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Physico-chemical and Biological Characterization of Groundwater: A Case Study of Auraiya District, Uttar Pradesh, India

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Abstract Groundwater is an important resource which is extensively used for agriculture, drinking, industrial and commercial purposes. Contamination and overexploitation of it may lead to the exhaustion of this vital resource. To assess the physico-chemical and biological characteristics for groundwater quality, five villages of the Auraiya District (Uttar Pradesh) India were selected from where the groundwater samples were collected during the period of January, 2015 to December, 2016. For each site and each season samples were collected in replicates. The pH at all the locations is mostly alkaline ranging between 7.2 - 8.1 which is well within the prescribed standard limits. Total Dissolved Solids (TDS) are ranging between 578 to 819 mg/l. Electrical Conductivity of the collected water samples, ranging from 903.3 - 1796.7 µS/cm. The value of BOD and COD were found to be ranging from 3-8.0 and 64-320 mg/l, respectively. Ratio of BOD:COD indicate that the groundwater quality is not polluted. The total coliforms are also negligible having values below the 2.0 MPN/100 mL at all the five locations indicating thereby that there is no bacteriological contamination of the groundwater. The water samples were also analysed to know the concentration of five heavy metals viz., Fe, Cu, Zn, Cd and Cr. The Cd and Cr were not detected in the samples while Fe, Cu, Zn levels were found to be within the prescribed standard limits given for drinking water. Results of the present study indicates that the quality of groundwater available in the bore wells and tube wells are suitable for drinking and domestic purposes as per the standards and which shows that the water quality is not affected by changes in the land use as well as industrial activities occurring in Auraiya district.

Keywords: *groundwater, physico-chemical-biological characteristics, heavy metals, total coliforms, BOD:COD ratio*

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1. Introduction

Water, in any region is an important natural resource which is used for different purposes like drinking, agriculture, industries etc. Rate of degradation of water resources has been increased in the recent years due to anthropogenic activities induced release of pollutants [1]. The situation is further aggravated by conversion in land use pattern and consequent changes in ecosystem processes, biogeochemical cycle’s and physical, chemical and biological properties of the surface, sub surface and groundwater [2,3,4]. Impact of human activities is directly reflected in the deterioration of water and soil quality parameters [5,6]. There is strong relationship between the water quality and quantity and the land use pattern and for the better management of the water resources, this relationship needs to be understood properly [7]. Among various land use patterns, urbanisation, industrialisation and type of agricultural activities, are the dynamic land use pattern that affect the waters availability and quality parameters [8,9,10]. India being a developing country is undergoing the process of urbanisation, industrialisation and commercialisation. Due to higher population growth rate and to fulfill the needs of the food and shelter of the growing population the land use pattern is also changing. More and more forested and agricultural land is converted into industrial, commercial and residential areas. Different types of agricultural practices also degrade the available soil and water resources and cause changes in the physico-chemical and biological properties of the soil, surface and underground water [11].

In India, there has been major change in the land use and land cover after the country shifted from the restricted economic phase to the liberal economic phase in the 1991 [12]. During the last two decades there has been a rapid economic and industrial development in the Yamuna river basin of Indian sub-continent. The entire Yamuna river basin comprising parts of Uttar Pradesh, Himachal

Pradesh, Haryana, Rajasthan and National Capital Territory (NCT – Delhi) is subject to diverse human activities, which have directly or indirectly affected the surface/sub-surface water quality and the environment and natural resources of this region [12].

To fulfill the need and economic development of its people, the state of Uttar Pradesh, India, also initiated conversion of agricultural land into industrial zones and took decision with regard to major change in land use pattern during the last three decades. In the transformation, the district of Auraiya was also included in the process of industrialisation and expansion of urban area for establishment of residential colonies for which land use conversion of forest and agricultural area was undertaken [12,13]. The district lies between 26.21° to 27.01°N latitude and 78.45° to 79.45°E longitude. The district is located on the central Gangetic river basin which was created in the year 1997. There are total of 848 villages and 3 tehsils. The total area of the district is 2016 Km^2 having the total population of 1.35 million and population density of 684 person per Km^2 [12,13,14,15]. The total road length is 2385 Km of which 77 Km belongs to National Highways, 95 Km to State Highways, 77 to main District Highway and 2170 belongs to other district and rural roads while the total rail line in the district is just 31 Km [14,15]. The Auriaya district receives rainfall mainly from the south west monsoonal winds where the average precipitation is 792 mm.

Table 1. Showing the type of soil and its characteristics in Auraiya district [13,15]

S.No	Soil type	Characteristics
1	Clay	Salinity, sodicity and ravines is the main reason for degradation of soil. A low lying bed of clay filled with water is used for growing rice.
2	Clay Loam	The soils of the area are affected by salinity, high levels of sodium and ravine topography. Here also the low lying areas filled with water of monsoon rain are used for growing rice crops.
3	Loam	The soils are broadly affected by salinity, high concentration of sodium and ravines topography. In this soil also the monsoonal water is collected in the low lying areas filled with water is used for growing rice.
4	Sandy	The salinity, sodicity and ravines are the main problems of the soil of this area and low lying beds are filled with water are used for growing the rice crops.
5	Loam	Higher levels of salinity, sodicity and ravines are the main problems of the soil. Rice is grown in the water filled low lying areas.

(*Source of table*: Census of India, 2011 and Krishi Vigyan Kendra, Auraiya district website)

