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ASSESSMENT OF SEASONAL CHANGES IN SURFACE WATER QUALITY OF THE RIVER GANDAK, A MAJOR TRIBUTARY OF THE GANGETIC RIVER SYSTEM IN NORTHERN INDIA

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Abstract: *Water quality of the River Gandak has been examined in special reference to Physico-chemical properties and seven heavy metals namely cobalt (Co), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), zinc (Zn), lead (Pb), and on seasonal basis for two consecutive years 2014-15 and 2015-16. Samples were collected from five stations namely Bagaha, Sangrmpur, Sahibganj and Sonpur Bridge. The value of measured physico-chemical parameters were as follows; Temperature (22.2-26.6 ºC), pH (8.1-8.3), Total Dissolved Solids (109-219 mg/l), Alkalinity (74-129mg/l), Sulphate (15.4-25.75), phosphate (0.05-0.10mg/l),Total hardness (135-164mg/l),Chloride (3.56-6.36),Nitrate (0.16-0.44mg/l), Dessolved Oxygen (5.6-8.7 mg/l), Biological Oxygen Demond (1.67-2.73 mg/l) and Chemical Oxygen Demond (8.70-17.43mg/l).The minimum concentration of Co, Cu,Cr, Ni, Cd, Zn, Pb and was recorded as 0.008, 0.017, 0.002, 0.008, 0.004, 0.021 and 0.004 mg/l respectively whereas the maximum value was recorded 0.018, 0.025, 0.004,0.019, 0.034, 0.096,and 0.026 mg/l respectively at different sites in surface water of the river Gandak. Most of the above values were found either below or closed the permissible limit set by World Health Organization (WHO) and United State Public Health Survices (USPHS). Water Quality Index (WQI) was ranged between 76-85 which indicates that the water quality is good. Correlation analysis among all considered Physico-chemical parameters and heavy metals shows good correlation with each other in both the years. The data generated may provide useful information to Governmental agencies to control the heavy metal pollution of the river at these urban centers which may even be worst in future scenario. The present experimental data indicates that the pollution level along the river Gandak is not very high but the increasing population load in the basin may cause irreparable ecological harm in the long-term.*

Keywords*: Gandak River water. Environmental pollution. Heavy metals contamination. Water Quality Index. Correlation matrix.*

Introduction: Rivers serve as the most important freshwater resource for human beings. Most of the Himalayan Rivers passes through various types of geographical areas which have their specific characteristic features. Rivers come in contact with different types of rocks in their pathway which are weathered by physical, chemical and biological processes. The weathered elements by the natural processes add directly in to the river system. Various types of chemicals also added in the rivers by anthropogenic activities which contribute in changing the physical, chemical, and biological properties of the rivers water. Besides these human influences, river water quality is also affected by other natural activities viz. geological, hydrological, and climatic factors [1]. They arrying approximately 2,000 km3 water globally [2]. Rivers present a continuously renewable physical resource used for domestic, industrial, and agricultural purposes, as means for waste disposal, transportation, getting food resources, and recreational activities [3].

Physico-chemical parameters viz. pH, BOD, DO, COD, nitrate, Phosphates etc indicates about the health of a river body. These parameters has become of public interest in the world because not only developed countries but also developing nations suffer the impact of pollution due to disordered economic growth associated with exploration of virgin natural resources [4]. In India, several studies have documented physico-chemical, biological, and toxicological aspects of the water and sediments of Ganga River [5,6]. Water quality is highly variable, which occur not only with regard to their spatial distribution but also over time.

Surface water quality of river is also greatly affected by various heavy metals. These are a special group of trace elements which have been shown to create definite health hazards when taken up by aquatic biota. Under this group are included, Cr, Cd, Ni, Zn, Cu, Pb and Fe. These are called heavy metals because in their metallic form, their densities are greater than 4g/cc. The contamination of river water and biota by heavy metals is one of the major concerns especially in many industrialized countries because of their toxicity persistence and bioaccumulation [7]. Many rivers of the world receive flux of sewage, domestic waste, industrial effluents and agricultural waste which contain substances varying from simple nutrients to highly toxic chemicals [8].

Heavy metal pollution of waste water is a significant environmental problem and has a negative impact on human health and agriculture [9]. The concentration of pollutants in water samples only indicate the situation at the time of sampling, while concentrations in the organism are the result of past as well as current pollution levels in the environment in which the organism lives [10]. A previous study indicated that potential sources of elevated levels of heavy metals were sewage wastes, wastes from metal processing industries and other household refuse [11]. Generally, the main natural source of heavy metals in water is weathering of minerals [12]. Industrial effluents and non-point pollution sources, as well as changes in atmospheric precipitation can lead to local increase in heavy metals concentration water. Also, total heavy metals concentrations in aquatic ecosystem can mirror the present pollution status of these areas [13] .Tannery industry contributes significantly towards exports, employment generation and occupies an important role in Indian economy. Heavy metals released from tanneries are kept under environment pollutant category due to their toxic effects on plants, animals and human beings. They interfere with physiological activities of plants such as photosynthesis, gaseous exchange and nutrient absorption and cause reduction in plant growth, dry matter accumulation and yield [14]. They cause direct toxicity, both to human and other living beings due to their presence beyond specified limits. The metals present in the soil can enter in the aquatic system by weathering, percolation, and surface runoff from agricultural land [15]. Soil can also be polluted by wastewater irrigation. These contaminated soils may have an impact on water quality. Therefore, protection of the soil around the industrial region is of prime importance for the quality of soil and water. Temporal variations in precipitation, surface runoff, interflow, groundwater flow, and pumped in and outflows have a strong effect on river discharge and subsequently on the concentration of pollutants in river water [16].

Water quality monitoring and evaluation is the foundation of water quality management; thus, there has been an increasing demand for monitoring water quality of many rivers by regular measurements of various water quality variables [1]. Assessment of seasonal changes in surface water quality is an important aspect for evaluating temporal variations of river pollution due to natural or anthropogenic inputs of point and nonpoint sources [17]. The present paper describes the physico-chemical properties and heavy metals concentration in the water of the river Gandak. It provides a scientific basis for pollution control and its monitoring. The obtained data provide essential information for the preventive measures and/or remedial actions to be taken to overcome the risk and impact increasing population in the river basin area.

Study Area: The River Gandak is known as both name Saligrami and Kali Gandaki in Nepal and Naraini in plain. Gandak River is one of the major tributary of the river Ganga and drains the area of both Nepal and India. It originates near the Nepal-Tibet border at an altitude of 7,620m to the north-east of Dhaulagiri and flows about 100 km in a South-Easterly direction in Nepal. It drains the central part of Nepal and separates the boundary of Utter Pradesh and Bihar after entering Champaran district (Bihar) at Trivani. It turns to the South-East and join the left bank of Ganga at Sonpur (Bihar). A number of tributaries, such as the Mayangadi, the Bari, the Trisuli, the Panchnad and the Sonhad join the river. The total drainage area of the river is 46,300 sq. km of which 7,620 sq. km is in India. The river flows across the Gangetic plain of Bihar state and eventually merges with the Ganga near at Hajipur or Patna. The entry point of the river at the Indo-Nepal border is at the convergence of Gandak, Known as Triveni. Here the rivers meet with Pachnad and Sonha also sliding into India from Nepal. Pandai River flows in to the Indian state of Bihar from Nepal in the eastern end of the Valmiki Sanctuary and finally meets Masan. The drainage area of this river in India is 7620 sqkm. After the river enters in India at Triveni, it flows for an extended length of 300 km and then joins the Ganga. Before merging with the river Ganga near Patna, it flows through the district of Champaran, Sarans, and Muzaffarpur. The total length of the Gandak River is 630 km out of which 330 km flows in Nepal and Tibet.

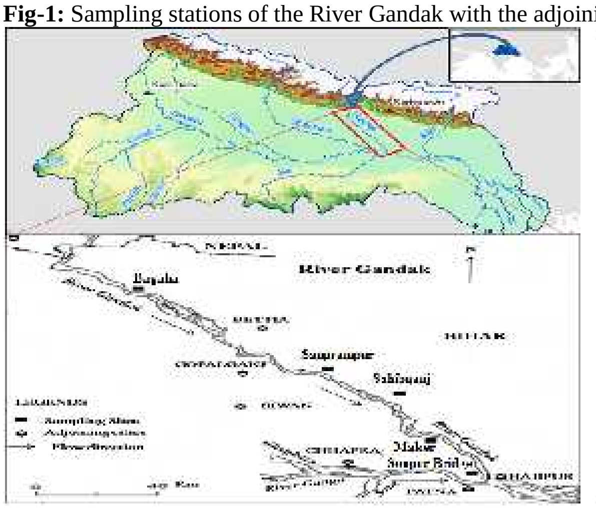
Study Area: A comprehensive survey was carried out during the year 2014-15 and 2015-16 in three consecutive seasons *i.e.* monsoon, winter and summer for the study purposes. The study area covers the entire stretch of the river Gandak in Indian Territory, which covers from Eastern Uttar Pradesh to Western part of Bihar in Middle Gangetic plain. The study sites are given in the Table: 1 with their geographical co-ordinates. There are five sampling stations were selected for the study purposes from Bagaha in West Champaran district (Bihar) to Sonpur Bridge in Saran district of Bihar (Fig:1).

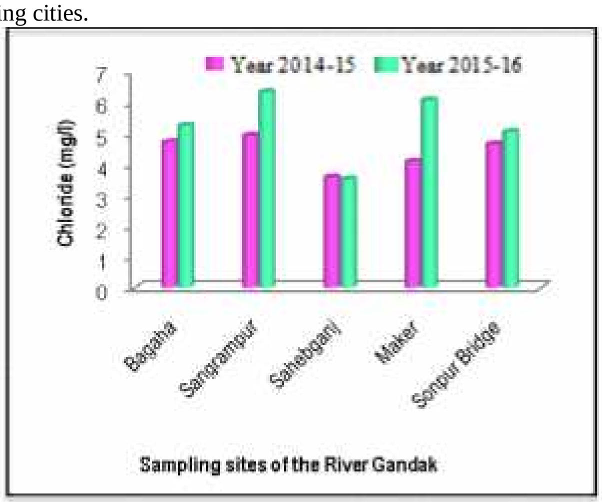
Materials and Methods

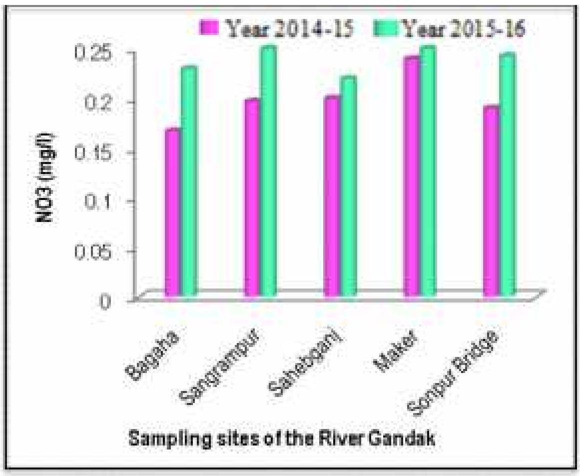
Table: 1 Sampling sites of the River Gandak with their geographical co-ordinates

