Seasonal Variations in Physicochemical Properties with Trace Metals and Microbial Status in Groundwaters of Biratnagar, Nepal

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Abstract:The abiotic and biotic examinations of ground water in Biratnagar city area were carried out to assess its quality on the basis of seasonal variations during post-monsoon(2015) and pre-monsoon(2016) period as unsafe drinking water is one of the major concerns in developing countries. Groundwater quality was determined by the examinations of some important water quality parameters such as temperature, pH, turbidity, electrical conductivity (EC), free carbon-dioxide (FCO_2), bi-carbonate (HCO_3), total hardness (TH), phosphate (PO_4-P), Nitrate-nitrogen (NO_3-N), Arsenic (As), Fluoride (Fl), Iron (Fe), Manganese (Mn), Cadmium (Cd), Zinc (Zn), Lead (Pb) as well as microbiological contamination level. From the present study, it was evident that most of the water quality parameters analyzed were within the WHO, BIS (Bureau of Indian Standards) and NDWQS (National Drinking Water Quality Standards-Nepal) limits for drinking water. Out of the total analyzed samples, the values of turbidity (67.27% in post-monsoon and 33.63% in pre-monsoon), Arsenic (38.18% in post monsoon and 52.72% in pre-monsoon), Fe and Mn (100% in both the seasons),) and microbial status (13.64%) in ground water samples exceeded the WHO guidelines.

Keywords: Groundwater, Physico-chemical parameters, trace metals, fecal coliform, Biratnagar, Nepal

I. Introduction

Water is the most essential substance for all life on earth and a precious resource for human civilization. About 97% water exists in oceans that is not suitable for drinking and only 3% is fresh water wherein 2.97% is comprised by glaciers and ice caps and remaining little portion of 0.3% is available as a surface and ground water for human use [1]. Reliable access to clean and affordable water is considered one of the most basic humanitarian goals, and remains a major global challenge for the 21st century. Inadequate water supply is still one of the major challenges in developing countries. The Joint Monitoring Program (JMP) for Water Supply and Sanitation, implemented by the World Health Organization (WHO) and UNICEF, reports that 783 million people in the world (11% of the total population) have no access to safe water, 84% of whom live in rural areas [2].

Increased urbanization and industrialization are to be blamed for an increased level of trace metals, especially heavy metals, in our waterways [3]. Many cities in Asia are facing increase in organic and nutrient material in drinking water due to the discharge of untreated domestic and industrial waste water into these resources [4]. Worldwide, more people are dying from poor quality of water per year than from all forms of violence including war and it is estimated that about 26% of all deaths are outcome from contagious diseases caused by pathogenic bacteria [5-6].

Still one billion people do not have clean water and 2.6 billion lack basic sanitation facilities in the world over [7-8]. Like many developing countries, Nepal faces a plethora of problems regarding both its drinking water quality and availability [9]. Growing population and unmanaged sewerage lines contaminate the surface and groundwater. Due to the leaching effects of these contaminates on the groundwater sources, fecal contamination of drinking water is emerging as a serious water quality problem in Nepal [10].

The groundwater quality of Terai and alluvial region of Nepal is poorly documented. Most of the studies on ground water quality in Nepal are confined to Kathmandu valley [9, 11-16]. Groundwater is abundant in the aquifers of the Terai region and is important source for domestic, industrial and agricultural uses. Exploitation of these aquifers, especially the shallow aquifer, has increased rapidly in recent years as a result of the increasing urbanization of the region. As a result, shallow ground waters are at risk from various contaminations. Arsenic in the Terai ground waters is a new emerging problem. No data are available for fluoride in Terai groundwaters.

Hence, a comprehensive study has been carried out to find out the quality of underground water by analyzing physicochemical, trace metals and biological variables with seasonal variations in Biratnagar city of Morang district in Terai region of Nepal.

II. MATERIALS AND METHOD

Study Area

The small and landlocked Kingdom of Nepal extends along the Great Himalayan Range between the latitudes 26^0 20' N to 30^0 27' N, and longitudes 80^0 04' E to 88^0 12' E, covering a distance of 885 km (from east to west), average width of 193 km (from south to north), and estimated area of 147181 sq km. The elevation of the country rises from 60 m mean sea level in the southern Terai to the crest of Himalayas reaching up to 8848 m at Sagarmatha (Mt. Everest) in the north [17]. The country borders India to the East, South and West and China to the North.Nepal has seven physiographic divisions from south to north and those include Terai, Siwalik Hills, Mahabharat 'Lek' (mountain range), Midlands, Himalayas, Inner Himalayas, and Tibetan marginal mountains [18].

Biratnagar city lies in the plain area of Morag district of eastern Nepal (Figure-1). The city is situated in the south-west corner of Morang district at 26° 23' N - 26° 30'N latitudes and 87° 14' - 87°18' E longitudes. The city is bordered by Kesalia River in the west, Tankisinwari Village Development Committee (VDC) in north, Singhiai River in east and Jogbani, (Araria district of Bihar, India) in south. Biratnagar is an industrial powerhouse of Nepal with many industries located in and around its suburbs. Biratnagar has traditionally been an agricultural hub and is home to many industries based on agriculture. Biratnagar city comprises of 22 wards and most of the people living in these wards depend on ground water sources i.e. shallow and deep tube wells for domestic purposes including drinking. According to 2011 census, population of Biratnagar was 2, 04,949. Nepal Water Supply Corporation Biratnagar (NWSCB) is the oldest corporation branch outside Kathmandu and serves more than 10,000 households. But this water supply is not enough to meet the domestic and irrigation demands for the increasing population in and around Biratnagar city. The data on groundwater quality of Biratnagar city has not yet been assessed properly.

