Final Report

Water Quality Assessment of Haridwar District

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PREFACE

The water of sound quality is the key for socio-economic functions on Earth. However, water resources are degrading, due to rise in pollutants caused by increased population and economy. The water resources for direct and indirect human use can be contaminated by pollutants of geogenic as well as anthropogenic origin. Human activities that lead to contamination of water resources include untreated wastewater discharge from industries and municipalities, leachates from solid waste dumping sites, agricultural activities, burning of fossil fuels, vehicular traffic, fireworks, etc. In fact, all the chemicals generated by human activity can and will find their way into water supplies and are related to population mortality Haridwar has been the subject of much scepticism in the last decade. In the last two decades, after the creation of Uttarakhand as the 27th state of India, unprecedented growth and industrialization has taken place in Haridwar and in turn the effluents, which deteriorated the water resources of the district. The deteriorated water quality has negatively impacted the health of the residents. In this report, attempts have been made to analyse the comprehensive drinking water quality of the district and its suitability for drinking water usage.

The report has been prepared by Er. Rajesh K. Nema, Sc. B; Dr. Rajesh Singh, Sc. D; and Dr. Pradeep Kumar, Sc. D under the guidance of Head, Environmental Hydrology Division.

(J. V. Tyagi)
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1 Introduction

With the growing human population and ever-increasing demand for domestic, agricultural, and industrial purposes, tremendous pressure has been mounted on the precious water resources. Because of the increasing demand and imprudent use of this natural resources, it is under continuous threat and its continuous depletion and deterioration of quality is observed in the Asian nation. The Indo-Gangetic plain, which is blessed with ample quantities of water resources, is also not spared. Haridwar district is also blessed with surface water and groundwater resources, however, due to increased anthropogenic activities the water resources are getting deteriorated. Over the period, around 7600 industrial units got established with most of the units in 17 industrial parks. The industries has put pressure on the fresh water of the district and the discharge from these industries is a source of pollution. Apart from this, the farmers grow sugarcane which is a water guzzling crop. In addition, due to the fast development of the district, the population has significantly increased and in turn the sewage from the habitation again find its way to the environment. It has been reported in the media and few research papers that the water quality of the district is deteriorating and impacting the health of people. A comprehensive water quality study of the district has not been conducted by any organization since a decade, and hence it was the need of the hour to monitor the comprehensive water quality of the district which is one of the most important and populous district of the state.

Thus, an in-depth study of groundwater quality of Haridwar district of Uttarakhand has been undertaken to assess the abstraction, temporal and seasonal variation in water quality and its quality for drinking, domestic and irrigation functions.

1.1 Objectives

- Spatial variability determination of ground water quality
- Statistical analysis and water quality indexing for different designated uses namely drinking, irrigation, and aquatic life.

1.2 Study Area

Haridwar district is located in the southwestern part of Uttarakhand state and lies between 29^{o}33' - 30^{o}14' N latitude and 77^{o}42' - 78^{o}20' E longitude at an average altitude of 230m. The district is bounded by Dehradun and Pauri in northeast, and Uttar Pradesh in southeast (Bijnor), south (Muzaffarnagar), and west (Saharanpur) (Figure 1.1). It has a total geographical area of 2360 km^2 comprising of 6 administrative blocks viz. Roorkee, Bahadrabad, Narsan, Khanpur, Laksar and Bhagwanpur. Haridwar is the most densely populated district of Uttarakhand having a population of 18,90,422 (Census, 2011).

1.2.1 Climate and Rainfall

Haridwar district has hot sub humid (dry) climate with three distinct seasons' viz. summer followed by rainy and winter seasons. The district experiences temperature in the range 5-37 °C with an average temperature of 22 °C and relative humidity in the range 37- 88%. The average normal annual rainfall in Haridwar district is 1174.3 mm, out of which 84% is received during monsoon season (June to October) and only 16% occurs during non-monsoon period (November to May). The district receives heaviest rainfall in northern part which gradually decreases towards south. The monthly distribution of rainfall during June, July and August are 387.8 mm, 304.7mm and 412.8 mm respectively (CGWB, 2016).

1.2.2 Physiography

Haridwar district can be broadly divided into structural hills, the upper piedmont plain or the Bhabar and the Tarai or the lower piedmont plain.

The complete northern and north-eastern part of the Haridwar district is covered by the structural hills called the Siwaliks with high relief and deep incised drainage with steep and sharp lenticular hill slopes and well defined crest line. The part of Siwalik falling in the district has middle and upper Siwaliks composed of sand stones, conglomerates, sands, clay, silt etc. The lower Siwaliks are missing in this district. These hills are traversed by many local minor and major faults.

The unit below the foothills of Siwaliks is Bhabar characterized by boulders, cobbles, pebbles sands and clays etc. and a steeper gradient around 10 to 20 meters/kms. Geologically the term Bhabar is used to describe the deposits formed along the foothill zone by coalescence of series of alluvial and talus cones, composed of heterogeneous materials ranging in texture from boulders, gravels to sand and silt. Locally this composition is governed by the parent rock Siwaliks and the drainage system and this varies from place to place. This Bhabar area covers most of the Bhagwanpur block and some part of Bahadrabad block.

Below Bhabar zone lies the Tarai or plains or the lower piedmont plain with sloping towards south with very low gradient around 1.2 meter/kms and is characterized by coarse to fine grained sand, gravels, clays etc. It is characterized by the sediments brought by river Ganga and Solani consisting of older alluvium. The younger alluvial plains lies along the river Ganga and Solani shows flat to gently sloping, slightly undulating terrain formed by extensive deposition of sediments brought by the rivers. It comprises of younger unconsolidated alluvial material of varying lithology and consisting of fluvial landforms like palaeo channels, meander, scar and point bars. Flood plains also exist all along the rivers, by deposition of sediments brought of recent origin.

1.2.3 Drainage & Soil

River Ganga is the major drainage system of the eastern part of the district and river Solani and its tributaries drains the northern and central part of the district. River Kotwali Ro, Rasawan Nadi and Pili Nadi emerging from Siwalik Hills in the eastern part of the district are the tributaries of River Ganga alongwith river Solani. Sipla nadi, Mohand Ro, Chillawal Ro, Ratmau Ro, and Gholna Ro are the tributaries of Solani river. Apart from these rivers, other seasonal river/nalas also contributes the river Ganga and Solani. The drainage pattern in the district is sub dendetric to dendetric and trills. The drainage courses of most of the nalas out falling in the various tributaries are broad, flat and occupied with cobbles, boulders and gravels. Most of these nalas are torrential, carried surface run off which fluctuate gently. Beyond the monsoon season most of these nalas as well as tributaries go dry. However, in Tarai belt, the drainage is more or less perennial as it receives effluent seepage through the ground water.

Soils play an important role in ground water recharge and the agriculture production of the area. The land of Haridwar district is highly fertile and is characterized under Indo-Gangetic alluvium group of soils and is represented predominately by loamy soils. The important soils of the district are Ultisols, which are the brown hill soil, occurring all through the northern part of the district in Siwaliks. These are the soils with a horizon of clay accumulation and low base supply. The Entisols, also called Bhabar soil, occurs all along the foothills of Siwaliks and extends up to Tarai. These are soils without pedogenic horizons. Though these soils consist of boulders, pebbles, sand, silt and clay but are also highly fertile. Molisols soil occurs in the southern part of the district also called the Tarai soil, which consist mainly of the fine-gained sand, silt and clay. These are soils with a nearly black; organic-rich surface horizon and high base supply. These three types of soils are mineral soils with organic matter less than 25%.

1.2.4 Land use, Cropping Pattern, & Groundwater

Total geographical area of Haridwar is 243000 ha out of which, around 64% is under cultivation, 35% is forest, 1% is barren and under non-agricultural use. Among land for agricultural use, 13 % is under rainfed and 87 % area is under irrigation.

The most important crops in the district are sugarcane, wheat and paddy. The crops grown among the cereals are rice, maize, sorghum, pearl millet in Kharif, wheat and Barley in Rabi and maize in Zaid season. In oilseeds, the major crops are soybean, groundnut, til and sunflower in kharif, mustard in Rabi and sunflower in Zaid. Among pulses, pigeon pea, urd, moong and cowpea in kharif, gram, pea and lentil in Rabi and urd/moong in Zaid season. The cropping intensity is 150 percent.

The depth to water level ranged from 1.96-69.30 m with an average of 10.74m during pre-monsoon and 1.57-52.20 m with an average of 10.51 m in post-monsoon. In Bhabhar formation depth to water level ranges from 10.91 m to 69.30 m whereas in the Gangetic alluvium it ranges from 2.50 m to 22.69 m. The stage of groundwater development is 66% and 3 blocks namely Bhagwanpur, Khanpur and Laksar are categorized under 'semi-critical'.

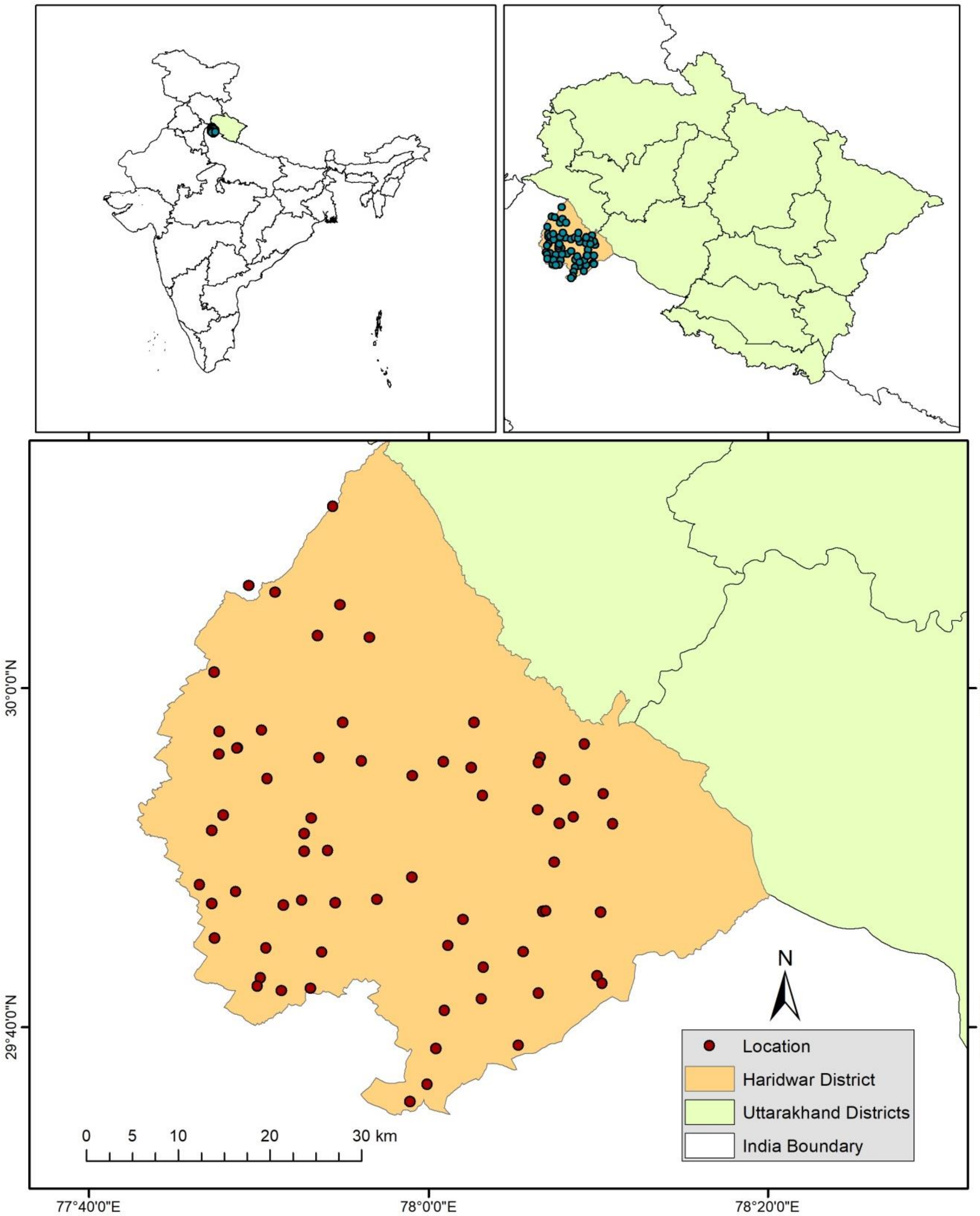


Fig. 1.1. Study Area and Sampling Locations.

1.3 Statement of Problem

Water of sound quality is the key for vital socio-economic function on Earth. Most users of water depend on adequate levels of water quality. When these levels are not met, these water users must either pay an additional cost for water treatment or incur at least increased risks of damage or loss. As populations and economies grow, more pollutants are generated and degradation of water resources has become one of the most pressing global concerns currently facing mankind. Increasingly, the major efforts and costs involved in water management are devoted to water quality protection and management. Conflicts among various users of water are growing over issues involving water quality and quantity. Evidently, there is a need for effective management efforts, where one possible action is to focus on minimizing pollutant producing areas to water resource areas.

Generally, water quality is the process to determine the chemical, physical and biological characteristics of water resources and identifying the source of any possible pollution or contamination, which might cause degradation of the water quality. Chemical weathering of the rocks leads to introduction of dissolved solids in the water resources and conversely water chemistry provides information on chemical erosion processes (Chetelat et al., 2008). Chemical weathering is a chemical reaction; therefore, it requires a “substrate” and “reacting agents” for it occur. The substrate on the earth surface are the minerals in rocks and the reacting agent are acids, such as, carbonic acids (HCO_3^-) derived from dissolution of CO_2); sulfuric acids (H_2SO_4 derived from pyrite oxidative weathering and a number of organic acids (oxalic, acetic, humic), which liberate protons to weather the mineral. In addition to these acids, H_2O also acts as an agent in dissolving evaporite minerals. In addition, the quality of water resources is also affected by the anthropogenic activities resulting in the degraded water quality. In case of ground water pollutants reaching the aquifers results in various reactions and most of the times enhances the microbial reactions leading to release of harmful contaminants like arsenic, uranium, fluoride etc. from the aquifer minerals making the water unfit for consumption. These types of changes occur over a prolonged time scale and hence, continuous monitoring of the water resources helps in avoiding the havoc that may happen due to consumption of contaminated water.

Our main interest is to analyze the water sample for organoleptic parameters, major ions, trace metals, pesticides, and microbes to understand the suitability of water for different usages and to understand the weathering processes controlling the water quality.

2 Methodology

2.1 Sampling Locations

Sampling locations were decided by dividing the district into a grid of 5x5 km and selecting one village in each grid (Figure 2.1.). The samples were collected from 68 locations (Table 1.1). For trace metal and pesticide contamination, samples were collected from 19 locations by dividing the district into 10x10 km grid. Few grids were in reserve forest with limited accessibility and therefore, samples were not collected from these grids.

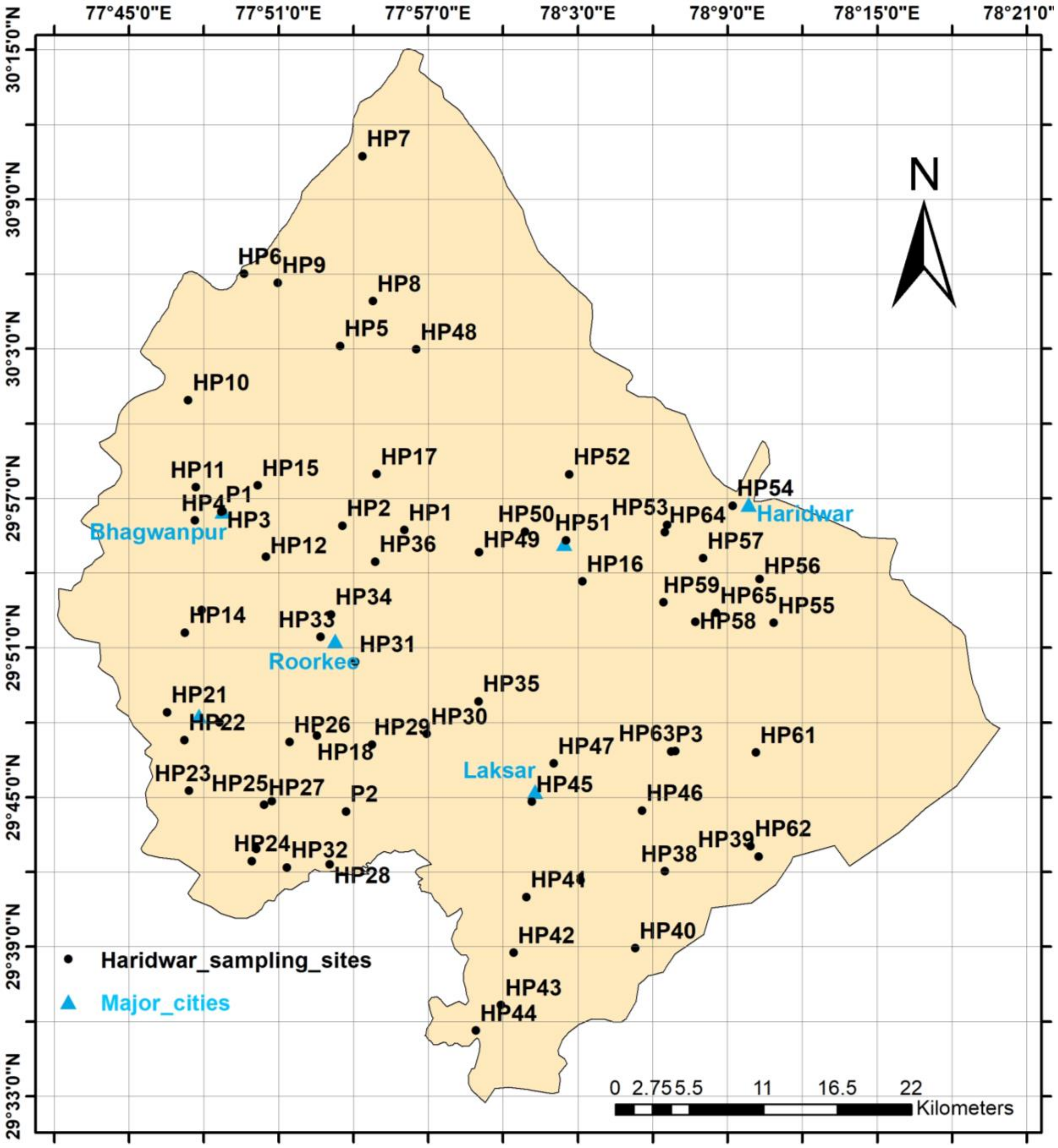


Fig. 2.1. Sampling sites of Haridwar District.

