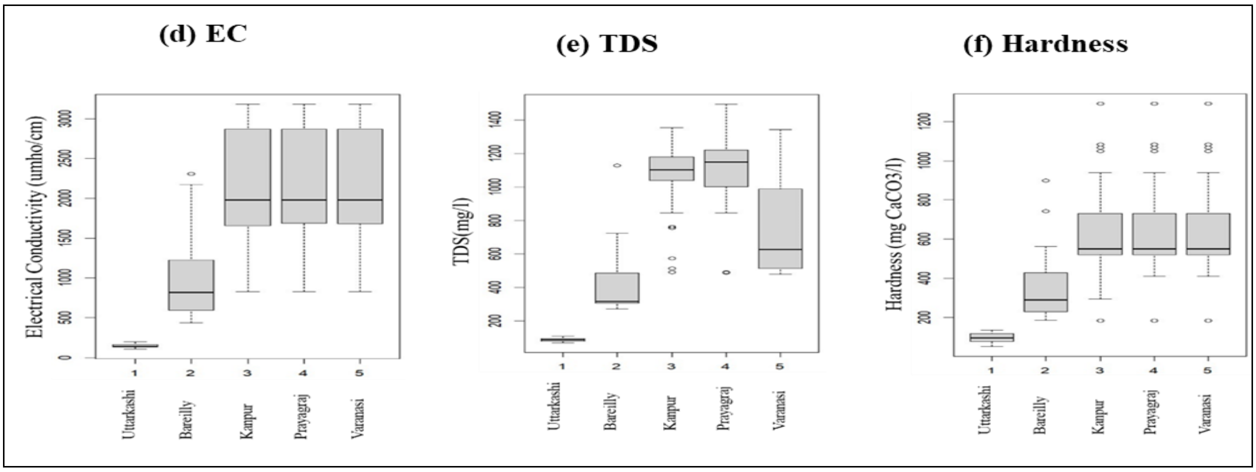


Fig 2: Boxplot graph of water quality parameters for annual data

3.2. Spatial variation of water quality parameters

The spatial map was plotted using the IDW (Inverse Distance Weighted) interpolation method for six different water quality parameters i.e. pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Hardness and Water Temperature (WT) respectively. These spatial maps were plotted for four seasons i.e. pre monsoon season (PreM), post monsoon season (PostM), monsoon season (MS) and winter monsoon (WM).

Fig. 3 shows the spatial variation of pH among the upper Ganga region (i.e Uttarkashi, Bareilly, Kanpur, Prayagraj and Varanasi) for four seasons. Pre-monsoon season shows the significant decreasing trend of pH in Kanpur and Varanasi which expands to Bareilly, Prayagraj and Varanasi. (Fig 2a and 2b). Whereas Z statistics of pH value does not show any significant spatial variation in monsoon season and winter monsoon season (Fig 2c and 2d).