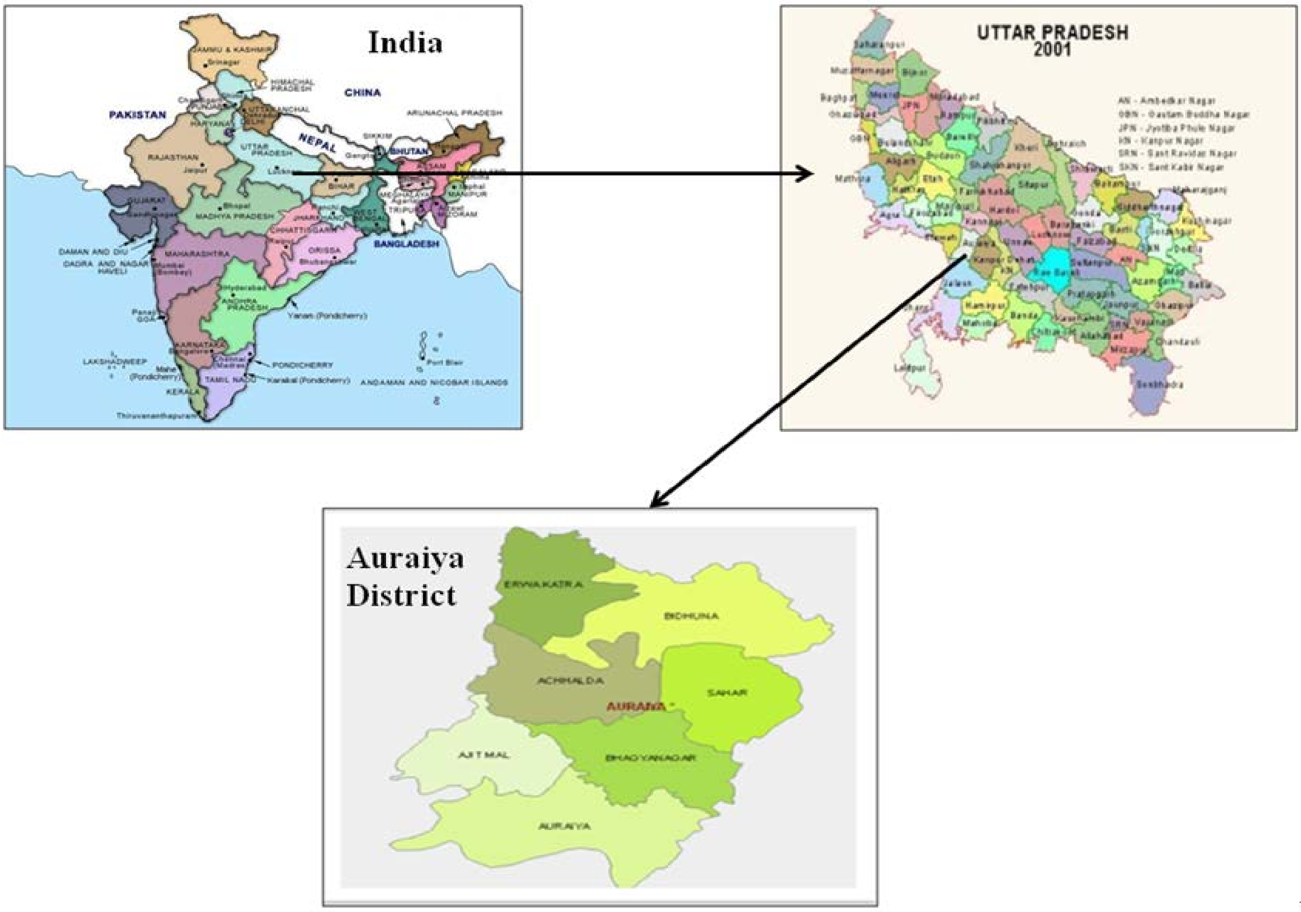

Figure 1. Map showing location of Auraiya district in state of Uttar Pradesh of India (Map taken from Census of India, Krishi Vigyan Kendra, Auraiya District) [13,15]

Different types of soils like, loam, sandy loam, sandy soils and clay are present in the Auraiya district. The soils of the Auraiya district are affected by increased salinity, sodicity, ravines etc as shown in Table 1. Auraiya district has been divided into four different types of Agro-ecological zones which is mainly based on the occurrence of type of soil, topography, type of irrigation available and pattern of agriculture by the Agricultural Department of Auraiya district. In low lying plain beds of clay, the water collects during the rainy season and generally rice crop is easily grown in these areas. The annual temperature range varies from 2.2°C to 44.4°C. The Auraiya has mainly an agriculture based economy where out of the total area of 2,06,126 hectares, 4321 hectares is forest, 5,865 hectares is non-agricultural land. The net cultivable land available in the Auraiya is 1,41,218 hectares, out of which 76,349 hectares of land is sown more than once in a year while 1,10,275 hectares of land is the net irrigated area. The average holding size of the land by the farmers is 0.84 hectares having cropping intensity of 164 %. The Figure 1 shows the location of the Auraiya district in state of Uttar Pradesh, India [13,14,15].

The Krishi Vigyan Kendra of Auraiya district has divided the agricultural farming into seven types of farming systems viz:- (1) Paddy-wheat-fallow (2) Bajra-Wheat-fallow (3) Maize-Toria-Wheat-fallow (4) Paddy-Wheat-Dhaincha, Paddy-Wheat-Moong (5) Okra-vegetable Pea-Colocasia/Cucurbits (6) Paddy-Wheat-Fodder Jowar (7) Paddy-Barseem. The 4,321 hectares of land is covered with forest where the main trees grown are the Kanji (*Millettia sps*), Mahua (*Madhuca sps*), Babool (*Acacia sps*), Semal (*Bombax sps*), Mango (*Mangifera sps*), Neem (*Azadirachta sps*), Jamun (*Syzygium sps*) [13]. Table 2 shows the data related to area, production and productivity of major crops cultivated in the district during the 2014-15.

Table 2. Area, Production and Productivity of major crops cultivated in the district 2014-15 [13,15]

S.No.	Name of Crop	Area (Hectares)	Production (100)	Productivity (100/hectares)
1	Paddy	6100	14792	27.69
2	Wheat	14584	24.75	28.03
3	Bajra	6400	8000	12.50
4	Gram	5000	5000	10.00
5	Mustard	6100	5490	9.00
6	Sugarcane	1000	-	567.65

(*Source*: table taken from Census of India and Krishi Vigyan Kendra, Auraiya district website).

The district can be divided in four parts from the point of view of natural water resources of available which are:- north-eastern part which has river Senger which flows across the city from west to east parallel to the major river Yamuna. It has tehsils Bharthana and Etawah on the banks of Sengar River. The southern portion which lies south of the Sengar River have Highlands besides which overlooks the Yamuna River which covers the areas coming under the major portion of the Auraiya tehsil. Across the Yamuna, where there is confluence of the rivers Sindh, Kuwari, Chambal and Yamuna, there lies a highland and broken landform topography which is called as *Janibrast*. These four parts of the district has marked variation in the topography. The River systems of the Auraiya and Etawah districts consists of mainly river Yamuna along with its two large tributaries i.e., the river Chambal and Kuwari, and the river Sengar and its tributary Sirsa. Along with it, small tributaries like river Rind, Arind and its tributaries, river Ahneya, Puraha and Pandu. The Auraiya also have some important Lakes located in Durmangadpur, Mundai, Hardoi, Barauli, Auton, Yakubpur, Tirhwa, Dhupkari or Thulpia and Manaura in tehsil Bidhuna [13,14,15].

The Auraiya district is considered to be backward districts from the industrial point of view. Only few Block areas belonging to the Dibiyapur, Bidhuna, Achhalda and Auraiya are the industrial areas which are moderately developed from the point of industrial establishment while three areas are mini industrial areas. Among the small and medium scale industries like rice mills, pulses mills, desi ghee mills, bricks making units are very well established along with it, some wooden furniture, steel furniture, product manufactured from cement are also moderately established. The Uttar Pradesh State Industrial Development Corporation (UPSIDC) [15] is in the process to develop Dibiyapur town of Auraiya into a Plastic city in an area of 314 acres of which 225 acres will be used for industrial purposes while remaining land will be used as a residential land. With regard to minerals, district is not so wealthy; the main available land resource is the mud which is mainly used in the manufacturing of the bricks which supplies to the nearby areas of the district.

The Auraiya district has total number of registered industrial units in the district is 2558.

