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Spatio-temporal Variability of Physico-chemical and Biological Water Quality Parameters of River Ganges in Six Cities Situated on Indo-Gangetic Plain Transect

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Abstract Rivers in any country are important lifeline for the population living around it whose water is used for drinking, agriculture, industrial and commercial purposes. The increasing anthropogenic activities like industrialisation, urbanisation and change in land use pattern, increased use of chemical fertilizer and pesticides in farming have lead to the discharge of the different types of contaminants in the river water. In the present article, the data has been acquired from Central Pollution Control Board, India which continuously monitors different kinds of water quality parameters every year at regular interval. The data analysis of the different biogeochemical water quality parameters of river Ganges has been carried out. In the present study, a total of six cities have been chosen to analyse the water quality of the river Ganges. The chosen six cities are Haridwar, Kanpur, Allahabad, Varanasi, Patna and Kolkata which are situated along the stretch of the river Ganges. The Haridwar is located at a place where the river Ganges enters the Northern Indian Plain from mountainous (Himalayan range) region while Kanpur, Allahabad, Varanasi and Patna are located on Plain and Kolkata is situated on the Deltaic region of river Hooghly which is one of the distributaries of river Ganges. For the analysis purpose, a total of eight water quality parameters which decide the contamination levels of the water bodies have been selected. These parameters are temperature, dissolved oxygen, pH, conductivity, Biological Oxygen Demand, Nitrate + Nitrite, Faecal Coliform and Total Coliform load. The study has been carried out with respect to the data from 2007 to 2016. In this ten years period, the data of four years i.e., 2007, 2010, 2013 and 2016 have been selected having gap of two years. In the spatial analysis of the result, it has been found that the river Ganges in Haridwar is least contaminated and the Kolkata is highly polluted in terms of the eight water quality parameters studied. In the correlation matrix analysis, the population of the city is negatively correlated with the altitude, temperature, dissolved oxygen while positively correlated with conductivity, BOD, Nitrate + Nitrite, Faecal Coliform and Total Coliform load. With regard to the Coliform contamination, except at Haridwar, rest of the river flow through the five cities indicated the Coliform contamination was many time above the standard limits prescribed by the CPCB.

Keywords: *Ganges River, Indo-Gangetic Plain, BOD, Coliform, water quality parameters*

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1. Introduction

Water is an important natural resource on the surface of the earth which is available in the seas, glaciers, rivers, lakes and groundwater. The water resource is used for different purpose like drinking, agriculture, industrial and commercial use [1]. The rate of pollution of groundwater and surface water has increased in the recent years due to different types of anthropogenic activities which has lead to the reduction and degradation of the water quality [2,3,4]. Among the anthropogenic activities which has lead to the degradation of the water quality are industrialisation, urbanisation, change in land use pattern, increased use of chemical fertiliser and pesticides etc. [5,6,7]. Of all the water bodies, rivers are first to get affected by the contaminants released by the human activities. The water quality of the rivers degrade due to the release of the chemicals from industries to the rivers, surface runoff from the agricultural land from which residue chemical fertilizers, pesticides, weedicides etc reaches to river along with rainwater, different types of contaminates washed off from the solid waste landfill sites during the rainy seasons and release of untreated sewage water directly to the rivers [8,9,10]. Rivers are the main sources of water for the human beings used for the different types of activities like drinking water, providing habitat to the aquatic organisms, transport, irrigation water for agriculture, production of energy through hydro power plants. During the higher precipitation there occurs flooding in the nearby regions while lower precipitation there occur drought in the region. The rivers form the important part of the hydrological cycle in the earth system [11,12].

India has diverse type of topography with Himalayan mountainous region in the North, Northern India plain located south of the Himalayas, further south of the plain is triangular shaped Peninsular plateau and coastal plains and Islands. In the present study, Northern Indian River is considered. The Northern Indian Plain which is also called as Indo-Gangetic plain is world's largest alluvial plain which lies between the Himalayas in the north and peninsula plateau south is a traditional plain made by the depositional work of alluvial sediments by the three important rivers named Ganga, Indus and Brahmaputra along with their tributaries. The Northern Indian Plain is made up of four geomorphological regions based on relief and structures are Bhabar, Terai, Bhangar, and Khadar. It spreads over 2.54 million km^2 covering the states of Punjab, Haryana, Rajasthan, Uttarakhand, Uttar Pradesh, Bihar, West Bengal etc. [13,14,15]. The Most of the Ganges river basin is in India and it extends over the nearby countries like Tibet, Nepal and Bangladesh. The basin has total area of 1.09 million km^2 of which the 0.86 million km^2 lies in India. The Ganges basin covers around 26.2 % of the total geographic area of India. The Ganges river and its tributaries basin covers the northern Indian states like Uttar Pradesh, Madhya Pradesh, Rajasthan, Bihar, West Bengal, Uttarakhand, Jharkhand, Haryana, Chhattisgarh, Himachal Pradesh and Union Territory of Delhi. The basin spreads from longitudes 73°2' to 89°5'E and latitudes 21°6' to 31°21' N while the its east-west extent and north-south extent is approx. 1,543 km and 1024 km, respectively. The Ganges River basin is bounded by the Himalayas on the north, by the Aravalli on the west, by the Vindhyas and Chhotanagpur plateau on the south and by the Brahmaputra Ridge on the east. Its left bank tributaries are Gomti, Gandak, Ghaghra, Karnali and right bank tributaries are Yamuna, Son, Mahananda, Chambal Damodar etc. River Ganga falls in Bay of Bengal where it forms the world's largest delta named as Sunderbans. The river Ganga provides water for irrigation to more than 30 % of the total land [16,17,18,19,20].

For the study related to water quality parameters, the six selected cities and their descriptions are given below:-

Haridwar:- The city of Haridwar lies at the place where the Ganga river enter northern India plain from the Himalayas mountainous region. The city is situated at the 314 m above sea level, where the temperature during the summer ranges from 25°C to 44°C and 1°C to 24°C. The district has area of 2360 km^2 and the city has area of 12.3 km^2. As per the census 2011 the population of Haridwar is 1.89 million. Due to the location in plain the city has been developed industrially during the last decade. The main industrial areas are BHEL Ranipur, Bahadrabad, SIDCUL, Jwalapur etc. The main industries present in the area belongs the chemical, manufacturing, IT, automobile industries, Pharma industries, Banking services etc. [21,22,23].