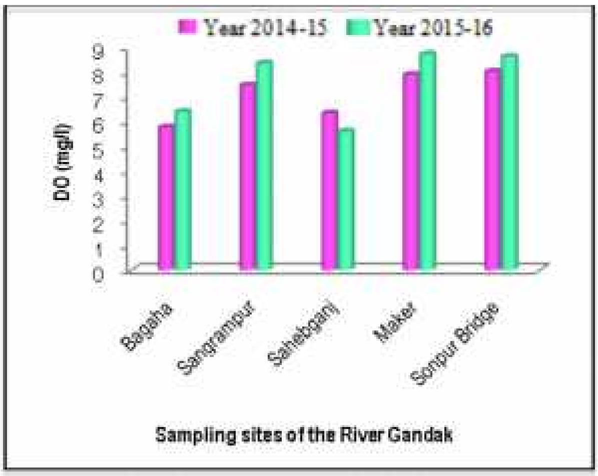
Study sites	Latitude	Longitude	Elevation(ft)	District	State
Bagaha	26º06′36″N	84º04′34″E	314	West Champaran	Bihar
Sangrampur	26º29′30″N	84º41′03″E	227	East Champaran	Bihar
Sahibganj	26º18′01″N	84º55′50″E	206	Muzaffarpur	Bihar
Maker	25º57′35″N	85º01′50″E	186	Maker	Bihar
Sonpur Bridge	25º41′30″N	85º11′24″E	160	Saran	Bihar

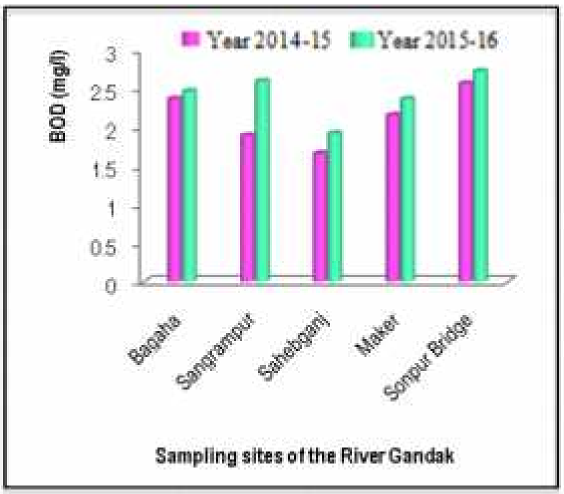
Fig-1: Sampling stations of the River Gandak with the adjoining cities.

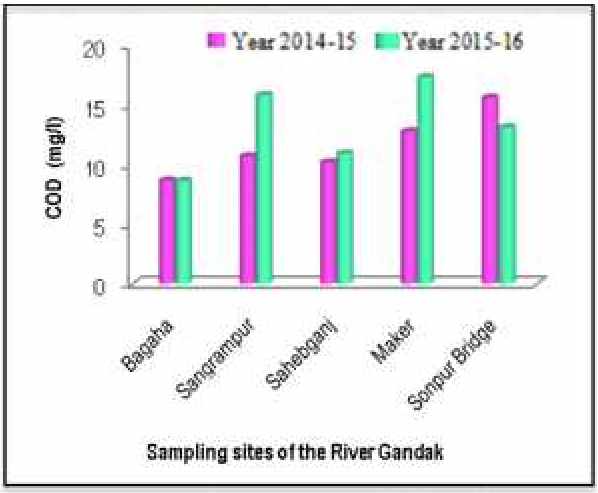












Sampling sites of the River Gandak: Bagaha is a small town of West Champaran district of Bihar. It is situated at the bank of river Gandak where Bihar, Utter Pradesh and Nepal are confluences. It has an average elevation of 135 meters (442 feet). It is located between 26º 06′ 36 ″N and 84 º 04′ 34″E. The town has more than 1,00000 people. The area is very fertile due to its location in the terai of Himalayas. There are many small scale industries like textile (colouring reagents), sugarcane industries have established in this region. The domestic and industrial wastes are released into the river by open drain. According to the 2011 census West Champaran district has a population of 3,922,780. Some agro-based industries have flourished here and are being run successfully. Sugar mills are established at Majhaulia, Bagaha, Ramnagar, Narkatiaganj, Chanpatia and Lauria. The last two units are closed at present. These are the main source of pollution of the river Gandak.

Sangrampur is located between 26º 29′ 30″N and 84º 41′ 03″E. According to the 2011 census East Champaran district has a population of 5,082,868. This gives it a ranking of 21st in India (out of a total of 640). The district has a population density of 1,281 inhabitants per square kilometer (3,320 /sq mi). Its population growth rate over the decade 2001-2011 was 29.01 %. As of 2011 it is the second most populous district of Bihar (out of 39), after Patna.

Sahibganj is a Town in Sahibganj Tehsil in Muzaffarpur District in Bihar State. The geographical position of this site is 26º 18′ 01″N and 84º 55′ 50 ″ E. According to the 2011 census Muzaffarpur district has a population of 4,778,610. Its population growth rate over the decade 2001-2011 was 27.54 %. It has many industries ranging from small to big. Prabhat Zarda Factory, Bharat Wagon and Engineering Ltd, N.T.P.C., Bihar Drugs & Organic Chemicals Ltd, a unit of IDPL, units of Leather Development Corporation, Muzaffarpur Dairy, a unit of the Bihar State Dairy Corporation unit Bihar State Cooperative Milk Producer's Federation Ltd, Muzaffarpur producing Sudha brand packaged milk are the major industries located in Muzaffarpur city and its periphery. Agro-based Industries likes Sugar mills, Britannia Biscuits have newly been established in City. The above industries are the main sources of Pollution.

Maker is a small town of Saran district. The District is one of the thirty–seven districts of Bihar state, India. It is located between 25º 57′ 35 ″ N and 85º 01′ 50 ″ E. According to the 2011 census Saran district has a population of 3,943,098, roughly equal to the nation of Liberia or the US state of Oregon. This gives it a ranking of 60th in India (out of a total of 640). The district has a population density of 1,493 inhabitants per square kilometre (3,870 /sq mi). Its population growth rate over the decade 2001-2011 was 21.37 %.

Sonpur Bridge is a town in the Indian state of Bihar, situated on the banks of the River Gandak in Saran district in the Indian state of Bihar. The town is located at 25° 41′ 30″N and85° 11′ 24″E at an altitude of 160 ft. It is on the confluence of four rivers. The current township Patna is just the modern version of the makeshift head quarters of military establishments of old Patna city which in turn was later version of Patliputra, the capital of Marya Empire. It is connected by two rivers, Ganges and Gandak. As of 2001 India census Sonpur had a population of 33,389.

Water Sampling Procedures: The periodic samplings were carried out in monsoon, winter and summer seasons (with three replicates) in two consecutive years 2013-2014 and 2014-2015. The site of sampling is selected randomly by considering the population, location and source of pollutions. There were five sampling stations were selected for the study proposes. River water samples were collected at depths varying from 15 to 30 cm with the help of a water sampler which consisted of a glass bottle and a cord tied to a lid. The whole assembly was lowered into water to the desired depths and the cord of the lid was pulled and released only when displaced air bubble ceased to come to the surface. The whole assembly was withdrawn and the water was then transferred into pre-cleaned polypropylene bottles. All the containers which used in sampling purposes were thoroughly washed and rinsed with 10% HNO_3 following by double distilled water. The bottles were filled leaving no air space, and then the bottle was sealed to prevent any leakage. Each container was clearly marked with the name and address of the sampling station, sample description and date of sampling. All the procedures were adopted according to the standard methods recommended by [18].

Analysis of Physico-chemical Parameters of Water Samples: The water samples were analyzed for various parameters in the laboratory of Botany Department, University of Allahabad. The standard methods recommended by [19] were adopted for determination of various physico-chemical parameters. Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Alkalinity, and Total Dissolved Solids (TDS) were measured using water analysis kit model ITS-701. All parameters multiprobes of the kit were calibrated together using the same standards and procedures. Electrical Conductivity was calibrated against 0.005, 0.05 and 0.5 M standard Potassium Chloride solutions. pH was calibrated with standard buffer solution at pH - 4 and pH - 9.2. Dissolved Oxygen was calibrated against Zero solution (Sodium Sulphite) and an air saturated beaker of water checked with a Winkler's titration. Temperature is factory set and cannot be adjusted, but was checked against a standard Mercury thermometer for consistency between multi-probes. Dissolved Oxygen was also measured by modified Winkler's method at the site. Total Suspended Solids (TSS) was measured by filtering 50 ml of water sample through Whatmann 41 filter paper. Total Hardness was analysed by multiprobe kit model 191 E. For the determination of Hardness, 50 ml of sample was buffered at pH 8 -10 (NH4Cl and NH4OH) and titrated against standard EDTA using Erichrome Black T as indicator. Chlorine was measured by Chlorine Meter Model: ITS-1001. Phosphate, Nitrate, Sulphate and COD was determined by Direct COD multiprobe measuring system. BOD was also determined by Direct BOD measuring system.

Preparation of Water Sample for the Analysis of Heavy Metals: For determination of heavy metals in water, water samples (50 ml) were digested with 10 ml of conc. HNO_3 at 80^0 C until the solution became transparent [20]. The solution was filtered through Whatman No. 42 filter paper and diluted to 50 ml with double distilled water. These samples were used to determine heavy metal concentrations by Atomic Absorption Spectrophotometer (Perkin-Elmer model 800, USA).

For evaluating precision and accuracy of the analytical procedure used in the above experiment, duplicates and analytical blanks were prepared and analyzed using the same procedures and reagents. The accuracy for each element Care was taken during sampling, handling and analysis to prevent the samples coming in to the contact with dust and metals. The obtained data have in general an error of less than ten percent when compared to reference sample data.

Heavy metals were determined by atomic absorption spectrophotometer (AAS). Atomic Absorption spectroscopy is an absorption methods where radiation absorbed by metal ions, excited atoms in the vapors state. In atomic absorption spectroscopy, the sample is first converted at a selected wavelength, which is characteristic of each individual element. The same experimental condition was also applied for the determination of the reference samples of known composition

Statistical and Computational Analysis

Mean: For a data set, the mean is the sum of the observations divided by the number of observations. It identifies the central location of the data, sometimes referred to in English as the average. The mean is calculated by stat software Statistica 8, using, and the following formula.

$\Sigma(X)\ M = N$

Where Σ = Sum of

X = Individual data points

N = Sample size (number of data points)

Standard Deviation (SD): The standard deviation is the most common measure of variability, measuring the spread of the data set and the relationship of the mean to the rest of the data. If the data points are close to the mean, indicating that the responses are fairly uniform, then the standard deviation will be small. Conversely, if many data points are far from the mean, indicating that there is a wide variance in the responses, then the standard deviation will be large. If all the data values are equal, then the standard deviation will be zero. The standard deviation is calculated by stat software Statistica 8, using the following formula.

$\Sigma(X\text{-}M)\ 2\ S2 = n - 1$

Where Σ = Sum of

X = Individual score

M = Mean of all scores

N = Sample size (number of scores)

Water Quality Index (WQI)

A commonly-used water quality index (WQI) was developed by the National Sanitation Foundation (NSF) in 1970 [21]. The NSF WQI was developed to provide a standardized method for comparing the water quality of various bodies of water. It is a 100 point scale that summarizes results from a total of nine different physico-chemical measurements completed by the data taken from the analysis of undertaken rivers water. These nine factors are as follows

1. Temperature
2. pH
3. Dissolved Oxygen
4. Turbidity
5. Fecal Coliform
6. Biochemical Oxygen
7. Total Phosphates
8. Nitrates
9. Total Suspended Solids

In these nine parameters some were judged more important than others, so a weighted mean is used to combine the values. According to the book *Field Manual for Water Quality Monitoring*, the National Sanitation Foundation (NSF) .When test results from fewer than all nine measurements are available, we preserve the relative weights for each factor and scale the total so that the range remains 0 to 100. The 100 point index can be classified into five grades, which are as follows; 0-25 (very bad), 25-50 (bad), 50-70 (medium), 70-90 (good) and 90-100 (Excellent).