Location Map of Study Area, Biratnagar,Nepal

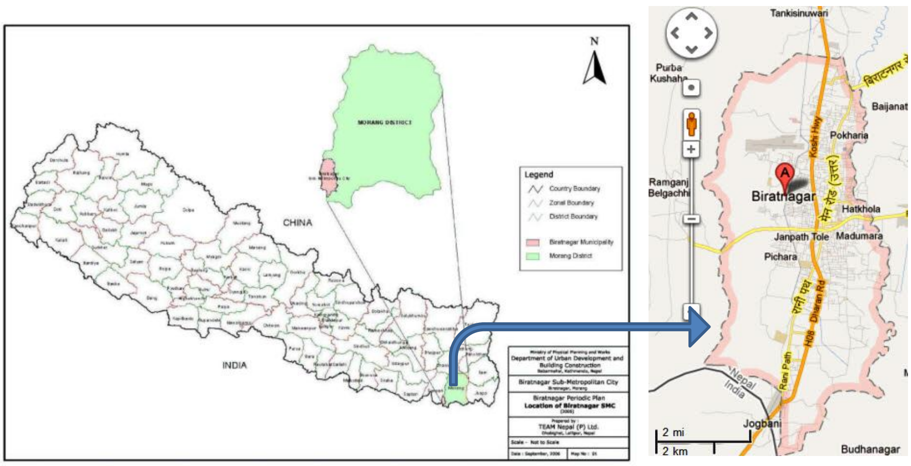

Figure1.Map of Biratnagar city, Nepal

III. METHODOLOGY

Groundwater samples were collected from 110 representative tube wells (five tube wells from each ward) of 22 Wards in Biratnagar city during post-monsoon 2015 and pre-monsoon 2016.110 tube wells (5 tube wells from each of 22 wards) were investigated for important physico-chemical parameters, arsenic and fluoride, whereas 44 tube wells (two tube wells from each ward) were examined for bacterial contamination and five representative tube wells from the five zones of the study area (ward nos. 4, 7, 10, 16 and 18) were tested for trace metals (Fe, Mn, Cd, Zn and Pb).

Sample locations were recorded using a Global Positioning System (GPS) Eterex-20. Physico-chemical properties of groundwater, concentration of trace metals (As, Fe, Mn, Cd, Zn and Pb), Fluoride and microbiological examinations were carried out for the assessment of drinking water quality. The parameters like temperature, pH, Dissolved oxygen, Free-carbon dioxide and Conductivity were determined on the spot while the rest of the parameters were analyzed in the Environment Biology Research Laboratory of University Department of T. M. Bhagalpur University, Bhagalpur, Bihar, India and Nepal Environmental Service Centre, Biratnagar. The overall analyses were done following the Standard Methods [19-20].The results were tabulated and compared to the guide-lines for drinking water [5, 21-22] as prescribed by WHO, BIS (Bureau of Indian Standards) and NDWQS (National Drinking Water Quality Standards-Nepal) limits for drinking water. The depth of the groundwater resources (tube wells) in the present study ranged from 20 to 200 feet.

IV. Results and Discussion

All the results for physicochemical and trace metal parameters for post-monsoon 2015 and pre monsoon 2016 are depicted in the Tables 1-4 and Figures 2-5.

Temperature

Groundwater temperature ranged from 19.84°C±0.13 to 22.34°C±0.23 in post-monsoon period and from 23.78°C±0.46 to 24.12°C±0.31^{0}C inpre-monsoon period. There was no significant difference in range of temperature in ground waters in post- and pre-monsoon period. Temperature impacts on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems [23].

Hydrogen- ion-concentration (pH)

The pH value ranged from7.5±0.21 (ward no. 4) to 7.68±0.11 (ward no. 9) during post- monsoon period and from 7.64±0.09 (ward no. 8) to 8.12±0.08 (ward no. 11) during pre-monsoon period. The pH value is an expression of the concentration of H^+ ion in the solution which is an important water quality parameter and a large variety of point and non-point source pollutants from industry, agricultural and domestic practices affect the pH of receiving water. The water having pH less than 6.5 may cause corrosion of metal pipes thereby releasing toxic metals like Zn, Pb, Cd and Cu etc. and pH higher than 8.0 adversely affect the disinfection process. The pH values were found within the prescribed guideline values of WHO, BIS and NDWQS-Nepal.

Turbidity

Turbidity values ranged from 4.94±5.83NTU (ward no 14) to 81.46±44.28 NTU (ward no. 10) during post-monsoon period and from 0.70±0.90NTU(ward no. 16) to 26.14±41.23 NTU (ward no. 2) during pre-monsoon period. Turbidity values, in 67.27% (n=74) water samples in post-monsoon and 33.63% (n=37) water samples in pre-monsoon period, were found to cross the WHO, BIS and NDWQS-Nepal prescribed limit of 5 NTU for drinking purposes.

Electrical Conductivity (EC)

EC values ranged from 277.8±55.12 µS/cm (ward no. 16) to 829.2±151.14 µS/cm (ward no. 12) during post-monsoon period and from 251.60±38.02 µS/cm (ward no. 20) to 806±0.195.50 µS/cm (ward no. 12) during pre-monsoon, all the values were within the permissible limits of WHO and NDWQS-Nepal guidelines. The BIS guideline for EC value is not available. The dissolution of ions in water makes it conductive and such ions may be beneficial or harmful to the body [24].

Dissolved Oxygen (DO)

The value of DO ranged from 1.64±0.09 mg/L (ward no. 9) to 4.92±0.18 mg/L (ward no. 11) during-post-monsoon period and from 3.60±0.49 mg/L (ward no. 10) to 4.48±0.33 mg/L (ward no. 6) during pre-monsoon, all the values being well within the WHO and BIS guideline value of 5 mg/L. The NDWQS-Nepal guideline value for DO is not available.

Free carbon-dioxide (FCO$_2$)

FCO$_2$ values ranged from 13.20±1.10 mg/L (ward no. 1) to 17.6±3.58 mg/L (ward no. 10) during post-monsoon period and from 12.40±0.89 mg/L (ward no. 1) to 15.60±1.67 mg/L (ward no. 8) during pre-monsoon, all the values crossing the WHO guideline value. The BIS and NDWQS-Nepal guideline value is not available for FCO$_2$.

Bi-carbonate (HCO_3^-)

The bicarbonate (HCO_3^-)values ranged from 24±3.74 mg/L (ward no. 12) to 152.8±33.90mg/L (ward no. 9) during post-monsoon period and from 44.80±3.63 mg/L (ward no. 1) to 153.60±61.11 mg/L (ward no. 12) during pre-monsoon. The permissible limit of bicarbonates is not recommended by WHO and NDWQS-Nepal, however BIS standard is 150- 300 mg/L.