Kanpur:- Kanpur is a city of Uttar Pradesh located on the bank of Ganga river, situated at the 126 m above sea level which is very well industrially developed and called as industrial and economic capital. As per the records, the total number of industries registered is 17444 units. The main type of industries present in Kanpur belongs to fertilizer, cement, machine tools, two and three wheelers, leather industries, textiles, plastics goods, Automobile parts, defence parts industries, Pharmaceuticals, handlooms and power looms, chemicals and paints, Thermal power plants and gas plants etc. As per the census 2011, the population of the Kanpur is 6.4 million as per 2011 census. It is spread over a 3155 Km^2. The average temperature varies between 1 to 45°C. The district is located 125 m above sea level [24,25,26].

Allahabad:- It is an ancient city located on the around the confluence of three rivers i.e., Ganga, Yamuna and invisible Saraswati. The city is situated at the 98 m above sea level. The population of the city as per census, 2011 is 5.95 million. The total geographical area of the district is 5482 Km^2. Allahabad has a humid subtropical climate. The annual mean temperature is 26.1°C. The main source of rain water is the rainfall from South west monsoon. The district has minerals like silica sand, stones used for construction. The district has 10047 registered industrial units. The district has different types of industries like cotton textile, agro based, chemical, minerals, engineering goods etc [27,28,29].

Varanasi:- Varanasi is also an ancient city located on the crescent shaped left bank of the Ganga River having the elevation of 81 m above sea levels. The temperature range varies from 5°C to 44°C. The population of the Varanasi is 3.7 million as per the census 2011. The total geographic area is 1535 km^2. The district receives rain from South West monsoon. The city has 7033 registered industrial unit located in three industrial areas. The district has industries based on Agro, textiles, wood leather, chemical, mineral, engineering and heavy machinery based etc [30,31,32].

Patna:- It is the most populous district of the state of Bihar having population of 5.8 million. Patna city is located on the southern bank of Ganga River. The climate is humid subtropical climate having temperature range of 2°C to 45°C. The total geographical area is 3200 km^2 having the density of 1800 per km^2 and situated 53 m above sea level. The district has 12231 registered industrial units while total number is 30577 units. The industries are based mainly on the agro based, mineral, cotton textiles, wood, petro based electrical and transport based industries etc [33,34].

Kolkata:- It is located on the distributaries of Ganga River called Hoogly river delta region. It is the capital of the state of West Bengal. The population of the district is 4.5 million as per 2011 census. The district is spread over the area 185 km^2. The climate of the Kolkata is tropical wet-and-dry climate having temperature range of 12 to 40°C. The main source of the rain is the South-west monsoon rainfall. The district is situated 9.14 m above sea level. The Kolkata is one of the oldest industrial districts. The district has different types of industries like mineral based, agro based, leather based, wooden based, electrical and heavy machinery, mining, cement, chemicals, pharmaceuticals, textiles, electrical and electronic industries, steel and heavy engineering, jewellery etc. The number of registered industrial units is 986 as per 2011 counting [35,36,37].

1.1. Water Quality Parameters

For the study purpose, the eight water quality parameters were selected i.e., temperature, dissolved oxygen, pH, conductivity, biological oxygen demand, Nitrate + Nitrite, Faecal Coliform and Total Coliform along with population and altitude of the city [38-43].

1.1.1. Temperature

The temperature of the river plays important role in the physical, chemical and biological characteristics. The temperature controls the metabolic and reproductive activities of aquatic organisms. The temperature is controlled by the seasons, day or night, distance from the glaciers, quantity and velocity of flow, effluent from the power plants and industries

1.1.2. Dissolved Oxygen

DO decide the quality of water which is measured in mg/l. The concentration of DO depends on temperature, flow, aquatic plants carrying out photosynthesis, organic waste present in the water body etc. The normal water contains DO in the range of 4-8 mg/l while below 2 mg/l is not good for aquatic organism.

1.1.3. pH

It is an important parameter which controls the spread of the aquatic life. It ranges from 1 to 14. Too high and low pH is harmful for the living organism present in the water bodies. Many factors control the acidity and alkalinity of the water which can be natural and artificial/manmade. The normal pH of water bodies varies in the range of 6 to 9.

1.1.4. Conductivity

The conductivity of the water is the measure of the passing of the electrical current. The conductivity of the water is due to the presence of the chemicals like nitrate, nitrite, chloride, phosphate, sodium, magnesium, calcium, iron, aluminium, oil, alcohol, sugar etc. These inorganic and inorganic compounds present in the water bodies are important from the point of the survival of the aquatic living organisms. It is measured in (µmhos/cm).

1.1.5. Biological Oxygen Demand

It is the most primary parameter used to see the pollution levels of the water bodies. It is the Biological Oxygen Demand (BOD) which is defined as the amount of oxygen consumed in the decomposition of organic matters by bacteria in the water body. It is measured in the units of mg/l. The amount of organic waste present in large quantity then the amount of the dissolved oxygen is consumed and water becomes deficient in oxygen content and then the anaerobic bacteria become active.

1.1.6. Nitrate + Nitrite

These are nitrogenous compounds available in trace amount which is measured in the mg/l. This is an essential nutrient for the photosynthetic autotrophs. It is less toxic even in higher concentrations aquatic living organisms. Very high concentration of nitrate can cause eutrophication and increase in the quantity of the algal blooms which can lead to the less space available for the aquatic animals. While nitrite is highly toxic to the living organisms present in the water bodies.

1.1.7. Faecal Coliforms

The water quality is decided by the presence of the Faecal Coliforms. These Coliforms are present in the intestines of the animals. Presence of it in the water bodies indicates the discharge or leakage of the sewage in the water bodies. Faecal Coliforms are themselves are not pathogenic but there high concentrations indicates the presence of disease causing microorganisms. It is measured in the units of Most Probable Numbers (MPN/100ml).

1.1.8. Total Coliforms

They are considered as indicator for the drinking water quality because of easy detection in the water bodies. The genera belonging to the Total Coliforms are *Escherichia*, *Citrobacter*, *Enterobacter* and *Klebsiella*. They are present in the soil, in water bodies which is been influenced by surface water, and in human or animal waste.

