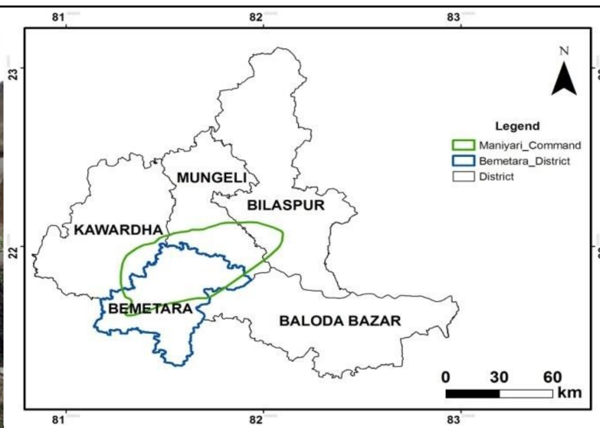
Title of the project: Groundwater Quality Assessment with Special Reference to Sulphate contamination in Bemetara District of Chhattisgarh State and Ameliorative Measures

(PDS No. NIH-29_2017-70)

National hydrology project
Department of Water Resources, River Development and GangaRejuvenation, Ministry of Jal Shakti, NewDelhi

National Institute of Hydrology, Roorkee

Study Area – Maniyari Shale Formation Region



National Institute of Hydrology
Roorkee – 247667, Uttarakhand

March 2021

Name: Dr. M. K. Sharma Designation: Scientist E		**National Institute of Hydrology Roorkee – 247667, Uttarakhand**

PREFACE

Sulphate extensively comes in water from both natural and anthropogenic sources. The natural sources include sulphur mineral dissolution, atmospheric deposition and sulphide oxidation from minerals. Human induced sources are power plants, coal mines and metallurgical refineries. In many potential sources, Gypsum is an important source in many aquifers having large amount of sulphate. In the last few decades, atmospheric deposition has become an important source of sulphate in soil and ultimately it goes to groundwater. Since sulphate is mobile in soil, addition into the soil will impact on shallow aquifer. The fate and transport of sulphate into the aquifer system affects the dynamics of hydrogeochemistry of aquifers. During these processes, sulphate is reduced and becomes very important for many subsurface systems, which has metal rich water with acidic medium, as mining sites acidic condition.

High concentrations of sulphate in the water, that we drink, can have a laxative effect when combined with calcium and magnesium, the two most common constituents of hardness. Sulphate in drinking water being a toxic impure having laxative effect on human health, occurrence of sulphate in groundwater, using as drinking water, needs a systematic study and assessment. It is in that context, groundwater quality assessment of district Bemetara with special reference to sulphate contamination is undertaken as a purpose driven study titled "Groundwater quality assessment with special reference to sulphate contamination in Bemetara district, Chhattisgarh and suggesting ameliorative measures" in collaboration with Water Resources Department (WRD), Raipur, Govt. of Chhattisgarh and Central ground Water Board, NCCR, Raipur under National Hydrology Project awarded vide letter No. X-87013/1/2016- NHP/4565-4587 dated 31.08.2017 for a period of 3 years duration. The activities to meet the objectives of the project were started from the month of September 2017 by recruitment of project staff, literature survey, field visit of the study area and by organizing two training courses. Support and help provided by Sri A. K. Shukla, Sr. Geohydrologist, WRD, Raipur during field investigations are highly appreciated. Groundwater level data provided by WRD, Raipur and aquifer parameters data and technical guidance provided by Mr. A. K. Patre, Scientist D, NCCR, CGWB, Raipur are duly acknowledged. The Technical Report titled "**Groundwater Quality Assessment with Special Reference to Sulphate Contamination in Bemetara District, Chhattisgarh and Suggesting Ameliorative Measures**" is prepared based on the work carried out under this PDS by Dr. M. K. Sharma, Scientist 'E' & Principal Investigator of the PDS and his team. The findings of the study will help in solving the problem of sulphate contamination in groundwater of the state of Chhattisgarh by adopting the suggested technique of artificial recharge in the degraded zones.

Place:Roorkee — Signature

Date:15.05.2021 — (M. K.Sharma)

<table>
<tr><th colspan="2">Project Team</th></tr>
<tr><td>Lead organization</td><td>Name and Designation (PI)*:
Dr. M. K. Sharma, Scientist ‘E’
Name and Designation(Co-PI)*:
Dr. C. K. Jain, Scientist ‘G’ (upto31.03.2019)
Dr. Surjeet Singh, Scierntsit‘F’
Dr. Pradeep Kumar, Scientist ‘D’
Name and address of leadorganization:
National Institute of Hydrology, Roorkee – 247667, Uttarakhand
Name and address of IA (if different from lead organization): WRD, Raipur</td></tr>
<tr><td rowspan="2">Partner organization/s
(enter each partner organization in a separate row)</td><td>Name and Designation (PI)*:
Mr. A. K. Shukla, Sr. Geohydrologist
Name and Designation (Co-PI)*:
Mr. Ashok Verma, Asstt. Geohydrologist (upto 30.06.2018)
Mr. P. C. Das, Asstt. Geohydrologist
Name and address of partner organization:
Water Resources Department, Raipur, Chhattisgarh
Name and address of IA (if different from partner organization): Same</td></tr>
<tr><td>Name and Designation (PI)*:
Mr. A. K. Patre, Scientist D
Name and address of partner organization:
CGWB, NCCR, Raipur, Chhattisgarh
Name and address of IA (if different from partner organization): WRD, Raipur</td></tr>
<tr><td>Consultant/s, if any
(enter each consultant in a separate row)</td><td>Name and Designation of consultant
Name and address of consultant’s organization</td></tr>
</table>

*If PI/ Co-PI are changed/ retired, enter those names as follows in above table
Name and designation (PIup to ___)
Name and designation (Co-PIup to ____)

Document control sheet

Title	Groundwater Quality Assessment with Special Reference to Sulphate Contamination in Bemetara District of Chhattisgarh State and Ameliorative Measures
PDS number	PDS No. NIH-29_2017-70
Date of approval	31 August 2017
Budget in time of original approval (For Partner and for Lead)	Rs. 25,39,600.00 (for Lead – NIH) Rs. 3,57,000.00 (for Partner – WRD, Raipur)
Revised Budget (For Partner and for Lead)	NA
Date of commencement	01 September 2017
Date of completion	31 March 2021
Number of page	137
Number of figures and tables	Figure – 68, Table - 31

Abstract

Groundwater is one of the most important sources for drinking water supply in the state of Chhattisagrh. The groundwater of Bemetara district is affected by sulphate contamination reported by Public Health Engineering Department, Durg. Therefore, Bemetara district is selected for the purpose-driven study of sulphate contamination in groundwater in collaboration of Water Resources Department (WRD), Govt. of Chhattisagarh, Raipur and NCCR, CGWB, Raipur. Based on the suggestion of WRD, Raipur the study is focused on Maniyari shell formation region for tracking the problem in a real sense. Hence, the study area is extended from the district Bemetara to Maniyari shell formation region. The high concentration of sulphate in groundwater is reported due to the dissolution of gypsum veins present within Maniyari shale formation. High concentration of sulphate in groundwater causes gastrointestinal irritation.