Total hardness (TH)

Total hardnessvalues ranged from 79.60±12.68 mg/L (ward no. 1) to 180±35.36 mg/L (ward no. 13) during post-monsoon period and from 140.00±31.62 mg/L (ward no. 1) to 252±30.33 mg/L (ward nos. 17, 21) during pre-monsoon period and, all the values were within the WHO, BIS and NDWQS-Nepal guidelines for TH for drinking water.

Phosphate (PO_4^-P)

Post-monsoon phosphatevalues ranged from 0.15±0.00 mg/L (ward no.13) to 0.17±0.01 (ward no. 2) whereas pre-monsoon phosphate values were in the range between 0.15±0.01 mg/L (ward no.1) to 0.18±0.00 mg/L (ward no.6),all the values well within the WHO guideline. The guideline values forPO_4^-P are not available in BIS and NDWQS-Nepal.

Nitrate-nitrogen (NO_3^-N)

Nitrate-nitrogen (NO_3^-N) values in the analyzed groundwater samples in the present study were found in the lower range similar to $PO4^-P$ values. NO_3^-N ranged from 0.34±0.00 mg/L (ward no. 1) to 0.39±0.04 mg/L (ward no. 3) and from 0.34±0.04 mg/L (ward no. 9) to 0.38±0.01 mg/L (ward no. 15) during post-monsoon and pre-monsoon periods respectively and all the values were well within the WHO, BIS and NDWQS-Nepal guidelines values.

Arsenic (As)

Arsenic (As) values in groundwater samples ranged from nil (ward no. 3) to 0.17±0.21 mg/L (ward no. 1) during post-monsoon periodand from 0.01±0.00 mg/L (ward. no 13) to 0.23±0.25 mg/L (ward no. 1) during pre-monsoon period. The concentrations of As in groundwater in most of the wards were found very low (below detection limit) in both pre-monsoon and post-monsoon period. However, As concentrations in 42 water samples (38.18%) during post-monsoon and in 58 water samples (52.72%) during pre-monsoon (N = 110) exceeded the WHO permissible limit of 0.01 mg/L. As per BIS and NDWQS-Nepal guideline values for As in drinking water, only 10 water samples (9.09%) during post-monsoon and 22 water samples (20%) during Pre-monsoon (N = 110) exceeded the prescribed limit. Inorganic arsenic is considered carcinogenic and is related mainly to lung, kidney, bladder, and skin disorders [25]. Clinical symptoms of acute intoxication of As include abdominal pain, vomiting, diarrhoea, muscular pain, and weakness with flushing of the skin [26].

Fluoride (Fl)

Fluoride is a naturally occurring chemical substance found in water, soil, foods and several other compounds in trace quantities [27].The fluoride content was found below detectable level in all the analyzed groundwater samples.

Iron (Fe)

The valuesof Iron (Fe) ranged from 0.39 mg/L to 6.73 mg/L during post-monsoon and from 0.35 mg/L to 1.79 mg/L during pre-monsoon period. During both post- and pre-monsoon, the concentration of Fe is beyond the WHO, BIS and NDWQS-Nepal permissible limit of 0.3 mg/L. Iron stains laundry and plumbing fixtures at levels above 0.3 mg/L; there is usually no noticeable taste at iron concentrations below 0.3 mg/L, and concentrations of 1–3 mg/L can be acceptable for people drinking anaerobic well water [23].

Manganese (Mn)

Mn values ranged from 0.37 to 5.96 mg/L during post-monsoon and from 0.21 to 1.50 mg/L during the pre-monsoon, all the values crossing the permissible limit of 0.2 mg/L Mn prescribed by WHO, BIS and NDWQS-Nepal for drinking water.It is important to state that the high or low Mn level detected in the water samples does not pose human health problems. These concentrations have the ability of discolouring water, i.e. high Mn concentrations result in black colouration, which leads to the staining of laundry and sanitary wares [28].

Cadmium (Cd)

Cd values were found to be same i.e. 0.0001 mg/L during both post and pre-monsoon periods which is under the WHO, BIS and NDWQS-Nepal permissible limit of 0.003 mg/L. Cadmium accumulates in the human body affecting negatively several organs: liver, kidney, lung, bones, placenta, brain and the central nervous system [29].

Zinc (Zn)

Zn concentrations in all the groundwater samples were found to be in the range of 0.005 mg/L to 0.7 mg/L during both post- and pre-monsoon periods, well within permissible and prescribed limit of WHO, BIS and NDWQS-Nepal. Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. The diet is normally the principal source of zinc. Although levels of zinc in surface water and groundwater normally do not exceed 0.01 mg/L and 0.05 mg/L respectively, concentrations in tap water can be much higher as a result of dissolution of zinc from pipes (23).

Lead (Pb)

Pb values were found to be similar i.e. 0.005 mg/L in all the groundwater samples examined during both post- and pre-monsoon periods, well within the WHO, BIS and NDWQS-Nepal permissible limit of 0.01 mg/L. Lead is a general toxicant that accumulates in the skeleton. Infants, children up to 6 years of age and pregnant women are most susceptible to its adverse health effects. Lead also interferes with calcium metabolism, both directly and by interfering with vitamin D metabolism. Lead is toxic both to the central and peripheral nervous systems, inducing subencephalopathic neurological and behavioural effects (23).

Microbiological Examination

A total of 44 groundwater samples (2 samples from each of 22 wards) were examined for faecal coliform bacteria and it was found positive only in 10 wards (ward nos. 2, 3, 4, 9, 10, 11,14,15,21 and 20) constituting 45,45% of the total. Faecal coliform in the water samples of these six wards ranged from 3 to 25 MPN/100 ml in post-monsoon months and from 5 to 20 MPN/100 ml in pre-monsoon months. The presence of coliform was possibly due to lack of concrete base plate of tube well and unsafe distance from all possible sources of contamination.The presence of total coliform in water is an indication of faecal contamination and is responsible for most water borne diseases such as meningitis, cholera and diarrhea as well as morbidity and mortality among children including acute renal failure and haemolytic anaemia in adults [30].