2. Methodology

In the present study, the data has been acquired from Central Pollution Control Board, which continuously monitors different kinds of water quality parameters every year at regular interval at all the cities located on the bank of the river Ganga. The data analysis of the different biogeochemical water quality parameters of river Ganges has been carried out. In the present study, a total of six cities have been chosen to analyse the water quality of the river Ganga. The chosen six cities are Haridwar located in Uttarakhand, while Kanpur, Allahabad and Varanasi are in Uttar Pradesh and Patna in Bihar state and Kolkata located in West Bengal states which are situated along the stretch of the river Ganges. The Haridwar is located at a place where the river Ganges enters the Northern Indian Plain from mountainous (Himalayan range) region while Kanpur, Allahabad, Varanasi and Patna are located on Plain and Kolkata is situated on the Deltaic region of river Hooghly which is one of the distributaries of river Ganges. For the analysis purpose, a total of eight water quality parameters which decide the contamination levels of the water bodies have been selected. These parameters are temperature, dissolved oxygen, pH, conductivity, Biological Oxygen Demand, Nitrate + Nitrite, Faecal Coliform and Total Coliform load. The study has been carried out with respect the data from 2007 to 2016. In this ten year period, the data of four years i.e., 2007, 2010, 2013 and 2016 has been selected having gap of two years. The correlation matrix and descriptive statistics were also carried out to reach the relationship between water quality parameters (temperature, dissolved oxygen, pH, conductivity, Biological Oxygen Demand, Nitrate + Nitrite, Faecal Coliform and Total Coliform load), altitude of the city above the sea level, population of the city.

3. Results and Discussion

The analysis of the data of related to the eight water quality paramaters of the river Ganga along with the altitude and population of the studied cities are presented in this section.

During the year 2016 (Table 1), the annual mean temperature of river water was found to be lowest at the Haridwar site (20°C), while it is highest at the Kolkata. The temperature is higher at Varanasi followed by Kanpur, Allahabad and Patna. Different types of living organism live at different temperature ranges in river water and also higher temperature helps higher levels of activities of microorganisms. The dissolved oxygen ranges from 6.1 to 7.7 mg/l and was highest at Allahabad and lowest at Kolkata. The pH was highest at Allahabad and lowest at the Haridwar having the value of 8.2 and 7.0, respectively. The monitoring station at Haridwar doesn't measures conductivity. The conductivity parameter was higher at Kanpur and lowest at Kolkata. The BOD ranged from 2.8 to 6.5 mg/l with the higher values at Kanpur and lower at Patna. The levels of Nitrate + nitrite was absent in at the Varanasi and Patna while it was higher at Haridwar (3.7 mg/l) and lower at Kanpur (0.3 mg/l). The Faecal Coliform load was highest at Kolkata (46500 MPN/100ml) and lowest at Patna (4950 MPN/100ml) while Total Coliform was lowest at Haridwar and highest at Kolkata followed by Kanpur, Varanasi, Allahabad and Patna.

Table 1. Data related to eight river water quality parameters at six cities during 2016

City (year 2016)	Temp (°C)	Dissolved O_2 (mg/l)	pH	Conductivity (μmhos /cm)	BOD (mg/l)	Nitrate + Nitrite (mg/l)	Faecal Coli form (MPN/ 100ml)	Total Coli form (MPN/100ml)
Haridwar	20	7.3	7.0	Data NA	3.7	3.7	Data NA	845
Kanpur	24.5	6.7	7.7	523	6.5	0.3	33550	77000
Allahabad	24	7.7	8.2	362	4.3	1.3	14850	43500
Varanasi	26	7.5	7.9	441	5.5	0.0	27500	48500
Patna	23	7.5	7.9	393	2.8	0.0	4950	13500
Kolkata	27.5	6.1	7.9	300	5.3	0.4	46500	131000

Table 2. Data related to eight river water quality parameters at six cities during 2013

City (year 2013)	Temp (°C)	Dissolved O_2 (mg/l)	pH	Conductivity (μmhos/cm)	BOD (mg/l)	Nitrate + Nitrite (mg/l)	Faecal Coli form (MPN/100ml)	Total Coli form (MPN/100ml)
Haridwar	19	6.5	7.8	Data NA	5.2	0.0	Data NA	1245
Kanpur	24.5	6.8	8.1	59	6.7	3.0	13292	70462
Allahabad	24.3	8.4	8.2	374	3.4	2.0	16100	22417
Varanasi	23.2	7.9	8.5	327	4.6	1.6	34500	49500
Patna	25.1	7.8	7.9	350	2.7	0.0	7378	19571
Kolkata	25.9	6.0	7.7	3.4	3.5	1.0	237059	855882

Table 3. Data related to eight river water quality parameters at six cities during 2010

City (year 2010)	Temp (°C)	Dissolved O_2 (mg/l)	pH	Conductivity (μmhos/cm)	BOD (mg/l)	Nitrate + Nitrite (mg/l)	Faecal Coli form (MPN/100ml)	Total Coli form (MPN/100ml)
Haridwar	21.2	6.3	7.5	230	6.7	Data NA	20	1260
Kanpur	25.3	6.3	7.7	47	6.1	1.12	8558	74167
Allahabad	24.6	7.8	8.3	445	3.9	1.87	2758	5083
Varanasi	24.9	7.3	8.3	337	8.9	Data NA	44000	71000
Patna	25.7	8.2	8.2	388	2.8	0.87	7711	21444
Kolkata	27.6	6.9	7.9	303	2.1	0.34	107500	233750

Table 4. Data related to eight river water quality parameters at six cities during 2007

City (year 2007)	Temp (°C)	Dissolved O_2 (mg/l)	pH	Conductivity (μmhos/cm)	BOD (mg/l)	Nitrate + Nitrite (mg/l)	Faecal Coli form (MPN/100ml)	Total Coli form (MPN/100ml)
Haridwar	20	6.7	6.8	482	1.8	3.8	23	1600
Kanpur	25	5.5	7.9	75	6.1	3.1	32889	76100
Allahabad	26	8.1	8.2	471	3.6	2.2	5051	7983
Varanasi	27	7.1	8.4	3.3	11.9	1.37	81714	125714
Patna	27	9.1	8.3	353	2.4	Data NA	10500	21000
Kolkata	28	6.7	7.8	292	2.0	0.23	140000	433750

During the year 2013, the annual mean temperature was highest and lowest at the Kolkata and Haridwar, respectively. The dissolved oxygen level ranged from 6.0 to 8.4 mg/l with highest levels at Allahabad and lowest at Kolkata. The pH level was higher at Varanasi and lower at Haridwar. Conductivity of the river water was lowest at Kolkata having the value of 3.4 µmhos/cm and highest at Allahabad with value of 374 µmhos/cm. The BOD values were highest at Kanpur and lowest at Patna. With respect to Nitrate + Nitrite concentration, the higher value was found at Kanpur and lowest at Haridwar and Patna. The Faecal and Total Coliform load was highest at Kolkata and Lowest at Haridwar.