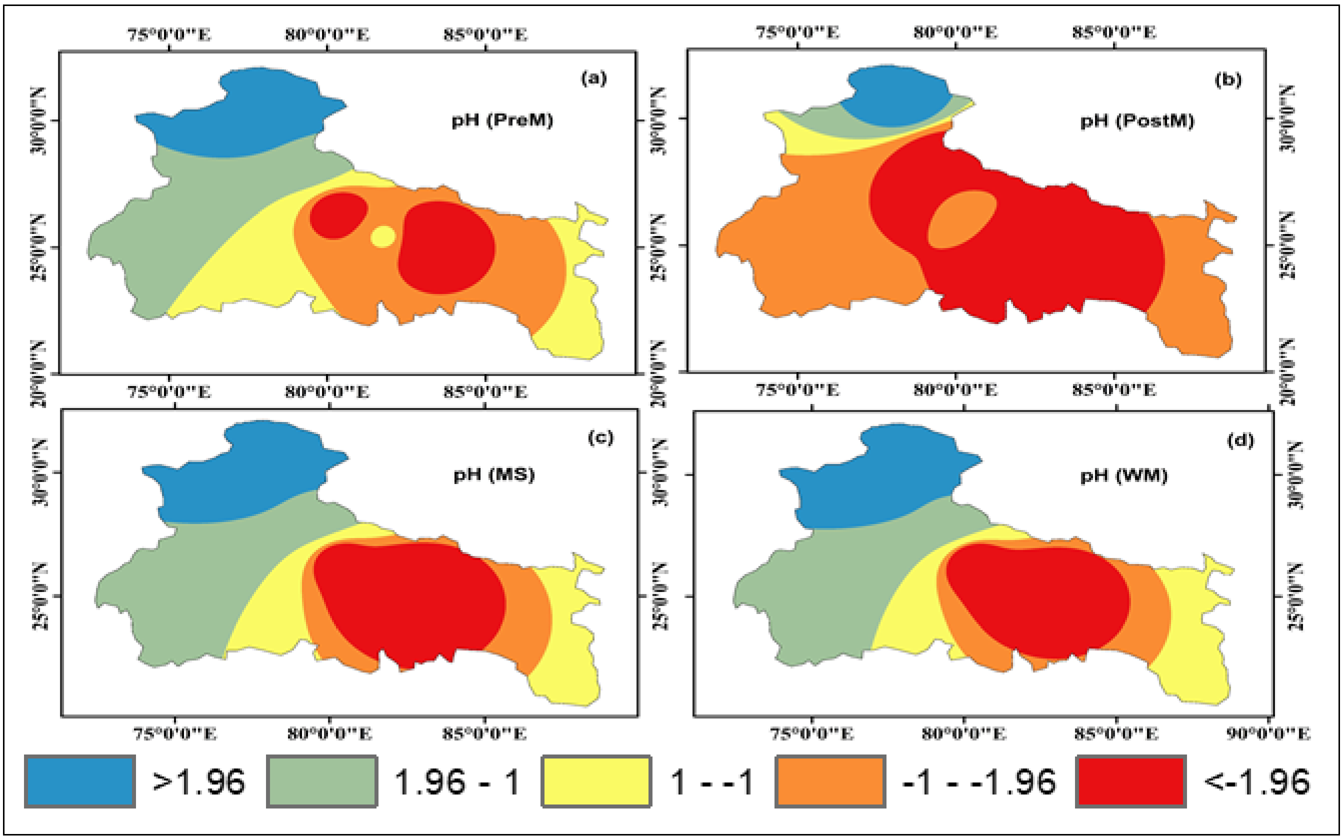


Fig 3: Representation of spatial distribution of Z statistics for pH for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

Fig. 4 depict the significant decreasing trend of EC in pre monsoon season for Bareilly and Prayagraj and the post monsoon shows the decreasing significant trend in Kanpur, Prayagraj, and Varanasi (Fig. 3a and 3b). The monsoon season and winter monsoon season show the significant decreasing trend in Bareilly, Kanpur which extends till Prayagraj and Varanasi (Fig.3c and 3d).