Correlation Study: The word correlation is made of Co-(meaning "together"), and Relation. When two sets of data are strongly linked together we say they have a high correlation. Correlation is Positive when the values increase together; and correlation is negative when one value decreases as the other increases. Correlation can have a value:

- 1 is a perfect positive correlation
- 0 is no correlation (the values don't seem linked at all)
- -1 is a perfect negative correlation.

Results and Discussions

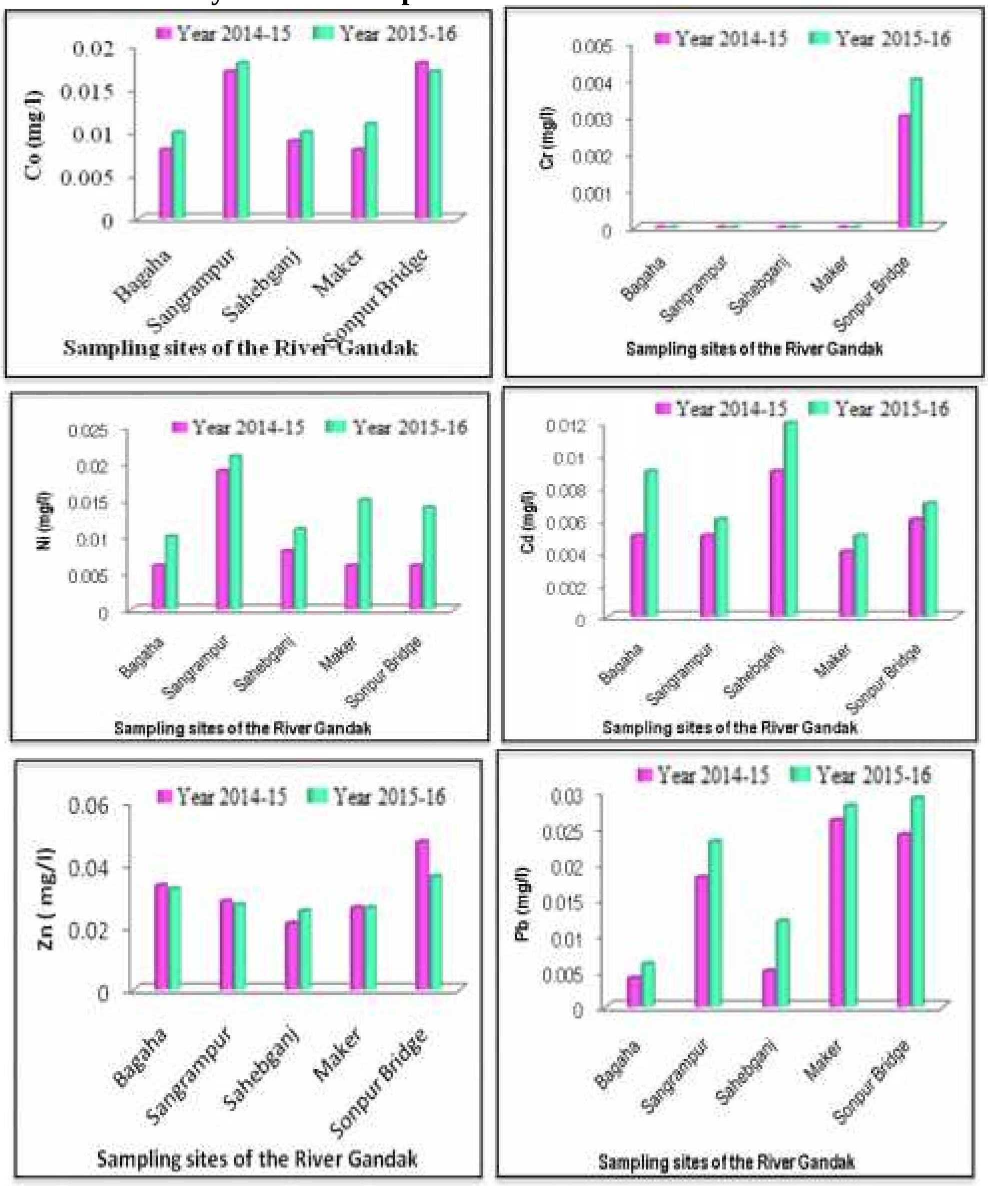
Assessment of Physico-chemical properties of the River Gandak at Different Sites: Physico-chemical status of the river Gandak showed seasonal variations at different undertaken sites. The experimental findings of physico-chemical analysis of water of river Gandak at various sites for two consecutive years2014-15 and 2015-16 is presented in Tables: 2.

Table: 2 Water quality status of the River Gandak at different sites in Bihar

	Physico-chemical properties of the river Gandak									
Parameters	**Bagaha,**		**Sangrampur**		**Sahibganj**		**Maker**		**Sonpur Bridge**	
	Year 2014-15 Mean ± SD	**Year 2015-16 Mean ± SD**	**Year 2014-15 Mean ± SD**	**Year 2015-16 Mean ± SD**	**Year 2014-15 Mean ± SD**	**Year 2015-16 Mean ± SD**	**Year 2014-15 Mean ± SD**	**Year 2015-16 Mean ± SD**	**Year 2014-15 Mean ± SD**	**Year 2015-16 Mean ± SD**
Temp (C^0)	23.27± 5.60	22.67± 5.61	25.4± 5.74	24.4± 6.16	26± 5.40	25.53± 8.90	25.9 ± 6.16	26.5 ± 5.5	25.6± 6.40	26.9 ± 6.28
pH	8.2± 0.10	8.13± 0.15	8.2± 0.10	8.23± 0.15	8.13± 0.15	8.2± 0.26	8.3± 0.2	8.17± 0.20	8.03± 0.25	8.2 ± 0.20
TDS	165± 15.13	125± 11.63	199± 41.21	187± 69.59	131± 21.47	109± 7.51	178± 19.85	194± 26.8	202± 45	219 ± 40.96
EC µmhos/cm	264± 27.87	232± 39.36	256± 70.18	259± 100	244± 39	216± 31.96	239± 40.67	267± 45.23	235± 56.9	199 ± 40.96
Alk (mg/l)	114± 22.36	110± 32.88	102± 26.81	74.47± 25.59	124± 17.43	128± 11.03	114± 16.35	129± 23	106± 40.64	124± 58.28
T.H (mg/l)	153± 18.52	148± 26.56	141± 19.07	164± 23.97	137± 31	135± 30.45	152± 28.40	142± 28	135± 11.37	150± 52.25
SO_4 (mg/l)	21.87± 4.98	23.53± 4.19	22.27± 2.15	25.37± 6.34	15.47± 4.14	16.33± 4.30	21.77± 1.76	23.87± 5.76	25.73± 4.13	25.37± 21.79
PO_4 (mg/l)	0.056± 0.030	0.07± 0.026	0.08± 0.03	0.10± 0.030	0.05± 0.01	0.07 ± 0.026	0.06± 0.01	0.05± 0.02	0.06 ± .015	0.046± 8.10
Cl (mg/l)	4.73± 0.91	5.27±1.05	4.95± 1.99	6.36± 2.00	3.6± 0.45	3.53± 0.750	4.1± 0.98	6.1± 0.81	4.67± 2.32	5.07± 0.005
Nitrate (mg/l)	0.167± 0.57	0.23± 0.057	0.197± 0.02	0.25± 0.043	0.20± 0.09	0.22± 0.16	0.25± 0.12	0.24± 0.06	0.19± 0.07	0.443± 2.89
DO (mg/l)	5.76± 1.38	6.4± 0.871	7.47± 1.56	8.36± 1.53	6.34± 2.25	5.6± 2.1	7.9± 0.40	8.73± 1.20	8.03± 1.46	8.63± 0.23
BOD (mg/l)	2.37± 0.25	2.47± 0.208	1.9± 0.20	2.6± 0.264	1.67± 0.47	1.93± 0.67	2.16± 0.66	2.37± 0.67	2.57± 0.41	2.73± 1.01
COD/(mg/l)	8.73± 0.50	8.70± 1.234	10.76± 6.49	15.93± 5.75	10.27± 3.20	11± 3.20	12.87± 6.16	17.43± 5.41	15.7± 6.8	13.2± 0.40
	Heavy Metals Concentration in water of the River Gandak									
Co(mg/l)	0.008± 0.005	0.010±0.002	0.017± 0.005	0.018± 0.009	0.009± 0.004	0.010± 0.005	0.008± 0.003	0.011± 0.005	0.018± 0.005	0.020± 2.72
Cu (mg/l)	0.018± 0.012	0.024± 0.017	0.017± 0.008	0.025± 0.014	0.023± 0.011	0.026± 0.010	0.022± 0.010	0.025± 0.013	0.025± 0.009	0.038± 0.007
Cr (mg/l)	0± 0.00	0 .00	0±0.00	0 ± 0.00	0.00	0.00	0± 0.00	0.00	0.003± 0.002	0.004± 0.012
Ni (mg/l)	0.006± 0.003	0.010± 0.004	0.019± 0.012	0.021± 0.012	0.008± 0.008	0.011± 0.009	0.006± 0.005	0.015± 0.006	0.006± 0.002	0.034± 0.003
Cd(mg/l)	0.005±0.003	0.009± 0.005	0.005± 0.002	0.006± 0.002	0.009± 0.010	0.012± 0.006	0.004± 0.003	0.005± 0.003	0.034± 0.002	0.007± 0.049
Zn (mg/l)	0.033±0.098	0.032± 0.012	0.028± 0.004	0.027± 0.011	0.021± 0.003	0.025± 0.010	0.026± 0.012	0.028± 0.011	0.032± 0.013	0.036± 0.002
Pb (mg/l)	0.004± 0.002	0.006± 0.003	0.018± 0.010	0.023± 0.014	0.005± 0.003	0.012± 0.005	0.026± 0.009	0.018± 0.009	0.024± 0.013	0.029± 0.011

Temperature: The basis of all life functions is complicated set of biochemical reactions that are influenced by physical factors such as temperature. No other factor has so much influence on temperature, [22]. It controls behavioral characteristics of organisms, solubility of gases and salts in water. At Bagaha the average temperature of the River Gandak was recorded as 23.27 ° C ± 5.60 ºC in the year 2014-15and 22.67ºC± 5.61ºC in 2015-16. At Sangrampur the average temperature was recorded 25.4 ° C ± 5.74 ºC in the year 2014-15and 24.4 ºC ± 6.16 ºC in 2015-16. At Sahibganj the average temperature was recorded 26 ° C ± 5.40ºC in the year 2014-15and 25.53 ºC±8.90 ºC in 2015-16. The average temperature was recorded 25.9 ± 6.16 ºC in the year 2014-15and 26.5 ± 5.5 ºC in 2015-16 at Maker. At Sonpur Bridge the average temperature was recorded 25.6 ºC ± 6.40 in the year 2014-15 and 26.9 ºC ± 6.28 ^{0}C in 2015-16. The temperature of water of the River Gandak at different sites are presented in Fig:2. Change in temperature was observed in water due to biotic and abiotic reactions and water temperature changes were according to change in atmospheric change as observed by [23]. In the river Gandak the maximum average temperature was recorded as 26.9 °C at Sonpur Bridge in the year 2015-16 whereas the minimum temperature was recorded as 22.7 ^{0}C at Bagaha in the year 2015-16 (Table 2). In all sampling stations the minimum temperature was recorded in winter season whereas the maximum in summer season for all the undertaken rivers. The similar observations were also reported by [24] in Narmada River.