Temperature during the year 2010 was lowest at Haridwar and highest at Kolkata followed by Patna, Kanpur, Varanasi and Allahabad. The dissolved oxygen was found to be highest at Patna and lowest at Haridwar and Kanpur. The pH was higher at Allahabad and Varanasi and lowest at Haridwar. With regard to Conductivity, the lowest value was at Kanpur and highest values at Allahabad. BOD ranged from 2.1 to 8.9 mg/l with lowest at Kolkata and highest at Varanasi. The Nitrate + Nitrite concentration was lowest at Kolkata and highest at Allahabad. The faecal (ranged from 20 to 107500 MPN/100ml) and Total Coliform load (ranged from 1260 to 233750 MPN/100 ml) was highest at Kolkata and Lowest at Haridwar.

On the analysis of the data of the year 2007, the annual mean temperature of the river water was highest at Kolkata and lowest at Haridwar. Dissolved oxygen ranged from 5.5 to 9.1 mg/l having the highest value at Patna and lowest at Kanpur. The pH value was highest at Varanasi (8.4) and lowest at Haridwar (6.8). The conductivity was highest at Haridwar and lowest at Kanpur having the values of 482 and 75 µmhos/cm, respectively. The BOD values was lowest at Haridwar (1.8 mg/l) and highest at Varanasi (11.9 mg/l). With respect to the Nitrate + Nitrite concentration, the lowest at Kolkata and highest at Haridwar. In this year also, the trend was same as that of the year 2010 where the Faecal Coliform load (ranged from 23 to 140000 MPN/100ml) and Total Coliform load (ranged from 1600 to 433750 MPN/100ml) was highest at Kolkata and lowest at Haridwar.

3.1. Comparison of river water quality parameters among six different cities which are Haridwar, Kanpur, Allahabad, Varanasi, Patna and Kolkata

At the Haridwar, the annual mean temperature of river water was found to be lowest which may be due to the water coming from the higher mountainous colder region which is due to the melting of the glaciers while it is highest at the Kolkata which may be due to its location near the Bay of Bengal sea where marine type of climate is dominant (Figure 1). The mean temperature is higher at Varanasi followed by Kanpur, Allahabad and Patna. Temperature of the water bodies is important parameter which impacts the growth and development of the aquatic living organisms, rate of photosynthesis, and solubility of the oxygen, sensitivity of the living organism residing in the water bodies towards diseases, pest and hazardous contaminants [44,45].

The annual mean value of the dissolved oxygen was found to be lower at Kolkata and Kanpur while higher at the Patna and Allahabad (Figure 2). Dissolved oxygen in water is essential for the respiration by the fishes and other aquatic organism. The dissolved oxygen values for freshwater is 4-8 mg/l, below which the level indicates the pollution level. Fishes need at least 4-5 mg/l of DO for their survival. In the river water, DO levels is maintained by diffusion of air from atmosphere and as a by product of photosynthesis carried out by the aquatic plants and algae. The dissolved oxygen level varies seasonally and over a 24 hours period. It also varies with the temperature of water and altitude. The colder water holds more oxygen than warmer water; also water has less ability to hold water at higher altitudes compared to lower altitudes. Thermal discharges, such as water used to cool machinery in a manufacturing plant or a thermal and nuclear power plant, raise the temperature of water which in turn lowers its dissolved oxygen content. Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when water and stream flows are low, water temperatures are high and aquatic plants have not been producing oxygen since sunset [46,47].

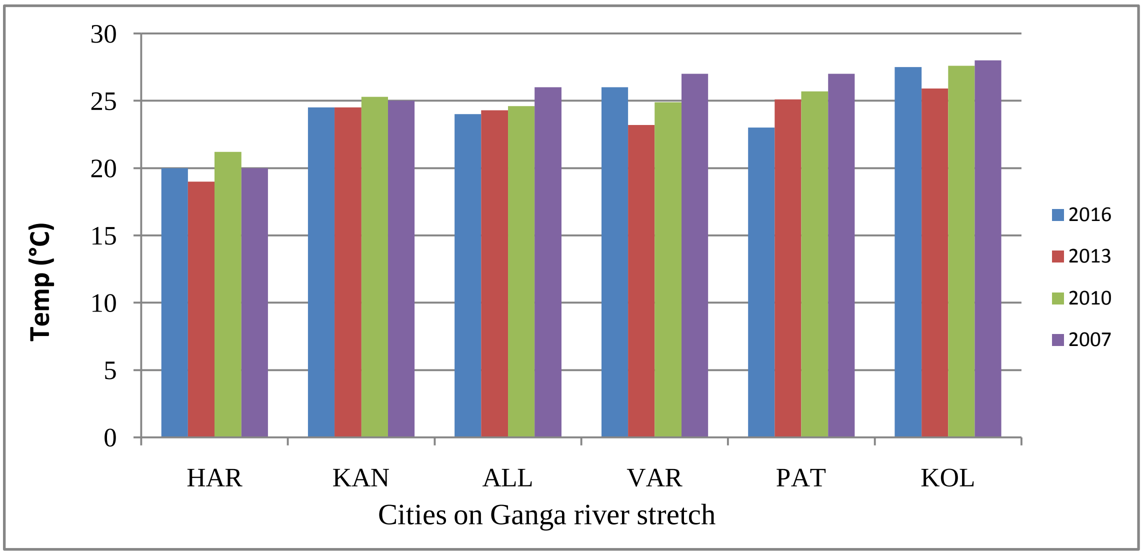

Figure 1. The bar diagram showing the temperature variation at six cities during the studied four years