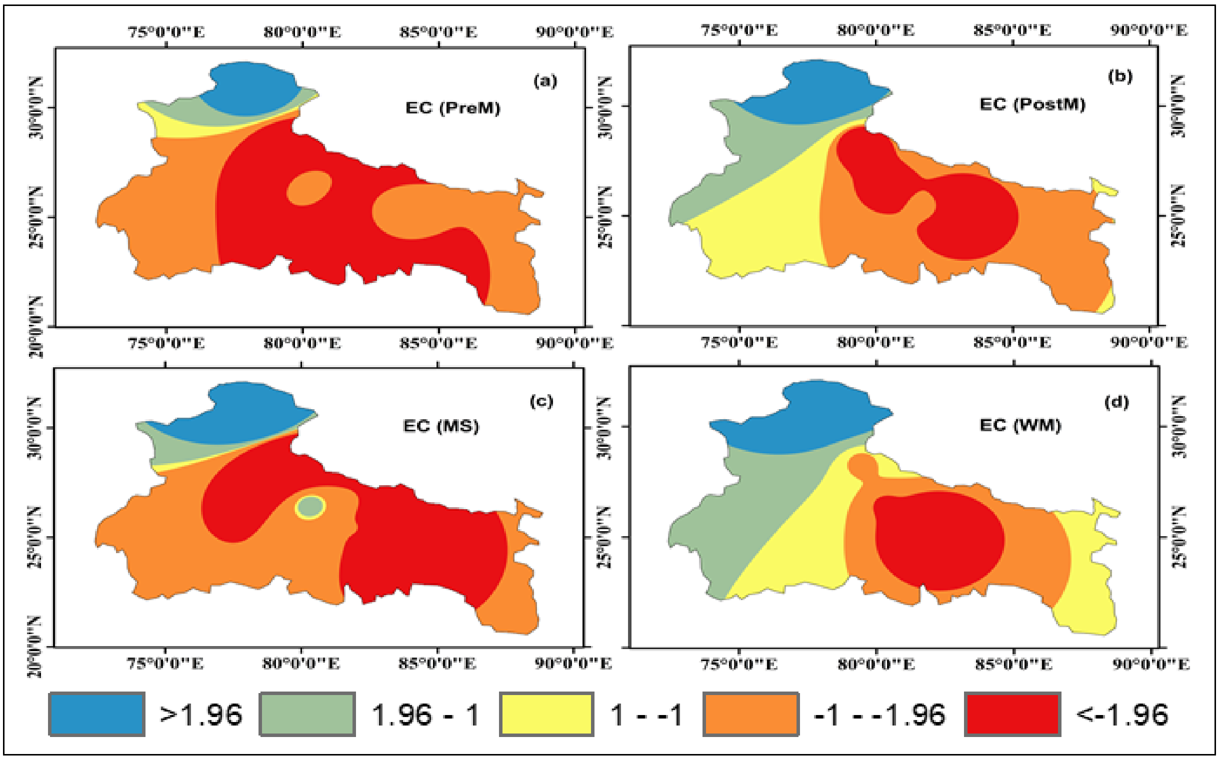


Fig. 4 Representation of spatial distribution of Z statistics for Electrical conductivity (EC) for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

Fig. 5 explain the spatial variation of dissolved oxygen (DO). Whereas significant increasing trend of DO does not show any changes in pre monsoon, monsoon season and winter monsoon season (fig.4a, 4c and 4d). It is protracted from Bareilly to Kanpur and Varanasi (Fig.4b). Other basin area shows the non-significant values of z statistics.