Small scale industries are the major employment giving industries in the region where the estimated average daily worker employed is more than 30 thousands while it is more than 3 thousand in the medium and large scale industries. The district has different types of industries which are mainly based on agricultural products viz., cotton textiles, woolen textiles, silk products, furniture made of wood, paper and paper based products, jute and jute based products, mineral based industries, small and medium engineering units, electrical goods, plastic based products, petroleum derived products, transport related equipments and parts, repairing and servicing industries [14,15].

The industrial development of the district was started during the year 2006-07 and from that year it continuously increased in area and number. The Auraiya also has two major industries which are public sector undertakings: first is the Gas Authority of India Ltd. (GAIL) which is located in the block of Pata of Dibiyapur town. GAIL is a public sector Navratna company involved in transmission and marketing business of gas in India. Gail has petro-chemical complex in Auraiya. Table 3 show the development and establishment of industries in last decade [14,15]. National Thermal Power Plant (NTPC) which is located in Auraiya block of Dibiyapur tehsil in Auraiya district is the second major industry. The thermal power plant use gas for the production of the electrical energy. The gas is used as fuel for the thermal power plant is made available from the nearby GAIL gas producing industry. This thermal power plant uses the water for the power plant from the Auraiya-Etawah canal [14].

Table 3. Showing the trend of establishment and development of the industries in last decade in Auraiya district [14]

S.No.	Year wise trend of industrial units registered	Total number of registered industrial units	Total employment (Persons)	Investment (Million INR)
1	2006-07	145	575	11.73
2	2007-08	46	133	12.070
3	2008-09	121	343	21.91
4	2009-10	162	537	59.60
5	2010-11	168	545	96.40
6	2011-12	161	335	50.20
7	2012-13	82	214	70.90
8	2013-14	333	1423	10.10
9	2014-15	306	3313	75.70
	Total	1624	7418	408.65

(*Source*: table taken from DIC Centre, Auraiya, Ministry of MSME, GOI, 2016).

Irrigation is the backbone of intensive agriculture. It contributes 56% of total food grain production. In Auraiya district, both surface and groundwater are being used for irrigation. Approximately, 82% (1193.55 sq. km) land of the total area is covered by various irrigation methods, out of which 54.36% area is shared by groundwater and remaining by surface water.

In Auraiya district, groundwater availability for use in different purposes such as domestic, industrial and agricultural sector is decreasing due to reduced water supply, lack of canal infrastructure and water reserving capacity of the reservoirs due to increasing siltation. It has been also observed that agriculture land in Auraiya district is also facing problem of salinity. Irrigation infrastructure development, without an adequate drainage system, and the use of poor quality groundwater for irrigation are the major reasons for development of salt affected lands in India. In fact, salt affected agricultural lands are of growing importance in such poor quality water irrigated areas of the world due to their direct adverse effect on world food production. The reports on groundwater quality of Auraiya district are very limited. With this background in the present study groundwater quality parameters were analysed and an attempt was made to see the impact of land use pattern changes on the groundwater quality.

2. Methodology

2.1. Hydrogeology of the Auraiya District

The geomorphological data of the district is collected from the literature. In the literature it has been reported that Auraiya district is a part of the Central Ganga Alluvial Plain. The thickness of the alluvium in the area is around 300m (Drilled depth) and approximately 250 to 300m thick Quaternary alluvium is deposited directly over Vindhyan formation of Pre-Cambrian age. The district can be divided in to Upland areas (Banda Alluvium and Varanasi Alluvium) and Low land areas (Older flood plain and Younger flood plain). Generally the area forms an extensively level tract which is intercepted at places by sand ridges particularly in northern parts of the district whereas in the southern parts ravine land developed extensively in the vicinity of river Yamuna and Chambal. The terrain has gentle slope from north-west to south-east with a gradient of 0.2 m/km. There is a wide variation in sediments assemblages which is in variant with different depositional environment from north to southern parts of the district. A thick multi-layered aquifer zones occurs within the depth range from 30 mbgl to 300 mbgl (Drilled depth of borehole) which are regionally extended. A thick sequence of gravel bed admixed with ferruginous material and clay encountered at 190 mbgl at Laharpur exploratory borehole in Bidhuna area and 180 mbgl at Dhaurara Slim Hole near Auraiya of Central Ground Water Board (CGWB) is a southern derivative. This inferred that the sediments derived from southern provenance are widely spread northwardly below the sediments brought from Himalayan provenance [17].

2.2. Sampling Procedure

Groundwater samples as grab samples were collected from deep bore wells and tube wells (>30m depth), from five representative villages were selected i.e., Ranipur, Peeparwaha, Bahadurpur, Achanakpur and Kachhpura of the Auraiya district. (Uttar Pradesh) India. The water samples were collected every month but for analysis and result purpose only data of four months representing four seasons are presented in the present study related to Auraiya district. The four months representative of four seasons were selected for the sampling are January (winter) April (summer), July (Monsoon) and October (Post monsoon).

Water samples were collected in replicates in the second week of the selected month. Samples were collected in clean and sterile white plastic bottles. Physicochemical and biological parameters like Color, pH, EC, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solid (TDS), Heavy metals like Zinc (Zn), Cadmium (Cd), Chromium (Cr), Iron (Fe), Copper (Cu) and Coliform load were analysed using standard methods. All chemicals used were of analytical reagent grade and double distilled water was used for preparation of reagents.

2.2.1. Colour and Odour Parameter

For recording water colour, an aliquot of approximately 10mL of sample into a glass test tube and on the basis of visual observation the colour odour were recorded.

2.2.2. pH Parameter

The pH of water sample was monitored by pH meter after calibration with standard buffer solutions of pH 4, 7 and 10 and setting it at room temperature.

2.2.3. Electrical Conductivity Parameter

Water samples were monitored by using EC meter, which is initially calibrated. EC meter probe was rinsed with deionized water (and blot dry) before inserting the probe into the separate water sample.

2.2.4. Total Dissolved Solid (TDS) Parameter

Water salinity is usually measured by the TDS (total dissolved solids) or the EC (electric conductivity). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm) or in the equivalent units of milligrams per liter (mg/l). The collected sample was mixed through stirring with and 250 ml of sample was filtered by applying vacuum and filtrate was collected in known weight containers. On completion of filtration, filter was washed with three successive 10 mL portions of reagent water to ensure complete transfer of dissolved constituents into the filtrate. Continue suction until all visible water has been removed from the filter. Then filtrate in the vessel kept in the oven rack for evaporation. After evaporation, for drying the sample, the vessel was kept in drying oven at 180 ± 2°C for at least one hour. After drying the vessel were kept in desiccators until they have reached balance temperature. Cooling time for vessels can be reduced by transferring the container to a cool rack prior to placing in the desiccators, TDS (mg/ml) = (Weight of dried sample with container (A) - Weight of container (mg) B) / Volume of sample.

2.2.5. Biological Oxygen Demand (BOD) Parameter

Biochemical oxygen demand (BOD) is a bioassay to measures quantity of the oxygen consumed by bacteria from the decomposition of organic matter under aerobic conditions. It indicates the amount of oxygen that aerobic aquatic organisms could potentially consume in the process of metabolising all the organic matter available to them. The consequence of high BOD is low levels of dissolved oxygen in affected waterways resulting in stress to aquatic organisms. To quantify the BOD (mg/l), the water samples were monitored for the dissolved oxygen (DO) levels initially i.e. on day 1 (D1) and on 5^{th} day (D5). Intermittent step followed as per the prescribed standard methodology [18].