Table 1. Physicochemical characteristics of groundwater in Biratnagar city, Nepal (Post-monsoon, 2015)

Ward No.	Temp	P^H	Turb	EC	DO	FCO_2	HCO_3^-	TH	PO_4-P	NO3-N	As	Depth
1	22.16±0.23	7.58±0.11	6.86±5.18	632.60±206. 20	1.68±0.11	13.20±1.10	58.40±19.26	79.60±12.68	0.17±0.00	0.34±0.00	0.17±0.21	63±7.78
2	22.10±0.24	7.64±0.11	50.18±51.87	656.2±113.73	1.64±0.09	14.4±1.67	55.2± 19.11	100.4±6.54	0.17±0.01	0.36±0.00	0.12±0.22	57.8±3.11
3	21.82±0.24	7.64±0.13	11.1±11.47	726.2±148.41	1.88±0.11	14.8±1.10	61.6±11.17	120±47.43	0.17±0.00	0.39±0.04	0.00±0.00	63.4±7.57
4	22±0.23	7.5±0.21	22±18.96	579±203.45	1.72±0.11	15±1.73	60.4±18.46	128.4±19.31	0.17±0.00	0.35±0.00	0.02±0.02	50.8±7.01
5	21.4±0.10	7.56±0.09	22.1±16.58	441.8±130.87	1.84±0.17	14.8±1.10	50.8±16.83	105.2±29.35	0.17±0.01	0.35±0.01	0.02±0.01	56.2±6.30
6	22±0.37	7.56±0.09	34.76±30.51	399.6±138.71	1.68±0.11	14.4±2.30	116±52.33	116±52.33	0.17±0.00	0.35±0.00	0.04±0.04	54±10.25
7	22.34±0.23	7.56±0.09	7.68±7.27	468.2±233.38	1.84±0.22	14.4±1.67	120.8±53.75	120.8±53.75	0.17±0.00	0.35±0.00	0.02±0.01	56.6±7.89
8	22.3±0.10	7.58±0.08	2.1±2.80	671.6±147.81	1.76±0.09	16±2.83	138±65.51	138±65.51	0.17±0.00	0.36±0.01	0.03±0.02	65.2±7.85
9	21.38±0.08	7.68±0.11	28.94±27.36	756±129.52	1.64±0.09	17.2±3.03	152±61.40	152±61.40	0.17±0.00	0.35±0.04	0.14±0.24	69.6±17.62
10	21.4±0.07	7.6±0.10	81.46±44.28	579.6±192.17	1.84±0.22	17.6±3.58	57.6±17.74	114±23.41	0.17±0.00	0.36±0.01	0.02±0.01	83.4±65.80
11	21.42±0.08	7.56±0.09	57.24±41.14	415.4±240.23	1.92±0.18	14.8±1.10	39.6±18.99	176.8±85.68	0.17±0.00	0.36±0.01	0.02±0.01	84.2±62.00
12	21.38±0.05	7.560.09	23.6±41.65	829.2±151.14	1.76±0.22	15.6±1.67	63.6±6.99	139.2±37.06	0.15±0.00	0.36±0.00	0.00±0.01	54.8±20.57
13	21.24±0.11	7.52±0.04	5.62±4.28	661.6±210.77	1.8±0.20	15.2±0.84	54±17.44	180±35.36	0.15±0.00	0.35±0.00	0.01±0.00	59±4.18
14	21.08±0.08	7.54±0.05	4.94±5.83	810.8±173.55	1.68±0.18	15.6±1.67	62±8.83	152.8±42.06	0.15±0.01	0.35±0.00	0.01±0.01	56.2±5.45
15	21.08±0.08	7.54±0.09	20.92±23.71	567.6±290.03	1.72±0.18	16±3.16	44.8±17.70	152.8±33.90	0.15±0.00	0.36±0.01	0.01±0.01	53.6±7.16
16	20.6±0.37	7.58±0.08	25.94±23.47	277.8±55.12	1.72±0.11	16.8±2.68	24±3.74	125.6±75.89	0.15±0.00	0.34±0.00	0.05±0.04	56.6±13.46
17	20.78±0.11	7.6±0.10	12.66±19.15	348.8±152.26	1.76±0.17	17.2±1.79	26.4±13.22	102.8±31.29	0.16±0.01	0.36±0.01	0.02±0.01	61.8±17.95
18	20.62±0.13	7.56±0.09	24.46±26.51	363.6±204.39	1.84±0.22	14.4±0.89	28.8±12.13	86±50.30	0.17±0.02	0.35±0.00	0.01±0.00	66.6±16.21
19	20.64±0.05	7.6±0.10	19.48±14.91	424.6±164.73	1.84±0.17	14.4±2.61	30.4±11.44	122±48.17	0.16±0.01	0.35±0.00	0.02±0.01	46.6±5.50
20	20.16±0.09	7.56±0.09	13.46±12.93	321.2±166.22	1.8±0.20	14.8±1.10	28.8±9.44	92±38.99	0.16±0.01	0.35±0.00	0.01±.01	59±6.52
21	20.02±0.04	7.62±0.16	13.76±13.26	574.2±283.09	1.68±0.11	14±1.41	38.4±7.92	144±55.5	0.17±0.02	0.35±0.00	0.01±0.01	50.4±11.41
22	19.84±0.13	7.56±0.09	27.3±35.48	546.2±197.60	1.72±0.18	13.2±1.10	31.6±12.84	106±35.07	0.16±0.00	0.35±0.01	0.02±0.02	53.2±11.34

Table 2. Physicochemical characteristics of groundwater in Biratnagar city, Nepal (Pre-monsoon,2016)

Ward No.	Temp	P^H	Turb	EC	DO	FCO_2	HCO_3^-	TH	PO_4-P	NO3-N	As	Depth
1	24.06±0.34	7.92±0.08	2.94±1.61	411.20±124.52	3.92±0.77	12.40±0.89	44.80±3.63	140.00±31.62	0.15±0.001	0.36±0.00	0.23±0.25	63±7.78
2	24.02±0.16	7.86±0.11	26.14±41.23	678.80±89.05	4±0.49	14±1.41	69.20±10.45	204.00±26.08	0.15.00	0.35±0.00	0.18±0.27	57.8±3.11
3	24.06±0.34	7.88±0.23	7.46±5.50	702.40±136.24	4.08±0.52	12.40±0.89	107.20±34.48	208±48.17	0.16±0.00	0.35±0.00	0.02±0.01	63.4±7.57
4	23.78±0.46	8.02±0.08	15.66±11.64	629.80±153.58	3.60±0.40	13.20±1.10	86±36.77	196.0043.36	0.17±0.01	0.35±0.01	0.04±0.02	50.8±7.01
5	23.96±0.45	7.96±0.23	7.78±5.69	521.20±287.39	3.52±0.33	13.20±1.79	124±27.02	240±37.42	0.17±0.00	0.36±0.01	0.03±0.01	56.2±6.30