Table 2.1 Details of Samples locations

S. No.	Location	Location ID	Latitude	Longitude
1	Piran Kaliyar	HW1	29.928575N	77.93405E
2	Imlikhera	HW2	29.9315N	77.8925E
3	Bhagwanpur	HW3	29.9411N	77.8124E
4	Khelpur	HW4	29.93499N	77.79395E
5	Mohand(Buggawala)	HW5	30.0517699N	77.89092E
6	Biharigarh	HW6	30.100717N	77.8233E
7	Mohan Pass	HW7	30.178755N	77.906006E
8	Hazara	HW8	30.081712N	77.913021E
9	Telpura	HW9	30.094025N	77.849371E
10	Hassanpur	HW10	30.015508N	77.78954E
11	Raipur	HW11	29.957197N	77.794576E
12	Bagwanpur Pond	HW12	29.940763N	77.811696E
13	Pohana	HW13	29.910895N	77.841337E
14	Ikbalpur	HW14	29.875259N	77.798393E
15	Bhalsua	HW15	29.860044N	77.787146E
16	Hallu Majra	HW16	29.958511N	77.836108E
17	Ibrahimpur	HW17	29.8942782N	78.053058E
18	Sohalpur	HW18	29.966109N	77.915487E
19	Manglaur	HW19	29.791191N	77.875683E
20	Latherdeva	HW20	29.799783N	77.810487E
21	Gadarjuda	HW21	29.71516N	77.83500E
22	Jhabreda	HW22	29.806754N	77.775247E
23	Kotwal	HW23	29.78818N	77.78708E
24	Sherpur	HW24	29.75412N	77.78989E
25	Narsan	HW25	29.707163N	77.831918E
26	Mundaki	HW26	29.745092N	77.54355E
27	Kabadpur	HW27	29.78684N	77.857396E
28	Nagla China	HW28	29.744804N	77.840273E
29	Nagla China Pond	HW29	29.740304N	77.89506E
30	Brhampur Jat	HW30	29.705018N	77.88408E
31	Banera Tanda	HW31	29.274248N	77.897477E
32	Thatulla	HW32	29.792257N	77.949069E
33	Dhandera	HW33	29.840431N	77.9011E
34	Mohamadpur (Rre)	HW34	29.839743N	77.877979E
35	Paniyala	HW35	29.857044N	77.87794E
36	Durga Chowk Rre	HW36	29.87222N	77.884928E

37	Sangipur	HW37	29.81394N	77.983566E
38	Mohmandpur	HW38	27.789094N	77.979125E
39	Saidabaad	HW39	29.694368N	78.051783E
40	Niranjanpur	HW40	29.700337N	78.108089E
41	Jaspur	HW41	29.630189N	78.166597E
42	Damanpuri	HW42	29.648828N	78.088246E
43	Lalchandwal	HW43	29.683133N	78.015609E
44	Khanpur	HW44	29.64577N	78.007032E
45	Chandpurkalan	HW45	29.61077N	77.998674E
46	Dhallawala	HW46	29.593688N	77.98176E
47	Laksar	HW47	29.746916N	78.019144E
48	Panchwali	HW48	29.740923N	78.092921E
49	Shetpur	HW49	29.772461N	78.033875E
50	Bandarjud	HW50	30.049557N	77.941796E
51	Santersahan	HW51	29.913891N	77.983943E
52	Begumpur	HW52	29.927523N	78.014624E
53	Bahadarabaad	HW53	29.921755N	78.041974E
54	Roshanabaad	HW54	29.968773N	78.873926E
55	Bhel(Visnulok Colony)	HW55	29.932079N	78.10967E
56	Haridwar Bus Stand	HW56	29.944905N	78.153291E
57	Shyampur	HW57	29.866543N	78.181007E
58	Gurukul Kangri	HW58	29.895941N	78.171551E
59	Kankhal	HW59	29.909805N	78.133759E
60	Katarpur	HW60	29.867199N	78.128514E
61	Bhadurpur Jud	HW61	29.880302N	78.107221E
62	Padartha	HW62	29.828673N	78123302E
63	Bhogpur	HW63	29.779714N	78.168963E
64	Fatwa	HW64	29.71722N	78.165471E
65	Jassodharpur Pond	HW65	29.780439N	78.11227E
66	Jassodharpur	HW66	29.7809N	78.1151E
67	Jawalapur Sarai	HW67	29.927059N	78.107979E
68	Alipur	HW68	29.8732N	78.1422E

2.2 Sample Collection and preservation

Sample collection was done in pre and post monsoon periods from selected locations of Haridwar district. Manual sampling with a plastic container in compliance with established standard norms was adopted. The hand-pumps were continuously pumped for at least 15 minutes prior to the sampling, to ensure the groundwater to be sampled was representative of groundwater aquifer. All the groundwater samples were collected from the sources, which are being used extensively. Groundwater samples were collected from the depth ranging from 60-180 ft with average depth 125 ft.

The water samples are collected in appropriate sampling bottles as given in table 2.2 using grab sampling method and preserved as per standard methods (APHA, 2017). Labels were used to prevent sample misidentification. For organoleptic, major ions and trace metal analysis, samples were collected in polyethylene bottles along with their GPS coordinates. For pesticide analysis, the samples were collected in amber color glass bottles and brought to lab in ice bath at around 6 °C and were kept in freezer maintained at 4 °C till extraction was completed. The extraction was completed within 7-days of collection and analyzed within 30 days of extraction.

Table 2.2 Sample Collection & Handling

Sr. No.	Parameter	Container	Sample Size (ml)	Preservation	Analysis Time
1	pH	--	--	--	Onsite
2	Temperature	--	--	--	Onsite
3	Conductivity	--	--	--	Onsite
4	Radon	--	--	--	Onsite
5	Major Ions	Plastic bottle	500	--	<10 days
6	Trace Metals	Plastic bottle	100	0.5 ml HNO_3	<30 days
7	Organic Compounds	Amber color glass bottle	1000	Cool, ≈4 °C	<30 days

2.3 Chemicals & Reagents

All chemicals used for analysis were of analytical reagent grade (Merck/BDH/ThermoFisher). Standard solutions of metals ions were procured from Merck, Germany. Pesticide standards were procured from Reagecon Diagnostics Ltd., Ireland. De-ionized water was used throughout the analysis work. All glassware and other containers used for trace metal analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 hours and finally rinsed with de-ionized water several times prior to use. All glassware for pesticide analysis were rinsed with chromatography grade solvents prior to use.

2.4 Analytical Methodology

The samples were analyzed as per Standard Methods for the Examination of Water and Wastewater (APHA, 2017). The details of analytical methods and equipment used in the study are given in Table 2.3.

The major cations and anions in the samples were analyzed with the help of Metrohm Ion Chromatograph. Ion chromatography is a form of liquid chromatography, in which ion exchange resins are employed to separate atomic and molecular ions for analysis. IC involves the retention of ions from the sample being retained based on ionic interactions. Quantification of cations and anions in the sample is based upon calibration curve of standard solutions of respective cations/anions. Ionic balance was calculated and the error in the ionic balance for majority of the samples was within 5%.

Table 2.3 Analytical Methods and Equipments used in the Study

Sr. No.	Parameter	Method	Equipment Used
A.	**Physicochemical**		
1	pH	Electrometric	pH meter - WTW
2	Electrical Conductivity	Electrometric	Conductivity meter - WTW
3	Total Dissolved Solids	Gravimetric Method	
4	Bicarbonate	Titration by H_2SO_4	Digital Burette
5	Calcium	Conductivity Method	Ion Chromatograph, Dionex (ICS 5000)
6	Magnesium		
7	Sodium		
8	Potassium		
9	Chloride		
10	Fluoride		
11	Nitrate		
12	Sulfate		
13	Phosphate		
B.	**Trace Metals**		
14	Arsenic	Digestion followed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	ICP-MS
15	Aluminium		
16	Beryllium		
17	Chromium		
18	Cadmium		
19	Cobalt		
20	Copper		
21	Iron		
22	Lead		
23	Manganese		
24	Mercury		
25	Nickel		
26	Selenium		
27	Uranium		
28	Zinc		
C.	**Pesticides & Polyaromatic Hydrocarbons**		
29	α-Hexachlorocyclohexane	Extraction followed by Gas Chromatography Mass	GC-MS-MS
30	β-Hexachlorocyclohexane		
31	δ-Hexachlorocyclohexane		

32	γ-Hexachlorocyclohexane	Spectrometry (GC-MS)	
33	Methyl parathion		
34	Malathion		
35	Chlorpyriphos		
36	Dieldrin		
37	Atrazine		
38	Alachlor		
39	Butachlor		
40	p-p-DDE		
41	o-p-DDE		
42	o-p-DDD		
43	p-p-DDD		
44	o-p-DDT		
45	p-p-DDT		
46	α-Endosulfan		
47	β-Endosulfan		
48	Endosulfan sulfate		
49	Ethion		
50	Acenaphthene		
51	Anthracene		
52	Benzo(a)anthracene		
53	Chrysene		
54	Fluoroanthene		
55	Fluorene		
56	Naphthalene		
57	Phenanthrene		

Perkin-Elmer Inductively Coupled Plasma Mass Spectrometer (ICP-MS) and Agilent ICP-OES was used for analysis of trace metals. The operational conditions were adjusted in accordance with the manufacture's guidelines to yield optimal determination. The calibration curve of mixed trace metal solution of 10, 50, and 100 ppb were prepared and with the help of same the concentration of metals in the samples were quantified. These calibration curves were determined several times during the period of analysis. The samples were digested in nitric acid and hydrogen peroxide for oxidation/removal of organics in Anton Paar Multiwave PRO Microwave Reaction System and filtered through 0.45 micron filter paper before injecting in ICP-MS.

The water samples for the analysis of pesticides were extracted with n-hexane three times, followed by three times extraction with dichloromethane and chloroform, and the combined extract was concentrated (1000 times) using Kuderna-Danish Assembly under reduced vacuum. The moisture from the extracts was removed using anhydrous sodium sulfate. This concentrated solution was filtered through nylon syringe filter (0.2 µm) and collected in 15 ml vial. Then, 1 µl of solution was injected with the help of auto-sampler with syringe (PAL RSI 85) in GC oven of GC-MS-MS system of Agilent Technologies Gas Chromatograph (8890 GC) coupled with triple quad mass spectrometer (7010 B MSQQQ) in the EI (Electron Impact) mode with the electron energy set at 100 eV and the mass range at m/z 5–1070. A capillary column HP 5 (30 m (length) x 0.25 mm (ID)) of 0.25 µm film thickness of coated material (5% diphenyl and 95% dimethylpolysiloxane) was used. The injector was set at 280 °C. The detectors used were MS detector. The temperature programmed as follow: 1 min hold at 60 °C with 40 °C/min rise up to 170 °C followed by 10 °C/min rise up to 310 °C. The flow rate of carrier gas (helium) was maintained at 1.0 ml/min. A post-run of 2 min at 310 °C was sufficient for the next injection. Identification of compounds was done by comparing the retention times with those of standard pesticides. The qualitative determination of the pesticides was carried out by comparing the retention time and peak area of the pesticides.

2.5 Statistical Analysis of the Contaminant Data

The water quality data was processed using different multivariate statistical techniques, such as Cluster Analysis (CA), Discriminant Analysis (DA), Principal Component Analysis(PCA), and Factor Analysis (FA) using SPSS and XLSTAT software's. Further, these techniques helped in providing information on the most meaningful parameters, which describes a whole data set affording data reduction with minimum loss of original information for formulating most appropriate adaptive measures for safe drinking water supplies and other inter sectorial demands.

The descriptive analysis for minimum, maximum, range mean, standard deviation, and Pearson's correlation coefficient (r) for different chemical and physical parameters and the principal component analysis (PCA) in the study were conducted by SPSS version-22 software.

Pearson's correlation analysis was used for revealing and highlighting the relationship among the parameter (Egbueri 2018, 2019). Correlation coefficients < 0.5 are supposed to exhibit poor correlation. The correlation coefficient of 0.5 is termed as good correlation and > 0.5 is termed to have excellent correlation (Kaiser 1958). Further, p values <0.01 and <0.05 indicate a strong and significant correlation among the parameters respectively (Goyal et al., 2021).

PCA was used to identify major variable factors responsible for the source (natural and anthropogenic) of solutes in the observed data set (Varol and Davraz 2015); (Zhang et al. 2016). Factor loading helps to arrive near the significant factor and the Kaiser Normalization scheme is used for the interpretation of the factor score on varimax rotation. The maximum variance factor selected which had Eigen value >1 (Demirel and Guler 2006; Singaraja et al. 2014).

The hydrochemical facies represents the dominancy of the major cations and anions in the groundwater (Subba Rao 2008; (Adimalla 2020) was prepared by the trilinear diagram (piper chart) using Grapher software version-14. Water Quality Indices (WQI) for drinking and irrigation usage were computed using MS-excel -2016.

2.6 Water Quality Indices (WQI)

WQI is used to classify the water quality based on different designated usage (Ahada and Suthar 2018; Egbueri, Mgbenu, and Chukwu 2019; Adimalla 2020; Jaswal et al. 2021; Shalumon et al. 2021)

The water quality indices for both pre- and post-monsoon samples were calculated by weighted arithmetic WQI by using simple formulas (Pant et al. 2021; Ahada, 2018). The Unit Weight (AWi), Relative Weight(Wi), Quality Rating (Qi), Sub-Index (SIi), and WQI was calculated for each parameter by use of equation (3.1), (3.2), (3.3), (3.4), and (3.5) respectively.

$$\mathrm{AWi} = 1/\sum_{k=0}^{n} 1/\mathrm{Si} \tag{3.1}$$

$$\mathrm{Wi} = \frac{\mathrm{AWi}}{\mathrm{Si}} \tag{3.2}$$

$$\mathrm{Qi} = \left(\frac{\mathrm{Ci}}{\mathrm{Si}}\right) \mathrm{X}\ 100 \tag{3.3}$$

$$\mathrm{SIi} = \mathrm{Wi}\ \mathrm{X}\ \mathrm{Qi} \tag{3.4}$$

$$\mathrm{WQI} = \sum_{i=0}^{n} \mathrm{SIi} \tag{3.5}$$

Where Ci: Measured concentration; Si: Standard Permissible Limit

WQI values in the range 0-25, 26-50, 51-75, 76-100, and >100 were classified as excellent, good, medium, poor, and unsuitable for use (Mgbenu and Egbueri 2019; Pant et al. 2021). The permissible limits for computing the WQI were considered from BIS (2012), BIS (1986), and WHO (2017).

3 Results & Discussions

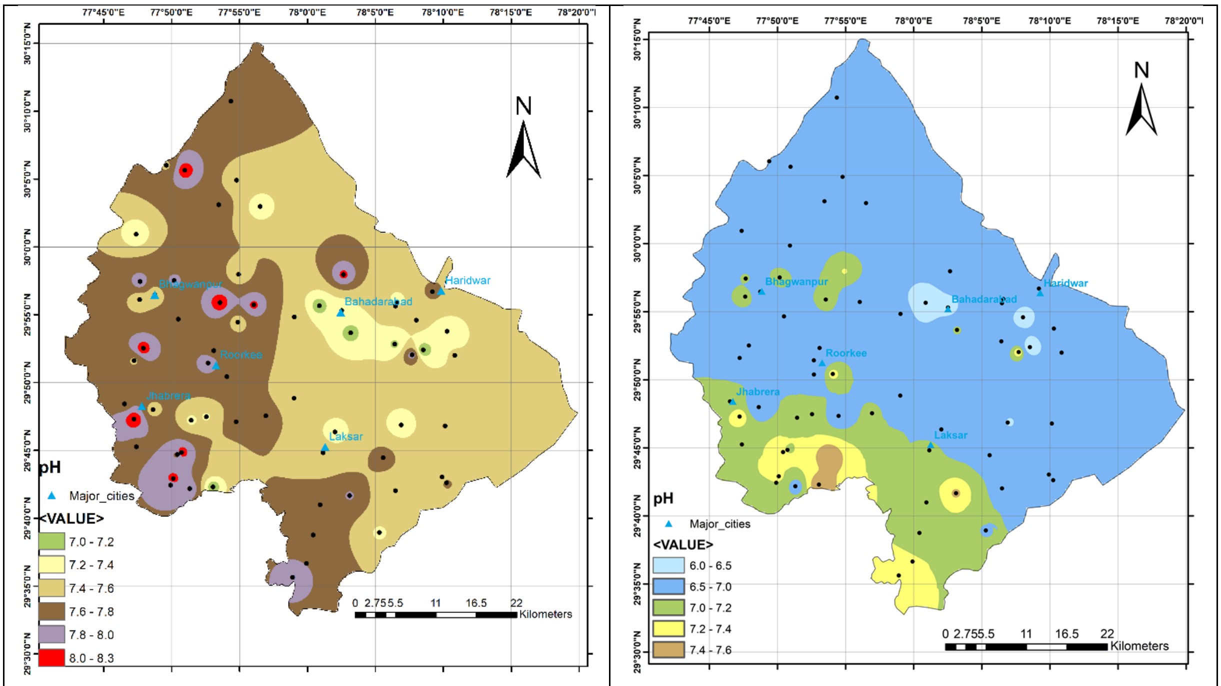
3.1 Water Quality Status

The water samples were collected in June 2019 and January 2020. The analytical results were plotted in contour maps using Arc-GIS. The results indicate variability in the water quality across the district which may be attributed to the geology and anthropogenic reasons.

3.1.1 Organoleptic Parameters

3.1.1.1 pH

pH is one of the most important parameters in water chemistry and influences other parameters. The pH has no direct impact on the health of consumers, however, it is one of the most important operational water quality parameter. BIS (2012) have prescribed pH value in the range of 6.5 to 8.5 for water used for drinking purpose. The pH of analyzed samples of the study area ranges from 6.95 (Alipur) to 8.27 (Kotwal) and 6.14 (Begampur) to 8.62 mg/l (Katarpur Pond) in pre-monsoon and post-monsoon respectively (Figure 3.1). The average pH in pre and post monsoon samples was observed to be 7.63±0.33 and 6.92±0.04 respectively. Around 0.1% samples exceeded the prescribed limit in post monsoon samples and none in pre-monsoon.



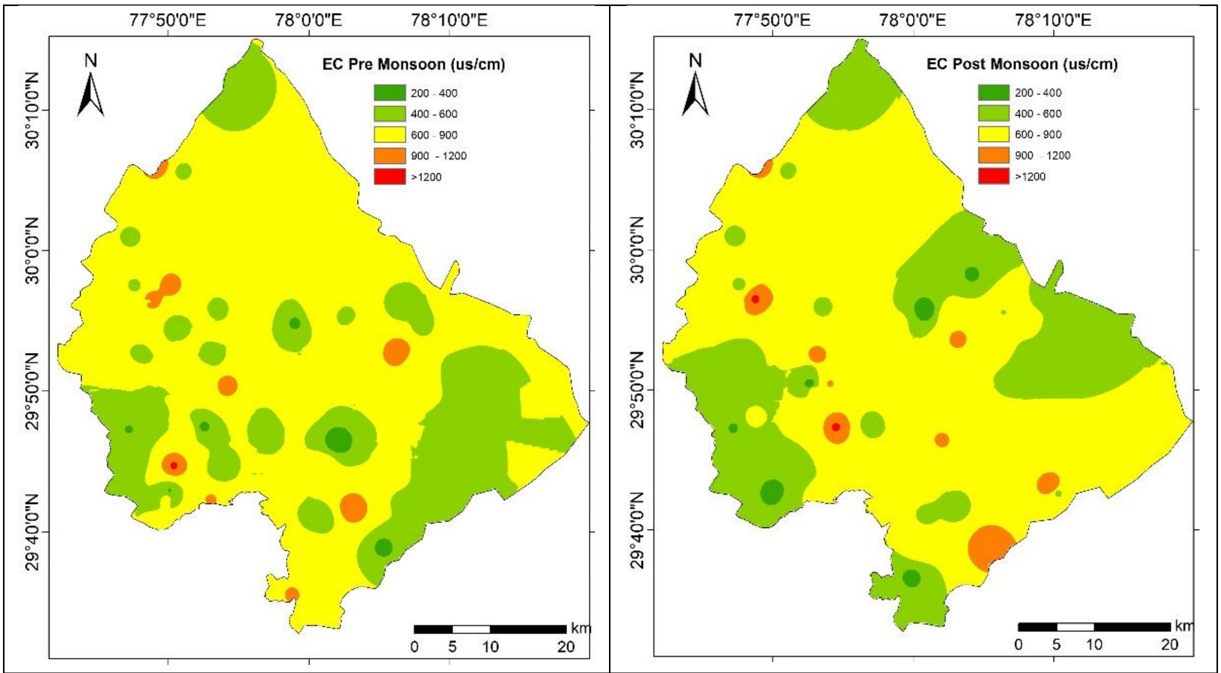
(a)	(b)

Fig.3.1. Spatial variation of groundwater pH during (a) pre & (b) post monsoon

3.1.1.2 Electrical Conductivity & Total Dissolved Solids

Electrical conductivity (EC) of water samples depend on the ions (impurity) present in the water and the temperature influencing mobility of the ions. The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water.