2.2.6. Chemical Oxygen Demand (COD) Parameter

The measurement of COD is based on the principle that most of the organic matters oxidizes when boiled with a mixture of potassium dichromate and sulphuric acid producing carbon dioxide and water. COD in water sample was analyzed through the American Physical and Health Association, American Water Works Association and Water Environment Federation methodology (APHA-AWWA-WEF) [19,20].

A sample is refluxed with a known amount of potassium dichromate in sulphuric acid medium and the excess of dichromate is titrated against ferrous ammonium sulphate. The amount of dichromate consumed is proportional to the oxygen required to oxidize the oxidizable organic matter. The organic matter present in sample gets oxidized completely by potassium dichromate ($K_2Cr_2O_7$) in the presence of sulphuric acid (H_2SO_4), silver sulphate ($AgSO_4$) to produce CO_2 and H_2O. The sample is refluxed with known amount of potassium dichromate ($K_2Cr_2O_7$) in the sulphuric acid medium and the excess potassium dichromate ($K_2Cr_2O_7$) is determined by titration against ferrous ammonium sulphate, using ferroin as an indicator. The dichromate consumed by the sample is equivalent to the amount of O_2 required to oxidize the organic matter. The calculation of the COD is done by using the formula: - COD (mg/l) = $(V_1 - V_2) \times N \times 8000/V_0$ where V_1 = volume of ferrous ammonium sulphate in blank; V_2 = volume of ferrous ammonium sulphate in sample; N = Normality of ferrous ammonium sulphate; V_0 = volume of sample.

2.2.7. BOD:COD Ratio

The BOD/COD ratio is considered a valuable indicator of organic matter degradation in groundwater [22]. According to Ngang and Agbazue [23], if the BOD:COD ratio in water is found to be higher or equal to a value of 0.8, the water is said to be highly polluted. The data collected for BOD and COD levels was analysed to generate BOD:COD ratio and categorise water quality.

2.2.8. Total Coliforms Load Parameter

The viable and recoverable colony forming units of Coliforms were monitored in water samples using i.e. a membrane-filtration method [19] The MF method provides a direct count of Coliform population in water based on the development of colonies on the surface of the membrane filter. A water sample is filtered through the membrane which retains the bacteria. After filtration, the membrane is placed on a selective and differential medium, mTEC, incubated at 35°C ± 0.5°C for 2 ± 0.5 hours to resuscitate injured or stressed bacteria, and then incubated at 44.5°C ± 0.2°C for 22 ± 2 hours. Following incubation, the filter is transferred to a filter pad saturated with urea substrate. After 15 minutes, yellow, yellow-green, or yellow-brown colonies are counted with the aid of a fluorescent lamp and a magnifying lens.

The following five heavy metals - Iron (Fe), Cadmium (Cd), Chromium (Cr), Zinc (Zn) and Copper(Cu) have been quantified in the collected water samples by Atomic Absorption Spectrophotometry (AAS) (Model Elico, No. 4141).

2.2.9. Iron (Fe) Content

For dissolved Fe in the filtered sample is directly aspirated to the atomizer. For total recoverable Fe, HNO_3 - H_2SO_4 digestion is to be carried out prior to aspiration of the sample. This method is applicable in the 0.1 to 10 mg/l range. Aspirate the sample solution and measure the absorbance at 248.3 nm. Determine micrograms of iron in the solution from the absorbance reading by referring to the calibration curve. The formula used is Fe (mg/l) = µg of Fe (in 100 m1 of the final solution) × $100/V_1 \times V_2$; Where, V_1 = volume in ml of the sample used; V_2 = total volume in ml of the digested solution used for Fe estimation.

2.2.10. Cadmium (Cd) Content

The cadmium content of the sample is determined by directly aspirating the sample into the flame of an atomic absorption spectrophotometer. The absorbance is measured at 228.8 nm using a cadmium hollow-cathode lamp. This method is applicable in the concentration range of 0.05 to 2 mg/l. The concentration of cadmium is measured by using the formula Cadmium (mg/l) = M × 100/V; Where, M = mass of cadmium in mg in the sample; V = volume of the sample in ml.

2.2.11. Chromium (Cr) Content

The chromium content of the sample is also determined by atomic absorption spectrophotometry. For dissolved chromium the filtered sample is directly aspirated to the atomizer. For total recoverable chromium, HNO_3 - H2SO_4 digestion is to be carried out prior to aspiration of the sample. Aspirate sequentially the standard solutions and measure the absorbance at 357.9 nm. *Chromium (mg/l) = µg of Cr (in 100 ml of the final solution) / V* Where, V = Volume in ml of the sample used.

2.2.12. Zinc (Zn) Content

The zinc content of the sample is determined by atomic absorption spectrophotometry. For dissolved zinc, the filtered sample is directly aspirated to the atomizer. For total recoverable zinc, an acid digestion procedure is done prior to aspiration of the sample. Zn (mg/l) = M × 1000/V, Where, M = mass of zinc present in mg in the sample; V = volume of sample in ml.

2.2.13. Copper (Cu) Content

The copper content of the sample is determined by atomic absorption spectrophotometry. For dissolved copper; the filtered sample is directly aspirated in to the atomizer. For total recoverable copper; an acid digestion procedure is carried out prior to aspiration of the sample. Copper (mg/l) = M × 1000/V; Where, M = mass (in g) of copper in the ample; V = volume of sample in ml.

2.3. Statistical Analysis

The statistical analysis was performed using Microsoft Excel- 2007. The data were presented as means ± standard deviations. The descriptive statistical analyses were also carried out for the water quality parameters viz., BOD, COD, TDS, EC, heavy metals like Iron, Cadmium, Chromium, Zinc and Copper, biological component: BOD and total coliforms load.

3. Results and Discussions

The groundwater samples collected during winter, summer, monsoon and post monsoon seasons from five villages were analyzed for physicochemical and biological parameters and results are given in Table 4. All the water samples were colourless and odourless. On comparing the variation in pH of water samples seasonally it was minimum during monsoon season as compared to other seasons, exhibited almost similar pH (Figure 3). In the Present study, pH is ranges from 7.2 to 8.1 during Pre-monsoon and 7.4 to 7.9 during Post-monsoon with a mean of 7.6. All the samples were within the maximum permissible limit i.e., 6.5 – 8.5 [24]. Minimal changes were observed during the both Seasons.

Electrical Conductivity in collected water samples, ranging from 903.3 µS/cm to 1220 µS/cm during Pre-monsoon and 1036.7 µS/cm to 1796.7 µS/cm during Post-monsoon with a mean of 1106.9 µS/cm during the present study. The results indicate that when all the samples EC values compared to drinking water permissible limit i.e., 1500 µS/cm (BIS, 2005), most of the samples value is below the critical limit. The exhibited EC levels in groundwater indicate that groundwater is usable and can be used directly for irrigation without dilution [25].