Seventy-two groundwater samples were collected from different drinking water sources extensively being used in the study area during pre- and post-monsoon seasons of the years 2018-19 and 2019-20 and analyzed for determination of physico-chemical parameters and metal concentrations. Hydro-chemical data for the pre- and post-monsoon seasons were processed as per BIS and WHO standards to examine the suitability of groundwater for drinking purposes. TDS, Total hardness, Calcium, Magnesium, Sulphate and Nitrate and metal concentrations viz; Fe, Mn, Pb, Cd and As in the groundwater at few locations in the study area were found exceeded the maximum permissible limit prescribed by BIS (2012) for drinking water. The quality of the groundwater was found to vary from place to place for varying depth of water table. Ionic relationships were developed and water types were also identified. Spatial distribution maps were prepared in the form of contour diagrams to identify degraded water quality zones, and also the possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water quality standards. Suitability of ground water for irrigation purpose was also assessed on the basis of total soluble salts, SAR, and RSC, and found to be fit for irrigation. Classification of water was made using Piper trilinear diagram, Chadha's diagram and U.S. Salinity Laboratory Classification. Majority of the samples from the study area was detected to belong to Ca-Mg-Cl-SO_4 or Ca-Mg-CO_3-HCO_3 hydrochemical facies, and fall under water types C3-S1 followed by C2-S1 for both pre- and post-monsoon seasons. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage.

Hydro-chemical data was also processed to understand the geochemical processes controlling the chemical composition of groundwater using Scatter Plots and Gibbs Plot, which indicated that hydrochemistry of groundwater is controlled by precipitation induced chemical weathering along with dissolution of rock forming minerals. Carbonate weathering is recognized as the major source of dissolved ions in the groundwater of the study area. Reverse ion exchange process controls the chemistry of groundwater of the region, which could be due to the excess of Ca+Mg. The source of sulphate in the groundwater is due to the occurrence of $CaSO_4$ i.e. Gypsum, as evident from the relationship between Ca and SO_4 (r^2>0.8), which is present in Maniyari shale formation of the region, could be the reason to have high sulphate concentration in the area. Further, groundwater quality was classified by calculating water quality index, and the ground waters are largely regarded between poor to good type in both seasons during the study period. In the post-monsoon season, the quality of groundwater at some locations was observed to be improved.

Groundwater level data, soil data, lithologs data and aquifer parameters data were processed and were used for development of groundwater model for estimating the artificial recharge in the identified degraded zones of sulphate contamination in the study area. Groundwater flow of the study area was simulated using MODFLOW for transient flow condition. Surface water hydrological features are considered as the boundary. The vertical discretization of 4-layers signifies the formations of variable thickness representing top soil of characteristics of aquitard, followed by an unconfined aquifer of variable thicknesses, then an aquitard of varying thicknesses, and then confined aquifer of variable thickness. The flow model was calibrated and validated satisfactorily following the guidelines of MODFLOW. For contaminant transport modelling, MT3D coupled with MODFLOW model was employed.

Pre- and post-monsoon data of physico-chemical parameters of different locations in the study area were analysed for % dilution of different parameters. These data helped identify the probable locations of artificial recharge for improving the quality of the degraded zones. TDS and sulphate dilution of more than 60% dilution was taken for the artificial recharge locations in Maniyari Region. Few scenarios by diluting groundwater quality through artificial groundwater recharge measures have been investigated at three different locations. It was observed that the concentration of sulphate decreased with increased in the rate groundwater recharge through injection well. For the low rate of recharge, the time taken to decrease the sulphate concentration within the permissible limit was found more. The groundwater recharge can also be practiced by a single well or multiple wells depending on the local site conditions and availability of source water for recharge of groundwater. This technique can be used to restore the quality and sustainable use of groundwater for drinking purpose in the degraded zones.

Originating unit	National Institute of Hydrology, Roorkee
Key words	Groundwater, Sulphate, Maniyari, Artificial recharge, Contaminant transport
Security classification	~~Restricted~~/ Unrestricted
Distribution	~~Restricted~~/ General

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1.0 INTRODUCTION

Groundwater plays an important role in our life support system as it is being used for different designated uses specially for drinking purpose. But due to unplanned urban development and growth in industrial and agricultural sectors, groundwater quality has deteriorated. Diffusion of urban sources likerunoff from city streets, gardening and commercial activities in urban environment and effluents from industrial sites also aggravate the problem of groundwater pollution.

Natural replenishment of groundwater resources occurs very slowly, therefore, excessive continued exploitation of groundwater at a rate greater than the natural replenishment causes decline in groundwater levels as well as deterioration of quality. Evidences of decline in quantity due to quality deterioration are more pronounced and corrective measures can be taken up to arrest the decline in quantity. But quality deterioration is more concealed and may result into complete deterioration of groundwater beyond correction, except leaving the aquifer without any groundwaterdevelopment.

The quality of groundwater in several villages of the Chhattisgarh state is totally saline and not evens a single perennial sourceofgroundwaterisfoundsuitable for drinking (CGWB Report, 2015). The EC ranges from 2000-4500 µS/cm and SO_4 ion varies from 250-800 ppm. Cases of gastro- intestinal disorders in the area are very high among inhabitants due to the permanent hardness in the drinking water. The higher rate of kidney and gallbladder stones in the area is also suspected due to constant consumption of hard water. Due to the salinity of groundwater the plumbing of domestic /minor irrigation wells collapse within a year or two. The G.I. pipe and its couplings get corroded fast causing undue economic pressure and increase the severity of salinity hazard (Mukherjee and Gupta, 2010). As per survey conducted by Central Ground Water Board, the sulphate concentration in the groundwater of Bemetara village of Bemetara district was observed to be 763 mg/L during the year 2014-15 (CGWB Report, 2015).

There is a serious problem of saline water in 113 villages of district Bemetara of Chhattisgarh state. Salinity increases due to increase in the concentration of dissolved elements of calcium and magnesium, chloride, carbonates and bicarbonates. 500 mg/L is the maximum acceptable concentration of total dissolved solids (TDS) prescribed by BIS (2012) for drinking purpose while there are 1200 to 2600 mg/L of TDS observed in the problematic villages of district Bemetara, which may cause health problem viz; digestion, high blood pressure, heart attack and kidney problems. Residents of these villages are facing the problems in washing the clothes, cooking the pulses etc. due to the use of saline water from hand pumps existing in the region. For the alternate sources, the residents of these villages are using contaminated water from ponds, rivers and drains in the area. To deal the saline water problem of these villages, the Government of Chhattisgarh approved a community water supply project for the amount of Rs. 190 crore considering the River Shivnath as a source of water supply, which will cater the need of fresh drinking water supply of 152 villages of Bemetara, Nawagarh and Saja Blocks of district Bemetara. This is the first project launched in district Bemetara in the state of Chhattisgarh, which will benefit about 2,06,465 villagers in coming 30 years as reported by PHED,Bemetara.