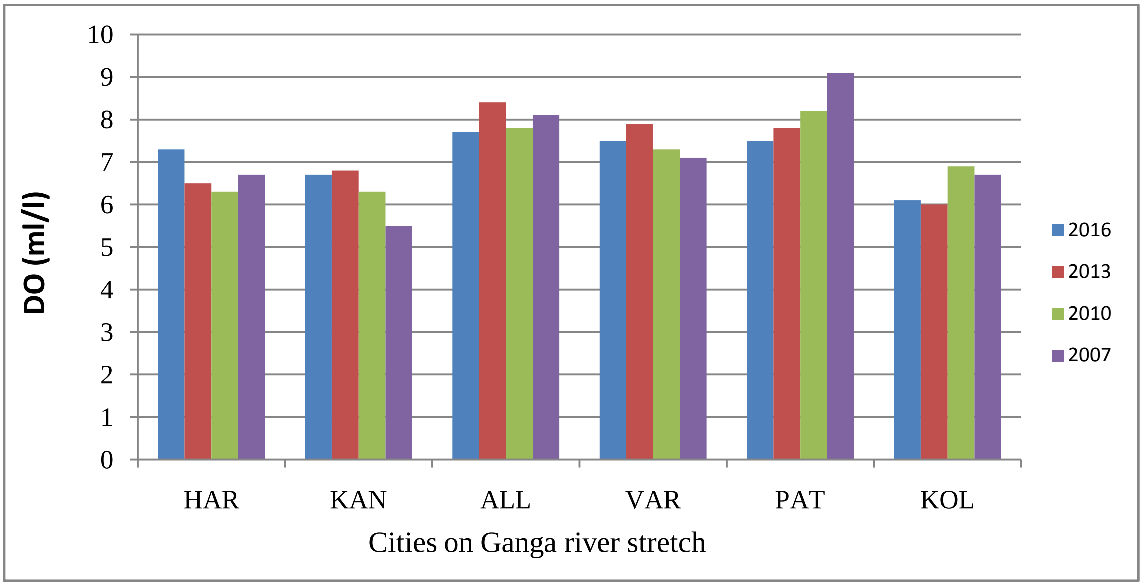

Figure 2. The bar diagram showing the dissolved oxygen variation at six cities during the studied four years

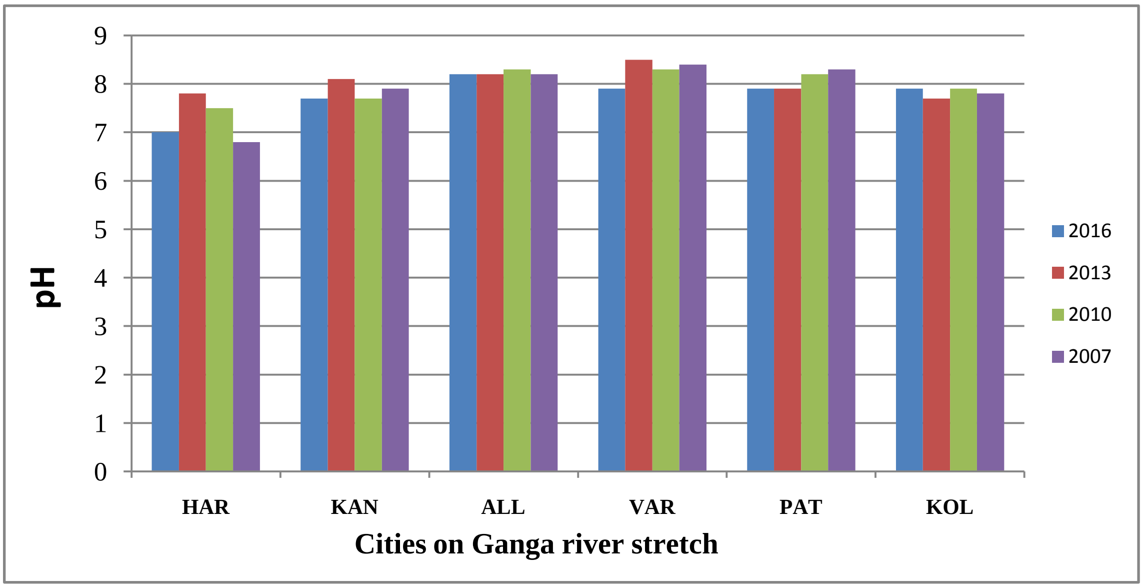

Figure 3. The bar diagram showing the pH variation at six cities during the studied four years

The average pH was found to be higher at the Varanasi (8.4) and Allahabad (8.2) and lowest at Haridwar (7.3). The pH at Kanpur, Patna and Kolkata was found to be 7.8, 8.1 and 7.7, respectively (Figure 3). The pH of river water is an important parameter which decides the quality of the water. As per the WHO (World Health Organisation) and CPCB (Central Pollution Control Board) guidelines, the pH range of the normal drinking water should be between 6.5 to 8.5. Higher and lower level of pH makes the water bodies not suitable to support the life. The lower level of pH is harmful for the fishes and other living organisms also it speeds up the leaching process of hazardous metals. A higher level of alkalinity shows that water is more disinfected.The dissolved carbon dioxide present in the unpolluted water body is the main reason for acidity. The alkalinity in the water is due to the presence of the alkaline compounds and salts, such as carbonates, bicarbonates and hydroxides [48,49].

The annual mean value of the conductivity of the water is found to have lower values at Kolkata and Kanpur while it is higher at Allahabad, Varanasi and Patna (Figure 4). The conductivity of the water is due to the occurrence of the dissolved inorganic solids like sulphate, nitrate, phosphate, chloride anions and sodium magnesium, calcium, iron, and aluminium cations. While presence of the some organic compounds viz., phenol, alcoholic compounds, sugar, different types of oil etc decreases the conductivity of water because they are bad conductors of the electrical current. Along with this the conductivity is also affected by the temperature i.e., higher the temperature, higher is the conductivity. However, significant increases in conductivity may be an indicator that polluting discharges have entered the water. Conductivity of the water bodies like rivers and streams is mainly affected by the geological structures through which it flows. Rivers which flow over the granitic bedrocks have lower levels of conductivity because it is made of inert minerals. While rivers which flows through the clayey soil have higher conductivity. The conductivity of the river water varies between 50 to 1500 µS/cm while to support the different types of aquatic living organisms, the conductivity of the water bodies should be between 150 to 500 µS/cm [50,51].