The TDS levels were ranges from 632 to 819 mg/l during pre-monsoon and 578 to 715 mg/l during post-monsoon season with a mean of 649.3 mg/l of the present study. The maximum and minimum concentrations were observed at Acchanakpur during pre-monsoon (819 mg/l) and at Peeperwaha during post-monsoon (548 mg/l) respectively. The concentrations of TDS from natural sources have been found to vary from less than 30 mg/l to as much as 6000 mg/l as per WHO [26], depending on the solubility of minerals in different geological regions. However in present study, TDS value of water samples are below the maximum permissible limits of WHO are 1000 mg/l. The low concentrations of TDS may also enhance water clarity and reduces odour. Kahlown et al. [27] reported that taste of water will be flat insipid due to extremely low TDS level.

The Biological Oxygen Demand (BOD) gives an idea of the quantity of biodegradable organic matter present in an aquatic system which is subjected to aerobic decomposition by microbes. BOD measurement highlights the biodegradability and self-purification capacity of natural water such as groundwater. It has been reported that if BOD level are between 1 and 2 mg/l indicates very clean water, 3.0 to 5.0 mg/l indicates moderately clean water and BOD > 5 mg/l indicates a nearby pollution source or polluted water COD on the other hand highlights the strength of biologically resistant organic toxins in contaminated water.

Among the five studied sites i.e., the BOD levels were found to be maximum at Bahadurpur and Kachhpura having values of 7.1 mg/l at both places and while minimum at Peeparwaha with value of 3.0 mg/l, respectively. The mean BOD levels for the region are 6 mg/l. BOD values at all the sites are less in pre-monsoon month as compared to post monsoon month to post monsoon month.

The higher BOD mean value of 7.0 ± 0.07 during monsoon season could be due to percolation of biodegradable organic matter and leaching of inorganic iron and/or manganese into groundwater aquifers. Seasonal variations in BOD were observed with a general increase during Monsoon and post monsoon season as compared to two other seasons. However the BOD values observed in the study above the maximum permissible level of 3.00 mg/l recommended by National Agency for Food and drugs Administration and Control [28] and World Health Organisation indicates that groundwater is not fit for drinking purposes [29].

The COD levels in water samples for five villages were in the range of 96-320mg/l. Among the five studied sites i.e., the COD levels were found to be maximum at Bahadurpur having values of 320 mg/l and minimum at Peeparwaha with value of 192 mg/l, respectively. The mean COD levels for the region are 166 mg/l. COD values at all the sites are less in pre-monsoon month as compared

The BOD/COD ratio is an important indicator of pollution levels in water bodies. In present study the range of BOD: COD was 0.02 - 0.07 it indicates groundwater resources are not polluted and is found to be in acceptable zone of BOD: COD ratio triangle as shown in Table 5 and Figure 2 [21]. It indicates that organic matter load in water can be safely disposed in environment without significant effect on the overall quality of the environment. Within the acceptable zone, organic matter may undergo decomposition at slow rate and finally cease the so called stable zone.

The Total coliforms population load was maximum at Bahadurpur and minimum at Kachhpura. The range varied from 0.1 to 0.8 MPN/100 ml. It indicates that water is safe for domestic and agriculture use. The population load of Total coliforms in the water indicates the sewage contamination of the water. The main source of the Coliforms in the soil and water bodies is the human and animal excreta.

The collected water samples were analysed for five heavy metals viz., Fe, Cu, Zn, Cd and Cr. The levels of Cd and Cr were not detected in the samples. The concentration of the Iron (Fe) in the water sample of the studied sites was in the range 0.1 to 0.7 mg/l, maximum levels observed in Bahadurpur and Ranipur and minimum in Achanakpur site samples. Effect of seasonal variation is not clearly distinct with respect to Fe levels in collected water samples.

Table 4. Shows the data related to the groundwater quality parameters in the water samples at the five sites (Mean ± SD)

S.No.	Site (Abbreviation)	pH	EC	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	Total coliforms Load (MPN/100ml)	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)
1.	Achanakpur (V1)	7.8 ±0.25	1242.6 ± 109	725.0 ± 71.8	6.5 ± 1.0	164.5 ± 50.7	0.5 ± 0.1	0.23 ± 0.1	1.2 ± 0.2	2.5 ± 0.2
2	Bahadurpur (V2)	7.7 ± 0.22	1205.7 ± 399	624.5 ± 111.6	6.2 ± 1.4	159.25 ± 108.0	0.8 ± 0.2	0.55 ± 0.1	1.3 ± 0.3	2.3 ± 0.4
3	Ranipur (V3)	7.7 ± 0.29	1076.8 ± 286	636.5 ± 58.7	6.0 ± 1.1	202.25 ± 15.2	0.5 ± 0.1	0.45 ± 0.1	1.4 ± 0.2	2.4 ± 0.7
4	Kachhpura (V4)	7.6 ± 0.30	1110.2 ± 134	671.1 ± 60.0	5.7 ± 1.9	152.0 ± 80.8	0.1 ± 0.0	0.33 ± 0.05	1.2 ± 0.3	2.2 ± 0.3
5	Peeparwaha (V5)	7.5 ± 0.13	900.5 ± 127	589.5 ± 30.3	5.1 ± 1.2	152.3 ± 30.6	0.3 ± 0.1	0.38 ± 0.1	1.3 ± 0.1	2.6 ± 0.3

Table 5. The BOD:COD ratio for the five selected sites during the four seasons and groundwater quality status

S.No.	Site (Abbreviation)	BOD: COD Ratio				Pollution Indication
		Winter	Summer	Monsoon	Post Monsoon	
1.	Achanakpur (V1)	0.05	0.03	0.03	0.05	Not Polluted
2	Bahadurpur (V2)	0.05	0.05	0.02	0.07	Not Polluted
3	Ranipur (V3)	0.02	0.03	0.03	0.03	Not Polluted
4	Kachhpura (V4)	0.07	0.04	0.03	0.04	Not Polluted
5	Peeparwaha (V5)	0.02	0.04	0.04	0.05	Not Polluted