Fig: 2 value of various Physico-chemical parameters at different site f the River Gandak



pH: The pH of water indicates the acidity of an aquatic system, and is influenced by nutrients, organic acids, metals, gases, algae (*i.e.*, photosynthesis), solar radiation (*i.e.*, temperature), and particulates [25] updated to 2012). It has no direct adverse effect on health, however, a low value, below 4.0 will produce sour taste and higher value above 8.5 shows alkaline taste. In the river Gandak the maximum average pH value was recorded as 8.3 at Maker in the year 2014-15whereas the minimum value of pH was recorded as 8.03 at Sonpur Bridge in 2015-16. The range of desirable pH of water prescribed for drinking purpose by ISI [26] and WHO [27] is 6.5 to 8.5 (Table 3). In present study the pH values of water of the undertaken rivers was found within the permissible limit setup by WHO. At Bagaha the average pH of the River Gandak was recorded as 8.2 ± 0.10 in the year 2014-15and 8.13 ± 0.15 in 2015-16. At Sangrampur the average pH was recorded 8.2 ± 0.10 in the year 2014-15and 8.23 ± 0.15 in 2015-16. At Sahibganj the average pH was recorded 8.13 ± 0.15 in the year 2014-15and 8.2 ± 0.26 in 2015-16. At Maker the average pH was recorded 8.3 ± 0.2 in the year 2014-15and 8.17 ± 0.20 in 2015-16. At Sonpur Bridge the average pH was record 8.03 ± 0.25 in the year 2014-15and 8.2 ± 0.20 in 2015-16 (Table 2). The pH values of water of the River Gandak at different sites are presented in Fig: 2. In the present study the pH value showed seasonal variability at all the sites throughout the year.

Table: 3 Comparative descriptions of ranges of present study of all considered parameters of the River Gandak with standard permissible limits.

Parameters	Gandak		Permissible limit (mg/l)	Standards
	Min	Max		
Temp (C^0)	22.5	26.9		
pH	8.1	8.3	6.5-8.5	USPHS
TDS	109	219	500	USPHS
EC µmhos/cm	199	267	300	USPHS
Alk (Mg/l)	74	129	-	-
SO_4 (Mg/l)	15.47	25.75	250	USPHS
PO_4 (Mg/l)	0.05	0.10		
T.H (Mg/l)	135	164	500	WHO
Cl (Mg/l)	3.56	6.36	250	USPHS
Nitrate (Mg/l)	0.16	0.44	10	USPHS
Do (Mg/l)	5.6	8.7	4.0-6.0	USPHS
BOD (Mg/l)	1.67	2.73	5.0	USPHS
COD/(mg/l)	8.70	17.43	4.0	USPHS
Heavy Metals in water				
Co(Mg/l)	0.008	0.018	-	-
Cu (Mg/l)	0.017	0.025	1.0	WHO
Cr (Mg/l)	0.002	0.004	0.05	WHO
Ni (Mg/l)	0.008	0.019	0.1	WHO
Cd(Mg/l)	0.004	0.034	0.005	WHO
Zn (Mg/l)	0.021	0.096	5.00	WHO
Pb (Mg/l)	0.004	0.026	0.05	WHO

According to [28] the pH of most natural water ranges from 6.5 - 8.5 while deviation from the neutral pH 7.0 as a result of the CO_2/bicarbonate/carbonate equilibrium [29]. Stated that intense photosynthetic activities of phytoplankton will reduce the free carbon dioxide content resulting in increased pH values [30] have asserted that the high pH is associated with the phytoplankton maxima. The high values may be due to attributed sewage discharged by surrounding city and agricultural fields. pH value is very important for plankton growth [31]. According to [32] pH is ranged 5 to 8.5 is best for plankton growth. pH range showed that the water of all the sampling sites of all the undertaken rivers was alkaline in nature and high in summer.

Total Dissolved Solid (TDS): A large number of salts are found dissolved in natural waters, the common ones are carbonates, bicarbonates, chlorides, sulphates, phosphates, and nitrates of calcium, magnesium, sodium, potassium, iron, and manganese, etc. A high content of dissolved solid elements affects the density of water, influences osmoregulation of freshwater in organisms, reduces solubility of gases (like oxygen) and utility, of water for drinking, irrigational, and industrial purposes. In the River Gandak TDS ranged from a minimum of 109 mg/l at Sahibganj in the year 2015-16 to a maximum of 219 mg/l at Sonpur Bridge in the year 2015-16. At Bagaha the average value of water of the river Gandak TDS was recorded as 165 ± 15.13 mg/l in the year 2014-15and 125 ± 11.6 mg/l in 2015-16. At Sangrampur the average value of TDS were recorded 199 ± 41.21 mg/l in the year 2014-15and 187 ± 69.59 mg/l in 2015-16. At Sahibganj the average value of TDS were recorded 131 ± 21.47 mg/l in the year 2014-15and 109 ± 7.51 mg/l in 2015-16. At Maker the average value of TDS were recorded 178 ± 19.85 mg/l in the year 2014-15and 194 ± 26.8 mg/l in 2015-16. At Sonpur Bridge the average value of TDS were recorded 202 ± 45 mg/l in the year 2014-15and 219 ± 40.96 mg/l in 2015-16. The TDS of water of the River Gandak at different sites are presented in the table 2.

TDS analysis has great implications in the control of biological and physical waste water treatment processes. Waters can be classified based on the concentration of TDS as, desirable for drinking (up to 500mg/L), permissible for drinking (up to 1,000mg/L), useful for irrigation (up to 2,000mg/L), not useful for drinking and irrigation (above 3,000mg/L). In present study TDS values were found far below the permissible level of drinking water standards of WHO (1000 mg/l). This result is also supporting the studies of [33].

Electrical Conductivity (EC): It is an excellent indicator of TDS which is a measure of salinity that affects the taste of potable water. At Bagaha the average EC of the River Gandak was recorded as 264 ± 27.87 mg/l in the year 2014-15and 232 ± 39.36 mg/l in 2015-16. At Sangrampur the average value of Electrical Conductance (EC) was recorded 256 ± 70.18 mg/l in the year 2014-15and 259 ± 100 mg/l in 2015-16. At Sahibganj the average value of Electrical Conductance (EC) was recorded 244 ± 39 mg/l in the year 2014-15and 216 ± 31.96 mg/l in 2015-16. At Maker the average value of Electrical Conductance (EC) was recorded 239 ± 40.67 mg/l in the year 2014-15and 267 ± 45.23 mg/l in 2015-16. At Sonpur Bridge the average value of Electrical Conductance (EC) was recorded 235 ± 56.9 mg/l in the year 2014-15and 199 ± 40.96 mg/l in 2015-16. The EC of water of the River Gandak at different sites are presented in the table 2.

Electrical conductivity is a numerical expression ability of an aqueous solution to carry electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations and temperature of measurement. It is an excellent indicator of TDS which is a measure of salinity that affects the taste of potable water [27]. Chemically pure water does not conduct electricity. Any rise in the Electrical Conductivity of water indicates pollution. Electrical conductivity measurements can be used to calculate total dissolved solids by multiplying electrical conductivity (in LS/cm) by an empirical factor which varies between 0.55 to 0.9, depending on the soluble components of the water and the temperature of measurements. The higher values are obviously due to the contamination river water may be due to the ions like OH-, CO3 Cl-, Ca+2 etc. Whereas the permissible limit is 300 μmho/cm prescribed by USPHS [34].

In the River Gandak EC ranged from a minimum of 199 µmhos/cm at Sonpur Bridge in the year 2015-16 to a maximum of 267 µmhos/cm at Maker in the year 2015-16. In present study values of EC were found below the permissible level of drinking water standards of USPHS [34] (300 mg/l) at most of the. EC for the river Gandak at different places are displayed in the Fig: 2. It was noted that Conductivity was maximum in the months of May-June when the water level in the rivers was minimum. The electrical conductivity during summer was maximum at most of the sites and lowest during monsoon. Lowest electrical conductivity during monsoon season may attribute to the increase level of water in the rivers due to rainfall, whereas increase in electrical conductivity may be attributed to decrease in the water level due to evaporation and increase in organic matters such as plant debris enter the riverine. Similar observation was made by [35]. In the present observation about the relationship between conductivity and TDS is very much similar to the findings of [36]. In present study conductivity decreased during monsoon followed by progressive increase in winter and summer was also recorded by [37,38].

Alkalinity: It is generally a reflection of the local geology and bicarbonates being leached from the soil. High alkalinity may indicate high levels of primary production and nutrient inputs. At Bagaha the average alkalinity of the River Gandak was recorded as 114 ± 22.36 mg/l in the year 2014-15and 110 ± 32.88 mg/l in 2015-16At Sangrampur the average value of alkalinity was recorded 102 ± 26.81 mg/l in the year 2014-15and 74.47 ± 25.59 mg/l in 2015-16. At Sahibganj the average value of alkalinity was recorded 124 ± 17.43 mg/l in the year 2014-

15and 128 ± 11.03 mg/l in 2015-16. At Maker the average value of alkalinity was recorded 114 ± 16.35 mg/l in the year 2014-15and 129 ± 23 mg/l in 2015-16. At Sonpur Bridge the average value of alkalinity was recorded 106± 40.64 mg/l in the year 2014-15and 124 ± 58.28 mg/l in 2015-16 (table2). However the prescribed limit for Total Alkalinity is 120 mg/l (USPHS). In the river Gandak the maximum average alkalinity was recorded as 129 mg/l at Maker in the year 2015-16 whereas the minimum alkalinity was recorded as 74 mg/l at Sangrampur in the year 2015-16.

In the present investigation, the alkalinities were maximum during summer and winter and minimum during monsoon. This may be attributed to increase the rate of organic decomposition during which CO is liberated, which reacts with water to form HCO, thereby increasing the total alkalinity in summer. The increased alkalinity during summer and winter was due to the concentration of nutrients in water. The decrease was due to dilution caused by the rainwater during monsoon. [39] showed alkalinity to be inversely correlated with the water level. Similarly, it was observed that the higher values of total alkalinity with high bicarbonate contents in the rivers. This was further supported by the observations made by Brion(1973), Wetzel; (1983), that the rivers are highly productive from the viewpoint of alkalinity of its water. Dilution plays an important factor in lessening the alkalinity values [40]. The total alkalinity remains always higher in eutrophic water [41]. Average values were higher in the river Ganga than other rivers i.e. Ghaghara, Gandak and Kosi indicating higher trophic status of the Ganga river.

Total Hardness (TH): The principal Hardness causing cations are the divalent Calcium, Magnesium, Strontium, Ferrous and Manganese ions. Total Hardness (TH) of the water of the river Gandak shows different level of variability at different sites in different seasons. A Bagaha the average value of total hardness was recorded 153 ± 18.52 mg/l in the year 2014-15and 148 ± 26.56 mg/l in 2015-16. At Sangrampur the average value of total hardness was recorded 141 ± 19.07 mg/l in the year 2014-15and 264 ± 23.97 mg/l in 2015-16. At Sahibganj the average value of total hardness was recorded 137 ± 31 mg/l in the year 2014-15and 135 ± 30.45 mg/l in 2015-16. At Maker the average value of total hardness was recorded 152 ± 28.40 mg/l in the year 2014-15and 142± 28 mg/l in 2015-16. At Sonpur Bridge the average value of total hardness was recorded 135 ± 11.37 mg/l in the year 2014-15and 150 ± 52.25 mg/l in 2015-16. The TH of water of the River Gandak at different sites are presented in the table 2. In the river Gandak the maximum TH noted as 164 mg/l at Maker in the year 2015-16 whereas the minimum value was recorded as135 mg/l at Sangrampur (2015-16).