The EC in the samples of the study area ranges from 209 µS/cm (Mohamadpur RRE) to 1281 µS/cm (Bhagwanpur) and 205 µS/cm (Begampur) to 2820 µS/cm (Manglor) in pre-monsoon and post-monsoon respectively (Figure 3.2). The average concentration of EC in pre and post monsoon samples was observed to be 650±247 µS/cm and 941±62 µS/cm respectively.



(a) (b)

Fig.3.2. Spatial variation of groundwater EC during (a) pre & (b) post monsoon

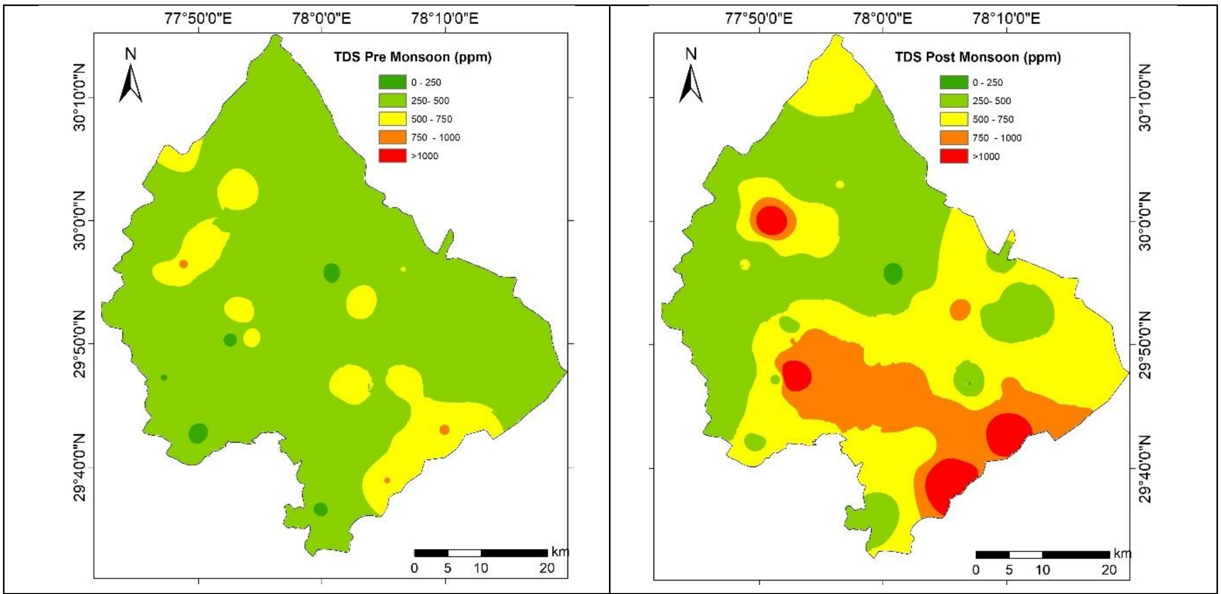
Total Dissolved Solids (TDS) in water includes all dissolved material in solution, whether ionized or not. TDS is numerical sum of all mineral constituents dissolved in water and is expressed in mg/l. TDS in water resources originates from weathering of minerals (natural sources), sewage, urban runoff and industrial wastewater. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals.

Based on TDS contents, water can be classified in to four categories as fresh, brackish, saline and brine water (Table 3.1). Around 10.8% samples were observed in the brackish water category during post-monsoon period.

The TDS levels in the water samples ranges from 133.8 mg/l (Mohamadpur RRE) to 819.8 mg/l (Bhagwanpur) and 131.2 mg/l (Begampur) to 1804.8 mg/l (Manglor) in pre-monsoon and post-monsoon respectively. The average TDS in pre and post monsoon samples was observed to be 416±158 mg/l and 602±40 mg/l respectively. Around 23.5% and 54.1% samples exceeded the acceptable limit in pre-monsoons and post-monsoon period respectively. None samples exceeded the maximum permissible limit for drinking water.

Table 3.1 Classification of Water Based on Total Dissolved Solids

TDS (mg/l)	Water Quality	% Samples	
		Pre-monsoon	Post-monsoon
0 – 1,000	Fresh Water	100	89.2
1,000 – 10,000	Brackish Water	Nil	10.8
10,000 – 100,000	Saline Water	Nil	Nil
>100,000	Brine	Nil	Nil



(a) (b)

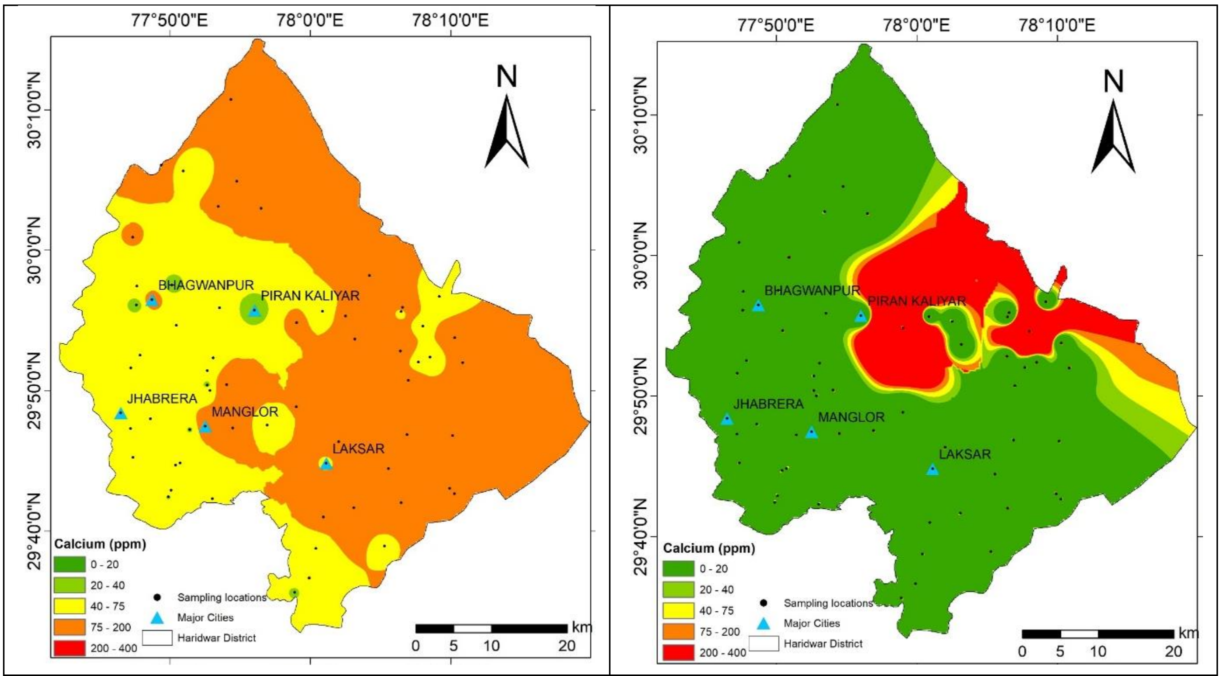
Fig.3.3. Spatial variation of groundwater TDS during (a) pre & (b) post monsoon

3.1.2 Cations and Anions

3.1.2.1 Calcium (Ca)

Drinking-water can be an important contributor of calcium and magnesium to those who are marginal for calcium and magnesium. Typical recommended dietary intake for Ca & Mg is 1000 mg/day and 200-400 mg/day respectively (WHO 2011), and a glass of milk (200 ml) can met ≈30% Ca and ≈15% Mg requirement (Brink et al. 1992, Gaucheron 2005). The recommended upper intake level for Ca is 2500 mg/day, and the individuals exposed to high concentration are protected by a tightly regulated intestinal absorption and elimination mechanism through the action of 1,25-dihydroxyvitamin D. WHO has not established any guideline value considering the fact that the levels found in drinking water does not pose a health hazard to humans (WHO, 2011). BIS (2012) have prescribed 75 mg/l as the acceptable limit and 200 mg/l as permissible limit in absence of alternate source for drinking and other domestic usage.

Ca concentration in the samples of the study area ranges from 28.9 mg/l (Mohamadpur RRE) to 152.4 mg/l (Dhandera) and 20.1 mg/l (Khelpur) to 229 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Ca in pre and post monsoon samples was observed to be 72.6±27.1 mg/l and 75.2±4.2 mg/l respectively. Around 45.31% samples exceeded the acceptable limit and 0% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 48.65% samples exceeded the acceptable limit and 1.35 % samples exceeded the permissible limit.



(a) (b)

Fig.3.4. Spatial variation of groundwater calcium during (a) pre & (b) post monsoon

3.1.2.2 Magnesium

The magnesium (Mg) is the nutrient for the human body so prescribed amount of mg is good for health. Its concentration in the analyzed samples ranged from 6.8 mg/l (Hassanpur) to 79.7

mg/l (Jassodharpur) and 2.43 mg/l (Sherpur) to 184 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Mg in pre and post monsoon samples was observed to be 30.92±1.8 mg/l and 35.94±3.84 mg/l respectively. Around 42.2% samples exceeded the acceptable limit and all were within the permissible limit in pre-monsoon, however, during post-monsoon period around 33.8% samples exceeded the acceptable limit and 5.4 % samples exceeded the permissible limit.

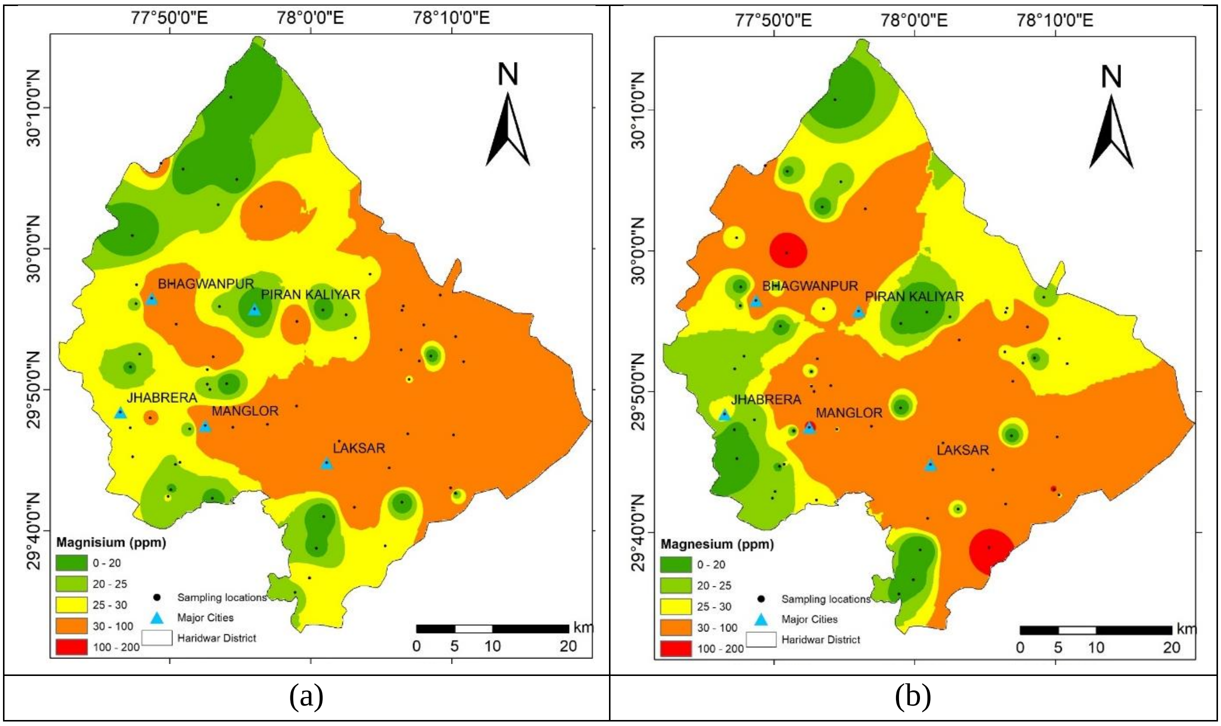
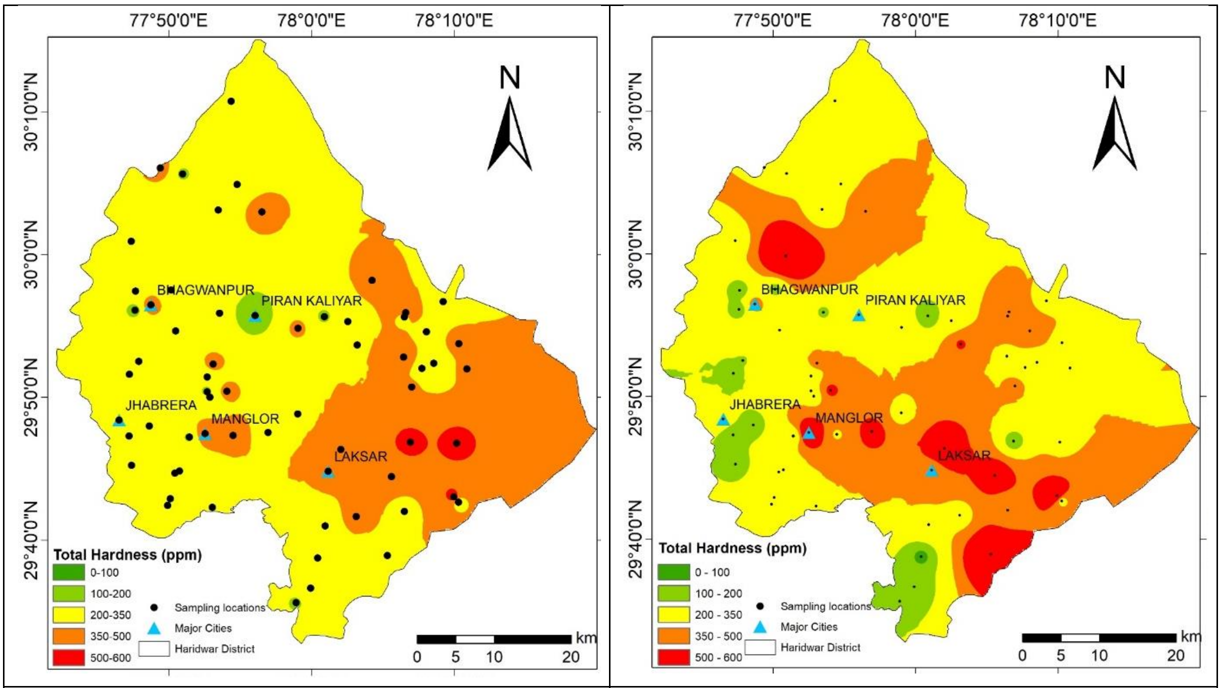


Fig.3.5. Spatial variation of groundwater calcium during (a) pre & (b) post monsoon

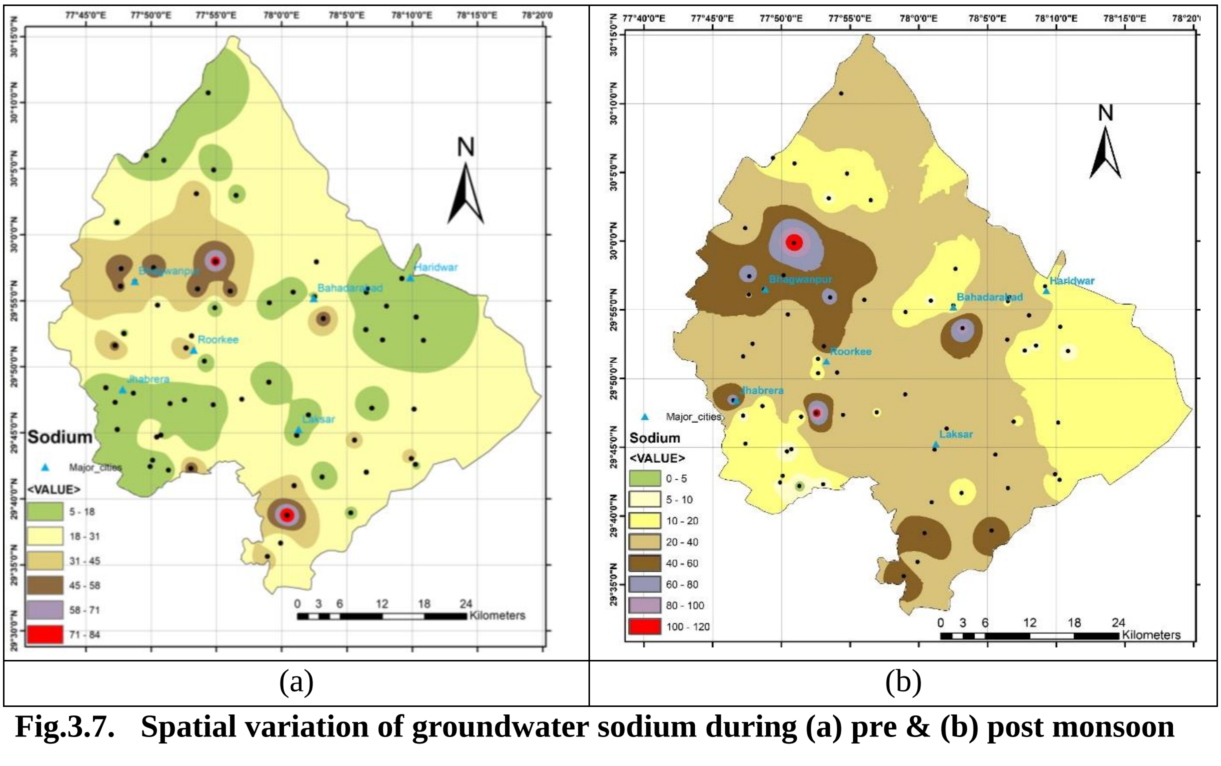
3.1.2.3 Total Hardness

Total hardness constitutes the calcium and magnesium present in water and is represented in terms of $CaCO_3$. There are two type of hardness in water – Ca and Mg associated with carbonate and bicarbonate are known as temporary hardness and the fraction associated with Cl, SO_4, and NO_3 are known as permanent hardness. Most of the hardness in the district was observed to be temporary/bicarbonate hardness except few locations. The total hardness in the samples of the study area ranges from 153.2 mg/l (Mohamadpur RRE) to 588 mg/l (Fatwa) and 71 mg/l (Khanpur) to 1340 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of total hardness in pre and post monsoon samples was observed to be 310.4±13.74 mg/l and 338.2±24.69 mg/l respectively. Around 87.5% samples exceeded the acceptable limit and all the samples were within the permissible limit for total hardness in pre-monsoon, however, during post-monsoon period around 77.0% samples exceeded the acceptable limit and 9.5 % samples exceeded the permissible limit.