6	24.020.16	8.04±0.11	11.76±9.86	444.40±79.66	4.48±0.33	14.80±2.28	113.60±24.39	176±21.91	0.18±0.00	0.36±0.01	0.05±0.04	54±10.25
7	24.06±0.34	7.92±0.08	6.64±8.90	439.40±203.14	3.60±0.28	12±0.00	78.40±35.98	216±55.50	0.18±0.00	0.37±0.00	0.03±0.02	56.6±7.89
8	23.92±0.28	7.64±0.09	2.36±1.21	644.60±106.74	4±0.40	15.60±1.67	71.20±58.01	220±37.42	0.17±0.01	0.36±0.01	0.08±0.10	65.2±7.85
9	24.10±0.34	8.04±0.11	2.10±1.06	690.80±177.81	3.52±0.82	12.40±0.89	136±39.47	204±47.75	0.18±0.00	0.34±0.04	0.02±0.02	69.6±17.62
10	23.96±0.55	7.94±0.15	5.30±1.62	567±230.20	3.60±0.49	13.201.79	86±36.77	196±43.36	0.16±0.00	0.36±0.00	0.03±0.02	83.4±65.80
11	24.02±0.37	8.12±0.08	14.50±11.39	387±211.96	3.20±0.49	14±2.00	186±67.68	240±37.42	0.16±0.01	0.36±0.01	0.02±0.02	84.2±62.00
12	23.80±0.47	7.83±0.17	1.24±0.48	806±195.50	3.92±0.33	13.20±1.79	153.60±61.11	196±51.77	0.17±0.01	0.36±0.00	0.14±0.24	54.8±20.57
13	23.98±0.42	8.08±0.08	1.12±0.48	667.60±63.51	4.08±0.52	13.60±1.67	74.40±40.73	196±43.36	0.16±0.00	0.36±0.00	0.01±0.00	59±4.18
14	23.78±0.52	8.08±0.08	16.62±20.65	653.20±127.51	3.68±0.87	12.80±1.10	57.20±29.79	240±37.42	0.16±0.01	0.36±0.01	0.02±0.01	56.2±5.45
15	23.88±0.59	7.94±0.18	6.52±7.76	521.20±293.10	3.60±0.49	14±1.41	118.80±42.51	212±36.33	0.16±0.00	0.38±0.01	0.02±0.01	53.6±7.16
16	23.96±0.18	8.04±0.11	0.70±0.90	329.20±110.46	3.52±0.33	14±1.41	99.20±45.00	172±30.33	0.16±0.00	0.35±0.00	0.03±0.02	56.6±13.46
17	24.06±0.34	7.94±0.15	1.38±1.25	363.60±121.39	4±0.40	12.80±1.10	148±54.04	252±30.33	0.16±0.00	0.38±0.01	0.03±0.01	61.8±17.95
18	24.10±0.27	7.90±0.07	2.34±1.45	513.80±194.32	4±0.28	12.40±0.89	151.60±63.43	204±32.86	0.16±0.00	0.36±0.01	0.02±0.02	66.6±16.21
19	24.10±0.32	7.98±0.13	11.82±17.16	383.60±148.32	3.76±0.46	12.80±1.10	88.40±32.94	172±30.33	0.16±0.00	0.37±0.01	0.02±0.01	46.6±5.50
20	24.12±0.31	8.02±0.13	3.66±2.88	251.60±38.02	3.68±0.44	14±3.46	72±50.58	252±30.33	0.17±0.01	0.36±0.00	0.02±0.02	59±6.52
21	24.02±0.37	7.86±0.28	2.88±4.17	614.20±270.50	4.16±0.46	14.80±1.79	108±33.47	212±30.33	0.18±0.01	0.36±0.01	0.02±0.01	50.4±11.41
22	24±0.16	7.88±0.13	11.74±13.17	528.20±185.29	3.84±0.36	13.20±1.79	138±36.33	248±30.33	0.17±0.01	0.36±0.01	0.03±0.02	53.2±11.34

All the parameters are expressed in ppm or mg/L except Temperature (^{0}C), pH, Turbidity (NTU) and EC (µS/cm)

Table 3. Range of variations in groundwater quality variables during post-monsoon (2015) and pre-monsoon (2016) periods

Water Parameters	Post-monsoon 2015		Pre-monsoon-2016	
	Minimum / ward	Maximum / ward	Minimum / ward	Maximum / ward
Temp	19.84±0.13(22)	22.34±0.23(7)	23.78±0.46(4)	24.12±0.31(20)
P^H	7.5±0.21(4)	7.68±0.11(9)	7.64±0.09(8)	8.08±0.08(13,14)
Turb	4.94±5.83(14)	81.46±44.28(10)	0.70±0.90(16)	26.14±41.23(2)
EC	277.8±55.12(16)	829.2±151.14(12)	251.60±38.02(20)	806±195.50(12)
DO	1.64±0.09(9)	1.92±0.18(11)	3.60±0.49(10)	4.48±0.33(6)
FCO_2	13.20±1.10(1)	17.6±3.58(10)	12.40±0.89(1)	15.60±1.67(8)

HCO_3	24±3.74(12)	152±61.40(9)	44.80±3.63(1)	153.60±61.11(12)
TH	79.60±12.68(1)	180±35.36(13)	140.00±31.62(1)	252±30.33(17,21)
PO_4-P	0.15±0.00(13)	0.17±0.01(2)	0.15±0.001(1)	0.18±0.00(6)
NO_3-N	0.34±0.00(1)	0.39±0.04(3)	0.34±0.04(9)	0.38±0.01(15,17)
As	0.00±0.01(3)	0.17±0.21(1)	0.01±0.00(13)	0.23±0.25(1)