The fate and transport of sulphate into the aquifer system affects the dynamics of hydrogeochemistry of aquifers. During these processes, sulphate is reduced and becomes very important for many subsurface systems. In addition, sulphate reduction has great significance for the system, which has metal rich water with acidic medium, as mining sites acidic condition. High concentrations of sulphate in the water we drink can have a laxative effect when combined with calcium and magnesium, the two most common constituents of hardness. Bacteria, which attack and reduce sulphates, form hydrogen sulphide gas (H_2S).No attempt has been made for assessment of ground water quality of district Bemetara with special reference to sulphate contamination so far, therefore, a purpose driven study titled “Groundwater qualityassessment with special reference to sulphate contamination in Bemetara district, Chhattisgarh and suggesting ameliorative measures” was proposed in collaboration with Water Resources Department (WRD), Raipur, Govt. of Chhattisgarh and Central ground Water Board, NCCR, Raipur under National Hydrology Project and awarded vide letter No. X-87013/1/2016-NHP/4565-4587 dated 31.08.2017 for a period of 3 years duration. The following objectives of the project were proposed:

i) Groundwater quality monitoring in pre-monsoon (April-May) and post-monsoon (October-November) seasons at identified locations.
ii) To map degraded groundwater quality zones and possible sources of pollution and identify specific parameters not conforming to drinking/ & irrigation water quality standards.
iii) To investigate the important geochemical processes responsible for groundwater contamination.
iv) Modelling flow and transport of sulphate contamination using MODFLOW & MT3D.
v) To suggest ameliorative measures to restore the quality and sustainable use of groundwater for drinking/ & irrigation purposes by investigating the hydro-geology of the area.
vi) Dissemination of knowledge and findings to field engineers/scientists and common people through the preparation of manual, leaflets, booklets and by organizing workshops/training.

2.0 REVIEW OFLITERATURE

Groundwater situation in different parts of India is diversified because of variation in geological, climatological and topographic set-up. The prevalent rock formations, ranging in age from Archaean to Recent, which control occurrence and movement of groundwater, are widely varied in composition and structure. Further, significant variations of landforms from the rugged mountainous terrains of the Himalayas, Eastern and Western Ghats to the flat alluvial plains of the river valleys and coastal tracts, and the aeolian deserts of Rajasthan are also responsible for non-uniform distribution of ground water. The rainfall patterns too show similar region wise variations. The topography and rainfall virtually control run-off and groundwater recharge (Master Plan, 2002). As water flows through the ground, the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater issaline.

Sulphate, normally found in air, water and soil, is one of the oxides of sulphur in the presence of oxygen. Due to its higher solubility in water, sulphate is found at very highconcentration in many groundwater and surface water system (MPCA, 1999). This process often occurs when sulfide minerals are mined. A large number of combustion activities all around the world leads to release of large amount of sulphur in the atmosphere. This sulphur further oxidized to sulphate and deposited on land surface through rainfall or dry deposition. Because sulphate occurs as a major dissolved ion, so its mobility in aquifer system is high (Sharma and Kumar, 2020).

Sulphate extensively comes in water from both natural and anthropogenic sources. The natural sources include sulphur mineral dissolution, atmospheric deposition and sulfide oxidation from mineral (Krouse and Mayer, 1999). Human induced sources are power plant, coal mines and metallurgical refinery (Seller and Canter, 1980). In many potential sources, Gypsum is an important source in many aquifers having large amount of sulphate. In the last few decades, atmospheric deposition has becomes an important source of sulphate to soil and ultimately it goes to groundwater. Since sulphate is mobile in soil, addition into the soil will impact on shallowaquifer.

Sulphates are a combination of sulfur and oxygen and are a part of naturally occurring minerals in some soil and rock formations that contain groundwater. As water moves through soil and rock formations that contain sulphate minerals, some of the sulphate dissolves into the groundwater. Minerals that contain sulphate include magnesium sulphate (Epsom salt), sodium sulphate (Glauber's salt), and calcium sulphate (gypsum). Sulphate minerals can cause scale buildup in water pipes similar to other minerals and may be associated with a bitter taste in water that can have a laxative effect on humans and young livestock that can lead to dehydration and is of special concern for infants. Elevated sulphate levels in combination with chlorine bleach can make cleaning clothes difficult. If sulphate in water exceeds 250 mg/L, a bitter of medicinal taste may render the water unpleasant to drink. Bureau of Indian Standards also prescribed 200 mg/L as maximum acceptable limit and 400mg/L as maximum permissible limit for drinking purpose (BIS, 2012). High sulphate levels may also corrode plumbing, particularly copper piping. In areas with high sulphate levels, plumbing materials more resistant to corrosion, such as plastic pipe, are commonlyused.

Geo-environmental conditions have a marked influence on the groundwater quality. Hydrogeochemical studies relevant to the water quality explain the relationship of water chemistry to aquifer lithology. Such relationship would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry. A number of hydrogeochemical studies relevant to the water quality have been carried out by differen tworkers for different regions of India (Kumaretal.,2006;

Reddy and Kumar, 2010; Vijaykumar et al., 2010; Srinivasamoorthy et al., 2012; Dhak et al., 2012; Sharma and Jain, 2014; Sharma et al., 2019).

Water quality index (WQI) is a means to summarize large amounts of water qualitydata into simple terms for reporting to management and the public in a consistent manner. It tells us whether the overall quality of water bodies poses a potential threat to various uses of water. Different workers have used WQI to assess the surface water quality and ground water quality (Singh, 1992; Subba Rao, 1997; Naik and Purohit, 2001; Mishra and Patel, 2001; Avvannavar and Shrihari, 2008; Kumar and Dua, 2009; Kumar et al., 2009, Singkran et al., 2010, Sharma at al., 2013; Singh et al., 2019).

Groundwater modelling has become an important tool for planning and decision making process involved in groundwater management. For managers of water resources, models may provide essential support for regulations and engineering designs affecting groundwater. This is particularly evident with respect to groundwater protection and aquifer restoration. Assessment of the validity of model-based-projections is difficult and often controversial. The success or failure of a model depends on the availability of field information and the type and quality of the mathematical tools. The mass transport processes determine the extent of plume spread and the geometry of the concentration distribution. Advection is by far the most dominant mass transport process in shaping the plume. Hydrodynamic dispersion is usually a second order process. The advective transport is controlled by the configuration of water table or piezometric surface, presence of sources or sinks, permeability distribution within the flow field and shape of flow domain. These parameters are important in controlling the groundwater velocity, which drives advective transport. Adding dispersion to advective transport can cause important changes in the shape of a plume. Other important process is sorption and irrespective of the model describing sorption, the process is of paramount importance in controlling contaminant transport (Gurunadha Rao & Dhar, 2000).

A groundwater model was developed using Visual MODFLOW software to understand the reasons for declining water table in Central Punjab, India. The groundwater flow model for the study area was formulated by using input hydrogeological data and appropriate boundary conditions. The outcome of modelling shows that this model can be used for prediction purpose in the future by updating input boundary conditions and hydrologic stresses during the preceding years (Kumar et al., 2010). Three case studies were presented to demonstrate the utility of groundwater flow and mass transport modelling for assessment and management of groundwater contamination due to discharge of industrial effluents from Hindustan Polymers Plant in Venkatapuram area near Visakhapatnam, India, the problem of contamination of drinking water supply well in the Sabarmati river bed near Ahmedabad and contamination of groundwater in Patancheru industrial development area from discharge effluents of chemical and pharmaceutical industries (Gurunadha Rao and Dhar, 2000). Migration pattern of organochloro pesticide lindane has been studied in groundwater ofmetropolitan city Vadodara, Gujarat using visual MODFLOW groundwater flow model and mass transport model MT3D and predicted the advancement of containment of plume size in the aquifer system both spatially and depth wise as aresult of increasing level of pesticide in river Vishwamitri (Sharma et al., 2015).