(a) (b)

Fig.3.6. Spatial variation of groundwater hardness during (a) pre & (b) post monsoon



(a) (b)

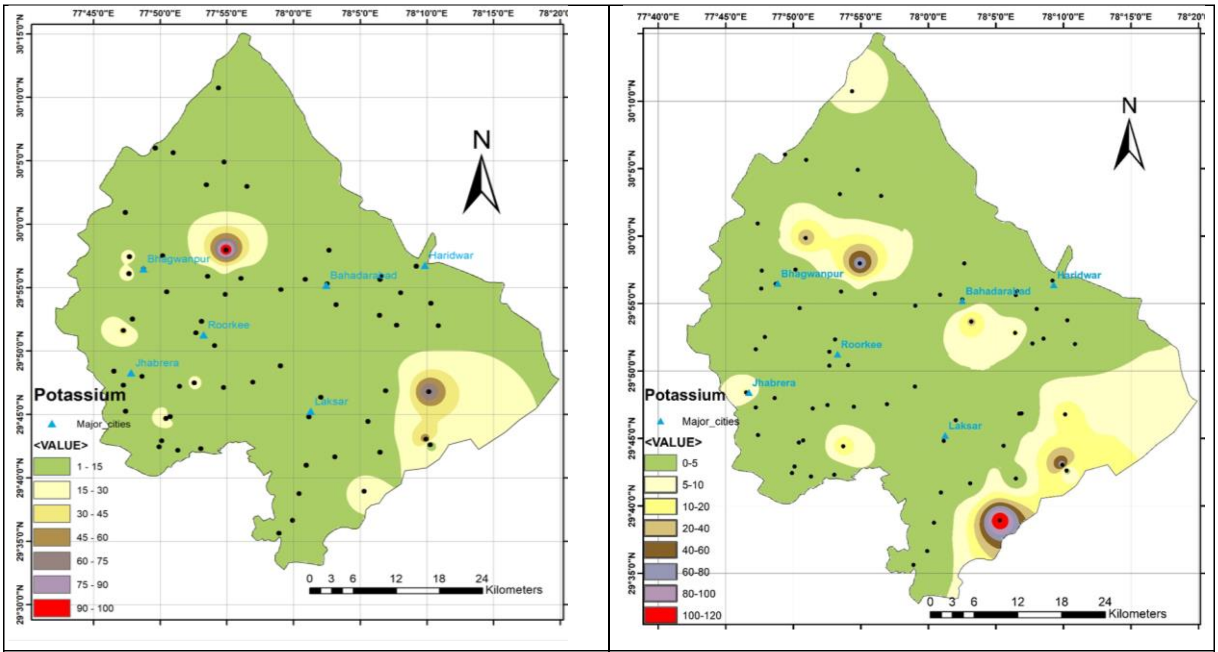
Fig.3.7. Spatial variation of groundwater sodium during (a) pre & (b) post monsoon

3.1.2.4 Sodium

The Na concentration in the samples of the study area ranges from 5.2 mg/l (Nagla China) to 118.2 mg/l (Piran Kaliyar) and 3 mg/l (Mohmandpur RKE) to 110 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Na in pre and post monsoon samples was observed to be 23.57±2.6 mg/l and 29.28±2.74 mg/l respectively.

3.1.2.5 Potassium

The K concentration in the samples of the study area ranges from 0.54 mg/l (Begumpur) to 99.5 mg/l (Manglor) and 0.72 mg/l (Begampur) to 96 mg/l (Damanpuri) in pre-monsoon and post-monsoon respectively. The average concentration of K in pre and post monsoon samples was observed to be 8.6±1.9 mg/l and 12.8±2.33 mg/l respectively.



(a) (b)

Fig.3.8. Spatial variation of groundwater potassium during (a) pre & (b) post monsoon

3.1.2.6 Alkalinity

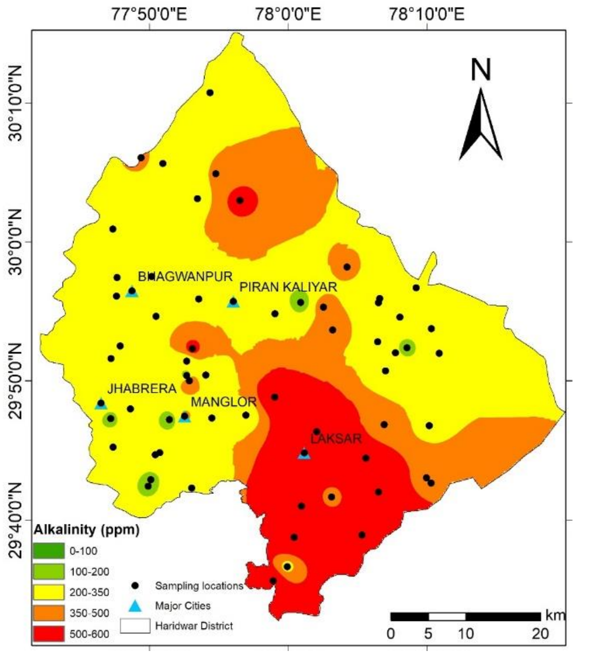
The Alkalinity in the samples of the study area ranges from 85.4 mg/l (Mohamadpur (RRE)) to 722 mg/l (Shetpur) and 78 mg/l (Mohmandpur RKE) to 540 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Alkalinity in pre and post monsoon samples was observed to be 344.39±19.0 mg/l and 290.41±10.46 mg/l respectively. Around 57% samples exceeded the acceptable limit and 6% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 63% samples exceeded the acceptable limit and all were within the permissible limit.

3.1.2.7 Chloride

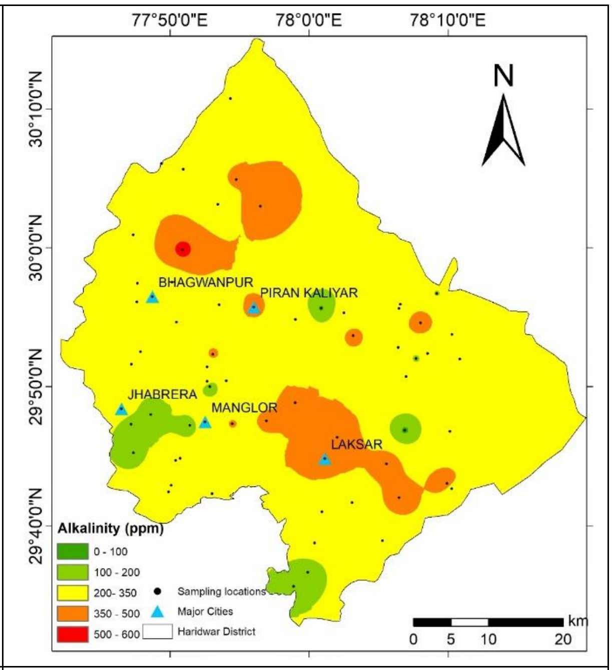
The chloride concentration in the samples of the study area ranges from ND to 194 mg/l (Manglor) and 2 mg/l (Khelpur) to 310 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of chloride in pre and post monsoon samples was observed to be 24.97±4.8 mg/l and 33.97±6.53 mg/l respectively. Al the samples were within the prescribed permissible limit for chloride in drinking water and around 1.4% samples exceeded the acceptable limit during post-monsoon period.

3.1.2.8 Sulfate (SO_4)

The SO_4 concentration in the samples of the study area ranges from ND (Pohana) to 230.8 mg/l (Fatwa) and ND (Piran Kaliyar) to 185.4 mg/l (Jhabreda)in pre-monsoon and post-monsoon respectively. The average concentration of SO_4 in pre and post monsoon samples was observed to be 26.4±4.2 mg/l and 24.7±4.32 mg/l respectively. Around 1.6% samples exceeded the acceptable limit in pre-monsoon, however, during post-monsoon period all the samples were within the acceptable limit.

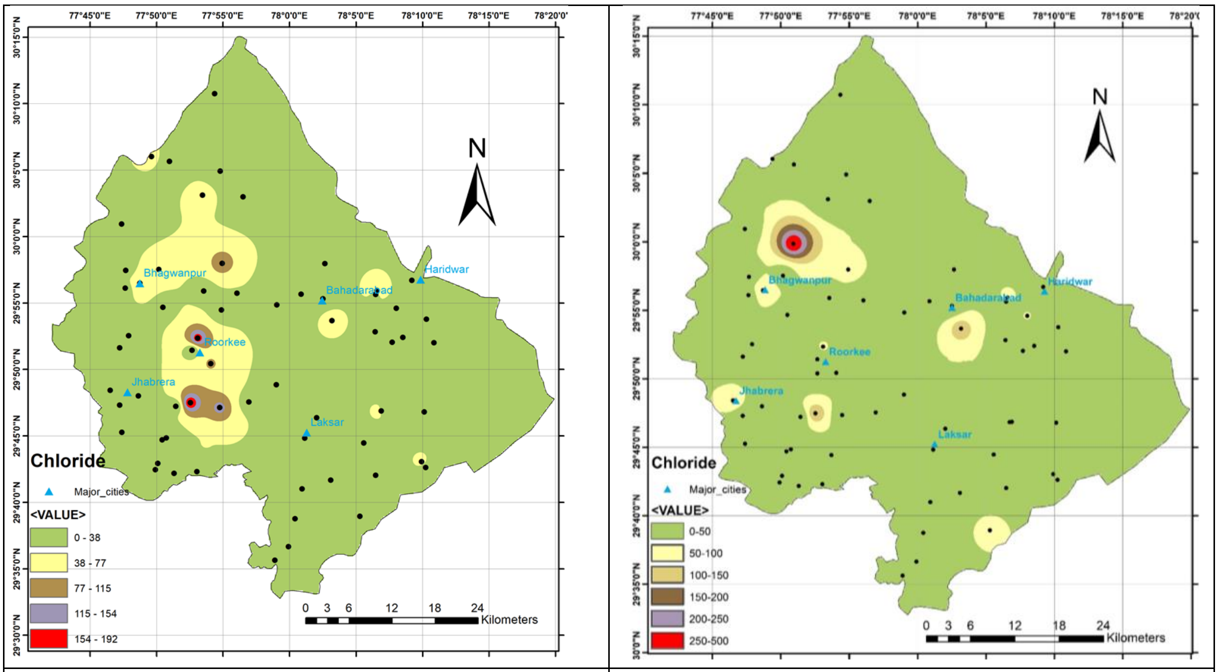


(a)



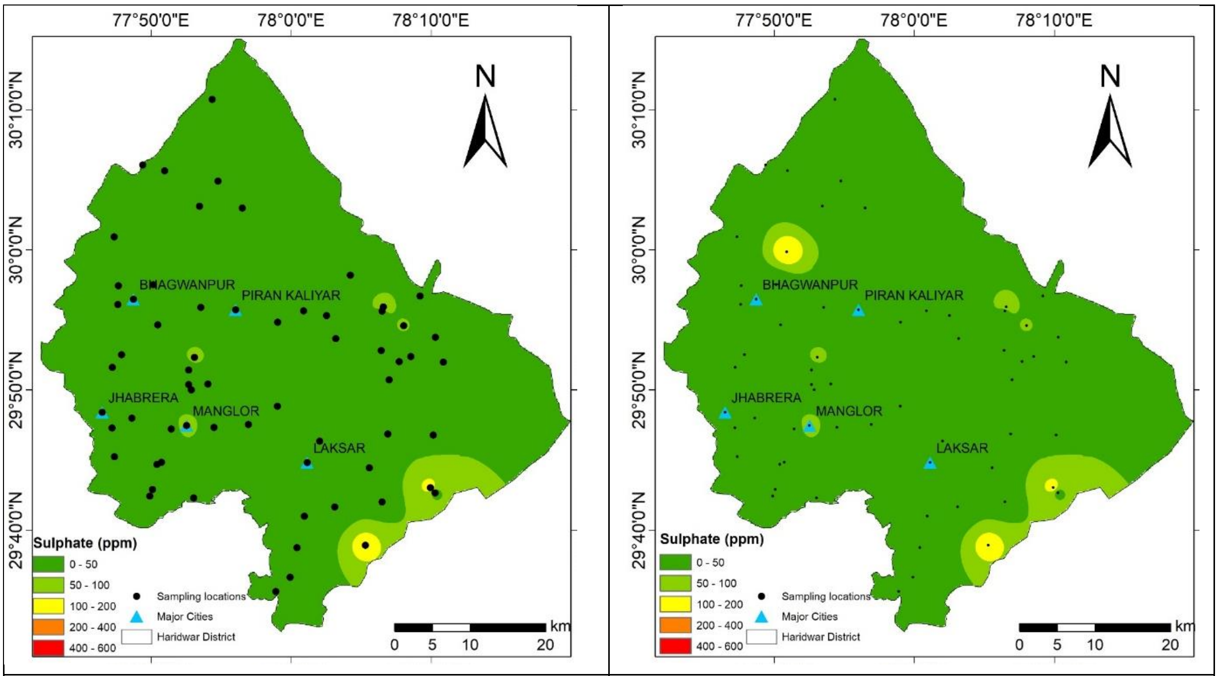
(b)

Fig.3.9. Spatial variation of groundwater alkalinity during (a) pre & (b) post monsoon



(a) (b)

Fig.3.10. Spatial variation of groundwater chloride during (a) pre & (b) post monsoon

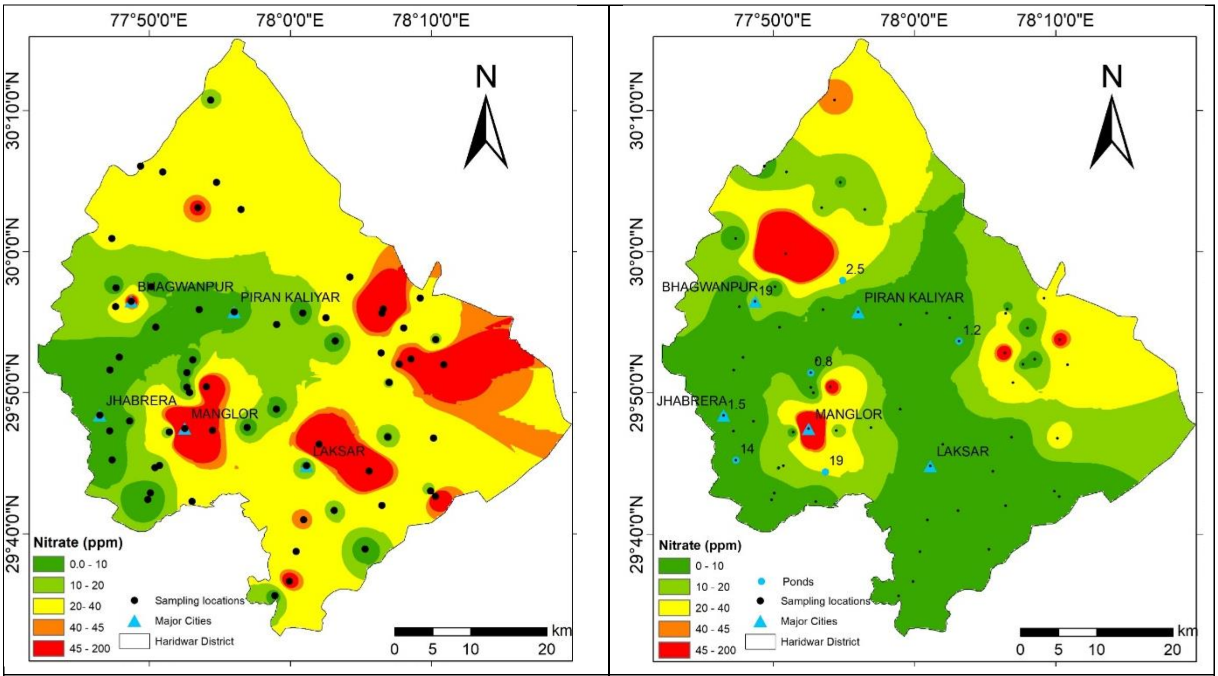


(a) (b)

Fig.3.11. Spatial variation of groundwater sulfate during (a) pre & (b) post monsoon

3.1.2.9 Nitrate

The NO_3 concentration in the samples of the study area ranges from 0.4 mg/l (Raipur) to 207.7 mg/l (Manglor) and ND (Piran kaliyar) to 243.8 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of NO_3 in pre and post monsoon samples was observed to be 27.2±4.5 mg/l and 13.4±4 mg/l respectively. Around 21.9% samples exceeded the permissible limit in pre-monsoon and 6.8% during post-monsoon period.



(a) (b)

Fig.3.12. Spatial variation of groundwater nitrate during (a) pre & (b) post monsoon

3.1.2.10 Ammonium (NH_4-N)

The NH_4-N concentration in the samples of the study area ranges from ND to 2.8 mg/l (Biharigarh) and ND to 2.4 mg/l (Ibrahimpur) in pre-monsoon and post-monsoon respectively. The average concentration of NH_4-N in pre and post monsoon samples was observed to be 0.12±0.04 mg/l and 0.08±0.03 mg/l respectively. Around 3.1% samples and 2.7% samples exceeded the maximum permissible limit for NH_4 in drinking water.

3.1.2.11 Phosphate

Phosphate concentration in groundwater is generally low due to -3 charge on the ion because of which it gets preferentially chemisorb on the soil/sediment particles. The PO_4 concentration in the samples of the study area ranges from ND to 1.5 mg/l (Latherdeva) and ND to 4 mg/l (Jassodharpur) in pre-monsoon and post-monsoon respectively. The average concentration of PO_4 in pre and post monsoon samples was observed to be 0.22±0.03 mg/l and 0.23±0.08 mg/l respectively.

3.1.2.12 Fluoride

The F concentration in the samples of the study area ranges from 0.04 mg/l (Alipur) to 0.96 mg/l (Biharigarh) and ND to 1.26 mg/l (Buggawala) in pre-monsoon and post-monsoon respectively. The average concentration of F in pre and post monsoon samples was observed to be 0.28±0.02 mg/l and 0.25±0.03 mg/l respectively. None of the samples exceeded the acceptable limit of 1.5 mg/l for F in drinking water.

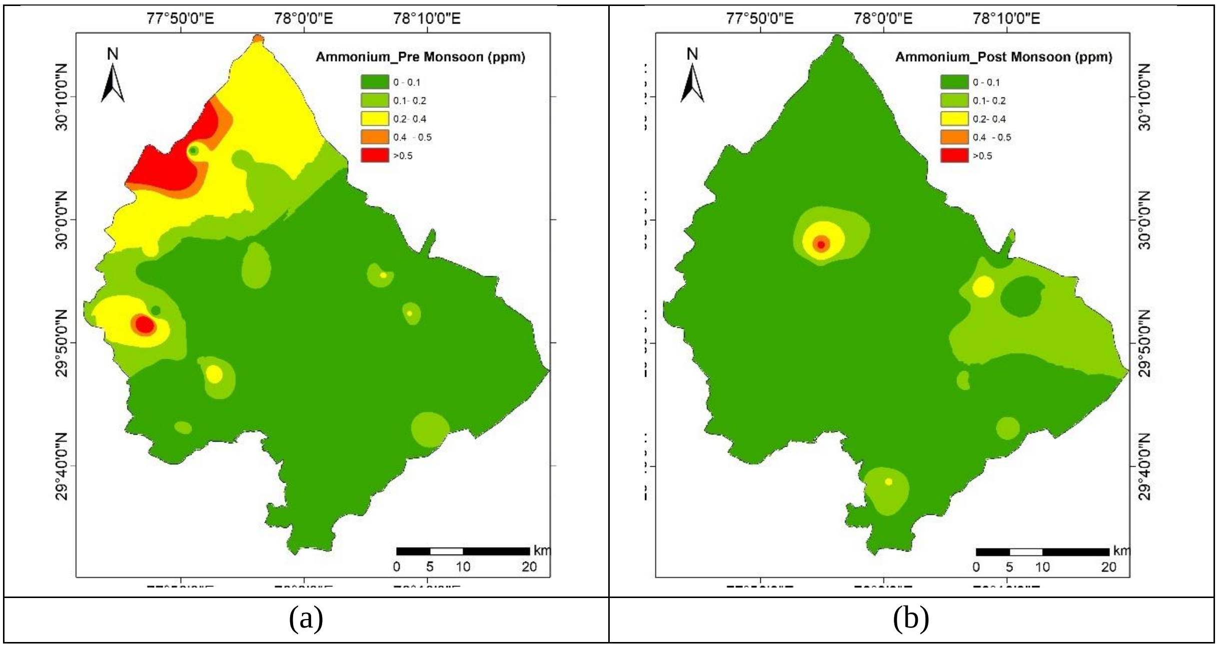
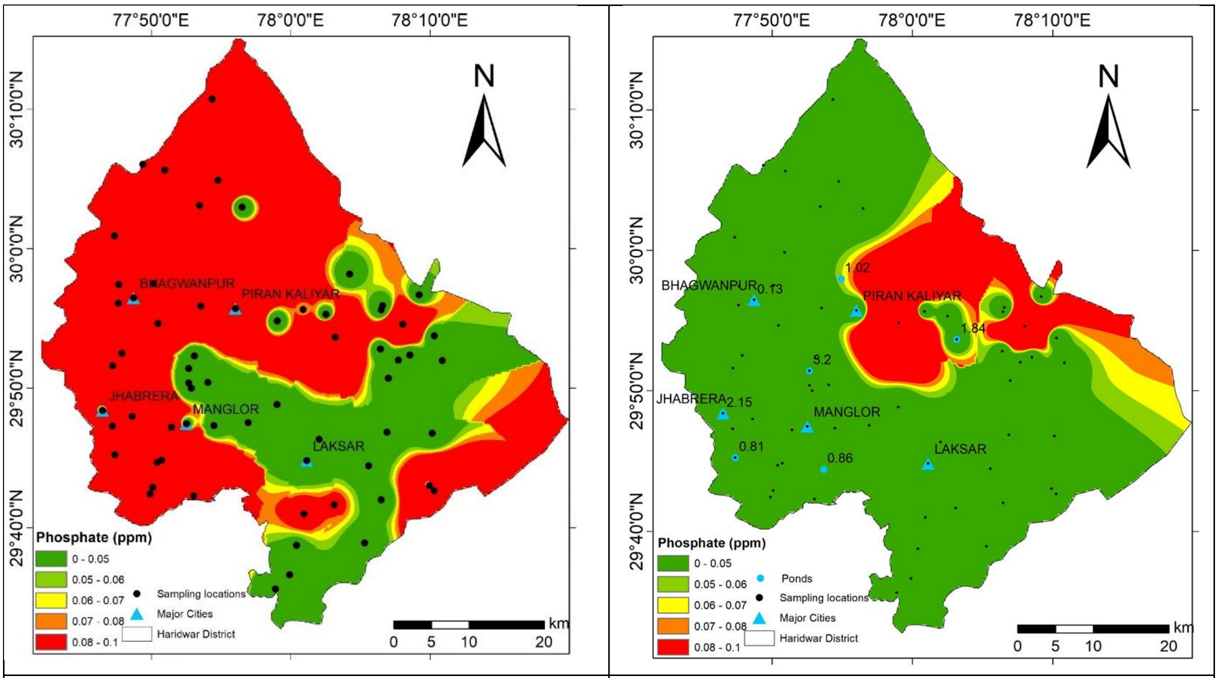