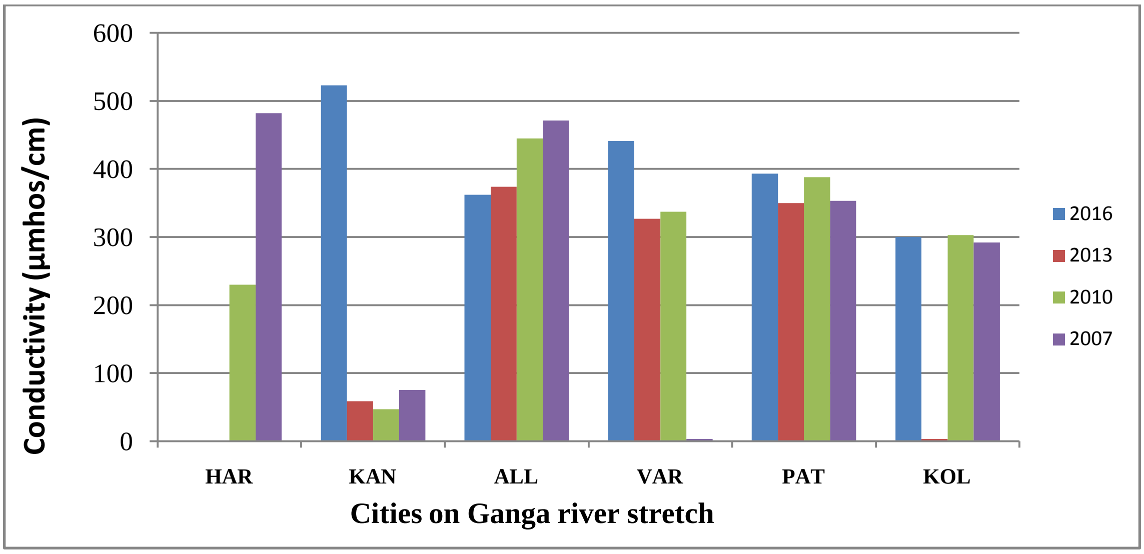

Figure 4. The bar diagram showing the Electrical Conductivity variation at six cities during the studied four years

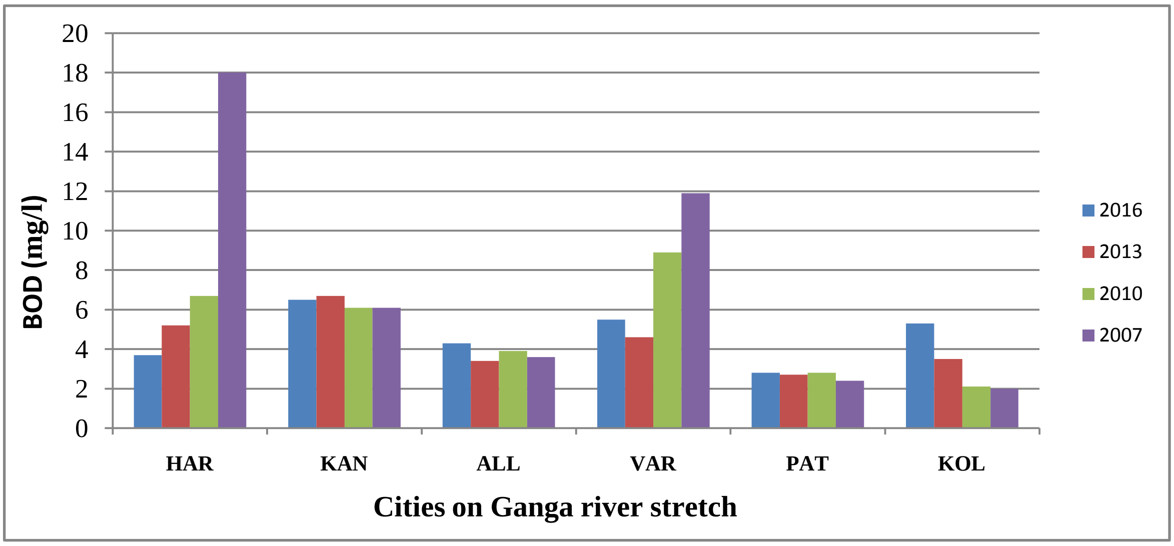

Figure 5. The bar diagram showing the BOD variation at six cities during the studied four years

The average value of the BOD at the Haridwar was found to be highest while it is lowest at the Patna (Figure 5). The Kanpur and Varanasi have the medium level of BOD. It is the amount of oxygen consumed by the bacteria for decomposition of the organic compounds and sulphides, ferrous iron and ammonia. The unpolluted natural waters have a BOD of 5 mg/L or less. The sewage water has BOD levels varying between 150 – 300 mg/L. (1991, Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods). The organic material present in the river water may consists of sewage released by the municipal bodies, organic manure used by the farmers, plant products like dead parts of the plants etc. Higher concentration of the nitrates and phosphates which is used by the farmers in the agriculture, reaching to the rivers may lead to the increase in the algal growth which when dies leads to the increase in the organic matter which in turn may lead to the increase in BOD. The higher levels of the BOD in Haridwar may be due to the release of dead plants and animals, leaves and woody debris from the forest at the higher reaches, animal manure used by the farmer in their field, effluents from pulp and paper mills, sewage and wastewater, urban storm water runoff etc. The lower level at Patna may be due to the addition of more water coming from the tributaries of Ganga. The lower level at Kolkata may be due to the less amount of the organic matter in the river [52,53].

Nitrate and nitrite values were found to be the lower in the Patna and Kolkata and higher at Haridwar and Kanpur (Figure 6). Nitrate and Nitrite are present naturally in the environment. The CPCB standards for nitrate and nitrite are 50 mg/l and 3 mg/l respectively. The nitrate concentration in water bodies are generally low (0 - 18 mg/l) but it can be increased due to the washed in from the residual fertilizers from agricultural fields and decomposition of human, animal wastes, sewage with rainfall and surface runoff of agricultural runoff. Nitrates are the essential for the growth of the plants and are the growth limiting factor for plants. The higher levels of Nitrates in the water bodies may result in proliferations of phytoplankton or macrophyte which is called the eutrophication phenomenon. Nitrite is an intermediate compound in the oxidation of ammonia to nitrate conversion. The major source of the nitrite and ammonia in the river water is sewage water released by the urban municipal bodies. Nitrite, even at low level is extremely toxic to aquatic life [55,56].