* Ward Nos. given in parenthesis

Table 4: : Heavy metal concentrations in groundwaters (N=5) of Biratnagar city in Post- and Pre-monsoon period (2015-16)

*Ward No.	Fe(mg/L)		Mn (mg/L)		Cd (mg/L)		Zn (mg/L)		Pb (mg/L)	
	Post-monsoon-2015	Pre-monsoon-2016	Post-monoon-2015	Pre-monsoon-2016	Post-monsoon-2015	Pre-monsoon-2016	Post-monsoon-2015	Pre-monsoon-2016	Post-monsoon-2015	Pre-monsoon-2016
4	6.73	1.46	2.47	0.98	0.0001	0.0001	0.07	0.07	0.005	0.005
7	0.39	0.35	0.37	0.21	0.0001	0.0001	0.005	0.005	0.005	0.005
10	0.94	1.79	0.83	1.50	0.0001	0.0001	0.005	0.005	0.005	0.005
16	0.70	0.37	5.96	1.44	0.0001	0.0001	0.005	0.005	0.005	0.005
18	0.66	0.68	2.40	1.06	0.0001	0.0001	0.6	0.6	0.005	0.005

***One water sample from each of five wards representing the five zones of the study area**

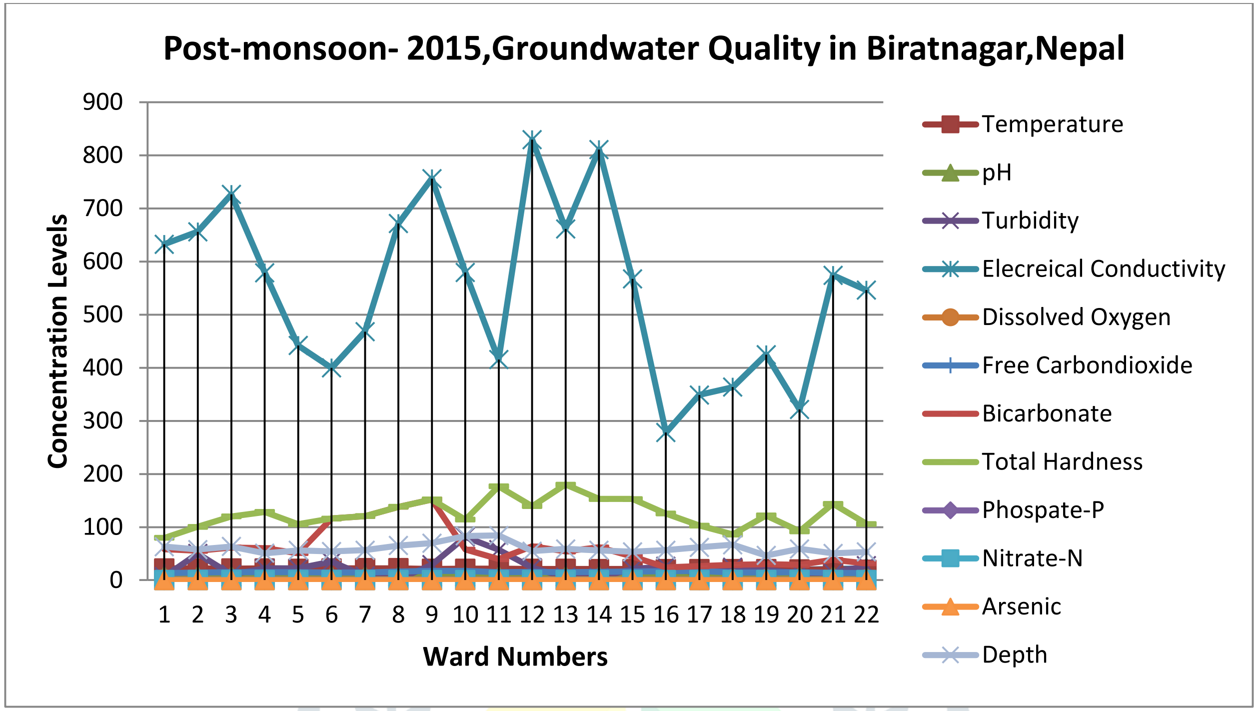

Figure 2.Concentrations of physicochemical parameters of groundwaters in Biratnagar city, Nepal during post-monsoon-2015