Fig.3.13. Spatial variation of groundwater NH_4-N during (a) pre & (b) post monsoon

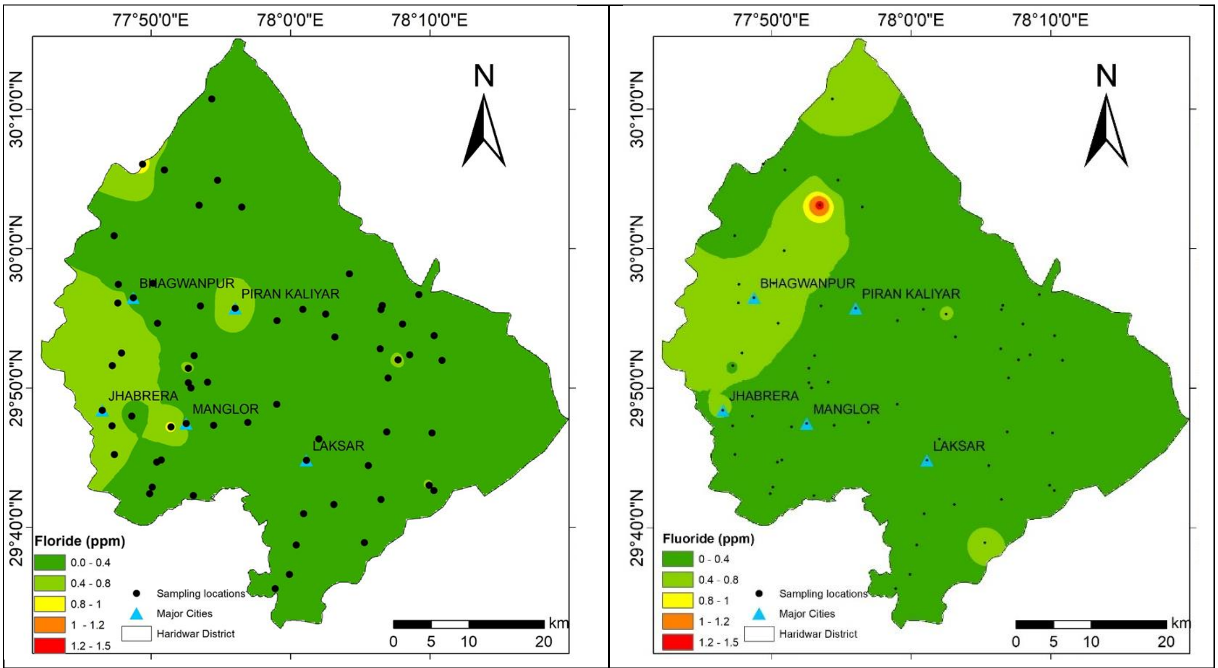
3.1.2.13 Silica

The Silica concentration in the samples of the study area ranges from 12.3 mg/l (Biharigarh) to 41.0 mg/l (Banera tanda) and 3.3 mg/l (Bhogpur) to 15.3 mg/l (Banera Tanda) in pre-monsoon and post-monsoon respectively. The average concentration of Silica (ppm) in pre and post monsoon samples was observed to be 25.6±0.74 mg/l and 9.7±0.32 mg/l respectively.



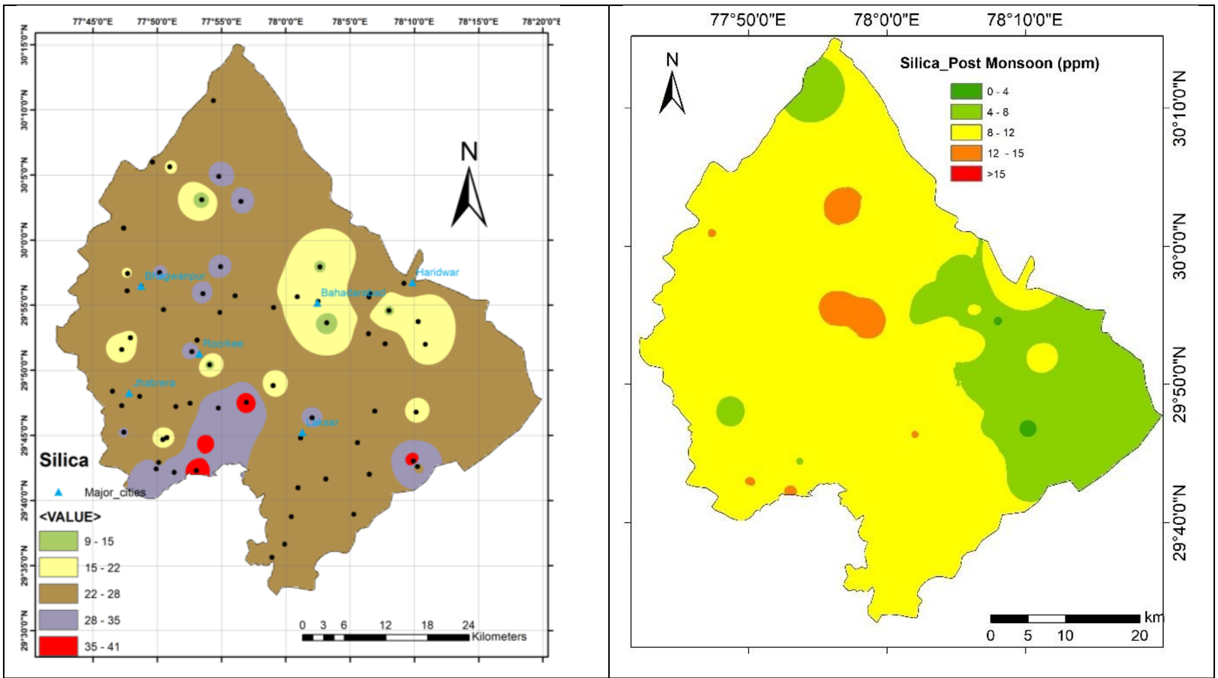
(a) (b)

Fig.3.14. Spatial variation of groundwater phosphate during (a) pre & (b) post monsoon



(a) (b)

Fig.3.15. Spatial variation of groundwater fluoride during (a) pre & (b) post monsoon



(a) (b)

Fig.3.16. Spatial variation of groundwater silica during (a) pre & (b) post monsoon

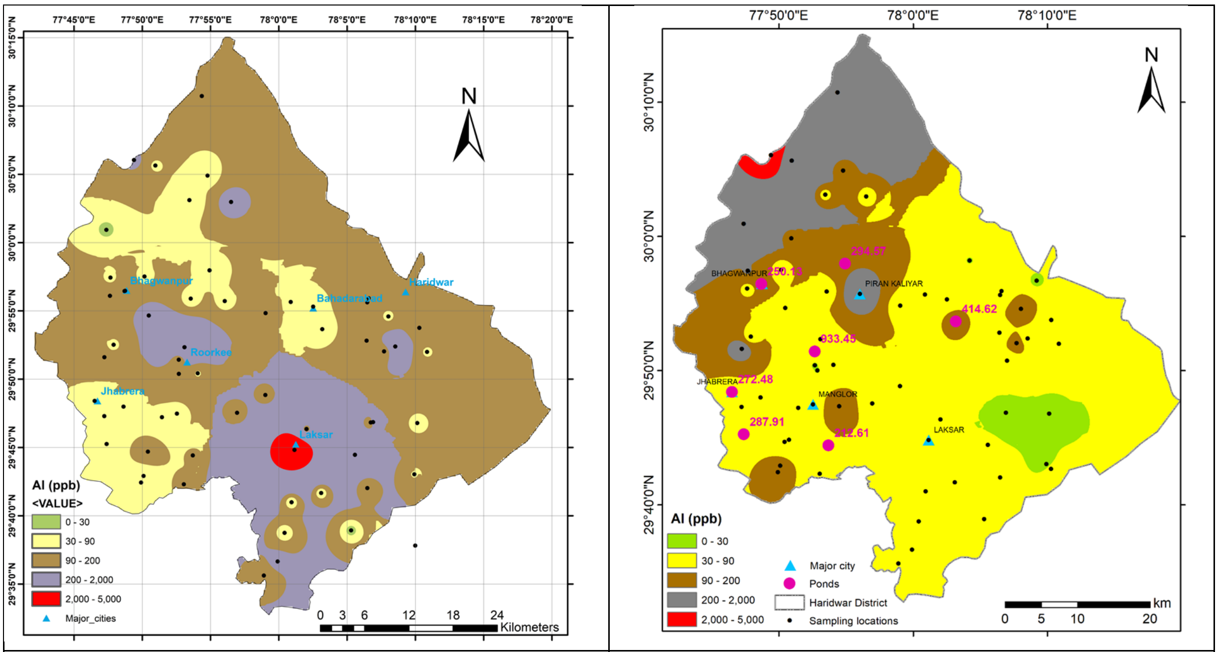
3.1.3 Trace Metals

3.1.3.1 Aluminium (Al)

The Al concentration in the samples of the study area ranges from 0.01 mg/l (Jaspur) to 4.9 mg/l (Dhallawala) and ND (Fatwa) to 4.4 mg/l (Biharigarh) in pre-monsoon and post-monsoon respectively. The average concentration of Al in pre and post monsoon samples was observed to be 0.21±0.07 mg/l and 0.19±0.06 mg/l respectively. Around 95.31% samples exceeded the acceptable limit and 12.5% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 89.19% samples exceeded the acceptable limit and 20.27 % samples exceeded the permissible limit.

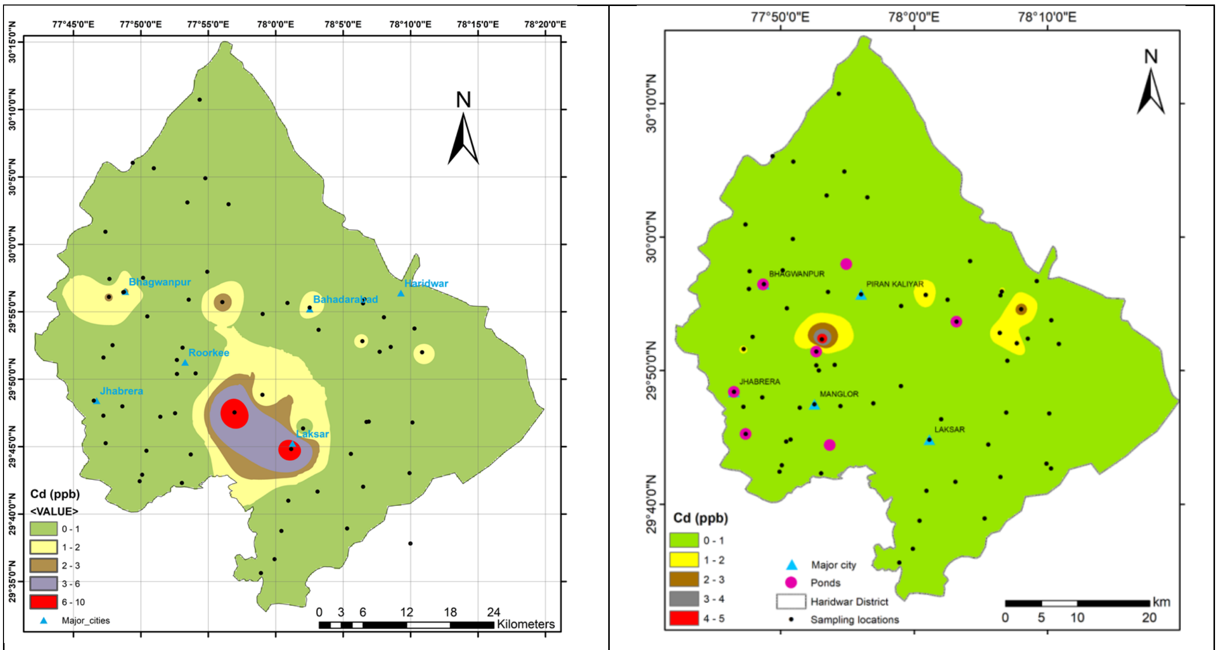
3.1.3.2 Cadmium (Cd)

The Cd concentration in the samples of the study area ranges from ND to 0.0094 mg/l (Banera tanda) and ND to 0.0046 mg/l (Durga Chowk RKE) in pre-monsoon and post-monsoon respectively. None of the samples exceeded the permissible limit of Cd for drinking water.



(a) (b)

Fig.3.17. Spatial variation of groundwater Al during (a) pre & (b) post monsoon

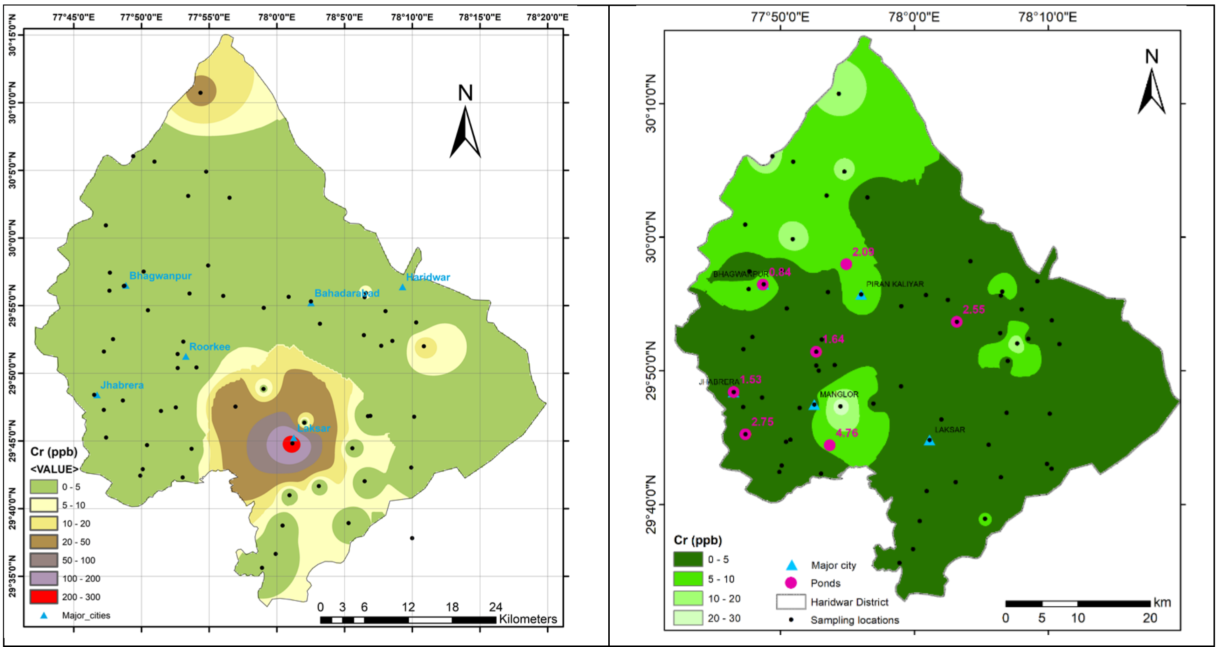


(a) (b)

Fig.3.18. Spatial variation of groundwater Cd during (a) pre & (b) post monsoon

3.1.3.3 Chromium (Cr)

The Cr concentration in the samples of the study area ranges from ND to 0.26 mg/l (Dhallawala) and ND to 0.026 mg/l (Banera Tanda) in pre-monsoon and post-monsoon respectively. The average concentration of Cr in pre and post monsoon samples was observed to be 0.006±0.004 mg/l and 0.004±0.0004 mg/l respectively. Around 1.56% samples exceeded the permissible limit during pre-monsoon and none exceeded the limit during post-monsoon.

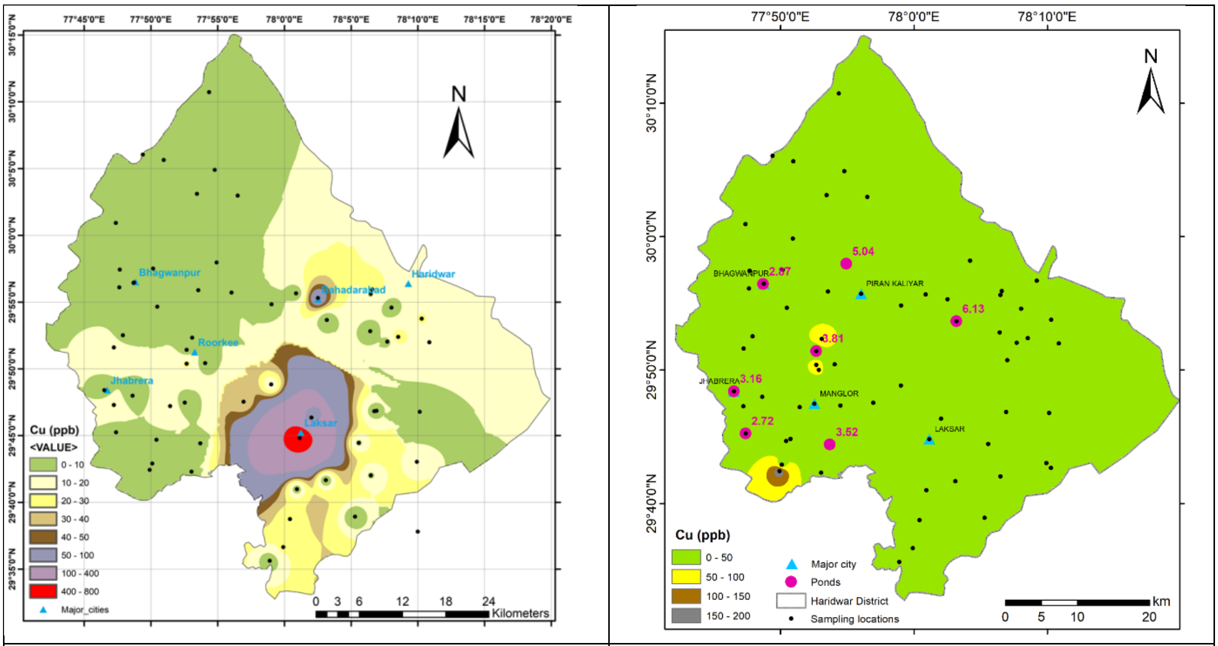


(a) (b)

Fig.3.19. Spatial variation of groundwater Cr during (a) pre & (b) post monsoon

3.1.3.4 Copper (Cu)

The Cu concentration in the samples of the study area ranges from ND to 0.688 mg/l (Dhallawala) and ND to 0.197 mg/l (Narsan) in pre-monsoon and post-monsoon respectively. The average concentration of Cu in pre and post monsoon samples was observed to be 0.03±0.01 mg/l and 0.009±0.003 mg/l respectively. Around 6.25% and 5.41% samples exceeded the acceptable limit in pre-monsoon and post-monsoon period respectively, however, all the samples were within the maximum permissible limit for Cu in drinking water.



