



Water pollution examination through quality analysis of different rivers: a case study in India

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Received: 12 February 2020 / Accepted: 17 August 2021 / Published online: 21 August 2021
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Abstract

Restoration of water quality at rivers is a big problem for water quality managers. This paper analyzes water quality parameters across five years from 2012 to 2016 in a case study of different Indian rivers. Recently, Indian rivers have experienced massive contamination and water quality depletion due to the entry of wastewater from different regions of India. The quality of Indian rivers has not yet reached the mark, after many efforts made by the Government of India. For this report, three major Indian rivers (Beas, Sutlej and Ganga) were considered for the water quality calculation. Temperature, dissolved oxygen (D.O), pH, biochemical oxygen demand (B.O.D) and fecal Coliform are the considered criteria for measuring the water quality of the mentioned rivers. Results from the study highlight the water quality of Indian rivers and the current pollution pattern for the river Ganga in 2019, which was not sufficiently discussed before. The level of degradation in water quality of Indian rivers is stated through this study.

Keywords Water quality · Dissolved Oxygen · Biochemical oxygen demand · Fecal Coliform

1 Introduction

The quality of river water is a significant matter of concern as the river is a resource for agriculture, residential use, hydroelectric power plant tourism, transportation, and others. Indian rivers are continually passing through many big cities and urban areas. The buildup of industries and cities which are near the rivers results in a huge amount of wastewater entering to the rivers and degrading the water quality of rivers year by year. The water quality can be measured using the river profile, with pollutant inputs reported by water monitoring systems installed at different locations. Many studies have highlighted the

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ecological position of river water, focusing primarily on mathematical and statistical models for the evolution of water quality (Ferencz & Balog, 2010; Pantelic et al., 2012) using various water quality indices such as river habitat survey (RHS), water pollution index (WPI) and water quality index (WQI) (Milanovic et al., 2006; Milanović et al., 2011). A river water quality monitoring system is needed to safeguard freshwater resources all over the world. Planners may use the tracked data to establish environmental programs. Measurement of the water quality with a large number of recorded parameters and samples is somehow difficult (Chapman, 1992; Pesce & Wunderlin, 2000). Recorded data need to be compared with local criteria for evaluating the water quality of rivers, but this approach is not appropriate for temporal and spatial trend analysis of water quality (Debels et al., 2005). Several researchers have used multiple parameters for researching water pollution measurements such as (Chen & Twilley, 1999) worked on biology modification for polluted water. House et al. (2001) worked to show the accurate percentage of nitrate and silicon in pure water, and Dwivedi (2000) presented the physico-chemical property for ponds water, etc. (Krishnan et al., 2020; Saravanan et al., 2018).

Researchers also conducted many studies on the water quality of the river in their country. Watelet and Johnson (1999) studied the water quality of the Raisin River in Canada; Obeid (1964) conducted a study about the Nile river; Fauvet et al. (2001) conducted a study about the Rhone river in France; Brooker and Johnson (1984) conducted a study about the Welsh river in the U.K. A study carried out by Putri et al. (2018); performed to measure the water quality of 14 major rivers of Taiwan. Another study described the water quality in the watershed having drained peat soils (Vassiljev et al., 2018). The water quality of the Atoyac river in Mexico was given in (Pérez Castresana et al., 2018). The risk of pollution is more severe in the dry season as compared with flood season (Liu et al., 2018). For assisting to maintain the water quality of eutrophic rivers, active prevention of collapses through regulation of discharge from rivers was recommended (Wang et al., 2019). The significance of managing and monitoring of environmental quality in regional lakes was emphasized in (Liu et al., 2020). data assimilation for water quality accuracy of the Yeongsan River in South Korea was given in (Loos et al., 2020).

A study (Karakus., 2020) has been conducted to evaluate the effects of soil type, slope characteristics and land use/land cover (LULC) changes on surface water quality for dry and rainy periods. (Yan et al., 2015) evaluated the pollution in water using GIS approach, single factor pollution index and comprehensive pollution index. In other study, Sharma et al., (2019a, 2019b), Koo et al. (2020), Amal et al. (2018) discussed about air pollution measurement for different geographical locations in India. Wu et al. (2020) has been conducted to examine the different factors, which can affect the residents. Sanitation facilities were provided to the different villages on the willingness of villagers. Tamiru (2019) have been used Macroinvertebrates as indicators for the analysis of water quality for River Shinta, Ethiopia. Another study (Pudza & Abidin, 2020) was conducted to investigate the batch adsorption using CR (congo red) as *Jatropha curcas* seed (chaff) and adsorbate. In another Study, (Majerek et al., 2019) discussed about the waste water from municipal wastewater treatment plant to Bystrzyca river.

Removing water contamination is an urgent need for many locations in India (Sharma et al., 2017, 2019a, 2019b). According to NEERI (National Environment Research Institute India) report, most of India's rivers are now polluted and need a powerful pollution monitoring program to assess the water quality (Jha et al., 1997, Sharma 2019, 2020, Nguyen, 2020). The Government has upgraded new policies to improve the quality of river water in India for the new river region (Khan, 2013; Sharma et al., 2016). Many regulations and policies have been introduced by the Government in terms to reduce the water pollution in India. Renovation and

restoration of water, National Lake Conservation plan, National Water Mission, Rain Water Harvesting, Sewage treatment, Agricultural runoff and many other policies have deployed that are related to the controlling of water pollution (APHA-AWWA-WPCF 1989). To regulate the water quality of rivers, an urgent solution such as a traditional monitoring system, updated industry policy and urban areas are needed.