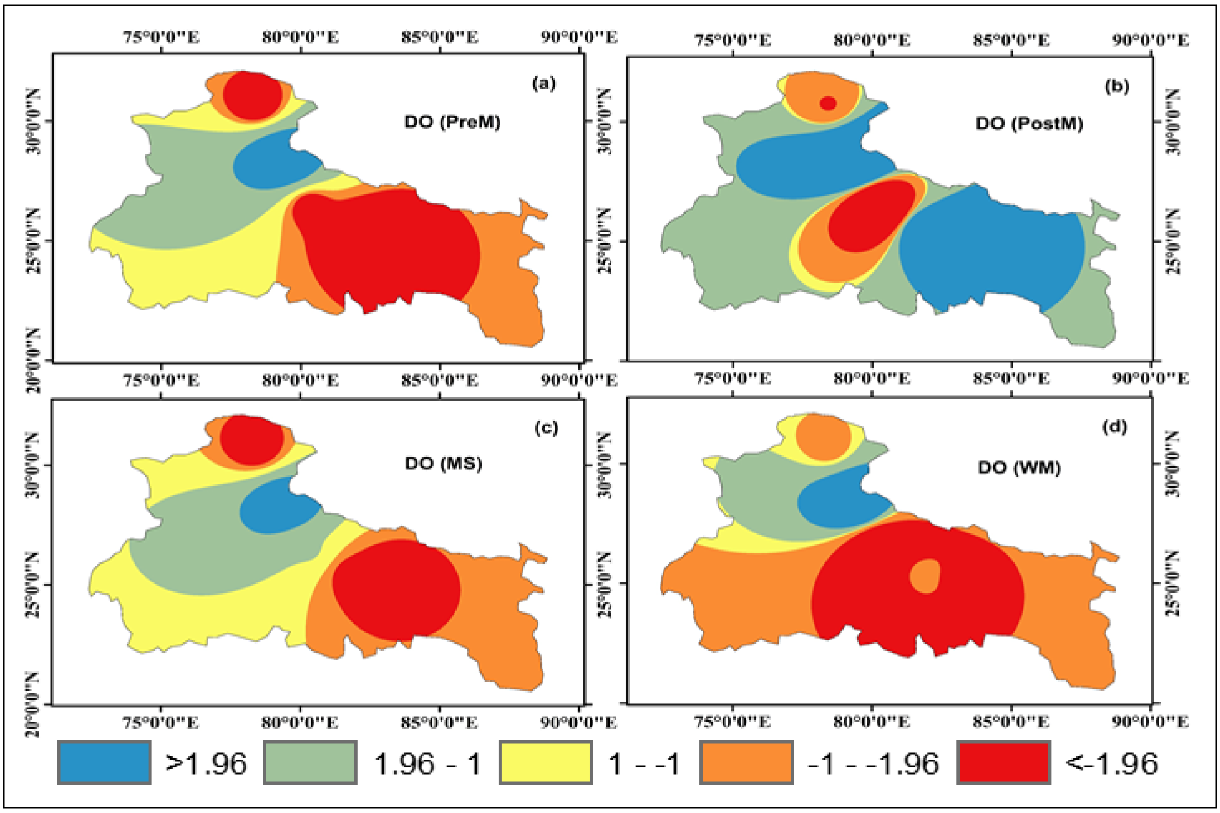


Fig 5: Representation of Spatial distribution of Z statistics for dissolved oxygen (DO) for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

Fig. 6 shows the spatial variation of total dissolved solids (TDS). In this figure it shows the increasing significant trend with the color of blue. Pre-monsoon and winter monsoon seasons do not show the spatial variation in Varanasi (Fig. 6a and 6d). The variation of z statistics spread out Kanpur to Varanasi (Fig. 6b and 6c).

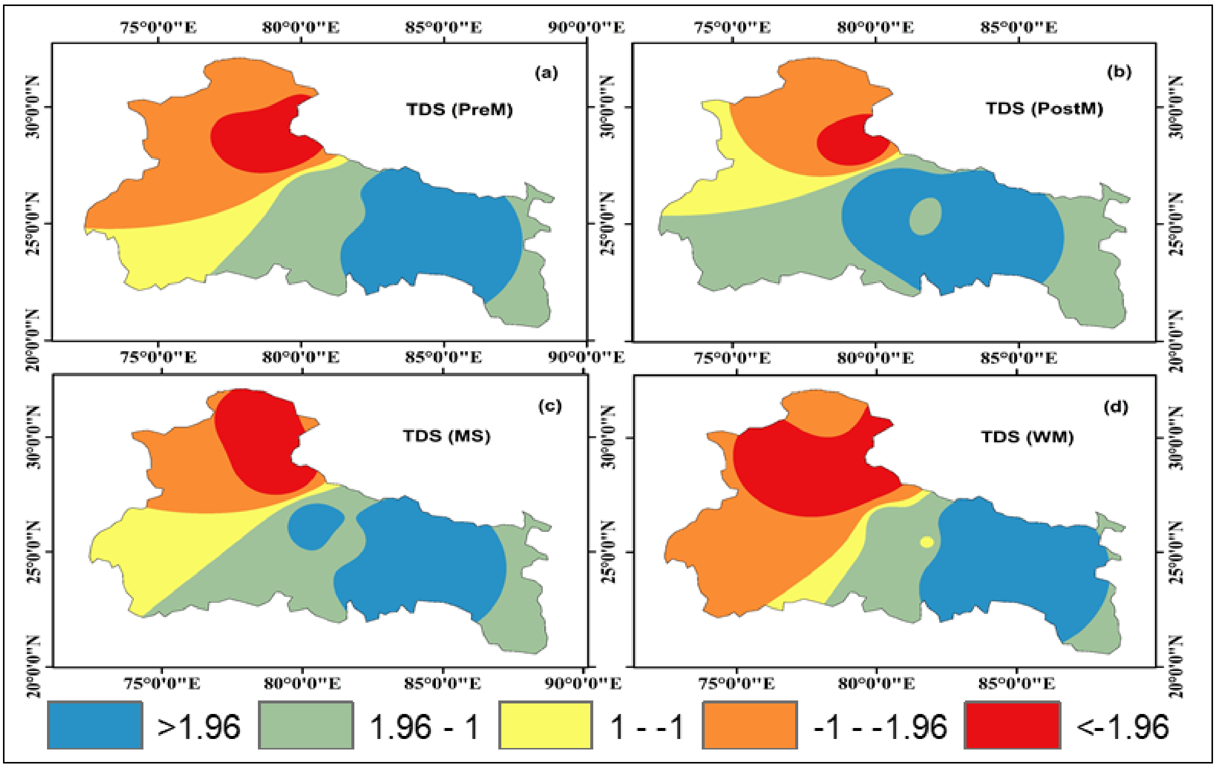


Fig 6: Representation of Spatial distribution of total dissolved solids (TDS) for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

Fig. 7 explain the spatial variation of hardness, which show the significant decreasing trend for pre-monsoon and monsoon season in Bareilly and Prayagraj, and extend to Varanasi (Fig. 7a and 7c). The variation of significant increasing trend for winter monsoon in Uttarkashi, Kanpur and Varanasi (Fig. 7d).