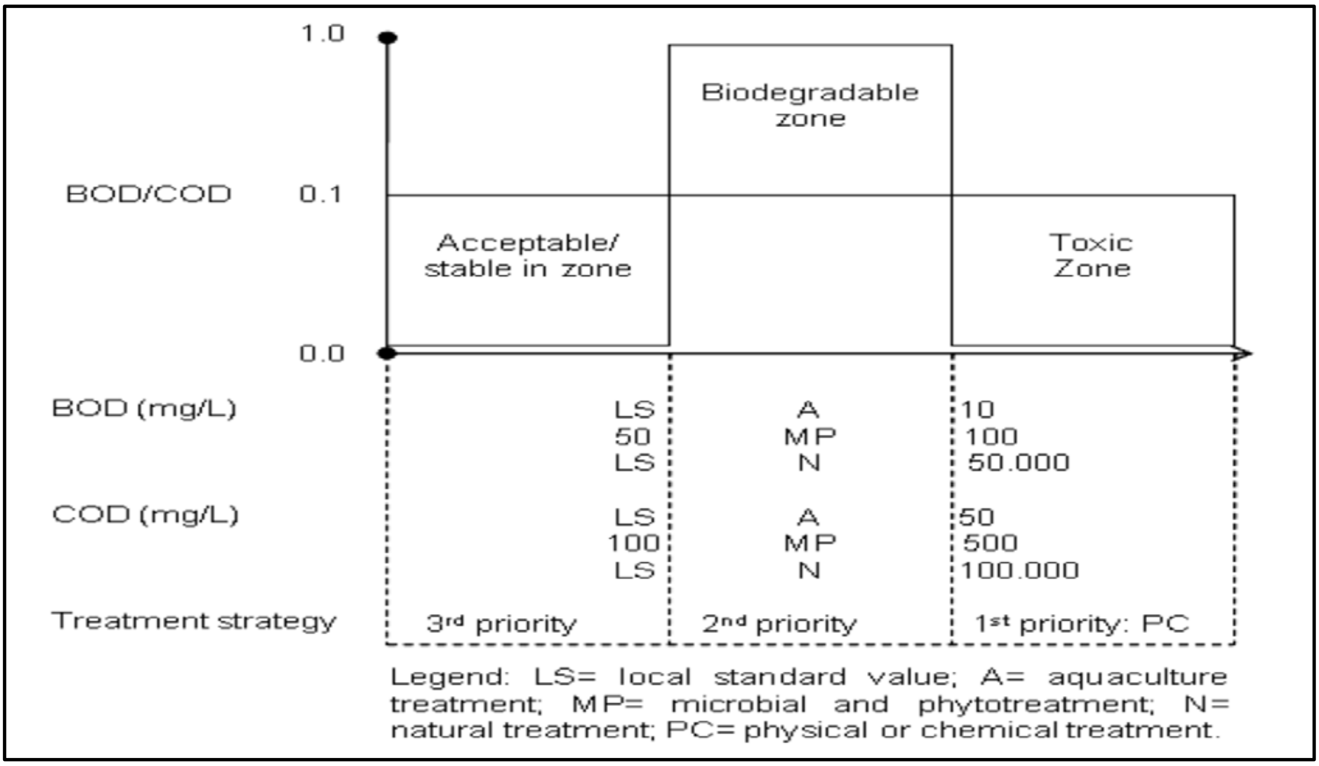

Figure 2. BOD: COD ratio triangle as adopted from Samudro et al. 2010 [30]

The concentration of Copper (Cu), the range of concentration was between 0.4 - 1.3 mg/l, maximum levels in Bahadurpur and minimum for Peeparwaha sites and did not exceeded drinking water standards 1.5 mg/l. Although Cu is an essential nutrient for all living organisms, the concentration from 0.25 to 1 mg/l is toxic to fishes; copper salts are used to control the algal growth.

The concentration of Zinc (Zn) at the selected sites observed was in the range of 1.2 -2.1 mg/l. The drinking water standard for zinc is 5 mg/l as per WHO [30], so there is no limitation of water consumption from this aspect. The adult requirement for Zn is 15 mg/day. Drinking water contributes about 3% of this requirement. Seasonally, Zn levels were minimum during monsoon season as compared to other three seasons, which have almost similar levels.

3.2. Seasonal Variation of Groundwater Quality Parameters

The studied water quality parameters were also studied seasonally. The samples were collected during the representative month for seasons viz., January (Winter), April (Summer), July (Monsoon) and October (Autumn). The seasonal variations of the studied water quality parameters are presented in the Figure 3 to Figure 11 in the form of bar diagrams. In the Figure 3 - Figure 11, the abbreviations V1, V2, V3, V4 and V5 are the representative of five sampling sites selected for study in the Auraiya district viz., Achanakpur, Bahadurpur, Ranipur, Kachhpura and Peeparwaha, respectively.

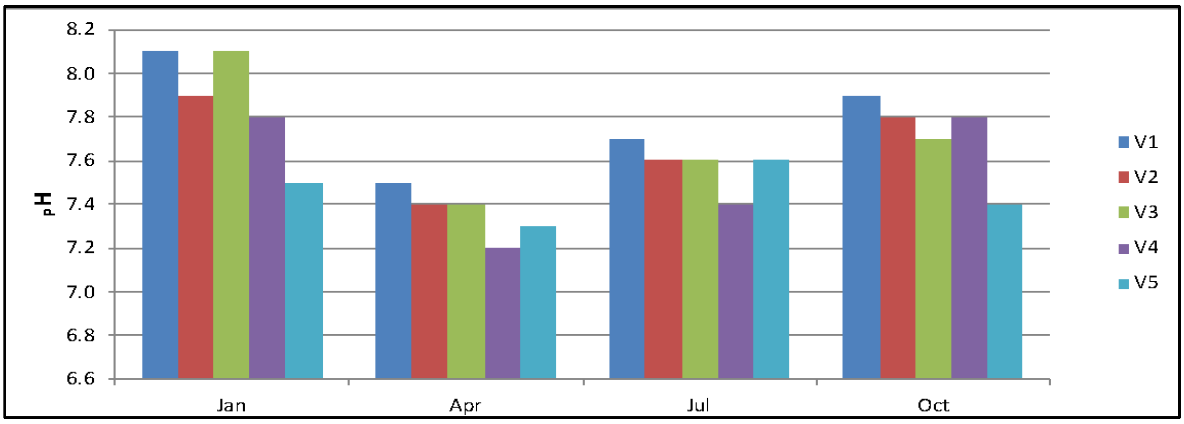

Figure 3. The variation in groundwater pH of different villages during different seasons

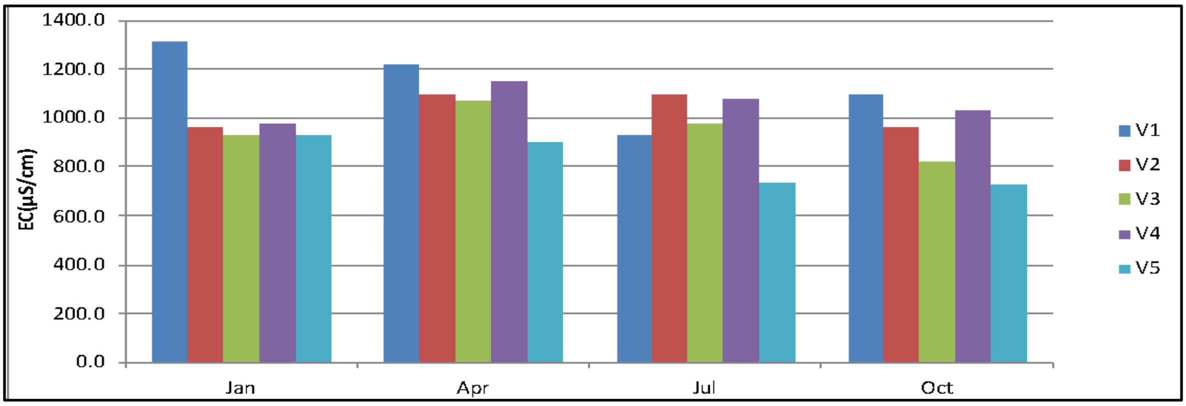

Figure 4. The variation in groundwater Electrical Conductivity of different sites during different seasons