There are three main objectives of this study: (1) to evaluate and analyze the water quality parameters of three major rivers (Beas, Sutlej and Ganga) for 9 different locations from 2012 to 2016 in a case study at India; (2) to compare the level of recorded water quality parameters for 9 considered locations; (3) to identify the most polluted location and river in India. In the previous studies, the authors have not discussed the appropriate number of rivers' water quality at different locations; therefore, this study takes nine different locations into consideration for the mentioned rivers.

Manali, Pathankot and Gurdaspur are three measuring locations for the measurement of Beas River. Also, Rampur, Ludhiana and Amritsar are three measuring locations for the measurement of Sutlej River, while Devprayag, Varanasi and Amritsar are considered as other three measuring locations for the measurement of Ganga River (Sharma et al. 2020b). The data for the rivers under consideration are assessed using the various water quality monitoring system developed by the Central Pollution Control Board (www.cpcb.nic.in) at different locations in India. Because of heavy domestic and industrial wastewater, few measuring sites are highly contaminated and these sites need to be monitored periodically for the quality assessment of rivers.

This study will help to monitor river water quality status from initial to final locations during its journey. If there is some doubt about the main sources of water contamination, the chemical discharge from industries, sewage discharge and wastewater from agricultural land are at the center. River water is not safe to bath and drink because of the pollution that is released from these sources.

The rest of the paper is organized as follows: Sect. 2 presents the materials and methods, the results are presented and discussed in Sect. 3, and finally the paper is concluded with Sect. 4.

2 Material and methods

2.1 Mathematical modeling

In this research, samples of river water are collected from various regions of India. The percentage of minerals for water from different locations would be different. The sampling distribution is proposed to transform the variable for various levels as per requirements.

Linear transformation is basically deals with one-dimensional vector space. In this research, the percentage of minerals of water samples, collected from various location, are vary abruptly. Linear transformation is applied to preserve the structure of a vector space of two-dimensional matrix data and also quality assessment of unstructured dataset. Finally, null hypothesis is explored that by default there is no relationship between standard water sample and collected water sample data (Sharma et al. 2020a). The reason for including the mathematical analysis and equations in the paper is to elaborate the data selection and data sorting methodology in brief. For linear transformation, we have

$$Y = AX, \quad \forall X \rightarrow Y(\text{column vector of the same size}) \quad (1)$$

If A is considered a non-singular matrix, then as per Jacobian transformation

$$\frac{DY}{DX} = |A| \text{ as an appositive sign} \tag{2}$$

As per Eq. (2), connected differential elements are defined by the relation in Eq. (3)

$$dy_1 dy_2 \dots \dots \dots dy_n = |A| dx_1 dx_2 \dots \dots \dots dx_n \tag{3}$$

From Eq. (2)

$$dY = |A|dX \quad \forall A \text{ is an orthogonal matrix and } |A| = 1 \tag{4}$$

It is considered that A is an orthogonal matrix. Thus, $Y=AX$ which transforms into a quadratic form of preserving from the standard value.

$$X'X \rightarrow Y'Y$$

$$(X - \mu)'(X - \mu) \rightarrow (Y - \eta)'(Y - \eta) \text{ where, } \eta = A\mu \tag{5}$$

After determining the dissimilarity, the distance from a standard value is evaluated by using the partitioning matrix.

$$A = \begin{pmatrix} A_1 \\ \cdot \\ \cdot \\ \cdot \\ A_k \end{pmatrix} \text{ where, } A_i = n_i \times n \quad \text{and} \quad \sum n_i = n \tag{6}$$

If matrix A is partitioned into k th numbers then $A_i A_j' = 0 \quad \forall i \neq j$. Therefore, as the partitioned matrix is partitioned into k number of sub-matrices, all k sub-matrices are orthogonal to each other, but may not be orthogonal themselves. Now, the transformation equation (see Eq. 1) is rewritten as

$$Y_1 = A_1 X, \dots \dots \dots, Y_k = A_k X, \tag{7}$$

where Y_1, \dots, Y_k are an exclusive subset of tested variables. According to the transformation in Eq. (7)

$$X'X \rightarrow Y_1' B_1 Y_1 + \dots \dots \dots + Y_k' B_k Y_k$$

$$(X - \mu)'(X - \mu) \rightarrow (Y_1 - \eta_1)' B_1 (Y_1 - \eta) + \dots \dots \dots + (Y_k - \eta_k)' B_k (Y_k - \eta_k), \tag{8}$$

where

$$B_i = (A_i A_i')^{-1} \quad \text{and} \quad \eta_i = A_i \mu.$$

Equation (8) determines the transformed expression of slices into quadratic form with exclusive subsets of tested variables. If A is fully orthogonal, each row is orthogonal to others. In this research, the sample space is considered as a vector space with a linear manifold created by the columns of a matrix B . Thus, $\Psi(G) \subset \Psi(B) = \Psi(BB')$. There exists another matrix E , so that

$$G = BB'E \text{ and } K = \text{rank}(B'E) \quad (9)$$

It is also mentioned that a set of linear equation $MX=T$ accepts a solution if $\text{rank}(M) = \text{number of rows in } M$ and it does not depend on T . Transforming all the variables x_1, x_2, \dots, x_n to testbed data variables of S ,

$$\int_S f(x_1, x_2, \dots, x_n) dx_1 dx_2 \dots dx_n = h(S) \text{ Where, } S = g(x_1, x_2, \dots, x_n) \quad (10)$$

Null hypothesis is tested for the sample that the median does not diverge from the true median with an alternative hypothesis. Thus, the medians were dissimilar.

$$\begin{aligned} H_0 &: \text{median}(x) = \text{median}(\Gamma(\alpha_{\text{shape}}, \beta)) \\ H_A &: \text{median}(x) \neq \text{median}(\Gamma(\alpha_{\text{shape}}, \beta)) \end{aligned} \quad (11)$$

The rate of type 1 error is the percentage of tests for rejection with the null hypothesis.