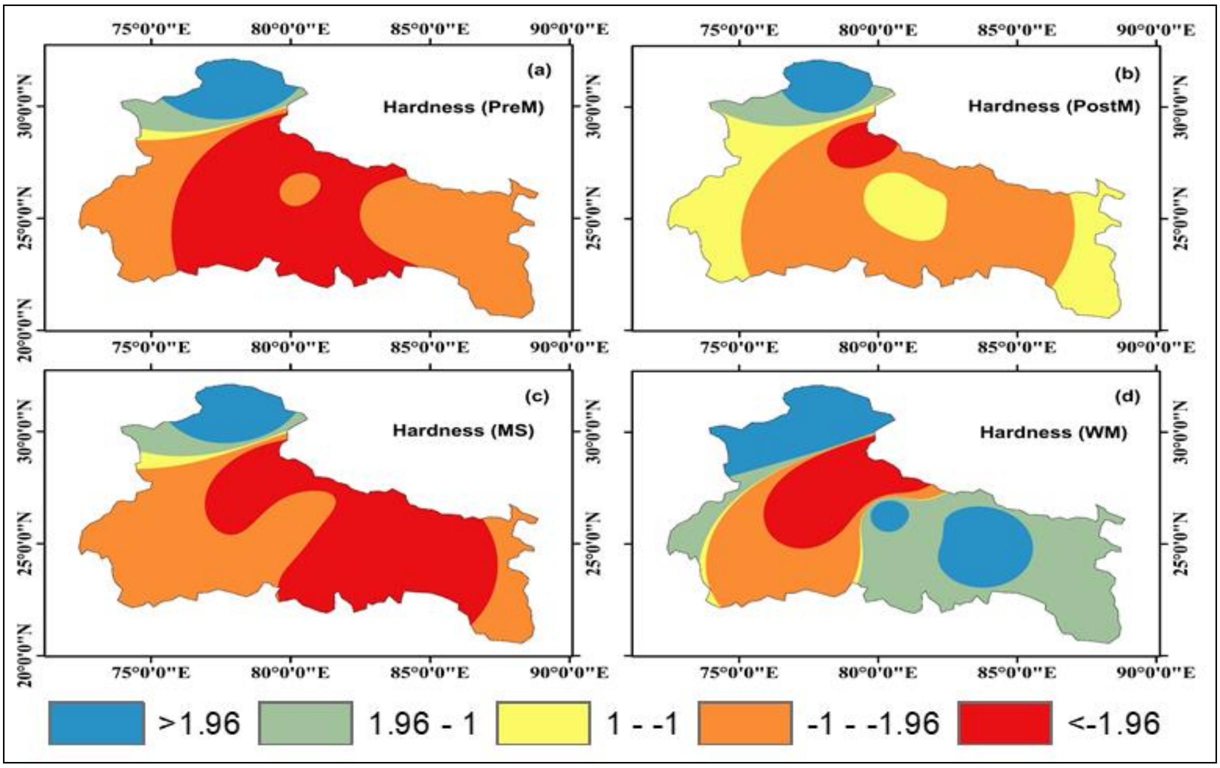


Fig 7: Representation of Spatial distribution of hardness for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

Fig. 8 shows no spatial variation of decreasing significant of z statistics for pre-monsoon and winter monsoon season (Fig. 8a and 8d). Also do not show any spatial variation of increasing significant of z statistics for post monsoon and monsoon season (Fig. 8b and8c).