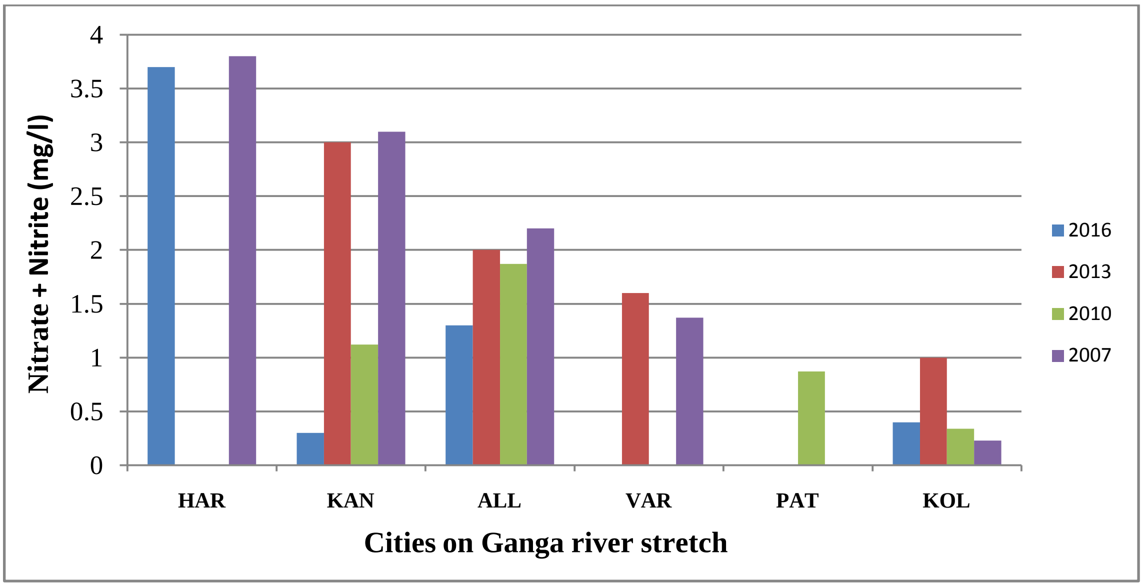

Figure 6. The bar diagram showing the Nitrate + Nitrite variation at six cities during the studied four years.

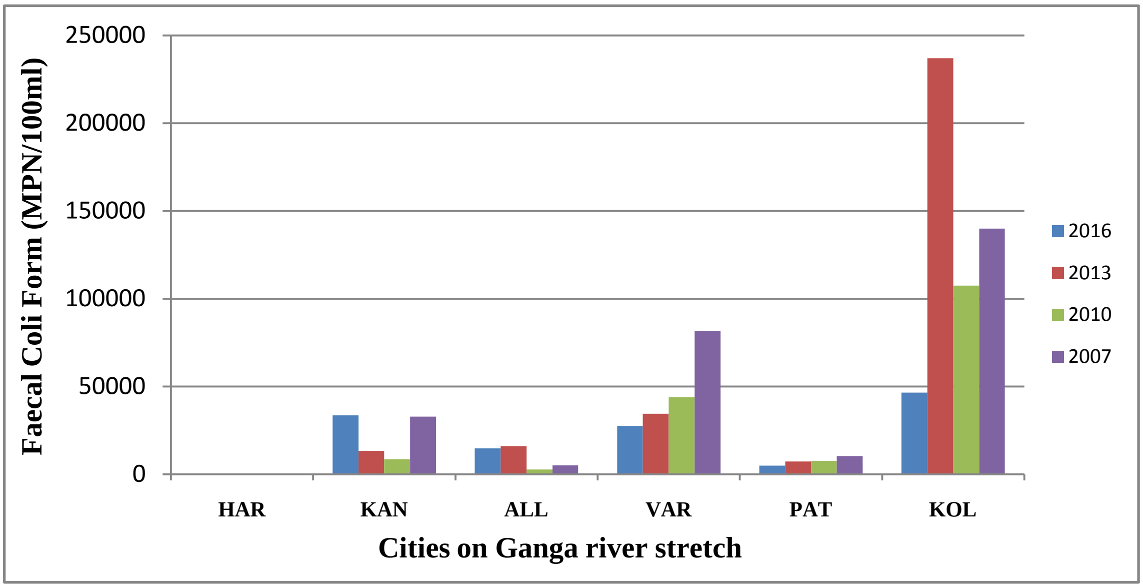

Figure 7. The bar diagram showing the Faecal Coliform load variation at six cities during the studied four years

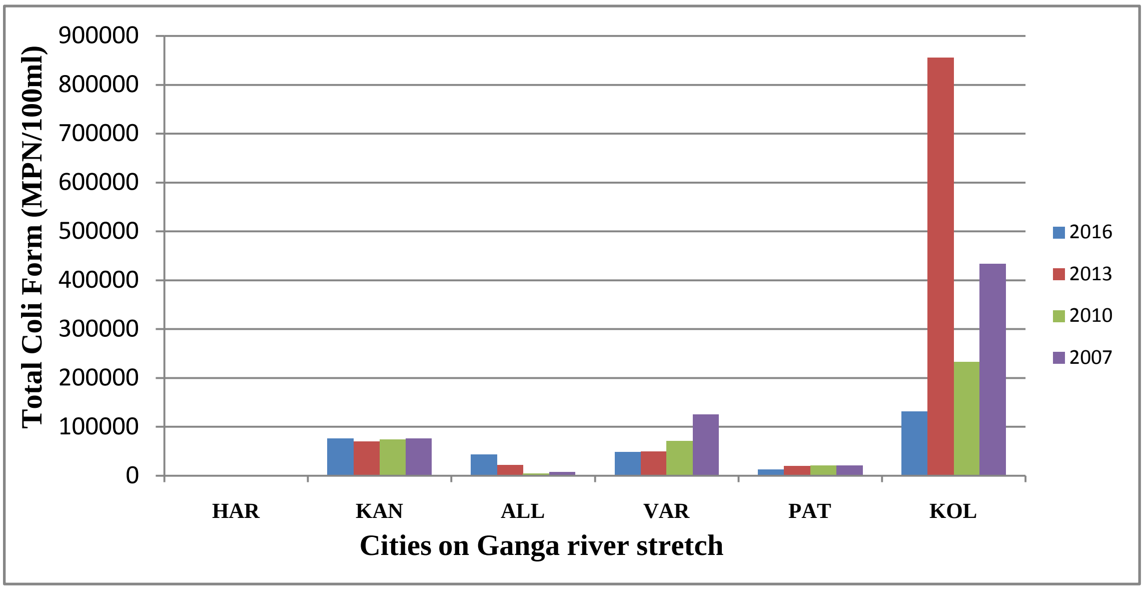

Figure 8. The bar diagram showing the Total Coliform load variation at six cities during the studied four years

The annual faecal coliform levels were found to be lowest at the Haridwar and highest at the Kolkata (Figure 7). The faecal load was higher at Varanasi followed by Kanpur, Allahabad and Patna. Faecal Coliform is a subset of total Coliform which represents the gram negative, rod-shaped, anaerobic bacteria like *Escherichia*, *Streptococci*, *Enterobactor*, *Enterococcus Klebsiella*, *Citrobacter*. The higher concentration of these bacteria indicates that there is presence of faces in the water body. Faecal coliform bacteria live in the intestines of mammals where they live in symbiotic relationship. The main source of the faecal coliform is the human and animal excretory products. The faecal coliform test is always done to see the water quality of the water i.e., it is an indicator for the quality of water. Faecal Coliform has shorter life period compared to other Coliform bacteria. Their presence in the water bodies shows that there is no proper treatment and disposal of sewage waste [57,58].