2.2 Considered water parameters for the study

2.2.1 (A) Temperature

Thermal pollution also affects the aquatic ecosystem. The primary source of thermal pollution is due to the hot water discharged from industries to the rivers. The industries use hot water as coolant (such as power generators, nuclear powers, etc.) which are the major sources of thermal pollution. Ecosystem biodiversity can affect any modification occur in the surrounding temperature.

2.2.2 (B) Dissolved oxygen (D.O), Biochemical oxygen demand (B.O.D)

The oxygen involved in the biochemical procedure for the time period of 5 days is called as BOD. The procedure is performed at 20^0 C. The presence of toxic metals can affect the BOD directly and indirectly. Turbidity can affect the DO of water(Mittal & Ratra, 2000).

2.2.3 (C) pH

In a sample, the H^+ concentration (negative log) is called pH. For the survival of the organism, pH is very much essential. Ph can directly affect the elemental mobilization(Schubert, 1980).

2.2.4 (D) Fecal coliform

It is indicated the occurrence of different kinds of pathogenic organisms and sewage contamination in the water. Fecal coliform is very important to be measured in water(APHA 1989).

3 Reference conditions

To classify the usages of Indian rivers, the following parameters have been decided by the CPCB India (Table 1). The water quality data have been measured from pollution monitoring systems installed by the central pollution control board (CPCB), India.

3.1 Dataset description

The research has included India's three major rivers (Beas, Sutlej, and Ganga) for water pollution assessment. The Beas River path passes through several northern Indian states such as Punjab and Himachal Pradesh. Eventually, it meets up into the Sutlej River in Punjab after traveling 290 miles (470 km). The Beas River drainage basin is nearly 7,839 sq mi (20,303 sq kilometers). Beas River is a great source of water for the villages, cities, and cities that come from the Himalayas to Punjab during their journey. Beas River is also known as Himachal Pradesh's natural beauty. Beas river flows from the Kullu to the south at Himachal Pradesh, from a height of 14,308 ft. Beas River encompasses numerous mountainous areas such as the hills of Mandi, Kangra and Shivalik, etc. (Fig. 1(a)). In Gurdaspur district, it was found that many sugar mills regularly drop their waste into the Beas River. Because of this contamination, the color of Beas river water has slowly turned into rust-brown. When the level of the Fecal Coliform is examined, it is found that Pathankot and Gurdaspur have a high level of the Fecal Coliform when it is compared with Manali, because of the wastewater that is released from the industrial and domestic discharge. Furthermore, it is obtained that many sugar mills regularly drop their release into the Beas River in Gurdaspur district.

For the water measurement of the Sutlej River, three major locations have been considered. These locations are Rampur, Ludhiana and Amritsar (Fig. 1(b)). Rampur is a small commercial hub located on NH22 in Himachal Pradesh. Rampur is located near one of the sides of the Sutlej river (Sharma et al., 2017). Rampur is also one of the best tourist places in Himachal Pradesh. In Ludhiana, the major sources of water pollution are sewage discharge, chemical substances, industries wastewater, runoff from the agriculture field and domestic waste. Amritsar city is located in Punjab state of India. Amritsar is a very important and largest city of Punjab.

The Ganga is the biggest river in the subcontinent of India. Ganga River is the biggest source of water that covers many cities, villages and towns in India. It has covered an area around 1,000,000 sq km (390,000 sq miles) with a length of 1560 miles or 2510 km (Fig. 1(c)). Ganga river covering many royal capitals in India such as Patliputra, Kannauj, Baharampur, Kolkata and Murshidabad. The Ganga river is a Goddess river for Hindu religion in India. Due to 400 million peoples living near the river and the sewage from different regions, the Ganga River facing the problem of extreme pollution. The industrial waste and non-degradable plastic from populated areas are also the major sources of pollution in the Ganga River. In India, it is suggested that water pollution is the cause of one-third of deaths and 80% illness. For the water measurement of the Ganga river, three major locations have been considered. These locations are Devprayag, Varanasi and Patna. Devprayag is located at 830 m above sea level (Trombadore, et al., 2020). It is a beautiful town situated in Uttarakhand, India. In Devprayag, the water quality is satisfactory and can be used for bath and drinking. Varanasi is a big city located in Uttar Pradesh, India. Varanasi is the oldest city in India.