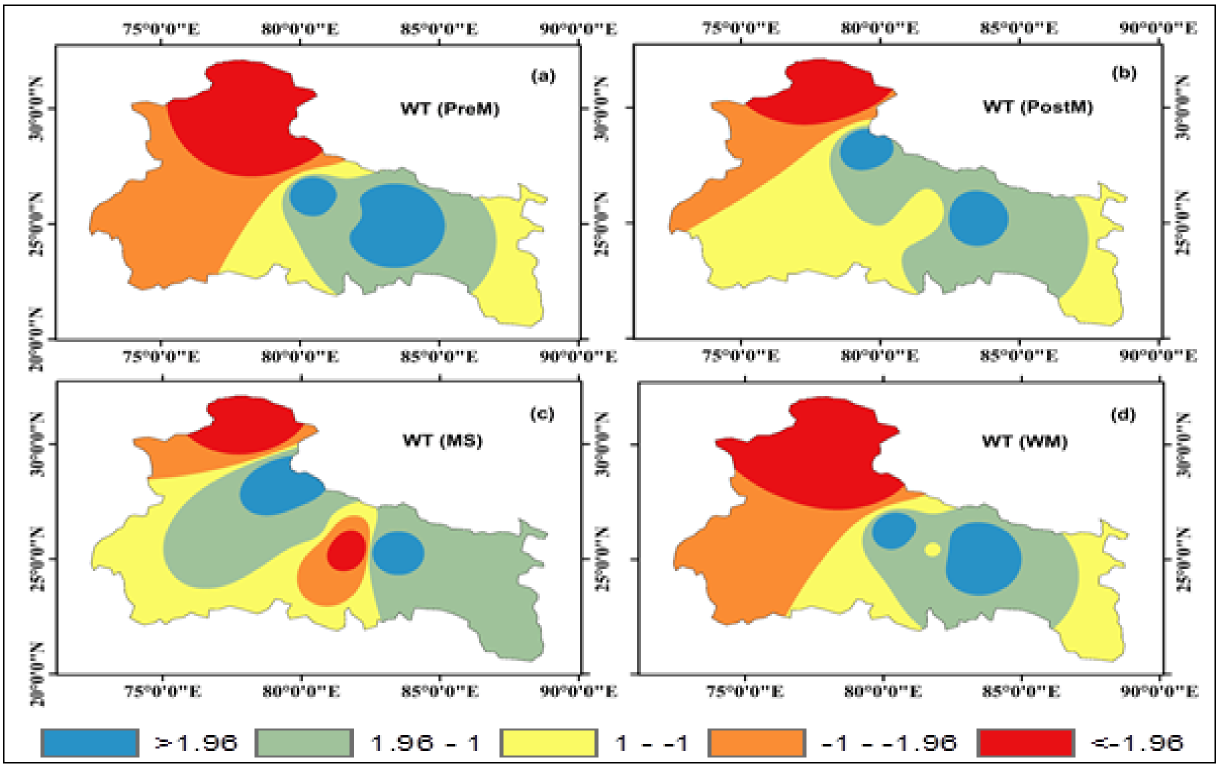


Fig 8: Representation of spatial distribution of water temperature (WT) for (a) pre monsoon season (b) post monsoon season (c) monsoon season (d) winter monsoon

3.3 Sen's slope Estimator

The result of sen's slope represented in the table 3.3. Which shows the increasing or decreasing quantity of water quality during the time period. Bold numbers represent the significant increasing or significant decreasing value corresponding to the Z statistics.

Table 3: Result of Sen's estimator for the seasonally water quality parameters during the period of 1985 to 2020 corresponding to Z statistics.

Parameters	Stations	Uttarkashi	Bareilly	Kanpur	Prayagraj	Varanasi
DO	PreM	-0.01	-0.16	0.00	0.01	0.00
	PostM	-0.01	-0.11	0.00	-0.01	-0.01
	MS	0.01	-0.13	0.00	0.00	0.00
	WM	-0.03	-0.13	0.01	-0.01	0.00
WT	PreM	-0.06	0.07	-0.16	-0.14	-0.16
	PostM	0.10	-0.19	-0.04	-0.03	-0.04
	MS	-0.04	-0.15	-0.08	-0.06	-0.08
	WM	-0.06	-0.10	-0.13	-0.11	-0.13
pH	PreM	0.00	0.07	0.01	0.01	0.01
	PostM	-0.01	0.06	0.00	0.00	0.00
	MS	0.00	0.03	0.01	0.01	0.01
	WM	-0.01	0.04	0.02	0.01	0.02
EC	PreM	-0.96	26.10	16.72	23.21	16.72
	PostM	-2.36	15.93	38.29	35.85	41.47
	MS	-1.48	9.20	-3.44	5.45	7.00
	WM	-2.00	21.66	47.03	47.71	47.03
TDS	PreM	0.13	11.86	-1.76	-0.48	-14.00
	PostM	0.00	8.66	-19.21	-5.99	-11.03
	MS	0.40	6.50	-17.42	-14.90	-30.14
	WM	0.07	12.93	-3.10	-2.69	-25.50
Hardness	PreM	-0.38	16.99	7.12	7.56	7.12
	PostM	-0.66	12.50	7.25	8.68	10.27
	MS	-0.30	11.04	5.03	6.36	5.12
	WM	-0.38	14.39	6.48	7.03	6.48