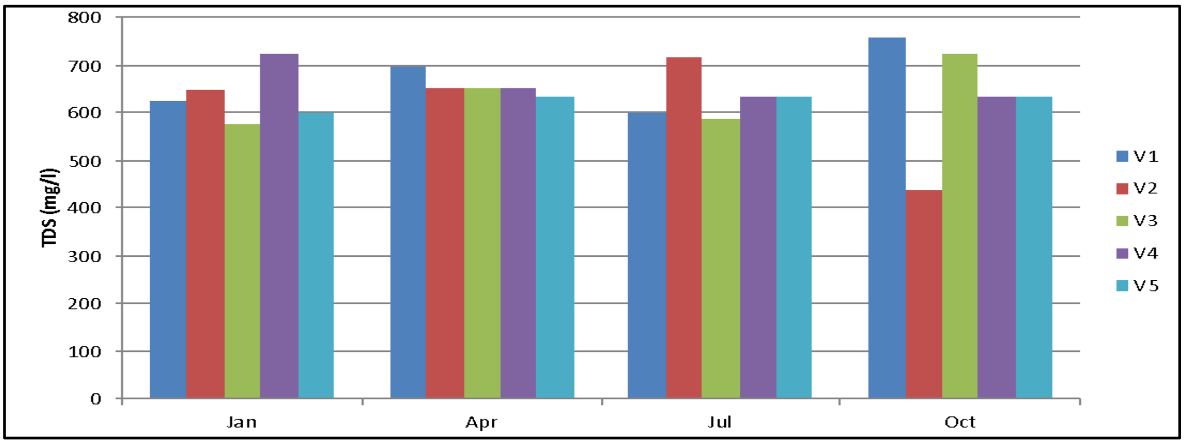

Figure 5. The Total Dissolved Solids levels in groundwater samples of different villages during different seasons

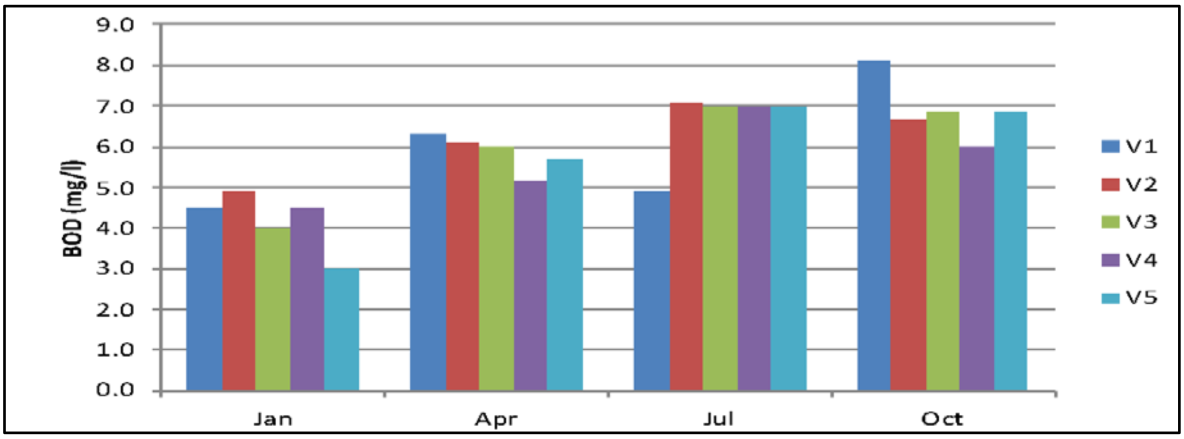

Figure 6. The Biological Oxygen Demand in groundwater samples of different villages during different seasons

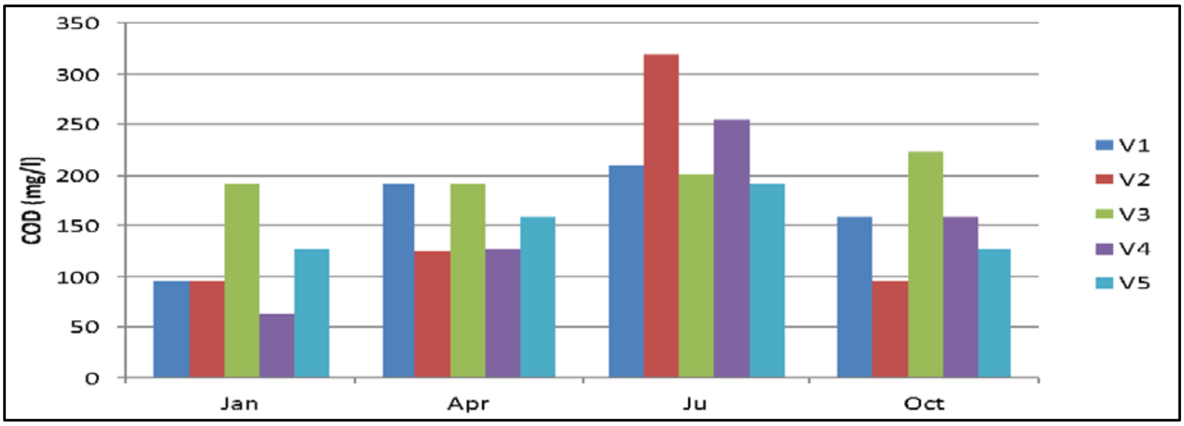

Figure 7. The Chemical Oxygen Demand in groundwater samples of different villages during different seasons

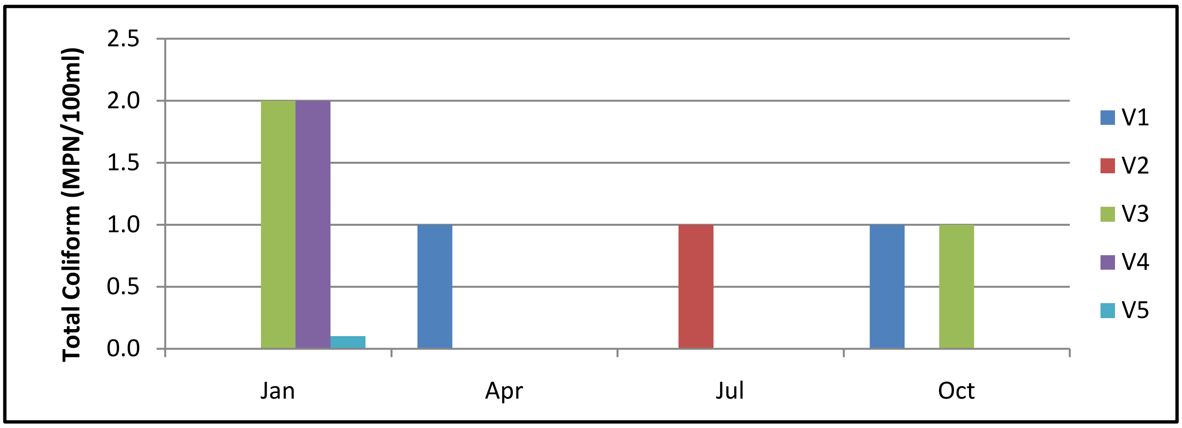

Figure 8. The Total coliforms population load in groundwater samples of different villages during different seasons