(a) (b)

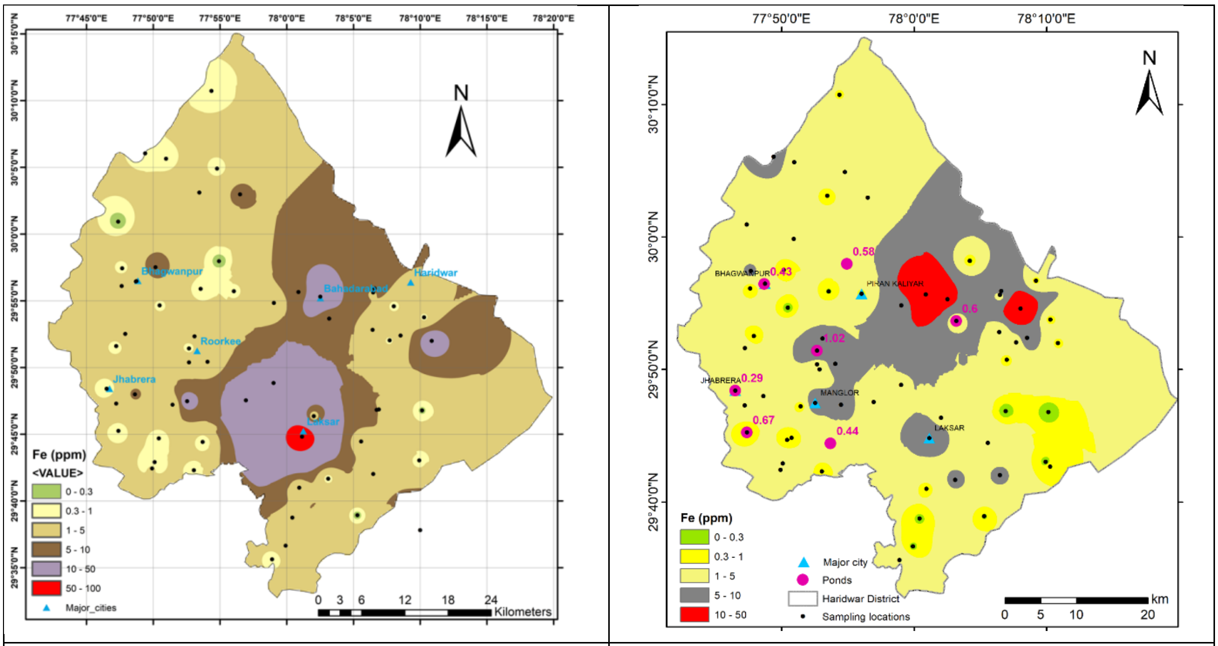
Fig.3.20. Spatial variation of groundwater Cu during (a) pre & (b) post monsoon

3.1.3.5 Iron (Fe)

The Fe concentration in the samples of the study area ranges from ND to 84.2 mg/l (Dhallawala) and ND to 32.3 mg/l (Kankhal) in pre-monsoon and post-monsoon respectively. The average concentration of Fe in pre and post monsoon samples was observed to be 5.0±1.42 mg/l and 3.25±0.64 mg/l respectively. Around 81.25% and 75.68% samples exceeded the permissible limit in pre-monsoon and post-monsoon respectively.

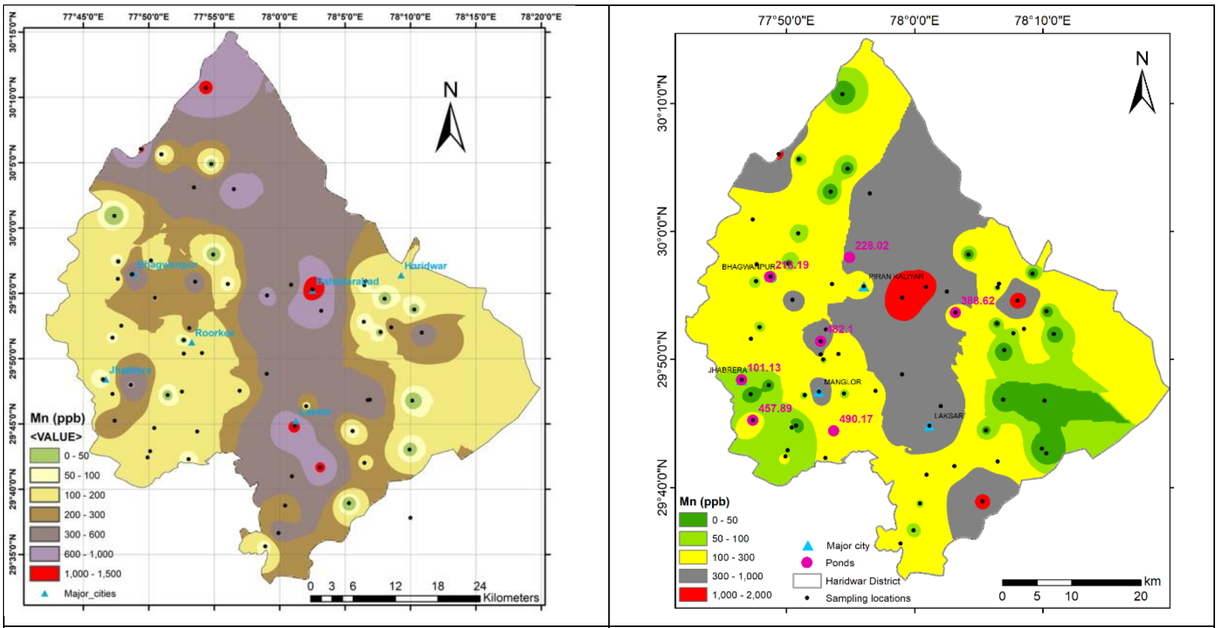
3.1.3.6 Manganese (Mn)

The Mn concentration in the samples of the study area ranges from ND to 1.5 mg/l (Begumpur) and ND to 1.77 mg/l (Santershah) in pre-monsoon and post-monsoon respectively. The average concentration of Mn in pre and post monsoon samples was observed to be 0.29±0.04 mg/l and 0.26±0.04 mg/l respectively. Around 62% samples exceeded the acceptable limit and 34% samples exceeded the permissible limit in pre-monsoon, however, during post-monsoon period around 52% samples exceeded the acceptable limit and 27% samples exceeded the permissible limit.



(a)	(b)

Fig.3.21. Spatial variation of groundwater Fe during (a) pre & (b) post monsoon



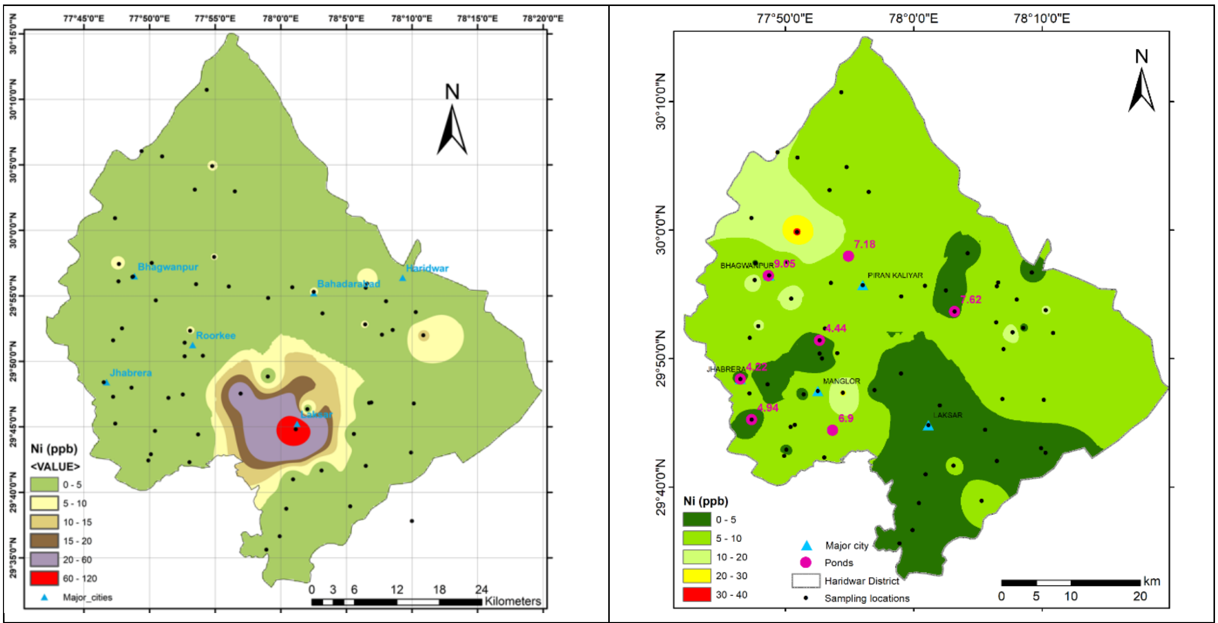
(a)	(b)

Fig.3.22. Spatial variation of groundwater Mn during (a) pre & (b) post monsoon

3.1.3.7 Nickel (Ni)

The Ni concentration in the samples of the study area ranges from 0 mg/l to 0.121 mg/l (Dhallawala) and ND to 0.03 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Ni in pre and post monsoon samples was observed to be

0.004±0.001 mg/l and 0.006±0.0005 mg/l respectively. Around 3.13% and 2.7% samples exceeded the permissible limit in pre-monsoon and post-monsoon period respectively.



(a) (b)

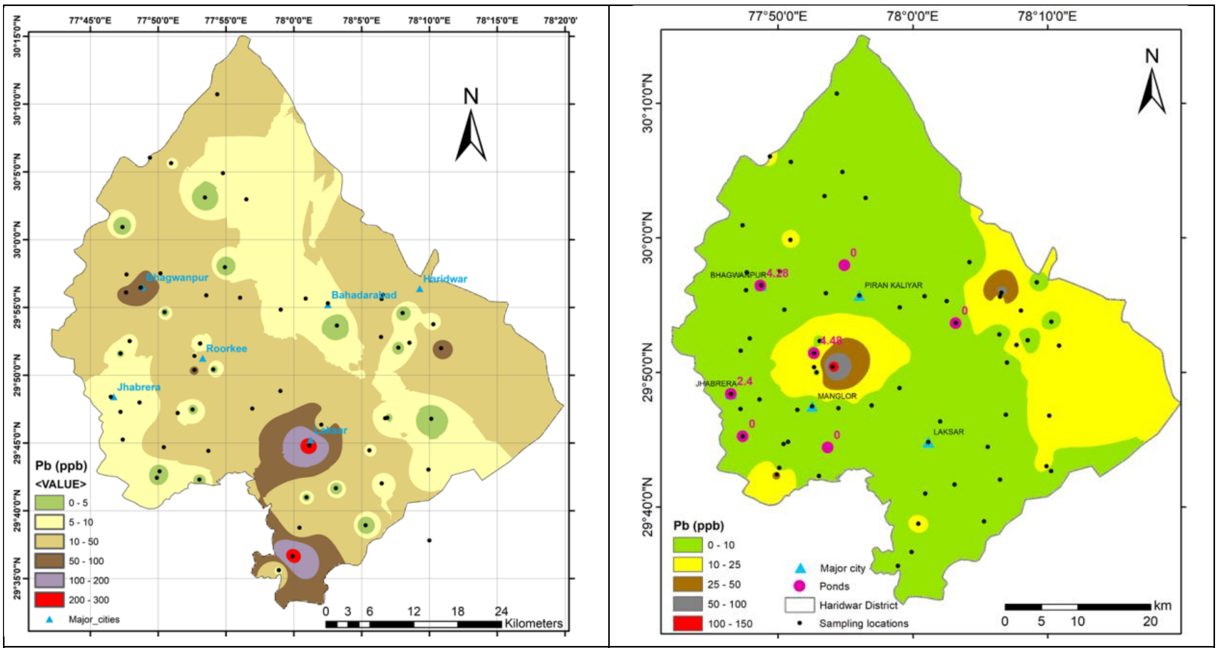
Fig.3.23. Spatial variation of groundwater Ni during (a) pre & (b) post monsoon

3.1.3.8 Lead (Pb)

The Pb concentration in the samples of the study area ranges from ND to 0.249 mg/l (Khanpur) and ND to 0.1278 mg/l (Dhandera) in pre-monsoon and post-monsoon respectively. The average concentration of Pb in pre and post monsoon samples was observed to be 0.02±0.005 mg/l and 0.007±0.002 mg/l respectively. Around 37.5% and 17.6% samples exceeded the permissible limit in pre-monsoon and post-monsoon period respectively.

3.1.3.9 Zinc (Zn)

The Zn concentration in the samples of the study area ranges from 0.014 mg/l (Jaspur) to 11.6 mg/l (Dhallawala) and 0.002 mg/l (Jassodharpur) to 10.6 mg/l (Sikroda) in pre-monsoon and post-monsoon respectively. The average concentration of Zn in pre and post monsoon samples was observed to be 1.57±0.3 mg/l and 0.77±0.18 mg/l respectively. Around 7.81% and 1.35% samples exceeded the acceptable limit for Zn in drinking water during pre- and post-monsoon period respectively and all the samples were within the permissible limit.



(a)	(b)

Fig.3.24. Spatial variation of groundwater Pb during (a) pre & (b) post monsoon

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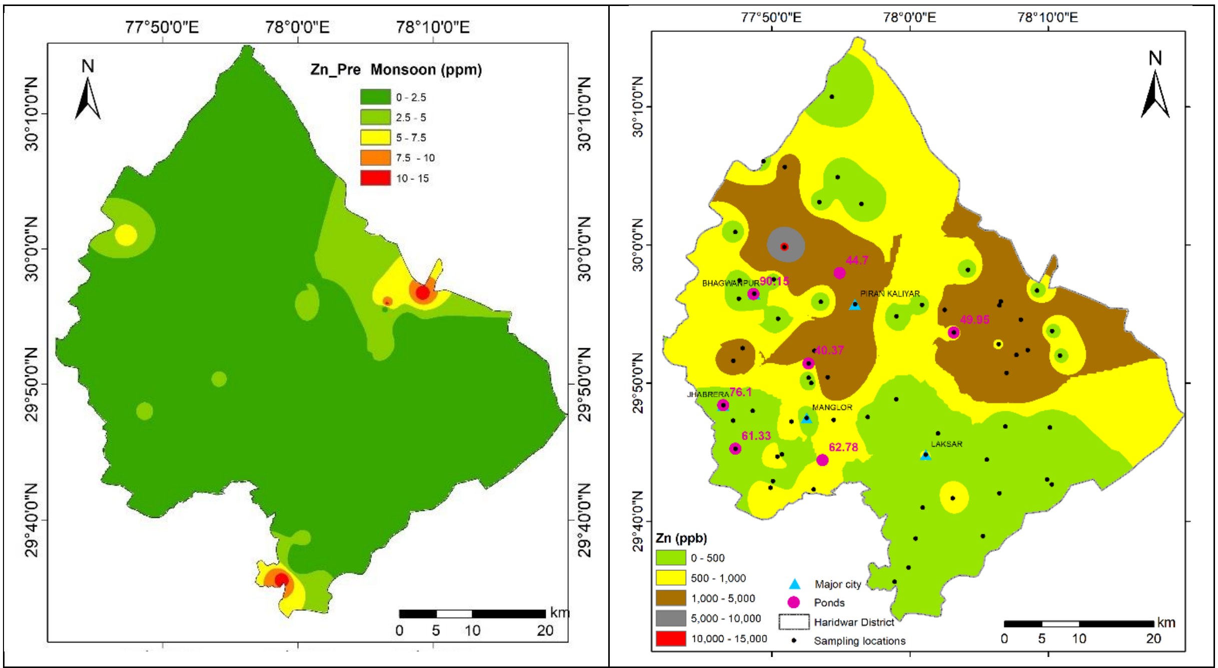


(a)	(b)

Fig.3.25. Spatial variation of groundwater Zn during (a) pre & (b) post monsoon

3.1.3.10 Boron (B)

The B concentration in the samples of the study area ranges from 0.00085 mg/l (Mundaki) to 0.16 mg/l (Telpura) with average concentration of 0.048±0.009 during post-monsoon period. None of the sample exceeded the acceptable limit.

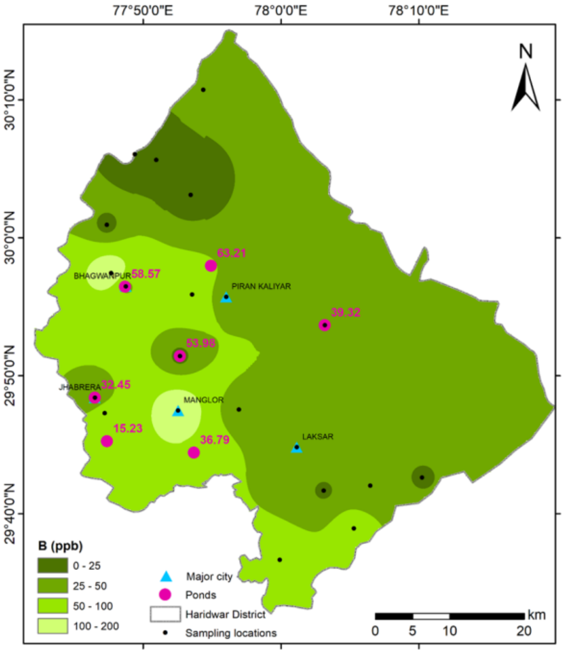


Fig.3.26. Spatial variation of groundwater B during post monsoon

3.1.3.11 Beryllium (Be)

The Be concentration in the samples of the study area ranges from Nil to 0.000217 mg/l (Kotwal) with average concentration of 0.00004±0.00001 during post-monsoon period. None of the samples exceeded the acceptable limit.

3.1.3.12 Mercury (Hg)

The Hg concentration in the samples of the study area ranges from ND to 0.000007 mg/l (Piran kaliyar) with average concentration of 0.00003±0.0000004 mg/l during post-monsoon period. Around 0% samples exceeded the acceptable limit.