Total Hardness, a measure of the concentration of calcium carbonate in water, affects the accumulation and toxicity of numerous metals to aquatic biota (*i.e.*, metals are less toxic to aquatic life in hard water). Hardness is a reflection of the type of soil minerals and bedrock in the local environment, as well as the hydrological characteristics of the area (*e.g.*, length of time water is in contact with bedrock). Based on present investigation, Hardness varied from 53 to 330 mg/l. However the permissible limit of Hardness for drinking water is 300 mg/l [26,42]. In the present study total hardness ranged from 426 to 108 mg/l in different seasons. These high values may be due to the addition of calcium and magnesium salts. The increase in hardness can be attributed to the decrease in water volume and increase in the rate of evaporation at high temperature. During winter, decomposition of organic matter became reduced and CO_2 is not liberated into the aquatic medium. Generally the dilution of hardness decreases with the advent of rains [43] and increases with the decrease in water levels **[44]**. [45] Reported total hardness was high during summer than rainy season and winter season. However [46] studied on Pethwadaj Dam, Nanded, Maharashtra, the maximum values were recorded during monsoon while minimum during winter. [47] Reported that the total hardness was higher in summer. In the present investigation, the alkalinities were lower in monsoon, moderate in winter and higher in summer.

Sulphates (SO_4^{--}): It is present in fertilizers they contribute to water pollution and increase sulphate concentration in water body. They also come from the runoff water, which contains relatively large quantities of organic and mineral sulphur compounds. The supply of sulphate ions in surface water under natural conditions are due to the reactions of water with sulphate containing rock and with the biochemical oxidation of sulphides and other compounds of sulphur. The most stable form of sulphur in water is at 25 °C. The maximum permissible and allowable concentration of Sulphate in drinking water is 200 and 400 mg/l, respectively, according to

WHO. In the river Gandak the sulphate concentration was recorded between 15.47-25.73 mg/l, where minimum value was noted at Sahibganj in the year 2014-15and the maximum average value was recorded at Sonpur Bridge in the year 2015-16 (table 2). Sulphate concentration ranged between 10.9-25.73 mg/l for all the undertaken rivers, which was observed below the permissible limit set up by WHO (Table 3). So the river Ganga and its tributaries are safe from sulphate contamination.

Discharge of industrial wastes and domestic sewage in water ends to increase its concentration. Sulphate is present in fertilizers they contribute to water pollution and increase sulphate concentration in water body. In present study SO_4^{--} of the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of Sulphates was recorded 21.87 ± 4.98 mg/l in the year 2014-15and 23.53 ± 4.19 mg/l in 2015-16. At Sangrampur the average value of Sulphates was recorded 22.27 ± 2.15 mg/l in the year 2014-15and 25.37 ± 6.34 mg/l in 2015-16. At Sahibganj the average value of Sulphates was recorded 15.47 ± 4.14 mg/l in the year 2014-15and 16.33 ± 4.30 mg/l in 2015-16. Sulphate (SO_4^{--}) concentration of the water of the river Gandak shows different level of variability at different sites in different seasons. At Maker the average value of Sulphates was recorded 21.77 ± 1.76 mg/l in the year 2014-15and 23.87 ± 5.76 mg/l in 2015-16. At Sonpur Bridge the average value of Sulphates was recorded 25.73 ± 4.13 mg/l in the year 2014-15and 25.37 ± 21.79 mg/l in 2015-16. The SO_4 concentration of water of the River Gandak at different sites are presented in the table 2. In present investigation the maximum value was recorded in summer whereas the minimum value was noted in rainy season at most of the sites of all the undertaken rivers. Maximum Sulphate concentration recorded during summer due to low level of water discharge and addition of large amount of domestic effluents in to rivers. However, the low Sulphate concentration was noted during winter may be due to biodegradation in low water level. Similar results have been also reported [48].

Phosphate (PO_4^{--}): In most natural waters, phosphorus ranges from 0.005 to 0.020 mg/L. Algae require only small amounts of phosphorus. Excess amounts of phosphorus can cause eutrophication leading to excessive algal growth called algal blooms. Phosphate (PO_4^{--}) concentration of the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of total hardness was recorded 0.056 ± 0.030 mg/l in the year 2014-15and 0.07 ± 0.026 mg/l in 2015-16. In present study phosphate (PO_4^{--}) concentration of the water of the river Gandak shows different level of variability at different sites in different seasons. At Sahibganj the average value of total hardness was recorded 0.05 ± 0.01 mg/l in the year 2014-15and 0.07 ± 0.026 mg/l in 2015-16. At Maker the average value of Phosphate was recorded 0.06 ± 0.01 mg/l in the year 2014-15and 0.05 ± 0.02 mg/l in 2015-16. At Sonpur Bridge the average value of Phosphate was recorded 0.06 ± 0.015 mg/l in the year 2014-15and 0.046 ± 8.10 mg/l in 2015-16 (Table 2).

Phosphorus is the most common nutrient limiting the growth of phytoplankton in lentic fresh water systems and concentrations are often related to the productivity of aquatic systems [49]. In the river Gandak the maximum concentration noted as 0.10 mg/l at Sangrampur in the year 2015-16 whereas the minimum value was recorded as 0.05 mg/l at Sahibganj (2010-11). Among the major nutrients, the importance of phosphates in water bodies is well documented by [38]. [50] Pointed out that the addition of phosphate brings about an eutrophication mechanism by increasing the bacterial content, increase in oxygen demand, increase in production of growth factors for the algae and lastly the increase in growth of algae. The increased phosphate levels also indicate high degree of pollution.

Chloride (Cl^{-}): Excessive chloride in potable water is not particularly harmful and the criteria set for this anion are based primarily on palatability and its potentially high corrosiveness. Chloride (Cl^{-}) concentration of the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of chloride was recorded 4.37 ± 0.91 mg/l in the year 2014-15and 5.27 ± 1.05 mg/l in 2015-16. At Sangrampur the average value of chloride was recorded 4.95 ± 1.99 mg/l in the year 2014-15and 6.39 ± 2.00 mg/l in 2015-16. At Sahibganj the average value of chloride was recorded 3.6 ± 0.45 mg/l in the year 2014-15and 3.53 ± 0.75 mg/l in 2015-16. At Maker the average value of chloride was recorded 4.10 ± 0.95 mg/l in the year 2014-15and 6.10 ± 0.81 mg/l in 2015-16. At Sonpur Bridge the average value of chloride was recorded 4.67 ± 2.32 mg/l in the year 2014-

15and 5.07 ± 0.05 mg/l in 2015-16. The Cl^- concentration of water of the River Gandak at different sites are presented in the table 2 . These values are usually in the lower range of values in different rivers of India. In the present study chlorine value was below the permissible limit, may be attributed to the absence of major pollutants. Excessive chloride in potable water is not particularly harmful and the criteria set for this anion are based primarily on palatability and its potentially high corrosiveness. Chloride in excess (> 250mg/L) imparts a salty taste to water and people who are not accustomed to high chlorides may be subjected to laxative effects.

In the River Gandak the maximum level of Chloride recorded as 6.36 mg/l at Sangrampur (2015-16) whereas the minimum concentration was recorded as 3.53 mg/l at Sahibganj (2015-16). The results indicate that the chloride content is much below the acceptable limit of 200mg/L set by WHO and of 250 mg/L according to ISI (Table 7). In the present investigation, the Chloride values were and maximum during summer and minimum during winter. It can be concluded that there was no definite pattern of Chloride fluctuation, lower value during winter could be attributed to dilution effect and renewal of water mass alter summer stagnation and also may be due to high sedimentation rate on relatively stableand total environmental condition. Maximum value during summer could be due to higher concentration of Chloride resulted. Similar results have been reported [51,48] that the Chloride maximum value recorded in May while minimum recorded in August. The increase in chloride concentration in Lakes, Rivers and dams is due to discharge of municipal and industrial wastes [52].

Nitrate (NO_3^{--}): In water, nitrogen may be found in a number of forms: oxygen -nitrogen, ammonia-nitrogen, nitrate-nitrogen, and nitrite-nitrogen. Within surface waters, these various nitrogen pools may exist in particulate or dissolved forms. Nitrate (NO_3^{--}) concentration of the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of nitrate was recorded 0.167 ± 0.57 mg/l in the year 2014-15and 0.23 ± 0.05 mg/l in 2015-16. At Sangrampur the average value of nitrate was recorded 197 ± 0.02 mg/l in the year 2014-15and 0.197 ± 0.02 mg/l in 2015-16. At Sahibganj the average value of nitrate was recorded 0.20 ± 0.09 mg/l in the year 2014-15and 0.22 ± 0.16 mg/l in 2015-16. At Maker the average value of nitrate was recorded 0.25 ± 0.0.12 mg/l in the year 2014-15and 0.24 ± 0.06 mg/l in 2015-16. At Sonpur Bridge the average value of nitrate was recorded 0.19 ± 0.07 mg/l in the year 2014-15and 0.44 ± 0.89 mg/l in 2015-16. The NO_3 concentration of water of the River Gandak at different sites are presented in the table 2. In the River Gandak the maximum level of NO_3 recorded as 0.25 mg/l at Sangrampur and Maker (2015-16) whereas the minimum concentration was recorded as 0.16 mg/l at Bagaha (2010-11). Nitrate concentration was found extremely below the permissible limit (10 mg/l) set up by USPHS, [36] (table 3) which indicates about water quality of the undertaken rivers less rich in nitrates.

[53] Pointed out that the tropical waters; particularly unpolluted ones are deficient in nitrates. In the river Ganga and its tributaries nitrates are relatively much lower than the limit. Nitrate value was higher in summer and lower in rainy season. [54] Oserved similar trend and suggested that in summer, denitrifying bacteria degrade organic matters in to nitrates. In winter, however, the activities of these bacteria goes down resulting in lower the organic matter degradation in winter. During the study Nitrate fluctuated between 0.15 to 0.98 mg/l for all undertaken rivers in present study at most of the sites. These values are much lower than the [55]. High concentration of nitrate is drinking water is toxic [56].

Dissolved Oxygen: Dissolved oxygen is essential for the survival of most aquatic biota. It is consumed by aquatic organisms including animals, plants, algae, and bacteria in the water column and sediments. The concentration of DO in surface waters is affected by water temperature; colder water can hold more DO than warmer water and saturation occurs at a higher concentration in winter. In present investigation concentration of Dissolve Oxygen in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of DO was recorded 5.76 ± 1.38 mg/l in the year 2014-15and 6.4 ± 0.87 mg/l in 2015-16. At Sangrampur the average value of DO was recorded 7.47 ± 1.56 mg/l in the year 2014-15and 8.36 ± 1.53 mg/l in 2015-16. At Sahibganj the average value of DO was recorded 6.34 ± 2.25 mg/l in the year 2014-15and 5.60 ± 2.10 mg/l in 2015-16. At Maker the average value of DO was recorded 7.9 ± 0.40 mg/l in the year 2014-15and 8.73 ± 1.20 mg/l in 2015-16. At Sonpur Bridge the average value of DO was recorded 8.03 ± 1.46 mg/l in the year 2014-15and 8.63 ± 0.23 mg/l in 2015-16. Results shows that all undertaken rivers accumulates good quantity of oxygen (between 5-9 mg/l), which is above the permissible limit 4-6 mg/l (USPHS), so it is helpful in survival of the aquatic life. Sources of DO to aquatic systems are aeration (*i.e.*, input of oxygen from the atmosphere) and photosynthesis by plants and algae.