Table 1 The parameters decided by the (Central pollution Control Board) for the best use of water

No	Parameters	Class to use water for different purposes				
		A Water sources for drinking, No conventional treatment, (after disinfection)	B (Organized) outdoor bathing	C Water sources for drinking, withconventional treatment, (followed by disinfection)	D fisheries and wild life	E Irrigation Etc
1	Total Coliform MPN / 100 ml	50	500	5000	-	-
2	Dissolved oxygen (D.O), mg/l	6	5	4	4	-
3	pH value	6.5 – 8.5	6.5 – 8.5	6 – 9	6.5 – 8.5	6.5 – 8.5
4	Biochemical oxygen demand (B.O.D), mg/l	2	3	3	-	-

* <http://www.cpcb.nic.in>, Accessed on 11th January 2011

Fig. 1 **a** Map shows the locations considered for the water quality measurement of Beas River. **b** Map shows the locations considered for the water quality measurement of Sutlej River. **(c)** Map shows the locations considered for the water quality measurement of Ganga River

4 Result and discussions

The river's safety can be assessed with the pH rating, as the river water can be used directly for public purposes such as bathing and drinking. DO is the highest measurement parameter to calculate for aquatic life. River water velocity, volume, and temperature are the parameters which can affect the DO value. When the river's water has a low level of oxygen then the water can have a bad odor. The dropping DO rates may also reflect the high BOD which can be hazardous to river diversity. The total coliform shows the river and cab water quality have a detrimental impact on a river's DO level. In this study, measurement of the water quality index was performed on three major Indian rivers for a period of 5 years.

4.1 Water quality measurement of BEAS River

The measurement of the water of the Beas River at different locations can be shown in Table 2.

It is observed that the pollution parameters are in moderate condition for river Beas at Manali but few parameters are not matched to standard values. The value of DO exceeds the standard value from 2012 to 2016 and increases in fecal coliform in 2016. However, Manali results are satisfactory as compared to other locations (Fig. 2(a)).

The Fecal Coliform was detected at a high level in Pathankot and Gurdaspur in comparison with Manali (Fig. 2(b-c)). It is related to the industrial and residential pollution wastewater. It was noticed in Gurdaspur district that many sugar mills drop their release into Beas River on a regular basis. The color of Beas river water has changed to rust-brown because of this pollution. The Punjab pollution control board paid a fine to sugar mill, but the results are not up to the mark.

4.2 Water quality measurement of Sutlej River

Measurement of the Sutlej River water at different locations can be seen in Table 3. Rampur is a small commercial hub in Himachal Pradesh, located at NH22. Rampur lies near one of the sides of the river Sutlej. Rampur is one of Himachal Pradesh's best tourist spots too. It is observed that few pollution parameters including Fecal Coliform and pH meet the standard values for Sutlej River at Rampur but DO and BOD do not meet the standard values (Fig. 3(a)). Several factories are located in Rampur near the domestic area. Industrial and domestic wastewater is Rampur's main source of pollution.

In Ludhiana, the pollution level is very high in comparison with Rampur. It can also be observed that parameters such as BOD and Fecal coliform were found at a critical stage. In Ludhiana, the major sources of water pollution are sewage discharge, chemical substances, industries wastewater, runoff from the agriculture field and domestic waste. In Amritsar, the water quality falls under moderate conditions. The FC value is under satisfactory condition but does not meet with standard values. Amritsar city is the center

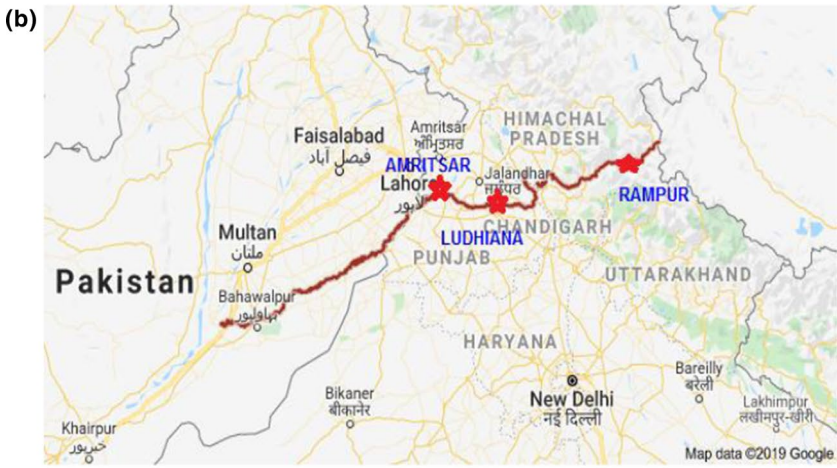


Table 2 Water quality measurement of the River Beas for the time period of five years (2012 to 2016)

Parameters	Water quality measurement for 2012		
	MANALI (Mean)	PATHANKOT (Mean)	GURDASPUR (Mean)
Temperature °C	7	19	19
DO(mg/l)	8.4	7.3	7.1
pH	7.8	7.3	7.3
BOD(mg/l)	0.45	0.75	0.8
Fecal Coliform(MPL/100 ml)	41.5	115	120
Parameters	Water quality measurement for 2013		
	MANALI (Mean)	PATHANKOT (Mean)	GURDASPUR (Mean)
Temperature	7	19	19
DO(mg/l)	9.3	7.5	8.5
pH	8.0	7.6	7.6
BOD(mg/l)	0.35	0.85	0.5
Fecal Coliform(MPL/100 ml)	55	125	101
Parameters	Water quality measurement for 2015		
	MANALI (Mean)	PATHANKOT (Mean)	GURDASPUR (Mean)
Temperature	8	17	16
DO(mg/l)	9.8	7.4	8.0
pH	6.3	7.5	7.4
BOD(mg/l)	0.1	0.6	0.7
Fecal Coliform(MPL/100 ml)	50	155	115
Parameters	Water quality measurement for 2014		
	MANALI (Mean)	PATHANKOT (Mean)	GURDASPUR (Mean)
Temperature	8.2	17	15.7
DO(mg/l)	9.1	7.7	7.6
pH	7.9	7.4	7.5
BOD(mg/l)	0.25	0.5	0.7
Fecal Coliform(MPL/100 ml)	27	170	105
Parameters	Water quality measurement for 2016		
	MANALI (Mean)	PATHANKOT (Mean)	GURDASPUR (Mean)
Temperature	28	17.5	15.5
DO(mg/l)	6.7	7.0	5.8
pH	8.2	7.2	7.2
BOD(mg/l)	2.1	0.75	0.9
Fecal Coliform(MPL/100 ml)	715	147	145

of Cultural, transportation and commercial activities. In Amritsar, the wastewater from the industries and domestic places are the major source of pollution. The rise in population is also the reason for having critical water pollution in Amritsar.