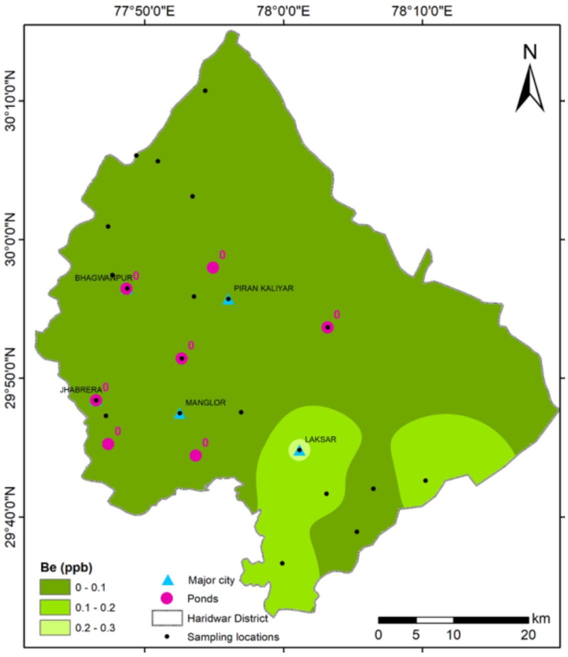


Fig.3.27. Spatial variation of groundwater Be during post monsoon

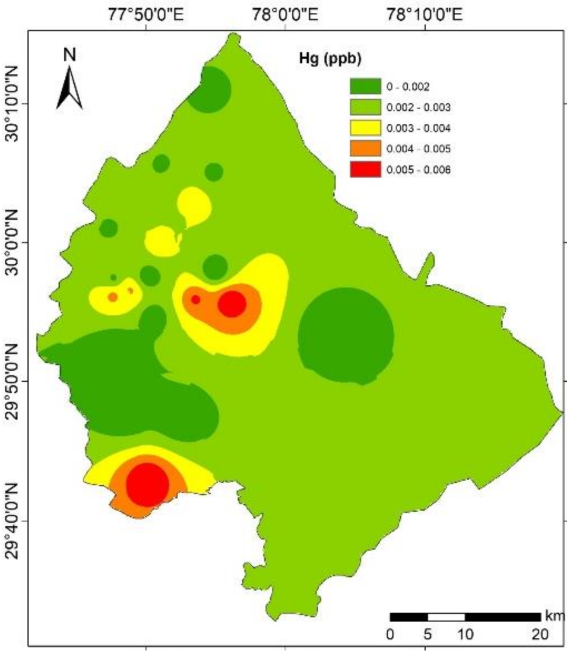


Fig.3.28. Spatial variation of groundwater Hg during post monsoon

3.1.3.13 Cobalt (Co)

The Co concentration in the samples of the study area ranges from ND to 0.008537 mg/l (Mohand Buggawala) with average concentration of 0.001±0.0005 mg/l during post-monsoon period. None of the samples exceeded the acceptable limit.

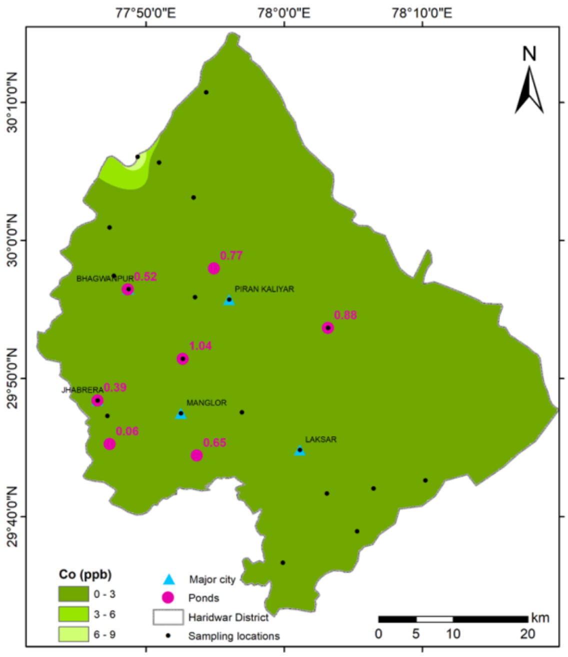


Fig.3.29. Spatial variation of groundwater Co during post monsoon

3.1.3.14 Uranium (U)

The U concentration in the samples of the study area ranges from 0.00004 mg/l (Mundaki) to 0.055611 mg/l (Bhalsua) with average concentration of 0.0078±0.0031 mg/l during post-monsoon period. Around 8.33% samples exceeded the acceptable limit.

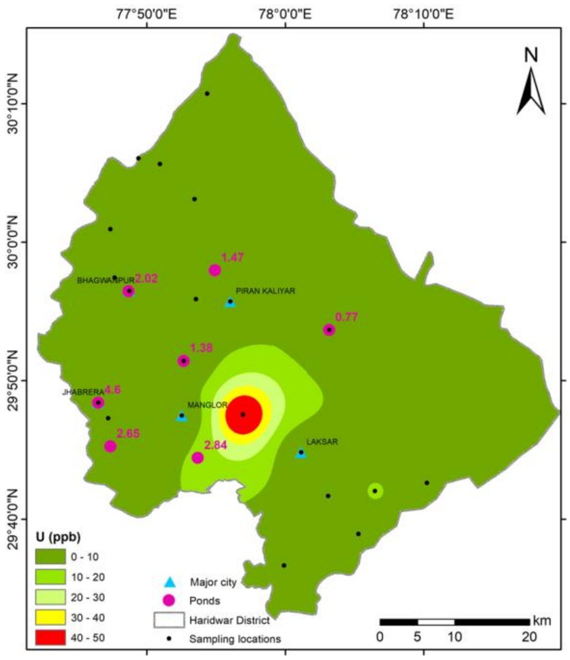


Fig.3.30. Spatial variation of groundwater U during post monsoon

3.1.3.15 Arsenic (As)

The As concentration in the samples of the study area ranges from ND to 0.014 mg/l (Gadarjuda) with average concentration of 0.0019±0.0009 mg/l during post-monsoon period. Around 12.5% samples exceeded the acceptable limit.

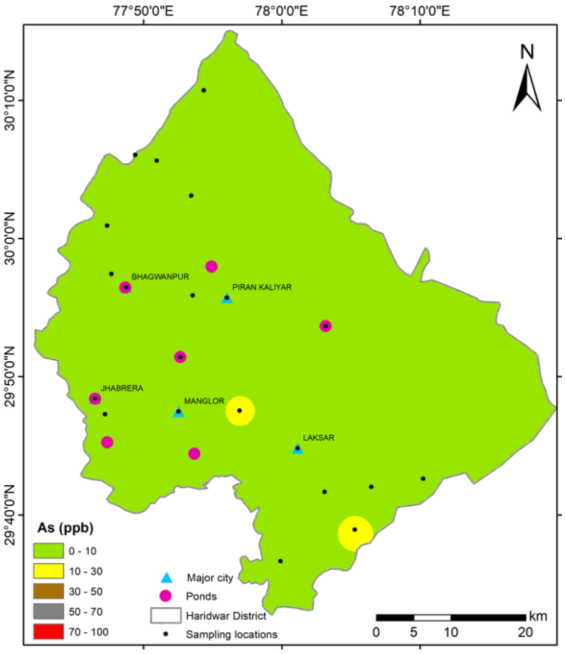


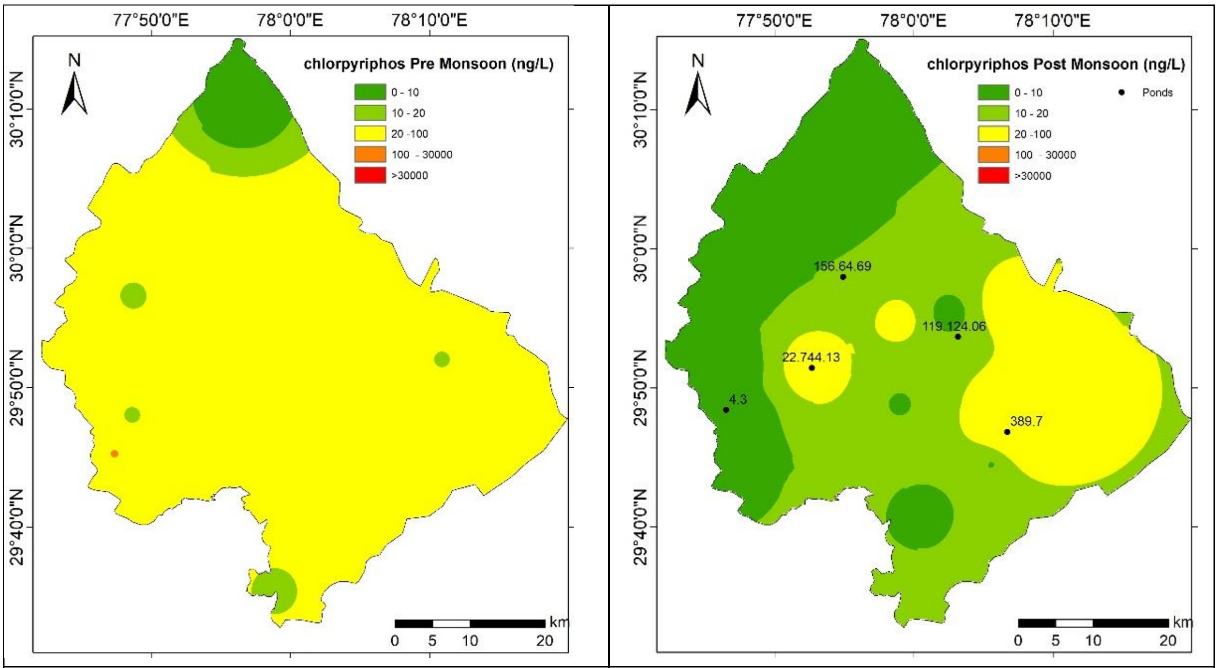
Fig.3.31. Spatial variation of groundwater As during (a) pre & (b) post monsoon

3.1.4 Pesticide Analysis

Pesticide is a composite term that encompasses all chemicals that are used to kill or control insects, weeds, fungi and other pests, to protect the crops. Although the use of pesticides has improved the agricultural yield and ensured food security, the quality of yield has significantly affected. Most of the pesticides are inherently toxic, not only to the pests, against which they are used, but also to other organisms. Long term and rampant use of pesticides results in persistence, bio-accumulation and long range transport of these hazardous chemicals. The toxicants affect entire ecological balance and result in severe health hazards to human beings.

The collected samples were analysed for alachlor, atrazine, butachlor, chlorpyriphos, dieldrin, α-Hexachlorocyclohexane, β-Hexachlorocyclohexane, δ-Hexachlorocyclohexane, γ-Hexachlorocyclohexane, Methyl parathion, Malathion, p-p-DDE, o-p-DDE, o-p-DDD, p-p-DDD, o-p-DDT, p-p-DDT, α-Endosulfan, β-Endosulfan, Endosulfan sulfate, and Ethion quantification. For pre-monsoon samples, only chloropyriphos was detected in the water samples in the range 14 ng/l to 101 ng/l (Fig. 3.32), however, atrazine (ND-3.04 ng/l) (Fig. 3.33), α-BHC (ND-4.2 ng/l) (Fig. 3.34), β-BHC (ND – 2.8 ng/l) (Fig. 3.35), γ-BHC (ND-5.01

ng/l) (Fig. 3.36), chlorpyriphos (ND-389 ng/l) (Fig. 3.32), isoproturon (ND-17.02 ng/l) (Fig. 3.37), malathion (ND-8.54 ng/l) (Fig. 3.38), and phorate (ND-230 ng/l) (Fig. 3.39) were detected in post monsoon samples. All the pesticides detected in the water samples were within the permissible limits prescribed by BIS (2012) for drinking water.



(a) (b)

Fig.3.32. Spatial variation of chlorpyriphos in groundwater during (a) pre & (b) post monsoon

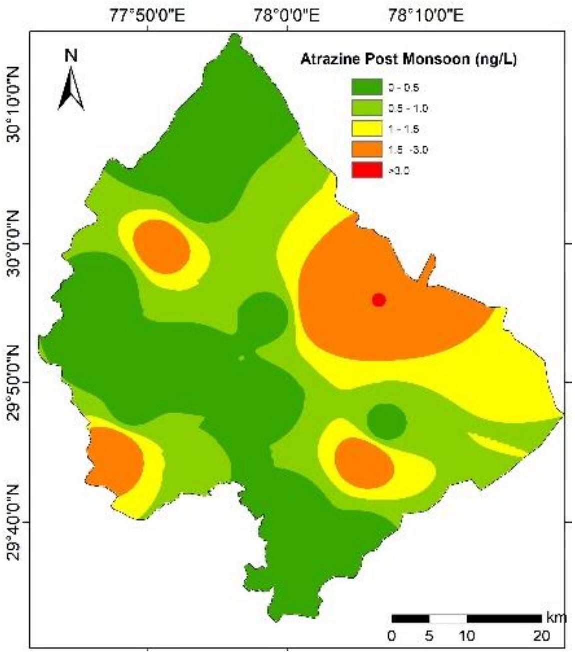


Fig.3.33. Spatial variation of atrazine in groundwater during post monsoon

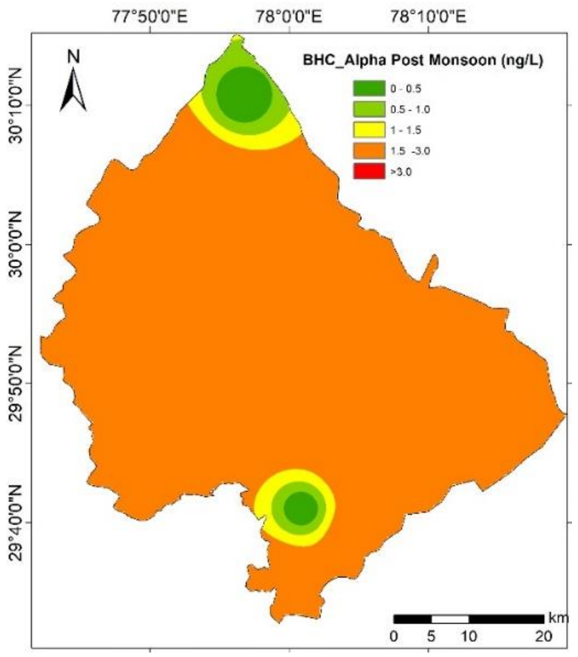


Fig.3.34. Spatial variation of α-BHC in groundwater during post monsoon

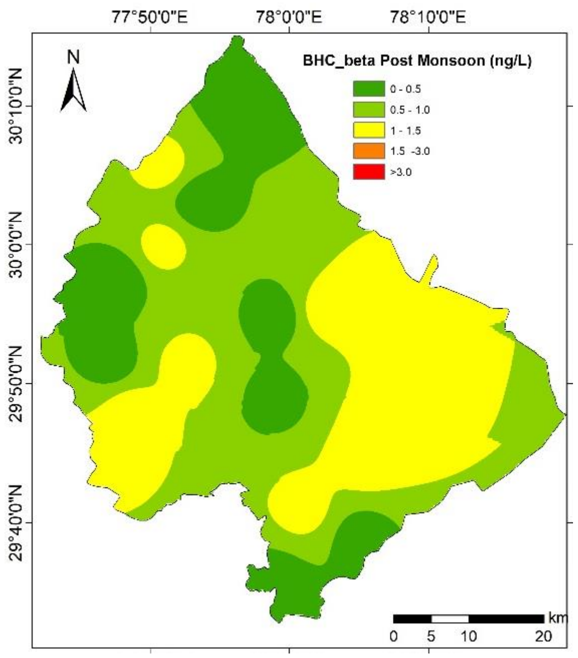


Fig.3.35. Spatial variation of β-BHC in groundwater during post monsoon

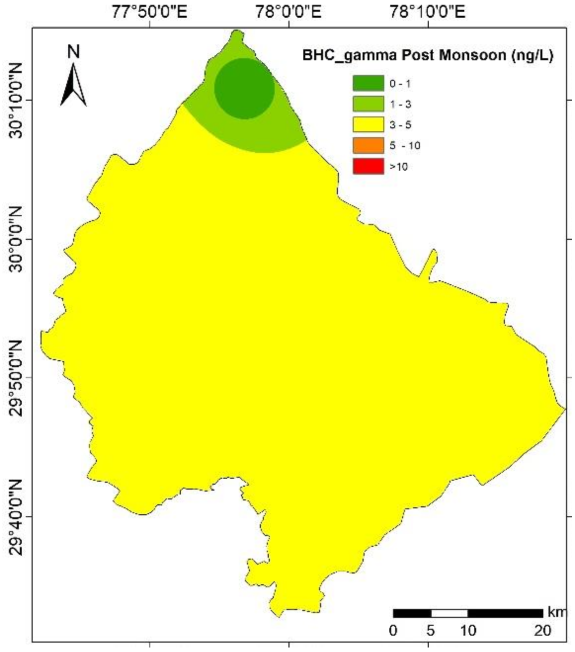


Fig.3.36. Spatial variation of γ-BHC in groundwater during post monsoon

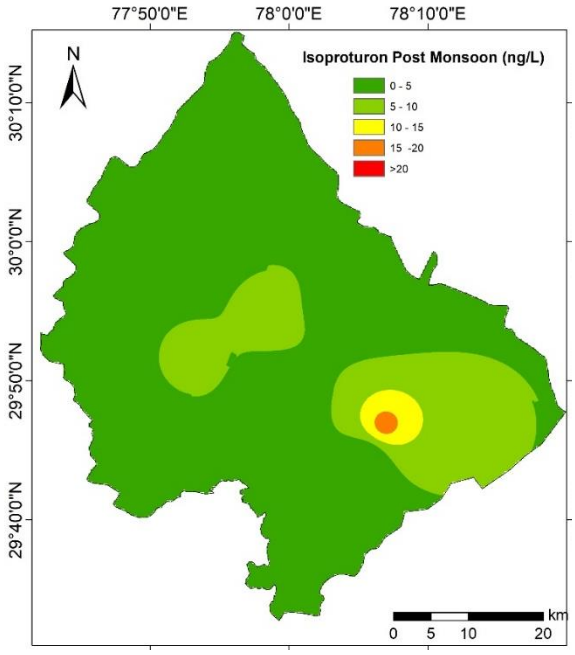


Fig.3.37. Spatial variation of isoproturon in groundwater during post monsoon

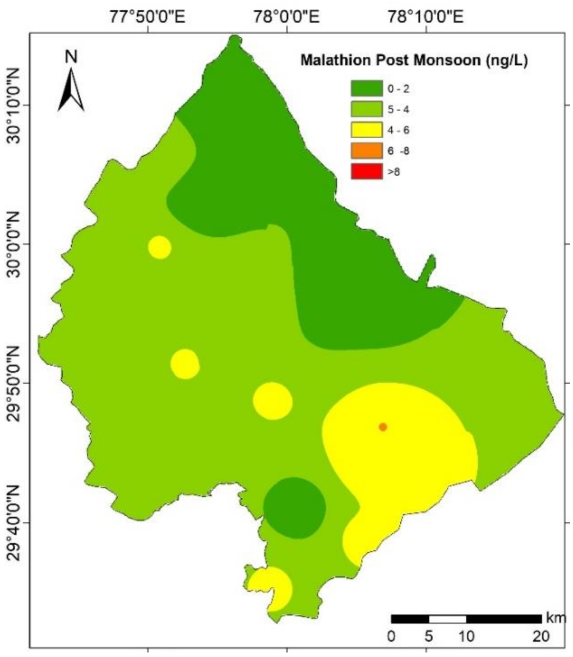


Fig.3.38. Spatial variation of malathion in groundwater during post monsoon

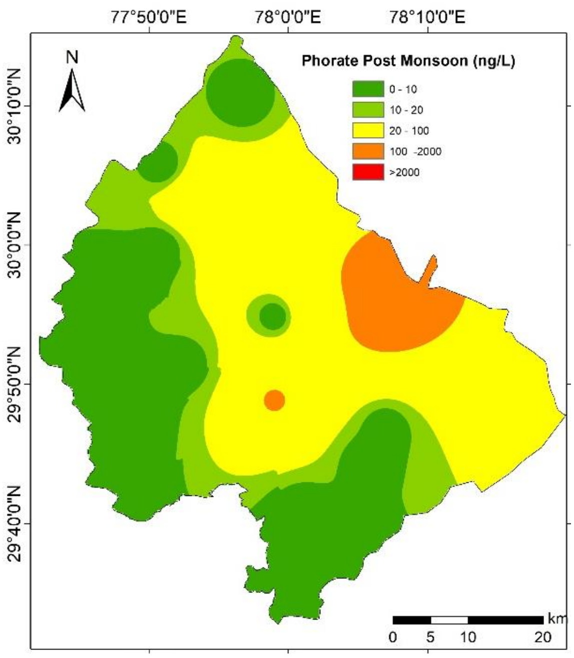


Fig.3.39. Spatial variation of phorate in groundwater during post monsoon

3.1.5 Microbiological Analysis

The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant. Infectious diseases caused by pathogenic bacteria, viruses and parasites are the most common and wide-spread health risk associated with drinking-water. Microbiological contamination is most likely to arise from the entry of fecal matter to waters. Specific waterborne disease outbreaks attributed to contaminated groundwater include cholera, salmonellosis, shigellosis, infectious hepatitis, gastroenteritis, and amoebic dysentery.