In present investigation Dissolved oxygen (DO) showed different level of seasonal variation throughout the year from site to site for the river Ganga and its tributaries. DO content was ranged from 5.0 – 9.0 mg/l in the study area in all the season during the study period, whereas the prescribed limit for DO by WHO is 5.0 mg/l. In the river Gandak the maximum DO noted as 8.7 mg/l at Maker in the year 2015-16 whereas the minimum value was recorded as 5.6 mg/l at Bagaha (2010-11). The maximum value was recorded in winter and minimum value was measured in the monsoon. The similar trends were also found by [57]. When temperature increases gas solubility of water decreases and microbial activity increases; both these changes can reduce DO in water. [58] Reported that dissolved oxygen is generally reduced during pre-monsoon due to increase respiration of biota, decomposition of organic matter, and raise in temperature, oxygen demanding waste and organic reduction such as hydrogen sulphate, ammonia, nitrite and ferrous iron. Dissolved oxygen showed a very clear picture. The increase of oxygen during winter months as in the present observation could be attributed to low temperature. Decomposition acts as the key role on oxygen content in nutrient rich tropical wetland where organic pollution is high and has very little oxygen dissolved in them. However, oxygen holding capacity of water reduces at higher temperature [59].

Biological Oxygen Demand (BOD): BOD values have been widely adopted as a measure of pollution effect. It is one of the most common measures of pollutant organic material in water. It indicates the amount of putrescible organic matter present in water. In present investigation BOD value in the water of the River Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of BOD was recorded 2.37 ± 0.25 mg/l in the year 2014-15and 2.47 ± 0.208 mg/l in 2015-16. At Sangrampur the average value of BOD was recorded 1.9 ± 0.20 mg/l in the year 2014-15and 2.6 ± 0.264 mg/l in 2015-16. At Sahibganj the average value of BOD was recorded 1.67 ± 0.47 mg/l in the year 2014-15and 1.93 ± 0.67 mg/l in 2015-16. At Maker the average value of BOD was recorded 2.16 ± 0.66 mg/l in the year 2014-15and 2.37 ± 0.67 mg/l in 2015-16. At Sonpur Bridge the average value of BOD was recorded 2.57 ± 0.41 mg/l in the year 2014-15and 2.73 ± 1.01 mg/l in 2015-16. The BOD of water of the River Gandak at different sites are presented in the table 2.

In the river Gandak the maximum BOD was noted as 2.73 mg/l at Sonepur Bridge in the year 2014-15whereas the minimum value was recorded as 1.67 mg/l at Sahibganj (2010-11). In the river Kosi the level of BOD was maximum 3.80 mg/l at Kursela in the year 2015-16 whereas the minimum value was recorded as 2.20 mg/l at Kosi Barraige Bhimnagar in the year 2010-11. The overall BOD range was noted between 1.67 to 6.67 mg/l for all the under taken rivers. BOD level exceeded than the permissible limit set by USPHS (Table 3) at many sites of the River Ganga.

BOD is the amount of oxygen required by the living organisms engaged in the utilization and ultimate destruction or stabilization of organic water [60]. It is very important indicator of the pollution status of a water body. Many workers like [61] showed higher BOD during summer due to low level at river discharge. In the present investigation the values of BOD clearly showed higher concentration during summer and comparatively low during winter and monsoon respectively [62]. In pre monsoon season maximum and minimum amount was found in monsoon season. Decrease of BOD during post-monsoon may be due to decrease in temperature which results in decrease in microbial activity and algal bloom. The present study supports the above findings. The present observation agrees with the findings of [63].

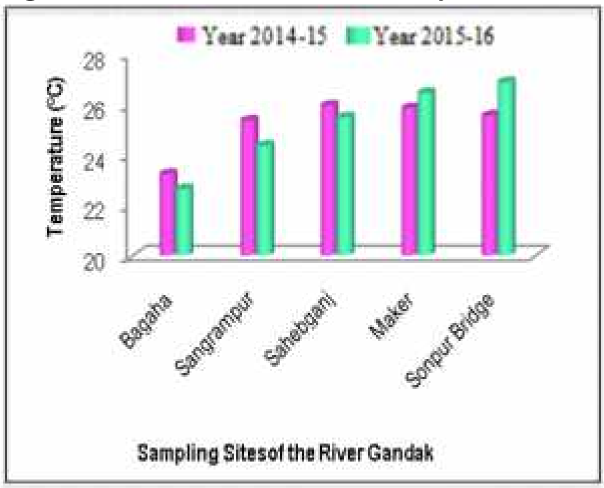
Chemical Oxygen Demand (COD): It is an important, rapidly measured parameter for industrial waste water studies and control of waste treatments. COD test is used to measure the load of organic pollutants in the industrial waste water. In present investigation the Value of COD in the water of the River Gandak shows different level of variability at different sites in different seasons. At Bagaha the average value of COD was recorded 8.73 ± 0.50 mg/l in the year 2014-15and 8.70 ± 1.234 mg/l in 2015-16. The minimum COD 8.2 mg/l was recorded in the winter season. At Sangrampur the average value of COD was recorded 10.76 ± 6.49 mg/l in the year 2014-15and 15.93 ± 5.75 mg/l in 2015-16. At Sahibganj the average value of COD was recorded 10.27 ± 3.20 mg/l in the year 2014-15and 11 ± 3.20 mg/l in 2015-16. At Maker the average value of COD was recorded 12.87 ± 6.16 mg/l in the year 2014-15and 17.43 ± 5.41 mg/l in 2015-16. At Sonpur Bridge the average value of COD was recorded 15.7 ± 6.8 mg/l in the year 2014-15and 13.2 ± 0.40 mg/l in 2015-16. The COD concentration of water of the River Gandak at different sites are presented in the table2. The maximum COD was noted as 17.43 mg/l at Maker in the year 2015-16 whereas the minimum value was recorded as 8.70 mg/l at Bagaha (2015-16).which was very much higher than maximum allowed limit of 4.0mg/L according to USPH Standard [36] (Table 3). COD ranged between 8.7 mg/l to 64.80 mg/l at all the sites of the considered rivers.

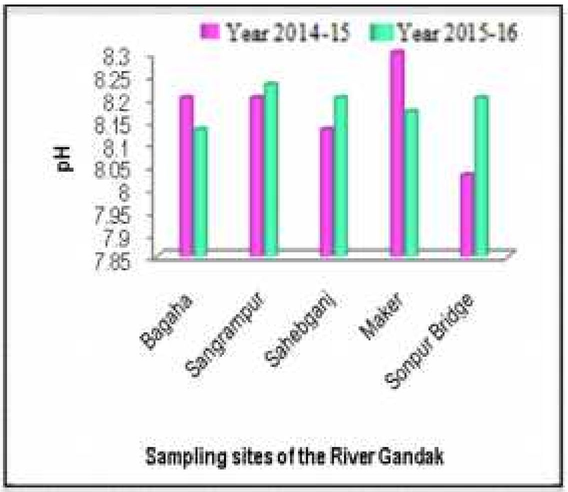
In present investigation the higher degree of pollution was recorded during summer season. And the highest COD also was noted during summer may be due to high concentration of organic pollutants and low discharge of to water. Chemical oxygen demand was found to be very low in monsoon season and very high pre monsoon. The above finding agrees with the COD values convey the quantity of oxidisable organic matter in the water. The increase of COD during summer in all the undertaken rivers are correlated with the decomposition of suspended organic matter which releases the soluble organic matter in the water. This type of relationship is also observed by [64]. The decrease in COD during the rainy season is due to dilution of dissolved organic matter. The high value of COD in the rivers during summer season is due to low water level and high decomposition rates.

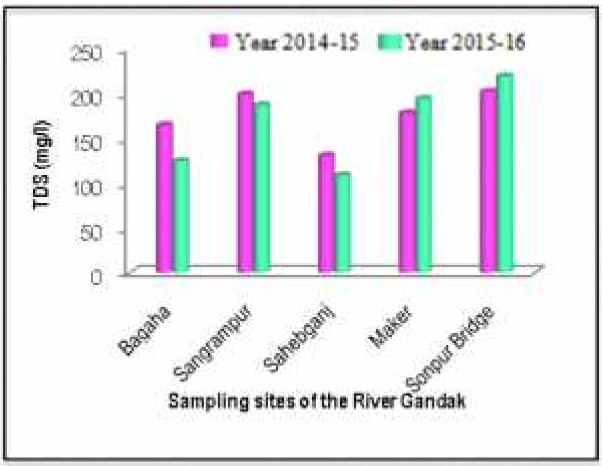
Heavy Metals Concentration in the Water of the River Gandak: Heavy metals concentration in water of the river Gandak showed seasonal variations at different undertaken sites. The status of heavy metals concentration of two consecutive years 2014-15 and 2015-16 is presented in table 2.

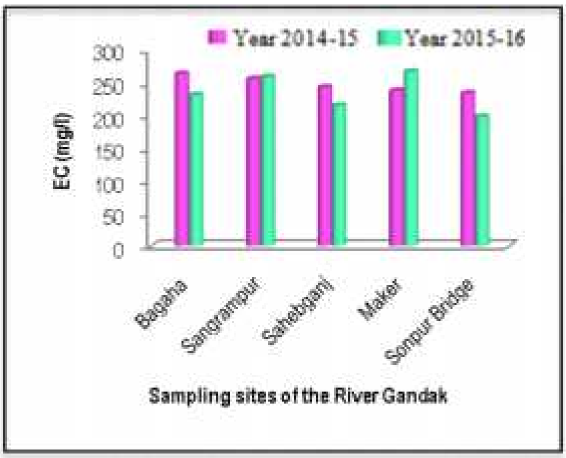
Cobalt (Co^{++}): In present study concentration of Co in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Co was recorded 0.008 ± 0.005 mg/l in the year 2014-15and 0.010 ± 0.002 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Co was recorded 0.017 ± 0.005 mg/l in the year 2014-15and 0.018 ± 0.00 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Co was recorded 0.009 ± 0.004 mg/l in the year 2014-15and 0.010 ± 0.005 mg/l in 2015-16. At Maker (Bihar) the average value of Co was recorded 0.008 ± 0.003 mg/l in the year 2014-15and 0.011 ± 0.005 mg/l in 2015-16 (Fig: 3). At Sonpur Bridge (Bihar) the average value of Co was recorded 0.018 ± 0.005 mg/l in the year 2014-15and 0.020 ± 2.72 mg/l in 2015-16 (Table2-6). In the river Gandak the maximum concentration of Co was noted as 0.018 mg/l at Sangrampur in the year 2015-16 whereas the minimum value was recorded as 0.008 mg/l at Bagaha (2010-11).

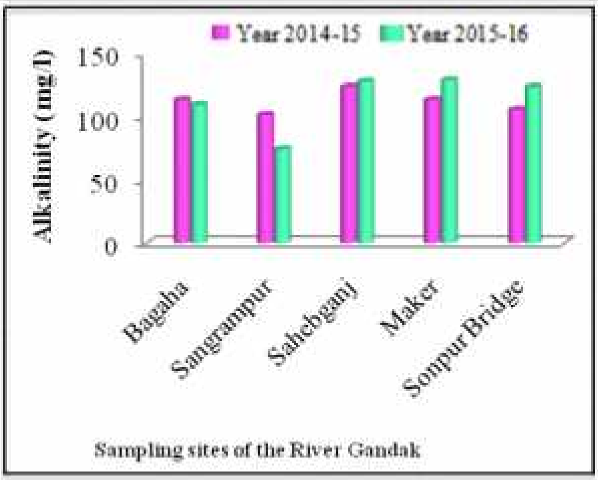
Fig: 3 Concentration of various heavy metals at different sites of the River Gandak.