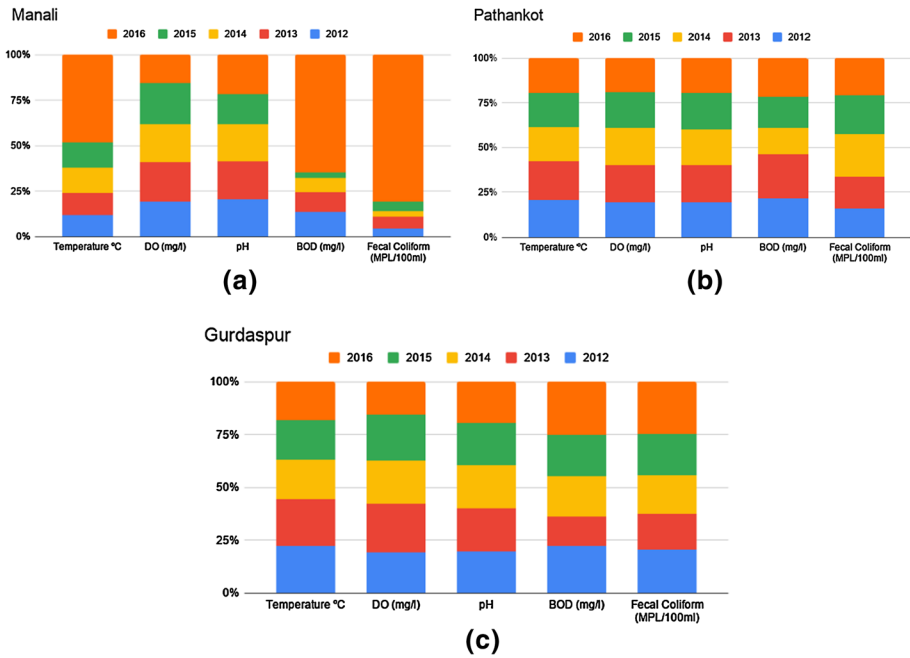


Fig. 2 a Water quality measurement for River Beas at Manali; b Water quality measurement for River Beas at Pathankot; c Water quality measurement for River Beas at Gurdaspur

4.3 Water quality measurement of Ganga River

The Ganga is the biggest river in the Indian subcontinent. The measurement of Ganga river water at different locations can be seen in Table 4. Devprayag is at an altitude of 830 m above sea level. It is a charming town in Uttarakhand, India. The water quality in Devprayag is satisfactory, and can be used for bathing and drinking. If the measurement parameters are compared for a period of five years, it is seen that parameters such as pH, BOD lies under normal values, but fecal coliform is at a high level in 2012, but it rapidly declines in the years to come. Fecal Coliform failed to meet 2012 standard values (Fig. 4(a)). This is due to the discharge of untreated sewage in Ganga, but it quickly comes down after several Sewage Treatment Plants (STPs) at Haridwar, Devprayag and Rishikesh have been built. Overall, Ganga’s water quality in Devprayag is not very bad as compared to other states like Uttar Pradesh and West Bengal.

Varanasi is a big city in Uttar Pradesh, India. This town is densely populated with 2063 people per square km. The city’s entire water wastage drains regularly into the Ganga River. The main attraction at Varanasi is that its 84 ghats are located around the city at a different location. The town is the host of many domestic and international people taking baths on the Ganga River’s many ghats. This is why the measurement of the water quality of the Ganga river is a matter of concern. Many criteria for water quality do not follow standard values (Fig. 4b).

Patna is situated in a western Bengal district. It comes under the authority of the metropolitan development region of Kolkata. Patna is the center of a great number of industries. Industry waste accounts for 25 percent of all water pollution entering the Ganga

Table 3 Water quality measurement of the River Sutlej for the time period of five years (2012 to 2016)

Parameters	Water quality measurement for 2012		
	RAMPUR (Mean)	LUDHIANA (Mean)	AMRITSAR (Mean)
Temperature °C	9	22	24
DO(mg/l)	8.8	4.2	5.15
pH	8.1	7.4	7.3
BOD(mg/l)	0.15	20.5	2.7
Fecal Coliform(MPL/100 ml)	96.5	50,000	405
Parameters	Water quality measurement for 2013		
	RAMPUR (Mean)	LUDHIANA (Mean)	AMRITSAR (Mean)
Temperature	14	21	28.7
DO(mg/l)	9.5	3.8	6
pH	7.9	7.1	7.4
BOD(mg/l)	0.2	6.5	2.7
Fecal Coliform(MPL/100 ml)	65	3050	595
Parameters	Water quality measurement for 2014		
	RAMPUR (Mean)	LUDHIANA (Mean)	AMRITSAR (Mean)
Temperature	13.4	19	16.3
DO(mg/l)	9.4	4.2	5.6
pH	8.1	7.1	7.3
BOD(mg/l)	0.2	11	2.4
Fecal Coliform(MPL/100 ml)	68.5	24,000	487
Parameters	Water quality measurement for 2015		
	RAMPUR (Mean)	LUDHIANA (Mean)	AMRITSAR (Mean)
Temperature	14	19	17.5
DO(mg/l)	9.4	4.2	5
pH	7.9	7.3	7.6
BOD(mg/l)	0.15	18.5	2.4
Fecal Coliform(MPL/100 ml)	70	38,500	550
Parameters	Water quality measurement for 2016		
	RAMPUR (Mean)	LUDHIANA (Mean)	AMRITSAR (Mean)
Temperature	15	26	18
DO(mg/l)	9.0	4.2	5.2
pH	7.5	7.5	7.2
BOD(mg/l)	0.1	23.1	2.7
Fecal Coliform(MPL/100 ml)	72	15,200	270