Microbiological examination of water samples is conducted to determine the sanitary quality and degree of contamination with wastes. The examination involves detection and enumeration of indicator organisms, rather than pathogens. The coliform group of bacteria is the principal indicator of suitability of a water for domestic, industrial, or other uses. Escherichia coli (*E. coli*) is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens. Fecal coliforms may enter surface water by a number of ways, from contaminated soil runoff from storm water, from vegetation and insects, wash from cities, or from direct sewage pollution by man or animals. BIS (2012) has prescribed absence of total coliform and *E. coli* bacteria in the drinking water. WHO (2017) also recommends that total coliforms and *E. coli* (or, alternatively, thermotolerant coliforms) should be absent in the drinking water and their presence indicate inadequate treatment or breaches in distribution system integrityColiforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material.

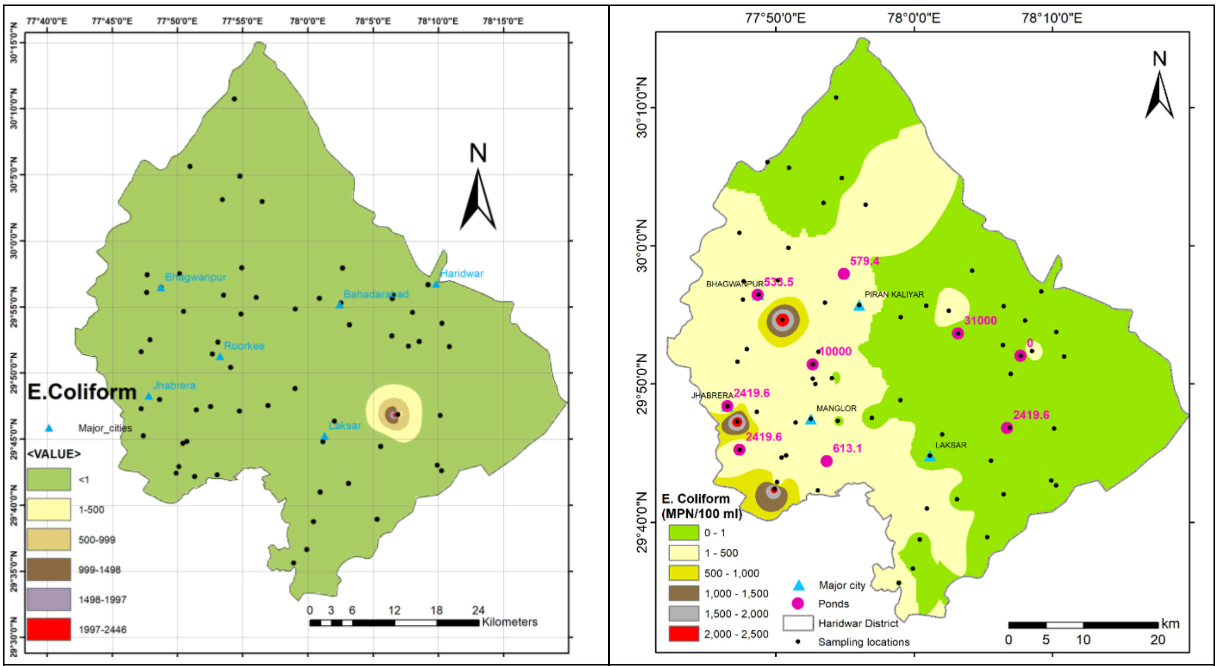
For safe drinking water, total coliform and E. coliform should be not be present in any 100 ml sample (BIS 2012).

3.1.5.1 E. Coli

During pre-monsoon period Escherichia coli (*E. coli*) was absent in all the analysed samples except one (Kangri), however, the number of samples with E-coli increased in the post monsoon period. Around 15% samples were detected positive with E-coli and should be used only after proper disinfection. The E-coli were detected in all the pond samples higher than 500 MPN/100 ml (Figure 3.39).

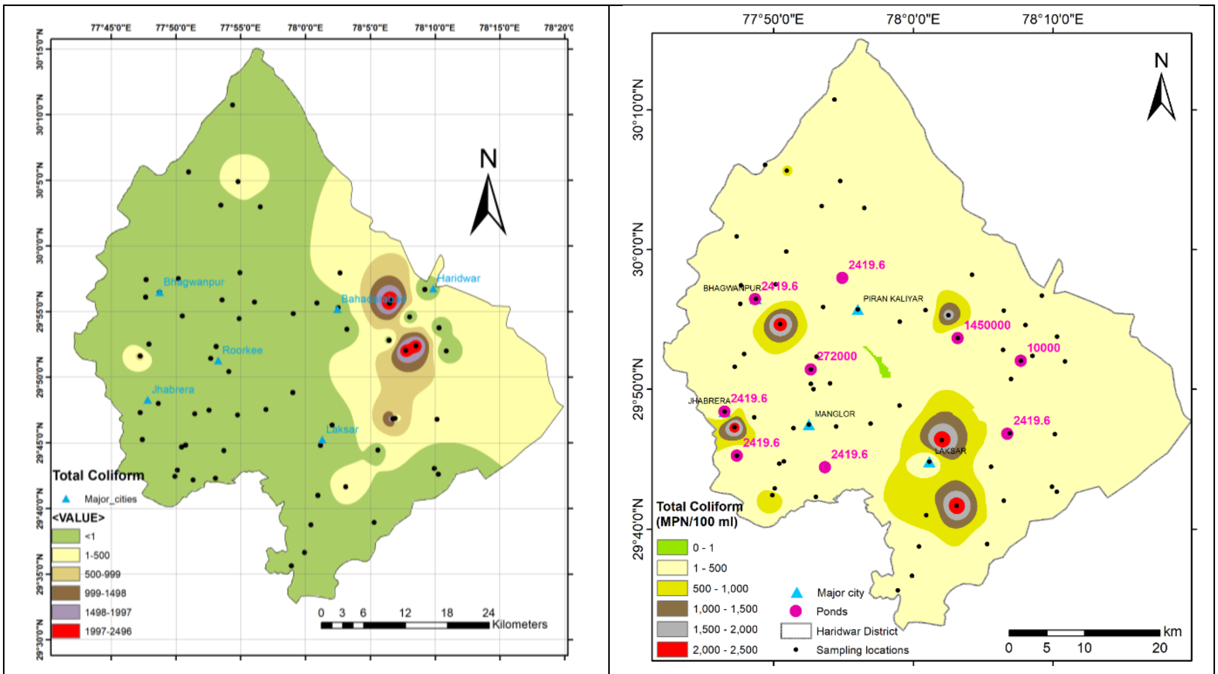
3.1.5.2 Total Coliform

Total coliforms in the water samples ranged from non-detectable to 2400 MPN/100 ml during pre- and post-monsoon period. Around 15% samples exceeded the limits prescribed by BIS (2012) for domestic usage during pre-monsoon and around 43% samples exceeded the limit during post monsoon period (Figure 3.40).



(a) (b)

Fig.3.40. Spatial variation of E-coli in groundwater during (a) pre & (b) post monsoon period

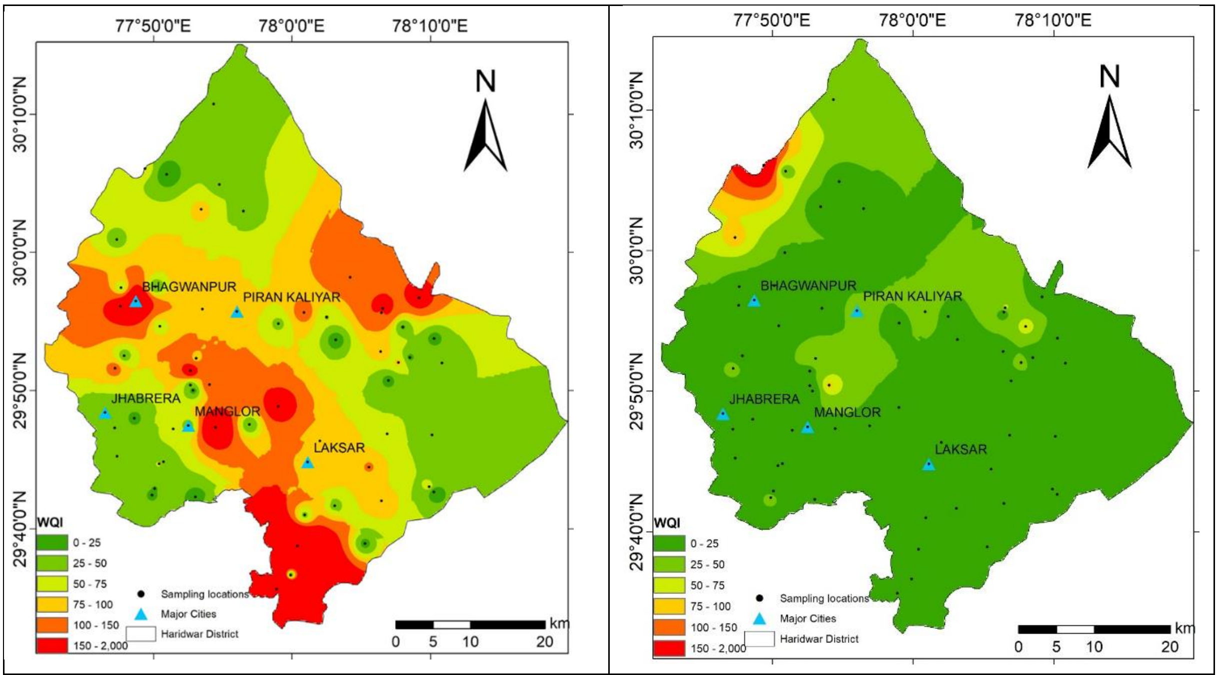


(a) (b)

Fig.3.41. Spatial variation of Total Coliform in groundwater during (a) pre & (b) post monsoon period

3.2 Suitability of Water for Drinking Purpose

The water quality indices for drinking water purpose was computed with reference value prescribed by BIS (2012) for drinking water and the values for parameters not mentioned in BIS (2012), the values prescribed by WHO (2017) was considered. The water quality indices of groundwater for drinking purpose ranges from 3.15 - 1831 and 2.44 – 295 for pre and post-monsoon period respectively (Figure 3.42). During the pre-monsoon period, 23.1%, 29.2%, 10.7%, 13.8%, 9.2%, and 13.8% samples were observed in excellent, good, fair, poor, very poor, and unfit categories respectively. Similarly, during post monsoon period, 80%, 12.3%, 3.1%, 3.1% and 1.5% samples were observed in excellent, good, fair, poor, and unfit categories respectively. The groundwater was observed more deteriorated during the pre-monsoon period. The parameters responsible for the poor water quality were due to Cu, Ni, Fe, Cd, Pb, Al, and Mn. Most of the samples were observed to be unfit for drinking purposes in pre-monsoon due to increased Cu, Ni, Fe, Cd, Pb, and Al concentration.

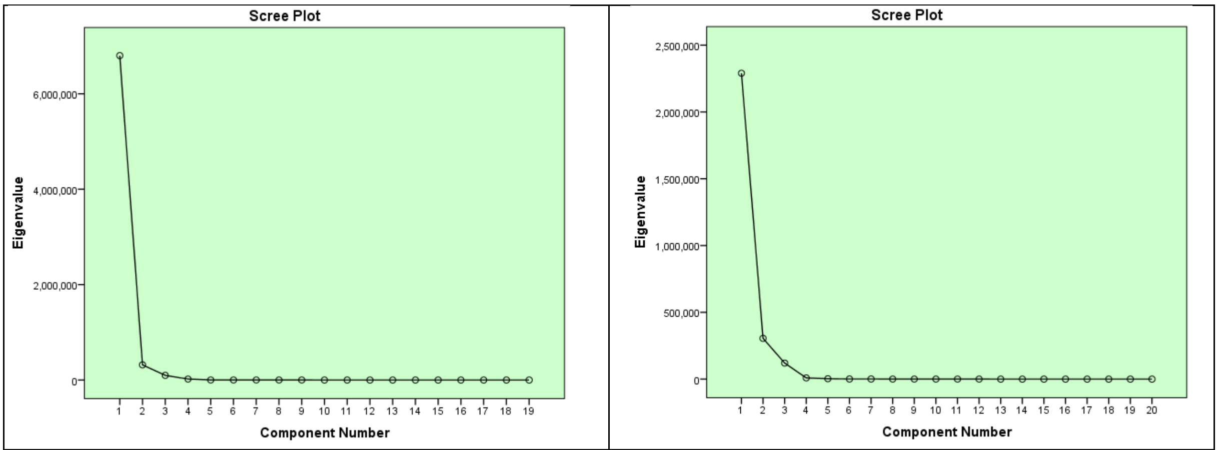


(a) (b)

Fig.3.42. WQI for domestic application (a) pre & (b) post monsoon

3.3 Sources of pollutants in Groundwater

Principal component analysis (PCA) is a multivariate statistical analysis for reducing the dimensionality of large datasets often difficult to interpret for increasing the interpretability without losing information (Jolliffe and Cadima, 2016). The PCA has helped in the identification of the major variable factors responsible for the pollution (Varol and Davraz 2015; Ismail et al. 2016; Zhang et al. 2016; Chabukdhara et al. 2017). In this study, Principal component (PC) extraction was done with minimum acceptable Eigen value as 1 (Kaiser 1958) and the components with eigen value <1 were discarded as noise data (Yong and Pearce 2013; Ledesma et al. 2015). The priority to define the informative factor was based on the factor loading: strong (>0.75), moderate (0.75-0.50), and weak (<0.50) (Varol and Davraz 2015). In this study, B, Cu, Co, Ni, Pb, Be, Se, Hg, U, Al, As, Cr, Fe, Mn, Zn, pH, F, Cl, NO_3, SO_4, NH_4, K, Ca, Mg, and Na were considered for PCA.



(a)	(b)

Fig.3.43. Scree Plot: (a) Pre-monsoon period (b) Post-monsoon period

In pre-monsoon, extracted principal component, PC1, with Eigen value >1 account for 93.89 % variance of the total variance with strong loading of Zn and moderate loading of Cr, Cu, Fe, Ni, and Pb (Table 3.3).

The principal components PC1 and PC2 for the post-monsoon samples account for 83% and 11% variance of the total respectively. PC1 was influenced by the strong loading of Zn, moderate loading of Ni, and weak loading of others. PC2 was influenced by the strong loading of Al.

High variance is an indicator of sporadic distribution and anthropogenic origin (Zhang et al. 2016), and the same was observed in this case indicating the source of Zn, Cu, Fe, Ni, and Pb is anthropogenic or influenced by anthropogenic inputs. The low variance is an indicator of even distribution and originated from natural sources, therefore, Al (strong loading) and other positive moderate loading in the groundwater may have originated from the dissolution of aquifer sediment (Zhang et al. 2016; Wang and Lu 2011).

Table 3.2 Principle component, Co-variance and contribution principal component analysis

	Pre-monsoon	Post-monsoon	
Component	**PC1**	**PC1**	**PC2**
% of Variance	93.89	83.75	11.29
Cumulative %	93.89	83.751	95.041

Table 3.3 Matrix of the principal component analysis loadings of heavy metals

Component Matrix[a]			
Elements	**Pre-monsoon**	**Post-monsoon**	
	PC1	**PC1**	**PC2**
Al	.471	-.014	.981
As	.471	-.088	-.038
Cd	.583	.404	.106
Cr	.599	.339	.269
Cu	.504	.148	-.010
Fe	.684	.188	.224
Mn	.269	-.026	.445
Ni	.640	.594	.303
Pb	.537	.340	-.012
Zn	1.000	.999	-.033
Ca	.025	.492	.080
Mg	.059	.392	.058
Na	-.032	.275	.057
K	-.053	.052	.048
NH_4	-.031	-.048	.070
SO_4	.138	.429	-.045
NO_3	.125	.593	-.046
F	-.136	-.040	-.063
Cl	.472	.442	.079
ALK	-.020	.302	.135

4 CONCLUSIONS AND SCOPE OF FUTURE WORK

Water is most precious natural resource on this planet Earth, and the life on the Earth depends on the presence of water. However, population explosion, industrialization, urbanization, unmanaged waste management and modern agricultural activities have resulted in pollution of the ground as well as surface water. The contaminated water consumption is the main source of human health problem in this twenty first century. Haridwar district of Uttarakhand has witnessed significant industrial growth and urbanization of creation of Uttarakhand in year 2000 and as a result the water resources of the district also got impacted. With the above background, this study was conducted to identify the status of groundwater of the district, the primary source of drinking water, in terms of its suitability for different designated usage and following conclusions can be drawn from the work carried out till date-

- **Organoleptic parameters:** Around 0.1% samples exceeded the maximum permissible limit for pH (8.5) in post monsoon samples and none in pre-monsoon. Based on TDS levels, around 10.8% samples were observed in brackish water category. Around 23.5% and 54.1% samples exceeded the acceptable limit of 500 mg/l in pre-monsoons and post-monsoon period respectively and none exceeded the maximum permissible limit of 2000 mg/l.

- **Major Ions:** In the study area, Ca, Mg, NH_4, NO_3, SO_4, and alkalinity content in the analyzed drinking water samples exceeded the acceptable limit for 45.3%, 42.2%, 3.1%, 21.9%, 1.6%, and 57% pre-monsoon samples, respectively. Similarly, during post-monsoon period, around 48.7%, 33.8%, 2.7%, 1.4%, 6.8%, and 63% samples exceeded the acceptable limits for Ca, Mg, NH_4, Cl, NO_3, and alkalinity respectively.

- **Trace Metals:** The samples were analysed for B, Fe, Co, Ni, Pb, Be, As, Se, Hg, U, Al, Cr, Cu, Mn, and Zn concentration. Around 95.3%, 6.3%, 81.3%, 62%, and 7.8% samples exceeded the acceptable limits for Al, Cu, Mn, Zn, and Cr during pre-monsoon respectively. During post monsoon, around 89.2%, 5.4%, 75.7%, 52%, 1.4%, and 12.5% samples exceeded the acceptable limits for Al, Cu, Mn, Zn, Cr, and As respectively. The prescribed maximum permissible limit was exceeded by Al, Cr, Fe, Mn, Ni, and Pb in 12.5%, 1.5%, 81.3%, 34%, 3.2%, and 37.5% pre-monsoon samples respectively, and by Al, Fe, Mn, Ni, Pb, and U in 20.3%, 75.7%, 27%, 2.7%, 17.6%, and 8.3% post monsoon samples respectively.

- **Pesticides:** The samples were analysed for alachlor, atrazine, butachlor, chlorpyripos, DDT, DDE, DDD, ethion, isoproturon, HCH, malathion, and phorate. All the pesticides were observed to be below the recommended limits for drinking water.

- **Suitability for Drinking Purpose:** Around 23.1%, 29.2%, 10.7%, 13.8, 9.2, and 13.8% pre-monsoon samples were observed in excellent, good, fair, poor, very poor, and unfit categories respectively. Similarly, during post monsoon period, 80%, 12.3, 3.1%, 3.1%, and 1.5% samples were observed in excellent, good, fair, poor, and unfit categories respectively. The parameters responsible for the poor water quality were Al, Pb, Cd, Fe, Ni, Cu, ad Mn.

- The PCA analysis indicated Zn, Cu, Fe, Ni, and Pb in the groundwater as a result of anthropogenic activities.

Although, this study resulted in comprehensive water quality status of the Haridwar district, following research questions needs to be further investigated-

1. The factors/mechanism responsible for the dissolution of As and other trace metals in the groundwater to minimize their concentration through in-situ measures.

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