The geophysical and geohydrological investigations and water quality monitoring has been carried out to generate database for development of groundwater flow and mass transport model for two year period for the assessment of groundwater contamination around Gujarat Refinary, Vadodara, Gujarat, India. The impact of the effluent seepage from ponds, lagoons and waste disposal facilities etc. within the refinery, the drain joining the Meni nadi and the Meni nadi on the groundwater regime through development of groundwater flows and mass transport models have been considered. The combined concentration of sodiumand chloride has been selected as contaminant for studying the contaminant migration pattern in the area. The groundwater contamination has been assessed through calibration of the mass transport model for a period of 35 years. The finding reveals that the present groundwater contamination is limited to small area as the wastewater treatment facilities and the associated lagoons are located on low permeability formations in the refinery area (Gurunadha Rao,2003).

A number of treatment technologies have been reported by different workers for remediation of groundwater. Pump and treat is the standard method used for remediation of groundwater for which sulfate is the primary contaminant. This approach is effective at controlling the contaminant plume, but is generally cost and time intensive. Electrokinetic methods are another possible in-situ alternative for remediation (e.g., Runnells and Wahli,1993). However, their use would typically be restricted to very small, shallow sites with relatively high concentrations. Interest is growing in the use of methods that are based on microbially-mediated processes as an alternative or adjunct to pump and treat. Two innovative, in-situ methods have been reported that involve the use of zero-valent iron (ZVI) and the addition of electron-donor substrates (Miao et al., 2012).

The effects of artificial recharge on ground water quality and aquifer storage recovery were studied with spreading basins constructed in the highly agricultural region of the Central Platte, Nebraska. Both NO_3-N and atrazine contamination dramatically improved from concentrations exceeding the maximum contaminant levels to those of drinking water quality. The water table at the site rose rapidly in response to recharge during the early stage then leveled off as infiltration rates declined (Ma and Spalding, 1997). Shi et al. (2016) investigated the effects of artificial recharge of groundwater on controlling land subsidence and its influence on groundwater quality and aquifer energy storage in Shanghai, China and The results based on the collected long-term historical data in the study area show that artificial recharge not only is beneficial to groundwater level rising and land rebound, but also provides cheap energy sources for industrial production. The groundwater quality presented the trend of desalination and a general increase in sulphate, iron and manganese contents, organic and nitrogenous compounds after the tap water injection. Chitsazan et al. (2018) studied the impact of artificial recharge on groundwater recharge estimated by groundwater modeling in Jarmeh flood spreading, Iran and reported that Jarmeh flood spreading not only has increased groundwater level in vicinity of recharged area, but also has increased water budget of the aquifer about 1.6 million cubicmeters.

Standen et al. (2020) reviewed on In-Channel Managed Aquifer Recharge (MAR) and its future potential in Europe and concludes that in-channel MAR solutions can increase water availability and improve groundwater quality to solve problems affecting aquifers in hydraulic connection with temporary streams based on experiences in other parts of the world and can be considered as a measure to mitigate groundwater problems including saline intrusion, remediating groundwater deficits, or solving aquifer water quality issues. Bahar et al. (2021) investigated the 3D modelling of solute transport and mixing during managed aquifer recharge with an infiltration basin located in Chassieu (Lyon area, France) and reported that capillary trapping promoted a retention of up to 20% of the injected tracer in the vadose zone, 0 to 24% of the injected solute concentration could be recovered depending on the piezometer location and the averaged concentration decreased by 50% if the measuring device is lowered by 5 m under the water table. These results were strongly site and event dependant but observed trends should be considered while discussing punctual water quality measurements used to monitor MARsystems.

Chenini et al. (2019) investigated the hydrogeological characterization and aquifer recharge mapping for groundwater resources management using multicriteria analysis and numerical modeling for a case study from Tunisia and reported that the high rechargeability index covers 45% of the total shallow aquifer extension and the medium index covers only 29%. Recharge rates are introduced to the established model using the software MODFLOW. The impact of the groundwater recharge is then evaluated by hydraulic heads simulation and water budget analysis. The model exploitation illustrates the impact of the water recharge on the hydraulic heads.

Nimje and Wayal (2019) studied the improvement in ground water quantity using rain water harvesting system in coastal area at Mumbai Refinery and reported that initially the water table at Mumbai Refinery was in the range of 6.5 m – 8.0 m before rainwater harvesting and 2.5 m–7.0 m after rainwater harvesting. The rainwater recharge improves the quantity of groundwater by improving water table depth. Suitable sites and structures for artificial groundwater recharge for sustainable groundwater resource development and management were identified. To increase the groundwater potential of the area, action plan for artificial groundwater recharge has been developed using remote sensing and GIS techniques. In the action plan, development of water harvesting structures (Check dam, Nala bund, Contour bund, Gully plug etc.) were proposed. These structures will provide a measure of artificial recharge in this hard rock terrain by collecting of the surface runoff and increasing the surface area of infiltration (Ahirwar et al., 2020). Reddy et al. (2020) studied ground water problems and artificial recharge techniques in Musunuru and reported that among all the recharge techniques, low budget soak pit method with materials like a reused plastic drum and locally available construction materials was choosen and contributed 85% of groundwaterrecharge.

Valhondo et al. (2020) studied six artificial recharge pilot basins to gain insight into water quality enhancement processes and reported that the systems are efficient in obtaining a broad range of redox conditions (at least iron and manganese reducing), contaminants of emerging concern are significantly removed (around 80% removal, but very sensitive to the compound) and pathogen indicators (E. coli and Enterococci) drop by some 3-5 log units after one year ofoperation.

In the present PDS, a simple concept of artificial recharge, which is cost effective, economically viable and environmental friendly has been suggested for remediation of groundwater with special reference to sulphate contamination considering contaminant transport, hydrogeology and system dynamics.

3.0 STUDY AREA AND DATAUSED

The Bemetara district is one of the newly formed districts of Chhattisgarh state, which formed on 1st January 2012 from the separation of Durg district (Fig. 1). The districtis moderately populated and situated in the central part of the Chhattisgarh State and covers an area of 2855 km^2. It falls in Survey of India Degree Sheet Nos. 64F and 64G bounded by latitude 21°22' to 22°03' N and longitude 81°07' to 81°55' E. It is surrounded by Durg district in the south, Rajnandgaon and Kabirdham district in the west, Mungeli district in the north and Baloda-Bazar and Raipur district in the East. Bemetara is the district headquarters and is well connected by road and railway. National Highway No. 12A connects Bemetara with Kabirdham. Bemetara is also connected by road with Raipur, Baloda-Bazar, Kabirdham and Durg with the other important towns in the district. Bemetara district is important district for Limestone deposit in Chhattisgarh. The minor mineral is Low grade. Limestones, Sandstone, Quartzite, River sand are also found in huge quantity. Cement Grade Limestone/Dolomite occur in the whole district. Different types of soils are found in the district viz; Red Soil (Bhata) Entisols, Sandy loams (Matasi) Inceptisols, Dorsa (Alfisols), Black (Kanhar) vertisols and Alluvial Soil (Kachhar). The main source of irrigation in the district is River Shivnath, Kharun, Haff, Sakari and Surahi etc. There is no any big dam in the district. The area has a tropical wet and dry climate, temperature remains moderate throughout the year, except from March to June, which can be extremely hot. In summer, the temperature can also go up to 50 °C. The city receives about 1300 mm of rain, mostly in the monsoon season fromlate June to early October. Winters last from November to January and are mild, although lows can fall to 5°C.