River. Furthermore, the main sources of water contamination are domestic water waste, river animal bathing, and other chemical waste from various towns along the river. The amount of pollution in Patna is very high according to the measurements. Most parameters for the water quality do not follow standard values (Fig. 4c).

The water quality of the considered rivers is degraded year by year (Table 5). The study has considered three categories for the analysis of rivers water quality that can be shown in Fig. 5. Out of three categories (Good, Marginal, Poor), water quality in the third category is rising year by year.

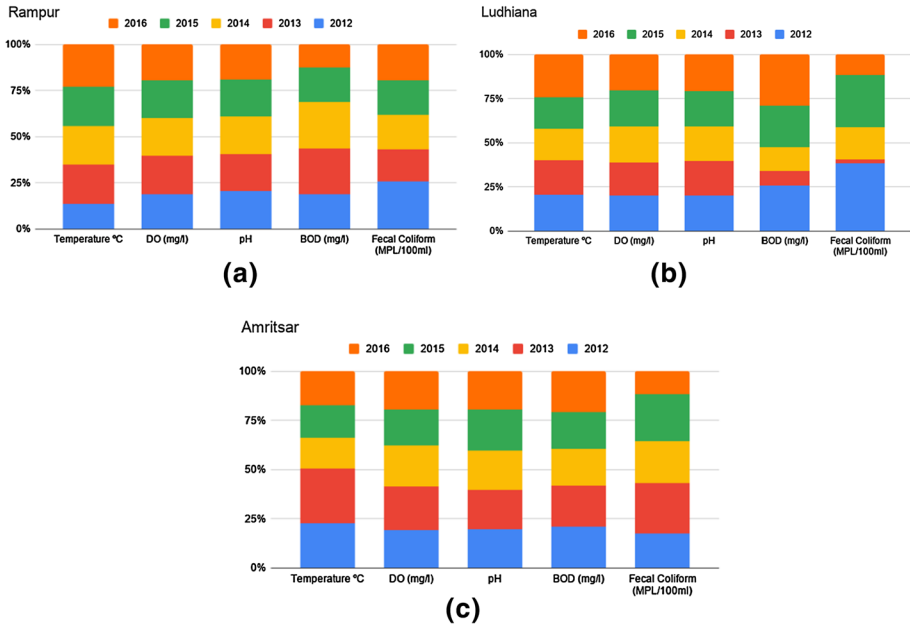


Fig. 3 **a** Water quality measurement for River Sutlej at Rampur; **b** Water quality measurement for River Sutlej at Ludhiana; **c** Water quality measurement for River Sutlej at Amritsar

Figure 5 also demonstrates how the other groups (Good and Marginal) fall down years after years. The research would help monitor the level of water quality in rivers. Pattern analysis of water quality parameters of rivers can be seen in Fig. 6 (a-e) for nine considered locations. Based on the findings from Tables 1 to 5, few measuring sites are highly contaminated due to their heavy household waste and water pollution from the industries. Ludhiana, Varanasi and Patna are mainly heavily contaminated areas. C metrics follow the standard values at a few places, such as Manali and Devprayag. The Beas river is the lowest polluted river and the Ganga river is the most polluted river out of the rivers listed. The water pollution level at Ludhiana and Varanasi is the highest among the nine locations considered. This is found that the main sources of water contamination at contaminated sites are household water waste, river animal bathing, and other industrial waste from different cities along the river. It is therefore recommended that strict measures should be taken against these practices so that the consistency of the water can be improved and freely used for drinking.

4.4 Latest pollution trend for the river ganga

As per the Central Pollution Control Board’s order, water pollution data for the year from 2017 to 2019 are not yet rectified. Because of this, this paper analyzes data up to 2016. Additionally, the current Ganga River pattern can be seen in Table 6. The data for the considered river were analyzed using various water quality monitoring systems installed at different locations in India by the Central Pollution Control Board.

Table 4 Water quality measurement of the River Ganga for the time period of five years (2012 to 2016)