Distribution of Z statistics of water quality parameters

Fig. 9 represents the Mann-Kendall Z statistics annual distribution of water quality parameters in all five stations. In this figure, DO show the negative significant trend in Bareilly and non-significant decreasing trend in Uttarkashi, Prayagraj and Varanasi & increasing trend in Kanpur. In Kanpur, Prayagraj and Varanasi WT shows the decreasing significant of Z statistics and remaining stations show the non-significant decreasing trend. In Kanpur, Prayagraj and Varanasi significant increasing trend was obtained by pH. Uttarkashi and Bareilly show the decreasing and increasing trend respectively. EC represents the negative significant in Uttarkashi and positive significant in Bareilly. The remaining stations show increasing non-significant of Z statistics. Significant increasing trend obtained by TDS in Bareilly and significant decreasing trend in Kanpur and Varanasi remaining two stations Uttarkashi and Prayagraj show the increasing and decreasing trend respectively. In this figure hardness show the highly significant increasing trend in Bareilly and also Kanpur, Prayagraj and Varanasi show the positive significant trend and Uttarkashi show the negative decreasing trend.

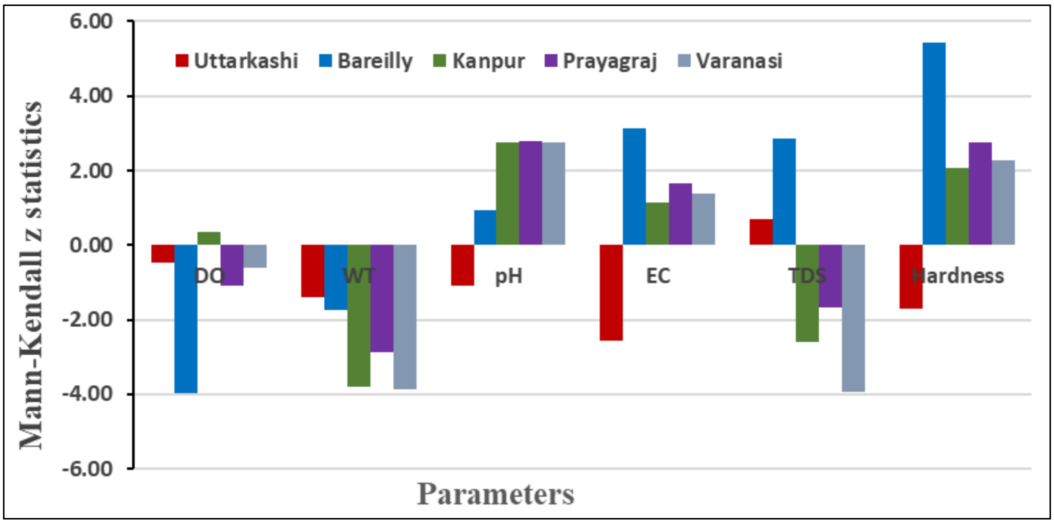


Fig 9: Mann-Kendall Z statistics distribution of water quality parameters for different stations

3.6 Analysis of change point

Change point are used to determine break down in time series water quality data in different years. Change point analysis of the observed water quality data was determined at annual time scale. Pettitt's test was used to analyze observed data from five stations of the Ganga basin in order to discover likely change years. The mean of the subseries before and after the change point year was also computed in order to evaluate the change in mean. The change point years at an annual timescale are displayed in Table 4 with the means of the series before and after the change point year.

Table: 4 shows the change point of DO at Uttarkashi in 2016, which have pre mean is 8.38 and post mean is 8.02. The WT and TDS represent the probable change point years are 2019 and 2018 respectively and pre or post mean are different to each other of WT and TDS likely 11.37 or 9.08 and 85.75 or 97.31. In Uttarkashi pH, EC and total hardness (TH) display the change point years are 2013, 2008 and 2006, pre mean of pH, EC and TH were found 8.00,156.90 and 91.72 respectively and post mean that of 7.81, 133.12 and 98.74 respectively.