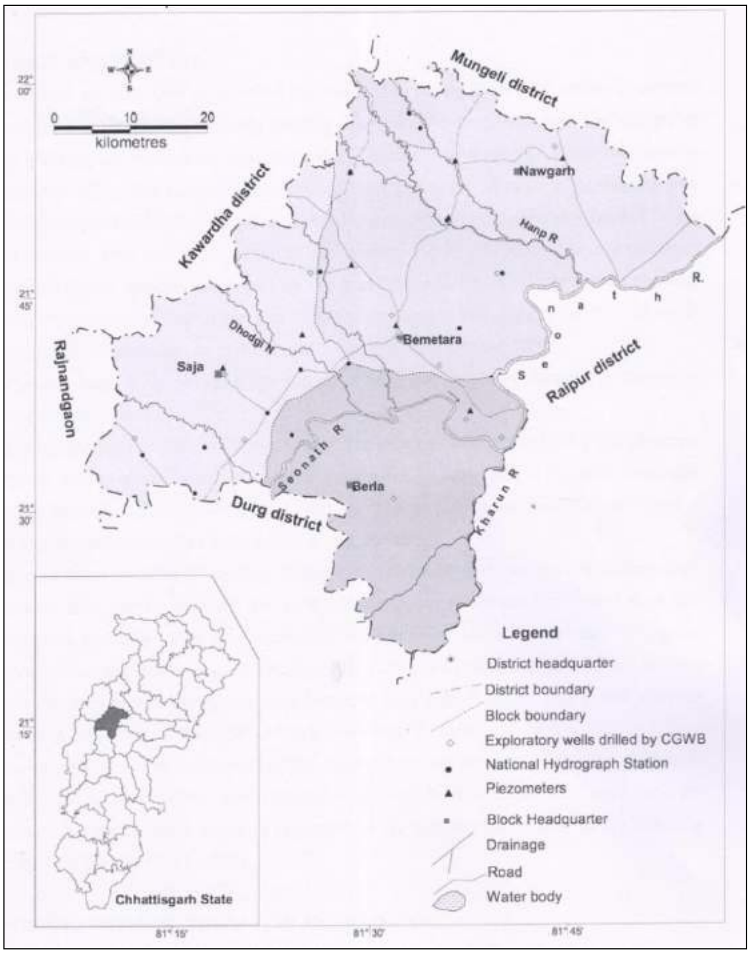


Fig. 1. Map of the district Bemetara.

Physiographically, the area in the Bemetara district has almost flat topography. The general slope of the district is towards the north east direction, in which the major streams of the district flow. Bemetara is located near the centre of a large plain, sometimes referred as the "rice bowl of India", where varieties of rice are grown. The Shivnath river flows to the east of the city of Bemetara, and the southern side has dense forests. The Maikal Hills rise on the north-west of Bemetara; on the north, the land rises and merges with the Chota Nagpur Plateau, which extends north-east across Jharkhand state. On the south of Bemetara lies the DeccanPlateau.

Geologically, the district comprises of rocks of the Meso-to Neo- Proterozoic sequence, is represented by the Chhattisgarh Supergroup, Raipur Group comprises Chandi formation, Tarenga formation, Hirri formation and Maniari formation. Chandi Formation of grey and purple stromatolitic limestone with arenite/ferruginous sandstone intercalations (Deodongar member); Tarenga Formation of greenish grey and reddish brown shale with chert/ porcellanite and green clay interbands; Hirri Formation by grey, thinly to thickly bedded dolomite and argillancous dolomite and Maniyari Formationn comprises reddish brown and purple non - calcareous shale with gypsum interbands. Quaternary is represented by pebble beds, (Khamaria pebble bed). Mineral deposits of Bemetara district include Dolomite, Limestone, Ordinary stone, Sand and Soiletc.

In district Bemetara, there are six rivers namely Shivnath, Kharun, Haff, Sakari, Surahi and Phonkriver. Shivnath river, a tributary of Mahanadi river, originates from Mountain at height of 625 meter at Panabaras situated in south western parts of Rajnandgaon and flows towards north east direction. It measures length about 345 km. City Durg is situated on east bank of Shivnath river. It flows towards north east passing through Khujji, Rajnandgaon, Durg, Dhamdha and Nandghat and joins (meet) Mahanadi near Shivari Narayan of Bilaspur District. Kharun river flows in eastern parts of the district starting from Petechua in Balod District. This river flows towards north and joins (meet) Shivnath river at Somnath near Simga. This river determines the boundary of Raipur and Durg district. The length of this river is about 120 km (District Survey Report, 2016).

Water Resources Department (WRD), Govt. of Chhattisagarh, collaborating agency suggested tofocus on Maniyari shell formation region to track the problem in real sense which will cover 9 blocks existing in five districts viz; Bemetara, Kawardha, Bilaspur, Mungeli and Baloda Bazar (Bhatapara). Therefore, study area is extended from district Bemetara to Maniyari shell formation region [Fig. 2(a)]. The drainage, geomorphology, lithology, soil map of study area were prepared in GIS platform and are presented from Fig. 3 to Fig.6.

Ground water level data, soil data, aquifer parameter data and litholog data, rainfalll data were collected from State Ground Water Survey, Durg, WRD, Raipur and CGWB, NCCR, Raipur and used for modeling.

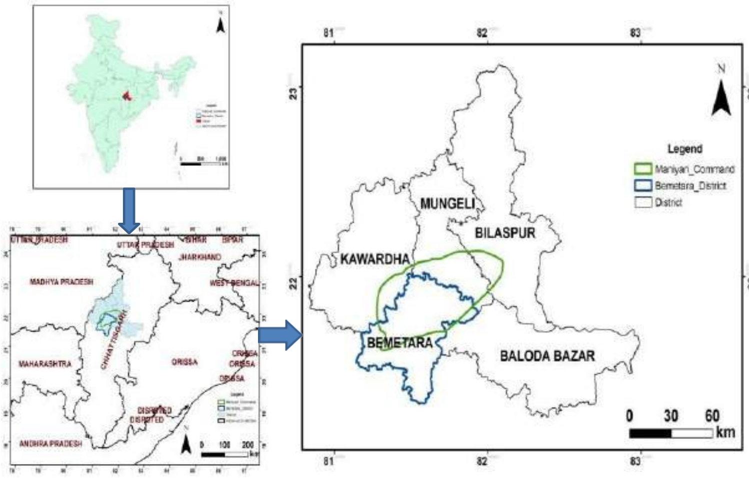
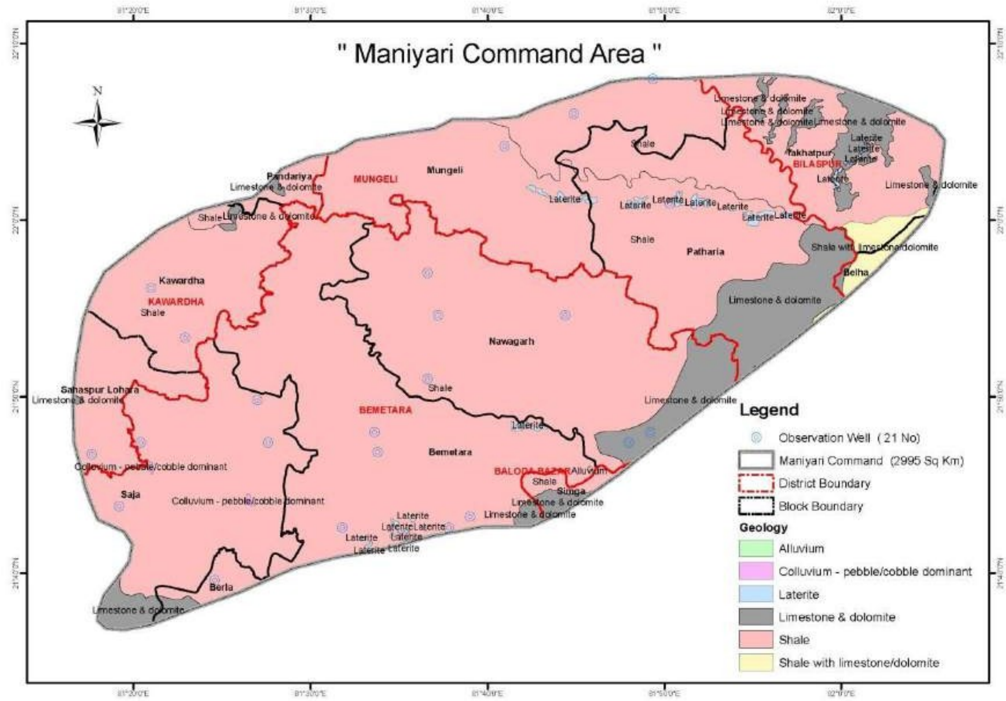