Parameters	Water quality measurement for 2012		
	DEVPRAYAG (Mean)	VARANASI (Mean)	PATNA (Mean)
Temperature °C	16	24	27
DO(mg/l)	19.6	7.9	8.0
pH	8.0	8.1	7.7
BOD(mg/l)	1.1	3.2	2.6
Fecal Coliform(MPL/100 ml)	200,000	6500	257,000
Parameters	Water quality measurement for 2013		
	DEVPRAYAG (Mean)	VARANASI (Mean)	PATNA (Mean)
Temperature	17	23.2	35
DO(mg/l)	9	8.0	7.6
pH	8.2	8.2	7.5
BOD(mg/l)	1.2	3	3.5
Fecal Coliform(MPL/100 ml)	78	6500	250,000
Parameters	Water quality measurement for 2014		
	DEVPRAYAG (Mean)	VARANASI (Mean)	PATNA (Mean)
Temperature	17	22.5	27
DO(mg/l)	8.4	8.3	6.7
pH	8.1	8.2	7.8
BOD(mg/l)	1.0	2.9	4.8
Fecal Coliform(MPL/100 ml)	500	2617	256,500
Parameters (Mean)	Water quality measurement for 2014 (Mean)		
	DEVPRAYAG (Mean)	VARANASI (Mean)	PATNA (Mean)
Temperature	18.5	21.5	27
DO(mg/l)	8.0	8.0	6.3
pH	8.0	8.4	8.2
BOD(mg/l)	1.0	5.5	4.2
Fecal Coliform(MPL/100 ml)	650	2250	78,500
Parameters	Water quality measurement for 2016		
	DEVPRAYAG (Mean)	VARANASI (Mean)	PATNA
Temperature	18	26	27
DO(mg/l)	8.9	8.6	7.1
pH	7.6	7.9	7.7
BOD(mg/l)	1.0	3.1	3.5
Fecal Coliform(MPL/100 ml)	600	1800	155,000

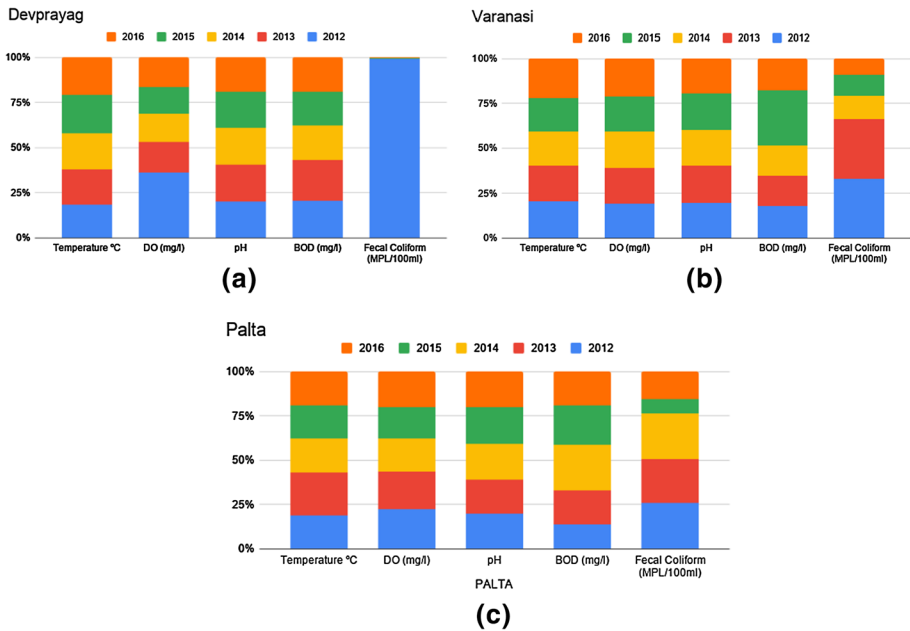


Fig. 4 **a** Water quality measurement for River Ganga at Devprayag; **b** Water quality measurement for River Ganga at Varanasi; **c** Water quality measurement for River Ganga at Patna

The water quality assessment shows that the water quality of the Ganga river is fine in Haridwar but it has deteriorated in Allahabad and Berhampur. Haridwar is one of the river Ganga’s initial points, and because of that Haridwar’s water quality is good.

As River Ganga reaching to further cities, due to their domestic and industries waste, the quality of river Ganga water going to degraded. Due to this water pollution source, the temperature of the river is rising in Allahabad and Berhampur (Fig. 7). Table 7 discussed about the comparative analysis with proposed work and existing work.