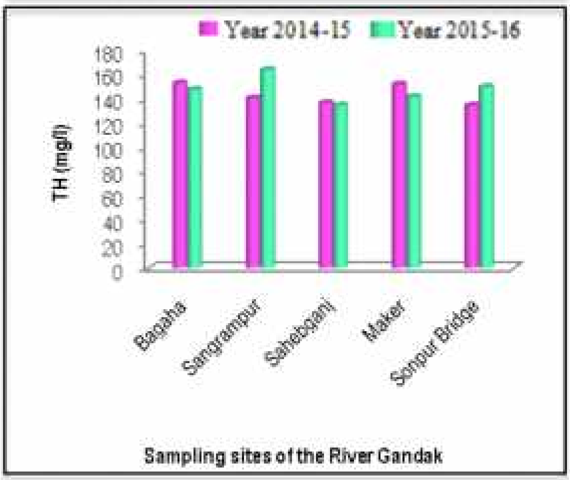


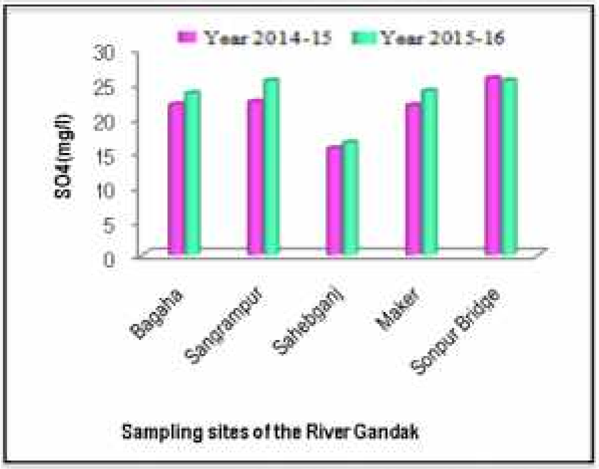


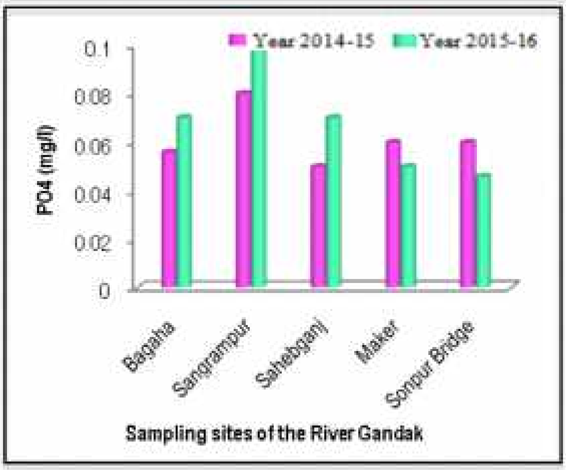












Copper (Cu^{++}): Concentration of Cu in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Cu was recorded 0.018 ± 0.012 mg/l in the year 2014-15and 0.024 ± 0.017 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Cu was recorded 0.017 ± 0.008 mg/l in the year 2014-15and 0.025 ± 0.014 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Cu was recorded 0.023 ± 0.011 mg/l the year 2014-15and 0.026 ± 0.010 mg/l in 2015-16. At Maker (Bihar) the average value of Cu was recorded 0.022 ± 0.010 mg/l in the year 2014-15and 0.025 ± 0.013 mg/l in 2015-16. At Sonpur Bridge(Bihar) the average value of Cu was recorded 0.025 ± 0.009 mg/l in the year 2014-15and 0.038 ± 0.007 mg/l in 2015-16. The Cu concentration of water of the River Gandak at different sites are presented in the table 2. In the river Gandak the maximum concentration of Cu was noted as 0.025 mg/l at Sahibganj in the year 2015-16 whereas the minimum value was recorded as 0.008 mg/l at Bagaha (2010-11).

In present investigation it was noted that the observed values were below the permissible limit of 0.05mg/L set by WHO (Table 7) and 1.0mg/L as per the USPH standards. It is important here to note that Cu is highly toxic to most fishes, invertebrates and aquatic plants than any other heavy metal except mercury. It reduces growth and rate of reproduction in plants and animals. The chronic level of Cu is 0.02–0.2mg/L [65]. Aquatic plants absorb three times more Cu than plants on dry lands [66]. Excessive Cu content can cause damage to roots, by attacking the cell membrane and destroying the normal membrane structure; inhibited root growth and formation of numerous short, brownish secondary roots. Cu becomes toxic for organisms when the rate of absorption is greater than the rate of excretion, and as Cu is readily accumulated by plants and animals, it is very important to minimize its level in the waterway.

Chromium (Cr^{++}): In present study concentration of Cr in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Cr was recorded 0.002 ± 0.001 mg/l in the year 2014-15and 0.004 ± 0.001 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Cr was recorded 0.002 ± 0.00 mg/l in the year 2014-15and 0.001 ± 0.00 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Cr was recorded 0.001 ± 0.002 mg/lin the year 2014-15and 0.003 ± 0.002 mg/l in 2015-16. It Maker (Bihar) the average value of Cr was recorded 0.004 ± 0.001 mg/l in the year 2014-15and 0.005 ± 0.002 mg/l in 2015-16. At Sonpur Bridge (Bihar) the average value of Cr was recorded 0.003 ± 0.002 mg/l in the year 2014-15and 0.004 ± 0.012 mg/l in 2015-16. The Cr concentration of water of the River Gandak at different sites are presented in Fig:3 and in table 2. Cr was detected only from Sonepur Bridge as 0.004 mg/l in the year 2015-16 whereas the minimum value was recorded as 0.003 mg/l at same place in the year 2010-11. Cr was not detected from the other sites of the River Gandak.

In the present investigation the average Cr content in water samples was found below, the permissible limit of 0.05mg/L set by [67] it has observed that chromium is a transition metal that is discharged into the environment through the disposal of wastes from industries like leather tanning and metallurgical, leading to contamination of river water and sediment both. Chromium is the main tanning agent and most hazardous chemical used in chrome tanning process. The excessive use of this chemical leads to higher concentration in the effluent. Chromium levels in the target area were found in very low amount in the undertaken rivers. It is the major chemical present in the effluent, which, when released into water percolates the layers of sediments. Cr compounds are used as pigments, mordents and dyes in the textiles and as the tanning agent in the leather. The sources of emission of Cr in the surface waters are from municipal wastes, laundry chemicals, paints, leather, road run off due to tire wear, corrosion of bushings, brake wires and radiators, etc. The high level of Cr in waste water effluent indicates excessive pollution from textile industries and tanneries, [68]. Acute toxicity of Cr to invertebrates is highly variable, depending upon species [69]. For invertebrates and fishes, its toxicity is not much acute. Cr is generally more toxic at higher temperatures and its compounds are known to cause cancer in humans. The toxic effect of Cr on plants indicate that the roots remain small and the leaves narrow, exhibit reddish brown discoloration with small necrotic blotches [66].

Nickel (Ni): Concentration of Ni in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Ni was recorded 0.006 ± 0.003 mg/l in the year 2014-15and 0.010 ± 0.004 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Ni was recorded 0.019 ± 0.012 mg/l in the year 2014-15and 0.021 ± 0.012 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Ni was recorded 0.008 ± 0.008 mg/lin the year 2014-15and 0.011 ± 0.009 mg/l in 2015-16. At Maker (Bihar) the average value of Ni was recorded 0.006 ± 0.005 mg/l in the year 2014-15and 0.015 ± 0.006 mg/l in 2015-16. At Sonpur Bridge (Bihar) the average value of Ni was recorded 0.006 ± 0.002 mg/l in the year 2014-15and 0.034 ± 0.003 mg/l in 2015-16. Fig: 3. In the river Gandak the maximum concentration of Ni was noted as 0.034 mg/l at Sonepur Bridge in the year 2015-16 whereas the minimum value was recorded as 0.006 mg/l at Maker (2010-11).

Cadmium (Cd^{++}): Concentration of Cd in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Cd was recorded 0.005 ± 0.003 mg/l in the year 2014-15and 0.009 ± 0.005 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Cd was recorded 0.005 ± 0.002 mg/l in the year 2014-15and 0.006 ± 0.002 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Cd was recorded 0.009 ± 0.010 mg/lin the year 2014-15and 0.012 ± 0.006 mg/l in 2015-16. At Maker (Bihar) the average value of Cd was recorded 0.004 ± 0.003 mg/l in the year 2014-15and 0.005 ± 0.003 mg/l in 2015-16. At Sonpur Bridge (Bihar) the average value of Cd was recorded 0.034 ± 0.002 mg/l in the year 2014-15and 0.007 ± 0.049 mg/l in 2015-16 (Table 2 and Fig:3). Where the minimum value was recorded as 0.005 mg/l in monsoon, moderate in winter which was 0.007 mg/l and maximum in summer season 0.009 mg/l. In the river Gandak the maximum concentration of Cd was noted as 0.034 mg/l at Sonpur Bridge in the year 2014-15whereas the minimum value was recorded as 0.004 mg/l at Maker (2010-11).

The values obtained for the river Gandak at Sonepur bridge was found to be higher than the permissible limit of 0.01mg/L set by WHO and also according to USPH standards (Table 7). It may harmful to the aquatic biota. Cd is contributed to the surface waters through paints, pigments, glass enamel, deterioration of the galvanized pipes etc. The wear of studded tires has been identified as a source of Cd deposited on road surfaces. The average Cd content in water samples was found to vary from river to river and place to place. Higher values of Cd in waste water effluent samples suggest the high level of pollution due to dyes paints and pigments manufacturing industries around. There are a few recorded instances of Cd poisoning in human beings following consumption of contaminated fishes. It is less toxic to plants than Cu, similar in toxicity to Pb and Cr. It is equally toxic to invertebrates and fishes [66].

Zinc (Zn^{++}): In present study concentration of Zn in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Zn was recorded 0.033 ± 0.098 mg/l in the year 2014-15and 0.032 ± 0.012 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Zn was recorded 0.028 ± 0.004 mg/l in the year 2014-15and 0.027 ± 0.011 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Zn was recorded 0.021 ± 0.003 mg/lin the year 2014-15and 0.025 ± 0.010 mg/l in 2015-16. At Maker (Bihar) the average value of Zn was recorded 0.026 ± 0.012 mg/l in the year 2014-15and 0.028 ± 0.011 mg/l in 2015-16. At Sonpur Bridge (Bihar) the average value of Zn was recorded 0.032 ± 0.013 mg/l in the year 2014-15and 0.036 ± 0.002 mg/l in 2015-16. The Zn concentration of water of the River Gandak at different sites are presented in the table 2 and Fig: 3. In the river Gandak the maximum concentration of Zn was noted as 0.096 mg/l at Sonepur Bridge in the year 2015-16 whereas the minimum value was recorded as 0.021 mg/l at Sahibganj (2010-11).