Fig. 2(a). Map showing Maniyari shell formation region



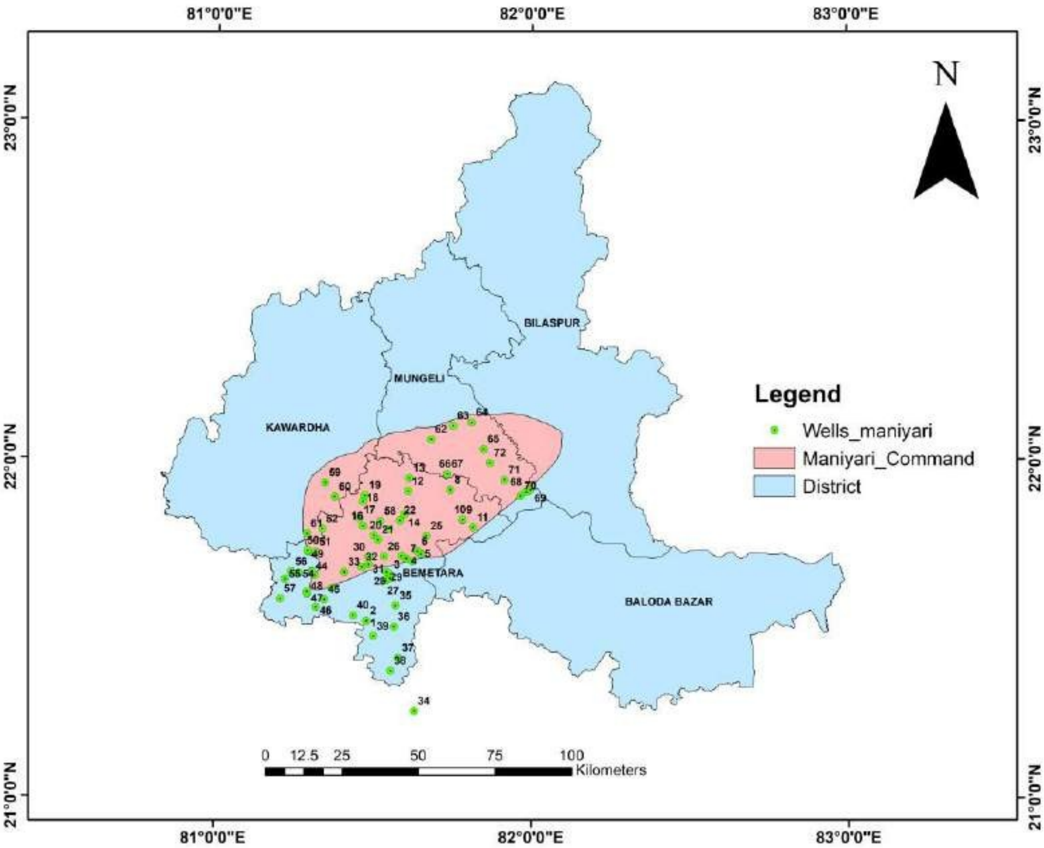


Fig. 2(b). Map showing locations of sampling sites in the study area

Fig. 2(c). Photographs showing groundwater sampling from handpumps, open wells, piezometric wells and groundwater level measurement in the study area