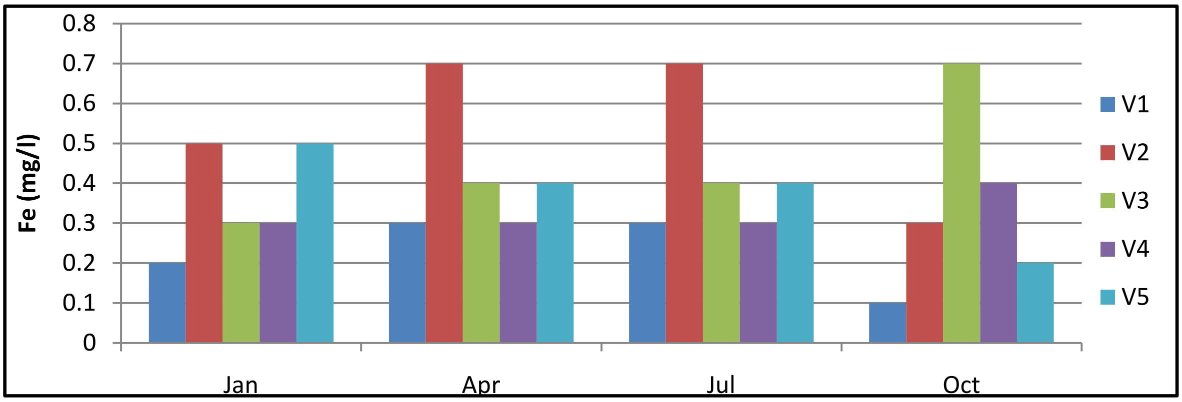

Figure 9. The Iron levels in groundwater samples of different villages during different seasons

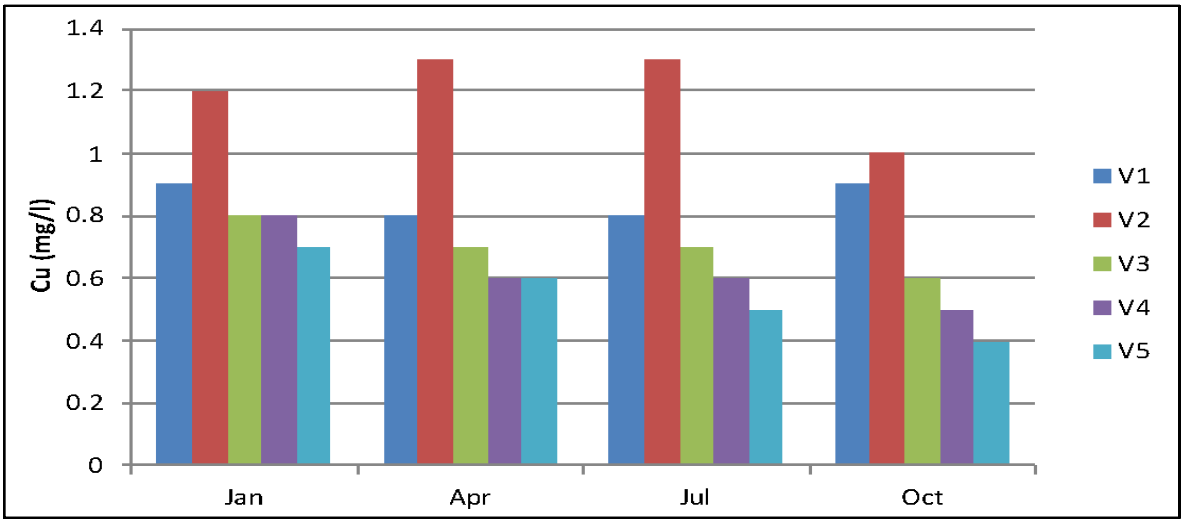

Figure 10. Copper levels in groundwater samples of different villages during different seasons

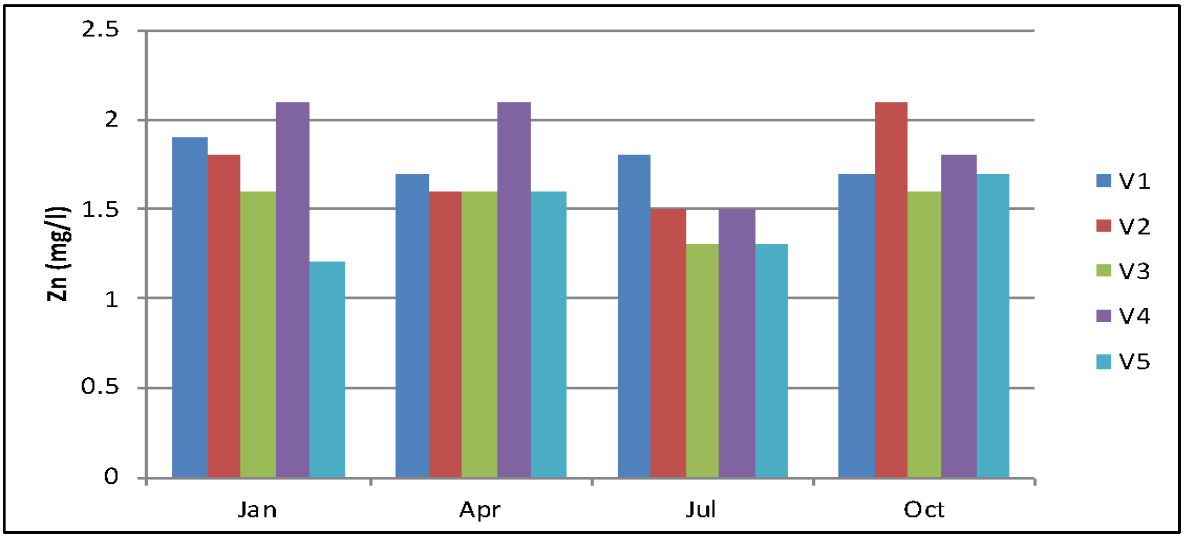

Figure 11. Zinc levels in groundwater samples of different villages during different seasons

4. Conclusions

The present study is carried out to assess the groundwater quality of Auraiya District industrial area, as limited number of reports is available on this aspect. Physico-chemical and biological parameters, groundwater quality indicators exhibited spatial and temporal variation i.e., variability in water quality of the selected villages as well as seasonally. Very few parameters exhibited exceedance of BIS permissible level and most of the parameters spatially as well as temporally within the prescribed limits of BIS standards. This indicates the quality of groundwater resources is good and can be utilized for meeting domestic demands.

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Conflict of Interest Statement

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

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