Zn concentration for the river Gandak was also found below the permissible limit of 5.5mg/L as per USPH standard (Table 7). Excessive concentration of Zn may result in necrosis, chlorosis and inhibited growth of plants**.** The overall concentration of Zinc as obtained from the analysis of water samples collected from different undertaken rivers varied from 0.004 mg/l to 0.096 mg/l. Since the desired level of Zinc is 5.0 mg/l (Prescribed by ISI), none of the samples has exceeded the limiting value. However result indicates leaching of Zinc from the waste dumping site confirming the presence of Zinc in the waste dumped

Lead (Pb^{++}): It is one of the oldest metals known to man and is discharged in the surface water through paints, solders, pipes, building material, gasoline etc. Lead is a well known metal toxicant and it is gradually being phased out of the materials that human beings regularly use. Combustion of oil and gasoline account for >50% of all anthropogenic emissions, and thus form a major component of the global cycle of lead. Concentration of Pb in the water of the river Gandak shows different level of variability at different sites in different seasons. At Bagaha (Bihar) the average value of Pb was recorded 0.004 ± 0.002 mg/l in the year 2014-15and 0.006 ± 0.003 mg/l in 2015-16. At Sangrampur (Bihar) the average value of Pb was recorded 0.018 ± 0.010 mg/l in the year 2014-15and 0.023 ± 0.014 mg/l in 2015-16. At Sahibganj (Bihar) the average concentration of Pb was recorded 0.005 ± 0.003 mg/lin the year 2014-15and 0.012 ± 0.005 mg/l in 2015-16. At Maker (Bihar) the average value of Pb was recorded 0.026 ± 0.009 mg/l in the year 2014-15and 0.018 ± 0.009 mg/l in 2015-16. At Sonpur Bridge (Bihar) the average value of Pb was recorded 0.024 ± 0.013 mg/l in the year 2014-15and 0.029 ± 0.011 mg/l in 2015-16. The Pb concentration in water of the River Gandak at different sites are presented in the table 2 and Fig: 3. In the river Gandak the maximum concentration of Pb was noted as 0.026 mg/l at Sonepur Bridge in the year 2015-

16 whereas the minimum value was recorded as 0.004 mg/l at Bagaha (2010-11).

Atmospheric fallout is usually the most important source of lead in the fresh waters [66]. The average concentration of Pb in water samples collected from the river Ganga and it's trbutaries was found below the permissible limit for lead in drinking water is <0.05mg/L according to the USPH drinking water standards. Acute toxicity generally appears in aquatic plants at concentration of 0.1–5.0mg/L. In plants, it initially results in enhanced growth, but from a concentration of 5 ppm onwards, this is counteracted by severe growth retardation, discoloration and morphological abnormalities. There is an adverse influence on photosynthesis, respiration and other metabolic processes. Acute toxicity of Pb in invertebrates is reported at concentration of 0.1–10mg/l, **[66]**. Higher levels pose eventual threat to fisheries resources.

Assessment of Gandak River Pollution through Water Quality Index (WQI): WQI of the River Gandak was ranged between76 to 85 (Table 4). Minimum WQI was noted at Bagaha and maximum was found at Sonpur Bridge. All the sites of the River Gandak have good quality of water. On the basis WQI of the it was found that water quality of the river Gandak is in good condition. Gandak river mainly passes through villages, towns and small cities which adds small quantity of pollutants into the river, so it maintains their good water quality, which provides a balance ecosystem for aquatic life.

Table: 4 Water Quality Index (WQI) of the River Gandak

Parameters	Water Quality Index (WQI) of the river Gandak at various study sites				
	Bagaha	Sangrampur	Sahebganj	Maker	Sonepur bridge
pH	78	75	78	76	80
DO (%)	54	81	52	85	85
BOD (mg/l)	72	75	84	75	70
Phosphate(mg/l)	97	96	97	98	97
Nitrate(mg/l)	97	97	95	97	98
Overall WQI	76	83	80	85	85

Correlation Study: Pearson Correlation Coefficients matrix, which can point out associations between variables that can show the overall coherence of the data set and indicate the participation of the individual chemical parameters in several influence factors, a fact which commonly occurred in hydrochemistry [70]. Pearson's correlation coefficient was calculated to determine a relationship among the physico-chemical characteristics and heavy metals concentrations in the water of the River Gandak. The values (r) ranged from 0.400 to 0.52 and 0.53 to above are significant at $P<0.05$ and $P<0.01$ respectively. Negative r values prefixed by (-) sign and positive values are without any prefix in the respective tables. Pearson's correlation coefficient matrix of the River Gandak for the year 2014-15 and 2015-16 separately presented in Table: 5-6. Correlation results reveals that most of the parameters except temperature, pH, TDS, Nitrate and DO shows positive correlation with each other in the year 2014-15. Whereas in the year 2015-16 most of all the parameters show positive significant correlation with each other except pH, nitrate and DO, which shows negative correlation.

The correlation coefficient (r) between each parameter pairs was computed by taking the average values of each season *i.e.* monsoon, winter and summer for all the sites of the River Gandak separately for the year 2014-15 and 2015-16. Correlation coefficient (r) between any two parameters such as water temperature, pH, total dissolved solids, total hardness, sulphates, chloride, phosphate, nitrate, dissolved oxygen and biological oxygen demand, COD and heavy metals in water of the River Gandak.

Conclusions: On the basis of experimental findings it was found that the river water in summer, monsoon and winter seasons show different level of fluctuations in Physico-chemical and heavy metals concentration from place to place. The seasonal changes in the water quality of the rivers were imparted mainly due to catchment characteristics and seasonal effects. These variations were noted due to the change in the volume of industrial and sewage waste being added to river at different stations of the stretch. Level of the most of the physico-chemical parameters were recorded below or close to the standard values whereas the concentrations of trace metals like Co, Cu, Ni, Zn and Pb in water of the river Gandak were recorded below the permissible limit at most of the selected sites, whereas the level of Cd in water exceeded the permissible limit at some places. The present experimental data indicates that the pollution level along the river Gandak is not very high but the increasing population load in the basin may cause irreparable ecological harm in the long-term well masked by short term economic prosperity. It also suggests a need of consistent, internationally recognized data driven strategy to assess the quality of waste water effluent and generation of international standards for evaluation of contamination levels.

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Table: 5 Pearson's correlation matrix of physicochemical parameters and heavy metal concentrations in water of the River Gandak in Indian Territory for the year 2014-15.

Parameters	Temp	pH	TDS	EC	Alk	T.H	SO_4	PO_4	Cl	NO_3	DO	BOD	COD	Co	Cu	Cr	Ni	Cd	Zn	Pb
Temp	1.00																			
pH	-1.00	1.00																		
TDS	-0.84	0.81	1.00																	
EC	-0.28	0.32	-0.29	1.00																
Alk	-0.71	0.74	0.21	0.88	1.00															
T.H	-0.73	0.75	0.23	0.86	1.00	1.00														
SO_4	-0.45	0.49	-0.12	0.98	0.95	0.94	1.00													
PO_4	0.04	0.00	-0.58	0.95	0.67	0.65	0.87	1.00												
Cl	-0.18	0.22	-0.39	0.99	0.82	0.81	0.96	0.97	1.00											
NO_3	-1.00	1.00	0.82	0.30	0.73	0.74	0.47	-0.02	0.20	1.00										
DO	-0.92	0.90	0.98	-0.11	0.38	0.40	0.07	-0.43	-0.22	0.91	1.00									
BOD	0.85	-0.83	-1.00	0.26	-0.23	-0.26	0.09	0.56	0.36	-0.84	-0.99	1.00								
COD	0.89	-0.87	-0.99	0.18	-0.32	-0.34	0.00	0.49	0.28	-0.88	-1.00	1.00	1.00							
Co	0.19	-0.15	-0.70	0.89	0.55	0.53	0.79	0.99	0.93	-0.17	-0.56	0.68	0.61	1.00						
Cu	0.24	-0.20	-0.73	0.86	0.51	0.49	0.76	0.98	0.91	-0.22	-0.60	0.71	0.65	1.00	1.00					
Cr	-0.14	0.19	-0.42	0.99	0.80	0.79	0.95	0.98	1.00	0.17	-0.25	0.40	0.31	0.94	0.93	1.00				
Ni	0.05	-0.01	-0.59	0.94	0.66	0.65	0.87	1.00	0.97	-0.03	-0.44	0.57	0.49	0.99	0.98	0.98	1.00			
Cd	-0.27	0.31	-0.30	1.00	0.87	0.86	0.98	0.95	1.00	0.29	-0.13	0.28	0.19	0.89	0.87	0.99	0.95	1.00		
Zn	-0.04	0.08	-0.51	0.97	0.73	0.72	0.91	1.00	0.99	0.06	-0.35	0.49	0.41	0.97	0.96	0.99	1.00	0.97	1.00	
Pb	0.08	-0.04	-0.61	0.93	0.64	0.63	0.85	1.00	0.97	-0.06	-0.46	0.59	0.52	0.99	0.99	0.97	1.00	0.94	0.99	1.00
Co	0.05	-0.01	-0.59	0.94	0.67	0.65	0.87	1.00	0.97	-0.03	-0.44	0.57	0.49	0.99	0.98	0.98	1.00	0.95	1.00	1.00

Table: 6 Pearson's correlation matrix of physicochemical parameters and heavy metal concentrations in water of the River Gandak in Indian Territory for the year 2015-16**.**

Parameters	Temp	pH	TDS	EC	Alk	T.H	SO_4	PO_4	Cl	NO_3	DO	BOD	COD	Co	Cu	Cr	Ni	Cd	Zn	Pb
Temp	1.00																			
pH	-0.99	1.00																		
TDS	0.07	0.07	1.00																	
EC	-0.34	0.47	0.91	1.00																
Alk	-0.47	0.59	0.85	0.99	1.00															
T.H	-0.27	0.41	0.94	1.00	0.98	1.00														
SO_4	-0.25	0.38	0.95	1.00	0.97	1.00	1.00													
PO_4	0.35	-0.21	0.96	0.76	0.66	0.81	0.82	1.00												
Cl	0.35	-0.22	0.96	0.76	0.66	0.80	0.82	1.00	1.00											
NO_3	-0.76	0.66	-0.70	-0.35	-0.22	-0.42	-0.44	-0.88	-0.88	1.00										
DO	-0.95	0.90	-0.36	0.05	0.18	-0.03	-0.05	-0.61	-0.62	0.92	1.00									
BOD	0.96	-0.92	0.33	-0.08	-0.22	-0.01	0.02	0.59	0.59	-0.90	-1.00	1.00								
COD	0.95	-0.90	0.37	-0.04	-0.18	0.03	0.06	0.62	0.62	-0.92	-1.00	1.00	1.00							
Co	0.36	-0.22	0.96	0.75	0.66	0.80	0.81	1.00	1.00	-0.88	-0.62	0.60	0.63	1.00						
Cu	0.51	-0.38	0.89	0.63	0.52	0.69	0.71	0.98	0.99	-0.95	-0.74	0.72	0.75	0.99	1.00					
Cr	0.29	-0.16	0.97	0.80	0.71	0.84	0.85	1.00	1.00	-0.85	-0.57	0.54	0.57	1.00	0.97	1.00				
Ni	0.61	-0.49	0.83	0.54	0.41	0.60	0.62	0.96	0.96	-0.98	-0.82	0.80	0.82	0.96	0.99	0.94	1.00			
Cd	0.42	-0.29	0.93	0.71	0.60	0.76	0.77	1.00	1.00	-0.91	-0.67	0.65	0.68	1.00	1.00	0.99	0.98	1.00		
Zn	0.25	-0.11	0.98	0.82	0.74	0.86	0.88	0.99	0.99	-0.82	-0.53	0.50	0.53	0.99	0.96	1.00	0.92	0.98	1.00	
Pb	0.23	-0.09	0.99	0.83	0.75	0.87	0.88	0.99	0.99	-0.81	-0.51	0.49	0.52	0.99	0.96	1.00	0.91	0.98	1.00	1.00