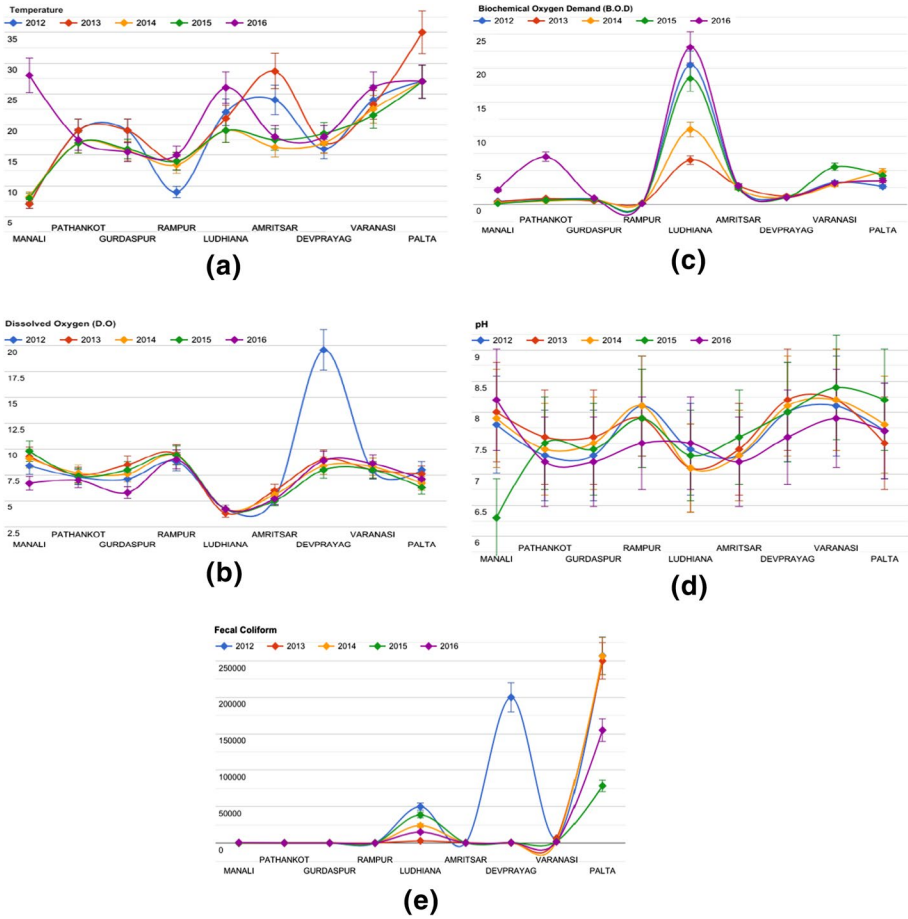


Figure 6 a–e Rivers water quality parameters for nine considered locations in India

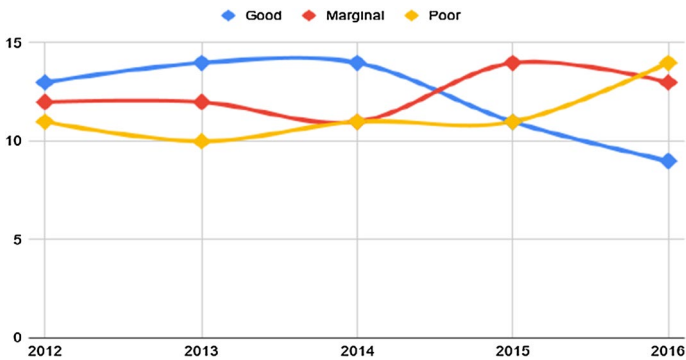
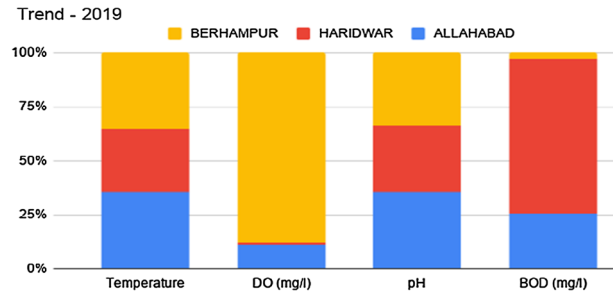


Fig. 5 Water quality trend analysis from 2012–2016 for the considered rivers

Table 6 2019 trend analysis of River Ganga for different locations

Parameters	Water quality measurement for 2019		
	ALLAHABAD (Observed)	HARIDWAR (Observed)	BER-HAMPUR (Observed)
Temperature	27.3	22.2	26.8
DO(mg/l)	1.04	0.10	8.22
pH	8.03	7.0	7.7
BOD(mg/l)	15.35	43.2	1.65

Fig. 7 2019 trend analysis of River Ganga for different locations

5 Conclusion

The goal of this research is to examine water quality for three rivers in India named Beas, Sutlej, and Ganga for five years period from 2012 to 2016. This research also addressed the current pollution pattern for the Ganga river. Based on the findings from Tables 1–5, few measuring sites are highly contaminated due to their heavy household waste and water pollution from the industries. Ludhiana, Varanasi and Patna are mainly heavily contaminated areas. Water quality metrics follow the norm values at a few places, such as Manali and Devprayag. River Beas is the lowest polluted river according to Fig. 6 (a-e), and river Ganga is the most polluted river out of considered rivers. The water pollution rates at Ludhiana and Varanasi is the highest among the nine listed locations. This is found that the main sources of water contamination at contaminated sites are household water waste, river animal bathing, and other industrial waste from different cities along the river. It is therefore recommended that strict measures should be taken against these practices so that the consistency of the water can be improved and freely used for drinking.

Table 7 Comparative analysis

S. No.	Authors	Descriptions	Limitations
1	Yan et al., (2015)	Water pollution has been evaluated using GIS approach, single factor pollution index and comprehensive pollution index	Water pollution analysis has been performed for one year only
2	Majerek et al. (2019)	Studied about the waste water from municipal wastewater treatment plant to Bystrzyca river	Only considered the municipal sewage for measuring the water quality of Bystrzyca river
3	Sharma et al. (2016)	Water quality of River Ganga has been measured for Varanasi district	Many critical polluted locations are absent in the study for the measurement of River Ganga
4	Sharma et al. (2017)	Water quality of River Sutlej has been measured for Punjab, India	Many critical polluted locations are absent in the study for the measurement of River Sutlej
5	Tamiru (2019)	Used Macroinvertebrates as indicators for the analysis of water quality for River Shinta, Ethiopia	Trend analysis for different years are absent in the study
6	Sharma et al., (2019a, 2019b)	Studied about the Air pollution measurement for different geographical locations in India	No discussion added about the analysis of water quality of Indian Rivers
7	Beshiru et al. (2018)	Discussed the water quality indices for the five Rivers in Nigeria	Trend analysis for different years are absent in the study
8	Proposed Work	This paper deals with the water quality parameters of different Indian rivers (Beas, Sutlej and Ganga) for the time period from 2012–2016. Latest pollution trend in 2019 for the river Ganga has also discussed	

Acknowledgements We sincerely acknowledge the Central Pollution Control Board (CPCB) India, for providing the data of Beas, Sutlej and Ganga Rivers for the measurement of water quality.

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