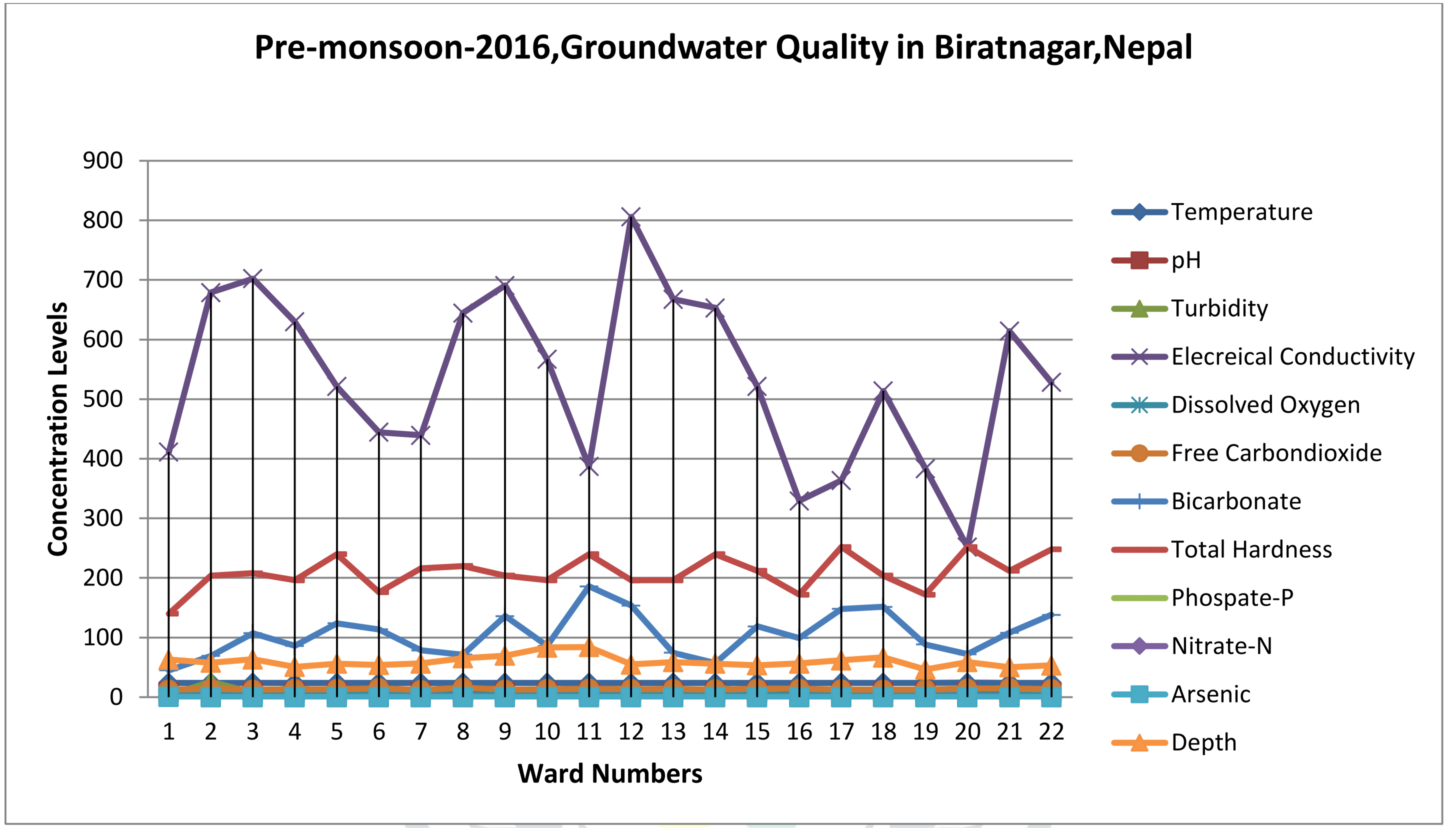

Figure 3. Concentrations of physicochemical parameters of groundwaters in Biratnagar city, Nepal during pre-monsoon-2016

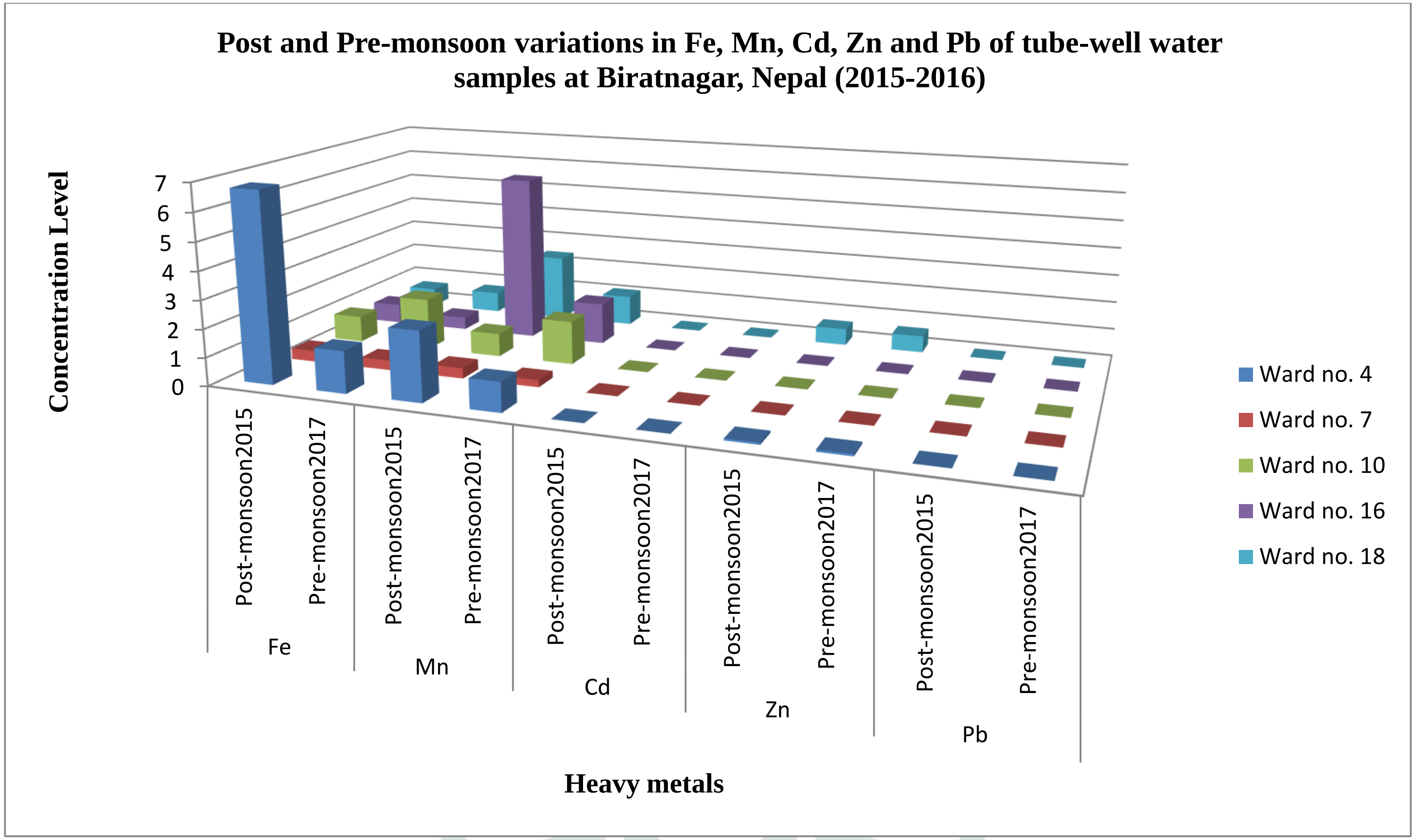

Fig.4: Post and Pre-monsoon variations in Fe, Mn, Cd, Zn and Pb of Tube-well water samples at Biratnagar, Nepal (2015-2016)