With regard to the Total Coliform contamination (Figure 8), the water in the Kolkata is found to be very high compared to the other studied cities located on the river Ganga while it is very low in Haridwar. The lower levels were found at Kanpur followed by Varanasi, Allahabad and Patna. They are the suitable microbial indicator of drinking water quality, because they can be very easily detectable in the water bodies. The Total Coliforms include those bacteria that are prolific in the soil and water bodies which have been influenced by surface water, and in human or animal waste. Total Coliforms are a collection of related bacteria that are (with few exceptions) not harmful to humans [58,59,60].

3.2. Correlation Analysis of Eight Parameters, Altitude and Population

The correlation study was carried out for total of ten parameters i.e., Population, Altitude, Temperature, Dissolved oxygen, pH, Conductivity, BOD, Nitrate + Nitrite, Faecal Coliform and Total Coliform load. Table 5, shows the correlation matrix for ten studied parameters. The population of the city located on the bank of the river is found to have negatively correlated with altitude, temperature, dissolved oxygen and positively correlated with BOD, Nitrate + Nitrite, Faecal Coliform and Total Coliform while no correlation with pH, conductivity. On correlating river location i.e., its altitude with water quality parameters, it was observed to be inversely correlated with temperature, pH, BOD, Faecal Coliform and Total Coliform and positively correlated with dissolved oxygen, conductivity and Nitrate + Nitrite levels. With increase in temperature of the water, there is decrease in DO, conductivity, Nitrate + Nitrite levels while there is increase in pH, BOD and faecal and Total Coliforms. Dissolved oxygen levels exhibited positive correlation with pH, conductivity and Nitrate + Nitrite levels and negative correlation with BOD and Faecal and Total Coliforms. The pH levels in the river water are neutral to alkaline in range and it was observed that the observed pH exhibited positive correlation with BOD and Total Coliforms and negative correlation with conductivity, Nitrate + Nitrite levels and Faecal Coliforms. BOD levels are in the range of 2-18 mg/l. BOD levels are positively correlated with Faecal Coliforms and Total Coliforms and negative correlation with Nitrate + Nitrite levels. The range of Nitrate + Nitrite levels on this transect was 0 - 3.8 mg/l. It has been prescribed that nitrate and nitrite ion concentration of less than 50 mg/l and 3 mg/l, respectively, will not cause Methaemoglobinaemia and thyroid effects in most sensitive sub-population, bottle - fed infants and consequently, other population subgroups. It has been recommended that combined nitrate plus nitrite (i.e., sum of the ratios of the concentrations of each of nitrate and nitrite to its guideline value should not exceed the value of 1) [49,58,59,60]. However, the data indicates that combined Nitrate + Nitrite levels on the observed transect was 0 - 3.8 mg/l, which is more than the recommended levels. The Nitrate + Nitrite levels are positively correlated with population, altitude and negatively correlated with temperature, Faecal and Total Coliforms. The Coliforms contamination in river streams indicates the presence of untreated sewage or soil runoff from adjacent residential and agricultural areas. According to prescribed standard limits of CPCB, the river stream should have Faecal Coliform count of in the range of 500 - 2,500 MPN (most probable number) per 100 ml are suitable for bathing. Except Haridwar, the rest of the stream flow indicated the Faecal and Total Coliforms load many time above the threshold limit. This indicates that below downstream of Haridwar, the Ganga River is exposed to various anthropogenic activities which results in severe pollution of river Ganga [49,50,56,57,59]. This information can be more appropriately analysed if CPCB, a reporting authority provide water quality data temporally also.

Table 5. Correlation matrix for altitude, population and eight river water quality parameters

Parameters	Population	Altitude	Temp (°C)	DO	pH	Conductivity (μmhos/cm)	BOD (mg/l)	Nitrate + Nitrite (mg/l)	Faecal Coli form (MPN/100ml)	Total Coli form (MPN/100ml)
Population	1									
Altitude	-0.78*	1								
Temp (°C)	-0.72*	-0.85*	1							
DO (mg/ml)	-0.69*	0.28	-0.52	1						
pH	0.45	-0.86*	0.69*	0.09	1					
Conductivity (μmhos/cm)	0.52	0.82*	-0.37	0.18	-0.61	1				
BOD (mg/l)	0.75*	-0.20	0.61*	-0.53	0.14	0.46	1			
Nitrate + Nitrite (mg/l)	0.74*	0.90*	-0.77*	0.18	-0.77*	-0.33	-0.35	1		
Faecal Coliform (MPN/100ml)	0.82*	-0.26	0.89*	-0.878	-0.42	-0.09	0.80*	-0.56	1	
Total Coliform (MPN/100ml)	0.87*	-0.62*	0.86*	-0.84*	0.40	-0.31	0.69*	-0.59	0.95*	1

4. Conclusions

The rivers are the life line for the population living on the bank. In the recent years, the high level of urbanisation, industrialisation and consumerism and over exploitation of the surface river water resources by the human beings has lead to the degradation of this precious water resource. The river Ganga which covers the 30 % of the area on India is also a victim of the water pollution. The six cities located are highly urbanised and industrialised, due to which different types of contaminant are release in the this water body due to which the quality of the water has gone down in the recent years. Of all the cities the Kolkata seems to have highly polluted river water which is located at the mouth of the river while Haridwar is least polluted river water. The Government of India started a flagship programme named Namami Gange Programme in the year June, 2014 with twin objectives of effective abatement of pollution, conservation and rejuvenation of National River Ganga. In this programme, creating Sewage Treatment Plants, River water front development, River surface cleaning, Biodiversity conservation, Afforestation and Public awareness programme, Industrial effluent monitoring etc., in every city located in the bank will be constructed along with release of only the treated water from the industries. A more comprehensive short and long term plan and faster implementation of the objectives of Namami Gange is needed to revive the river Ganga and make it free of contaminants.

Conflict of Interest Statement

All authors hereby declare that there is no conflict of interest.

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