At Bareilly station where 2016 was found probable change point year for TDS and TH, pre and post mean that for 353.27, 295.38 and 718.85, 644.34 respectively. There are other parameters such as DO, WT, pH and EC found the change point year were 2012, 2013, 1998 and 2008 correspondingly.

Kanpur and Varanasi represent the change point year of pH in 2017 and pre and post mean are 7.93 and 8.37 respectively. At Prayagraj and Varanasi where 2000 was found change point year for DO and pre mean represent the same value is 7.82 and post mean are 7.87 and 7.88 corresponding stations. EC and TDS show the same change point year in 2007 at Varanasi where pre and post mean of EC are 1878.91 and 2462.10, TDS shows the pre and post mean are 526.20 and 734.07.

The findings in Khatoon and Khan (2013) [15] and Pathak and Mishra (2020) [14] are addressed with the decreasing trend in the DO series acquired in the current study at Kanpur and Varanasi. Similarly, in the current study DO was found within decreasing trend at Bareilly while in other stations it's contradictory. Conversely, the trends in DO identify in this study are contradictory with those at Varanasi in Maji and Chaudhary (2019) [16] and the identified increasing trends in WT, TDS and EC are consistently with the trend found in Khatoon and Khan (2013) [15]. Similar findings in this study identified EC and total hardness have increasing trend except Uttarkashi and show the conversely result with WT. In the study Rai *et al.* (2011) [17] found consecutive increasing trend of hardness. Oxygen is less soluble in water at high temperatures, as a result of the temperature consecutive rise, which causes the dissolved oxygen to drop. A plant that grows too quickly may have high nutrient levels, which might cause respiration and decomposition to reduce DO. Increasing trend indicates amount of water quality parameters continuous increases. if the hardness, EC, WT and TDS increases in water then it affects the quality of water.

Table 4: Change point detection analysis of water quality data of upper Ganga basin

Uttarkashi						
	DO	**WT**	**PH**	**EC**	**TDS**	**TH**
CP_year	2016	2019	2013	2008	2018	2006
mean_pre	8.38	11.37	8.00	156.90	85.75	91.72
mean_post	8.02	9.08	7.81	133.12	97.31	98.74
Bareilly						
	DO	**WT**	**PH**	**EC**	**TDS**	**TH**
CP_year	2012	2013	1998	2008	2016	2016
mean_pre	5.33	23.60	8.15	708.03	353.27	295.38
mean_post	3.40	21.47	7.94	1319.27	718.85	644.34
Kanpur						
	DO	**WT**	**PH**	**EC**	**TDS**	**TH**
CP_year	2019	2008	2017	2007	2018	2005
mean_pre	7.83	25.98	7.93	1879.21	1079.95	525.72
mean_post	8.03	24.69	8.37	2425.88	530.916	722.14
Prayagraj						
	DO	**WT**	**PH**	**EC**	**TDS**	**TH**
CP_year	2000	2007	2018	2008	2015	2006
mean_pre	7.82	26.31	7.93	1866.99	1168.63	518.79
mean_post	7.87	24.72	8.42	2521.88	660.45	752.84
Varanasi						
	DO	**WT**	**PH**	**EC**	**TDS**	**TH**
CP_year	2000	2008	2017	2007	2007	2005
mean_pre	7.82	25.98	7.93	1878.91	877.80	526.20
mean_post	7.88	24.64	8.37	2462.10	616.15	734.07

4. Conclusion

To identify the water quality trends, the present study examined water quality data for the upper Ganga basin of 35 years (from 1985 to 2020). Results shows the EC and Hardness highly increased whereas DO and WT show the decreasing trend for annual. Seasonally, the trend analysis gives the positive results by hardness mostly in Bareilly. DO and WT show the negative result in Uttarkashi and Kanpur. Except Uttarkashi, other centers displayed increasing trend in pollution levels with extremely high rates of organic and pathogenic pollutant deposition in river Ganga. The change point analysis shows changes the water quality pattern was observed mostly between the years 2015 to 2019. When it came to the highest hardness ratings, Bareilly and Prayagraj were determined to be the most contaminated region. In Bareilly, DO were discovered to be minimal. 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 municipal and agriculture water. When choosing certain parameters to test often in order to regularly assess the state of the water quality, trend analysis of the parameters related to water quality can be helpful. This will facilitate regulatory agencies' ability to put control measures into place and offer warnings when water quality begins to decline.'

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