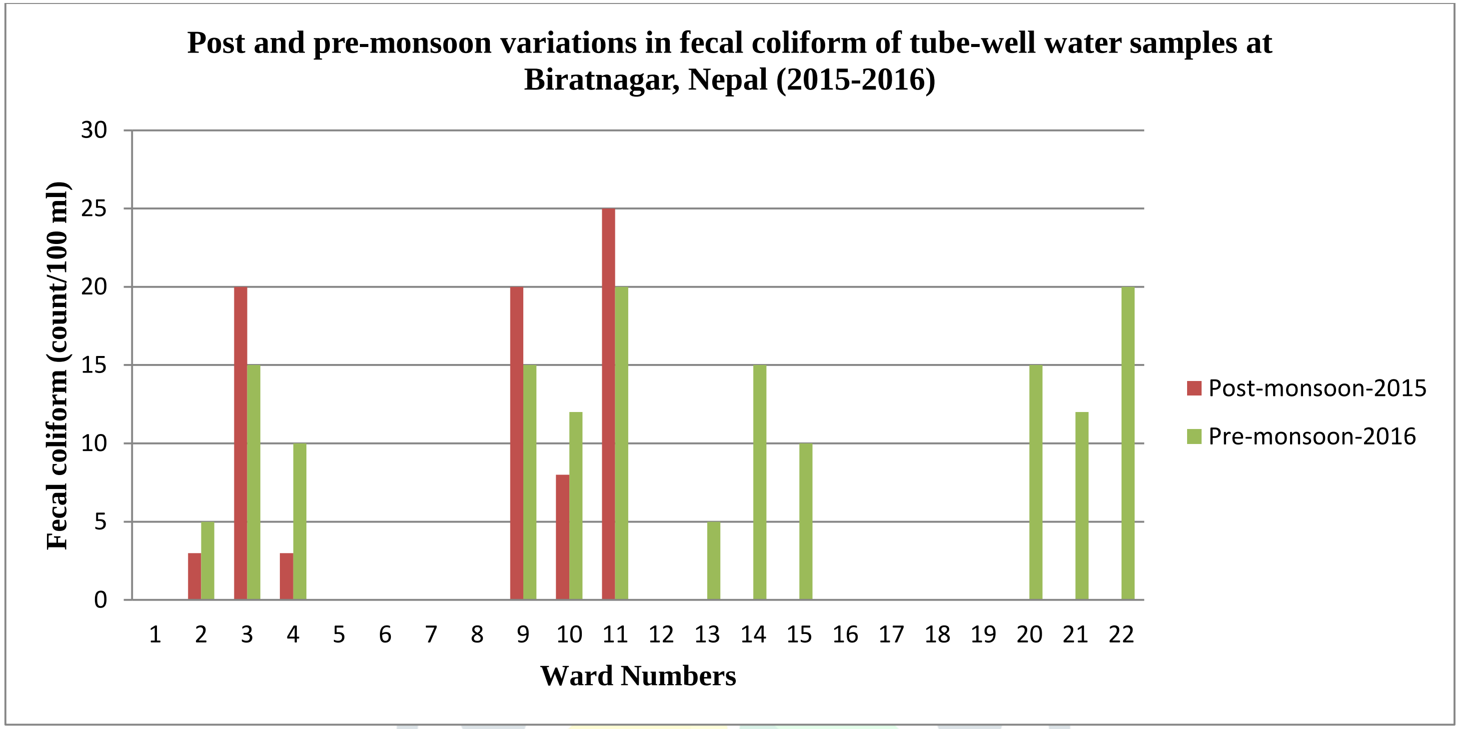

Fig. 5: Post and Pre-monsoon variations in Fecalcoliform of Tube-well water samples at Biratnagar, Nepal (2015-2016)

VI. Conclusion

This paper describes a survey carried out in the Biratnagar city, Nepal to assess the groundwater quality for human consumption. As a consequence, this research provides baseline groundwater quality data in this area. Out of all the water quality parameters analyzed in the present study, pH, phosphate (PO_4-P) and Nitrate- nitrogen (NO_3-N), were found to be within the WHO, BIS (Bureau of Indian Standards) and NDWQS (National Drinking Water Quality Standards-Nepal) limits for drinking water, therefore, do not pose any threat to the health of human beings. On the other hand, the higher turbidity values were recorded from 75 water samples (67.27%) during post-monsoon and 37 water samples (33.63%) during pre-monsoon (N=110). The cause of higher value of turbidity in groundwater during post-monsoon is due to mixing of soil particles partially coated with organic materials, microbes and other contaminants. In case of arsenic, higher values were recorded from 58 water samples (52.72%) during pre-monsoon and 42 water samples (38.18%) during post-monsoon. It was observed that concentration of arsenic were relatively higher during pre-monsoon period than post-post-monsoon period. It might be due to lesser recharge rate of water table during pre-monsoon period. The higher values of iron, manganese and MPN coliform were also recorded during the investigation. On the basis of the results obtained on physico-chemical including heavy metals and microbiological variables of groundwaters (mainly shallow tube wells), it has been concluded that the groundwater sources with elevated levels of turbidity, arsenic, iron, manganese and faecal coliform are unsuitable for drinking and other domestic purposes before proper treatment. People using water from these contaminated sources for drinking and other domestic purposes are susceptible to water-borne diseases. Therefore, it is strongly recommended to keep the groundwater sources at the safe distance from all the possible sources of contamination.

From the present study the quality of groundwaters in Biratnagar city may not appear gloomy but it definitely gives early warning and suggests taking appropriate measures to protect these water sources from contamination. Though the present study was aimed to generate baseline data on groundwater quality of Biratnagar city in Nepal, it needs further detailed investigations and monitoring to keep the groundwater sources in Biratnagar city safe for drinking and other domestic uses.

VII. Acknowledgements

The authors are grateful to the University Department of Botany,T. M. Bhagalpur University, Bhagalpur, Bihar (India) and Nepal Environmental Service Centre, Biratnagar for providing laboratory facilities. The authors are also thankful to Dr. Braj Nandan Kumar and Dr. Ranjan Kumar Mishra for their precious help during the research both in field and lab.

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