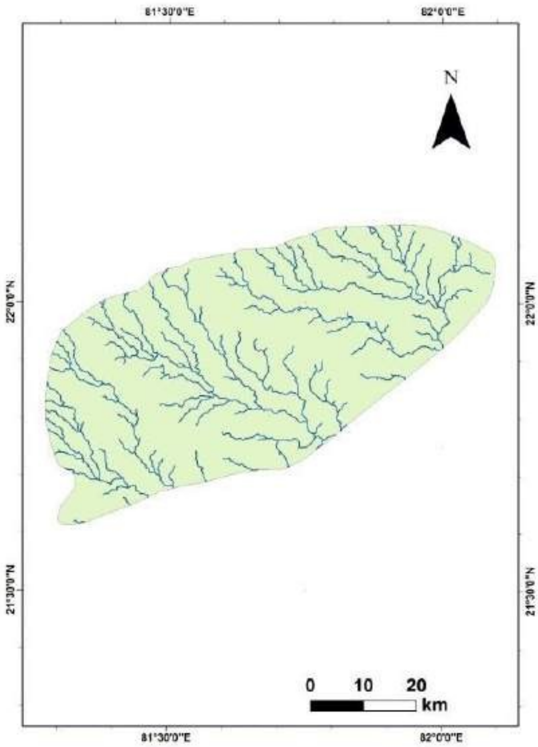


Fig. 3. Map showing drainage network of study area

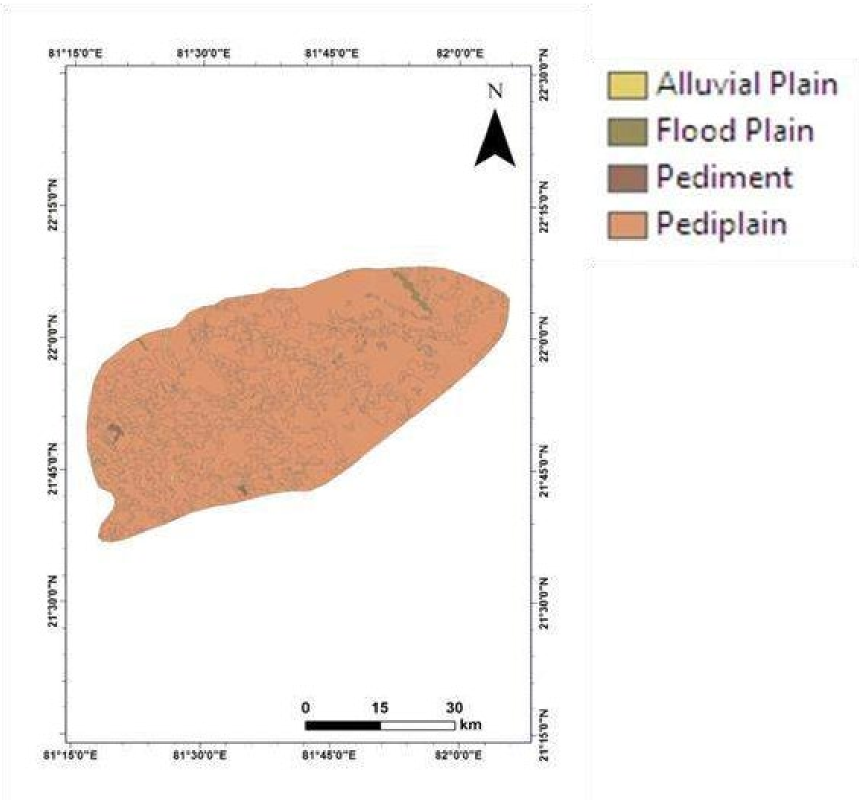


Fig. 4. Geomorphological map of study area

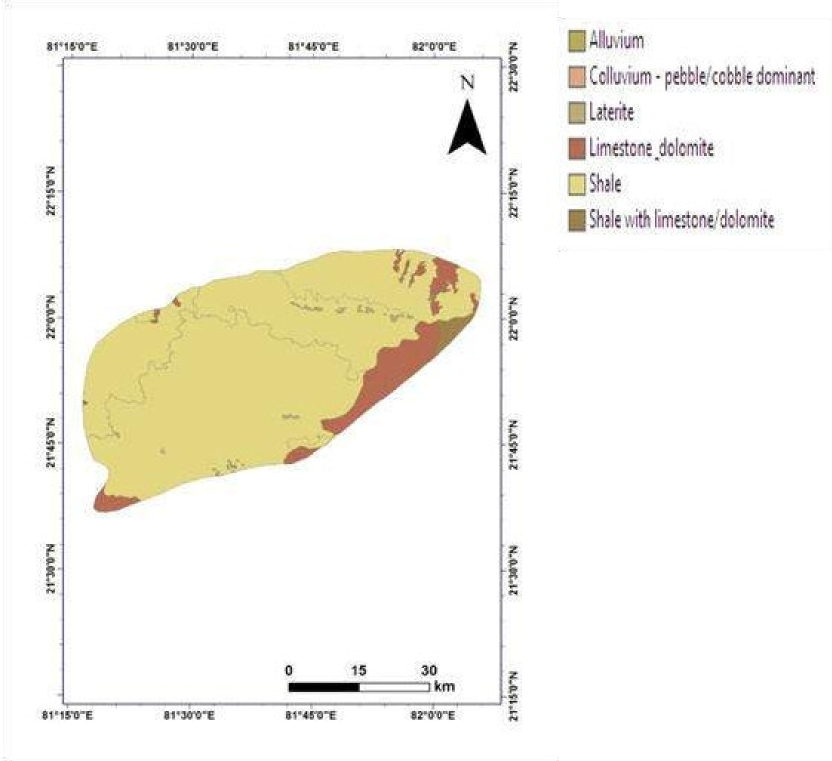


Fig. 5. Lithological map of study area

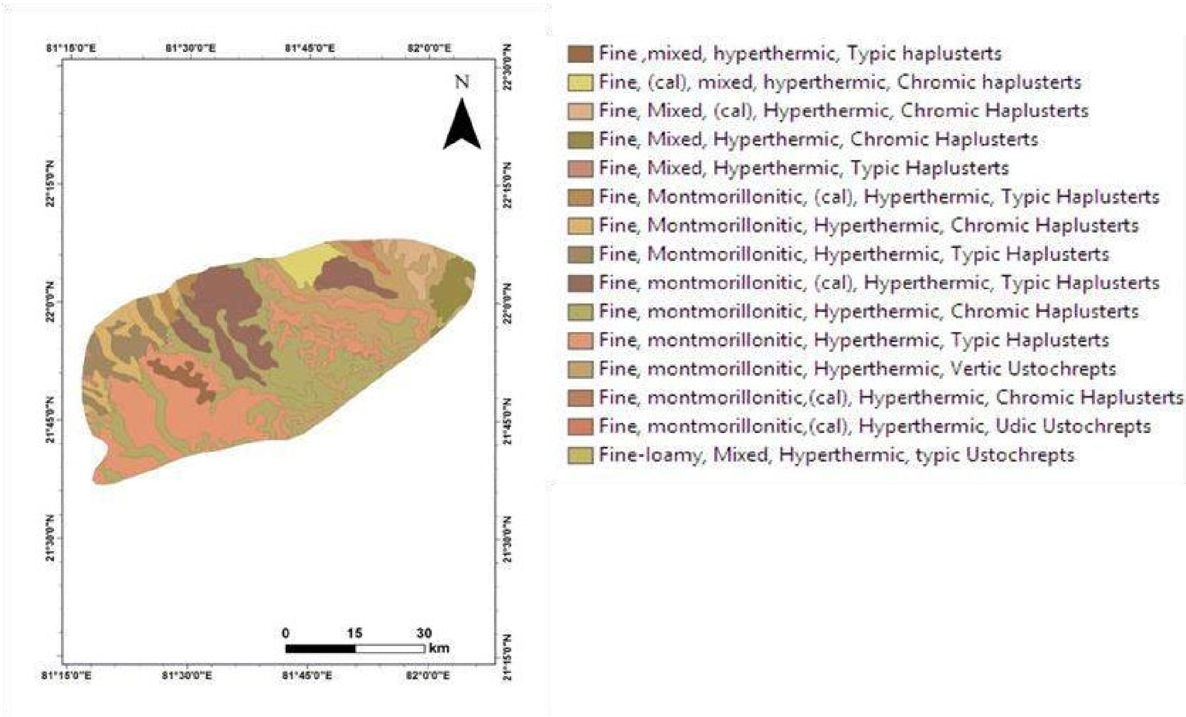


Fig. 6. Soil map of study area

4.0 METHODOLOGY

Water Resources Department (WRD), Govt. of Chhattisagarh, collaborating agency suggested to focus on Maniyari shell formation region to track the problem in real sense which will cover 9 blocks existing in five districts viz; Bemetara, Kawardha, Bilaspur, Mungeli and Baloda Bazar (Bhatapara). Therefore, study area is extended from district Bemetara to Maniyari shell formation region. Sixty two ground water samples during pre-monsoon (May 2018) and seventy two ground water samples during post-monsoon season (January 2019) during the year 2018-19, seventy two ground water samples during pre-monsoon (June 2019) and post-monsoon seasons (December 2019) during the year 2019-20 were collected from various abstraction sources of groundwater of the study area extensively being used for drinking purpose in collaboration of Water Resources Department (WRD), Govt. of Chhattisagarh, Raipur [Fig. 2(b)]. The samples were preserved as per standard procedures and were analyzed for physico chemical as well as metal analysis in the NIH water quality laboratory as per APHA (2012). A brief methodology of the study is described asbelow:

i) Literature survey on assessment of groundwater quality and issues in theregion.
ii) Analysis of groundwater resources in the Bemetaradistrict.
iii) Collection of existing meteorological and groundwater qualitydata of various locations of the Bemetara district andanalysis.
iv) Collection of groundwater levels and lithological data from State Groundwater Department.
v) Hydrogeological characterization of the study area and establish specific linkages of groundwater quality with hydrogeology.
vi) Collection of groundwater samples from selected sources in pre-monsoon (April-May) and post-monsoon (October-November) season at identifiedlocations.
vii) Analysis on flow and movement ofgroundwater.
viii) Analysis for physico-chemical parameters: pH, EC, TDS, Alkalinity, Hardness, Major Cations (Na, K, Ca, Mg), Major Anions (HCO_3, Cl, SO_4, NO_3), Minor Ions (F, PO_4,) and Toxic (Heavy) Metals: As, Cd, Cr, Pb, Cu, Ni, Fe, Zn, Mn in the collected water samples.
ix) Processing of hydro-chemical data for pre- and post-monsoon seasons as per BIS and WHO standards to examine the suitability of ground water for drinkingpurpose.
x) Ionic relationships developed and water types have been identified. Spatial distribution maps have been prepared in the form of contour diagrams to identify degraded water quality zones, possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water qualitystandards.
xi) Suitability of ground water for irrigation purpose has been assessed on the basis of total soluble salts, SAR and RSC. Classification of water has been made using Piper trilinear diagram, Chadha'sdiagram, U.S. Salinity LaboratoryClassification.
xii) Processing of hydro-chemical data to understand the geochemical processes controlling the chemical composition of groundwater using Scatter Plots and Gibbs Plot.
xiii) MODFLOW & MT3D has been used for modelling flow and transport of sulphate, the model has been calibrated using data collected along space & time for a period of oneyear.
Visual MODFLOW Flex Premium Version 2010 (MODular 3-dimensional finite difference groundwater FLOW model) MT3D developed by McDonald and Harbaugh of USGS, USA has been used to simulate three dimensions groundwater flow.

Modular structure consists of main program and independent modules; the modules are grouped into packages. Groundwater flow has been simulated using a block centered finite difference approach. The finite-difference equations are solved using the Strongly Implicit Procedure (SIP) or using the Slice-Successive Over relaxation (SOR) methods. After flow simulation, MT3D module has been run to study the contaminant (Sulphate) migration pattern in the groundwater in space and time for predictionpurposes.

xiv) Suggesting ameliorative measures to control/ restore the groundwater quality for sustainable use by various users investigating site-specific measures considering contaminant transport, hydrogeology and system dynamics (flow-movement of groundwater, hydrogeology, managed aquifer recharge, withdrawal patterns, etc.).

5.0 RESULTS ANDDISCUSSIONS

5.1 Water Quality Evaluation for DrinkingPurpose

Sixty two groundwater samples during pre-monsoon (May 2018) and seventy two groundwater samples during post-monsoon season (January 2019) during the year 2018-19, seventy two groundwater samples during pre-monsoon (June 2019)and post-monsoon seasons (December 2019) during the year 2019-20 were collected from various abstraction sources of groundwater of the study area extensively being used for drinking purpose. The details of sampling locations and source and depth wise distribution are given in Table 1(a)&(b) and 2(a)&(b) respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 3(a)&(b). Distribution of different water quality constituents with depth and season are given in Table 4(a-b) to 12(a-b) and variation of different water quality constituents in pre- and post-monsoon seasons during the year 2018-19 and 2019-20 are given in Fig. 7(a-c) and 8(a-c) respectively. Spatial distribution maps are presented in the form of contour diagrams in Figs. 9(a-d) to 16(a-d).

General Characteristics

The pH values in the ground water of the study area mostly fall within range 6.6 to 8.7 during pre-monsoon season and 6.4 to 7.4 during post-monsoon season of the year 2018-19 and in the range 6.2 to 7.7 during pre-monsoon season and 6.1 to 7.2 during post-monsoon season of the year 2019-20. The pH values for most of the samples are well within the limits prescribed by BIS (2012) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the study area vary widely from 570 to 4898 μS/cm during pre-monsoon season and 364 to 8944 μS/cm during post-monsoon season of the year 2018-19 and from 357 to 14914 μS/cm during pre-monsoon season and 413 to 5118 μS/cm during post-monsoon season of the year 2019-20. The maximum conductivity value of 14914 μS/cm was observed in the sample of village Kunra of district Bemetara during pre-monsoon season.

In the study area, the values of total dissolved solids (TDS) in the ground water varies from 399 to 3429 mg/L during pre-monsoon season and 255 to 6261 mg/L during post-monsoon season of the year 2018-19. About than 84% samples were found above the acceptable limit but within the maximum permissible limit of 2000 mg/L in pre-monsoon season and about 78%samples were found above the acceptable limitbut within the maximum permissible limit of 2000 mg/L in post-monsoon season [Table 4(a)]. During the year 2019-20, TDS varies from 250 to 10440 mg/L during pre-monsoon season and 289 to 3583 mg/L during post-monsoon season of the year 2019-20. About 61% samples were found above the acceptable limit but within the maximum permissible limit of 2000 mg/L in pre- monsoon season and about 69% samples were found above the acceptable limit but within the maximum permissible limit of 2000 mg/L in post-monsoon season [Table 4(b)]. The variation of TDS in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(a) & 8(a). The TDS distribution maps for the pre-monsoon season is shown in Fig. 10(a-d). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the acceptable limit and 2000 mg/L asthe maximum permissible limit has been suggested for drinking water (BIS, 2012). In the study area, Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 2012).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. The alkalinity value in the groundwater of the study area varies from 61 to 412 mg/L during pre-monsoon season and 75 to 460 mg/L during post-monsoon season of the year 2018-19 and from 83 to 354 mg/L during pre-monsoon season and 52 to 415 mg/L during post-monsoon season of the year 2019-20. None of the sample exceeds the maximum permissible limit of 600 mg/L during pre-and post-monsoon season. The variation of alkalinity in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(a) &8(a).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 200 mg/L as acceptable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 2012). The total hardness values in the study area range from 182 to 2098 mg/L during pre-monsoon season and 119 to 1983 mg/L during post-monsoon season of the year 2018-19. About 55% of the samples of the study area crosses the acceptable limit of 200 mg/L but are well within the permissible limit of 600 mg/L and 45% sample crosses the permissible limit of 600 mg/L during pre-monsoon season [Table 6(a)]. During the post-monsoon season 4% of the samples fall within acceptable limit of 200 mg/L and 31% sample crosses the permissible limit of 600 mg/L because of the dilution. During the year 2019-20, Total hardness varies from 119 to 3267 mg/L during pre-monsoon season and 116 to 2125 mg/L during post-monsoon season of the year 2019-20. About 53% of the samples of the study area crosses the acceptable limit of 200 mg/L but are well within the permissible limit of 600 mg/L and 38 % sample crosses the permissible limit of 600 mg/L during pre-monsoon season [Table 6(b)]. During the post-monsoon season 4% of the samples fall within acceptable limit of 200 mg/L and 32 % sample crosses the permissible limit of 600 mg/L because of the dilution. The variation of hardness in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(a) & 8(a). The hardness distribution map for the pre-monsoon season is shown in Fig. 11(a-d).

In ground water of the study area, the values of calcium range from 54 to 587 mg/L during pre-monsoon season and 28 to 601 mg/L during post-monsoon season and the values of magnesium vary from 7.3 to 201 mg/L during pre-monsoon season and 8.5 to 144 mg/L during post-monsoon season during the year 2018-19. During the year 2019-20, the values of calcium range 26 to 569 mg/L during pre-monsoon season and 26 to 648 mg/L during post-monsoon season and the values of magnesium vary from 10 to 488 mg/L during pre-monsoon season and 9 to 259 mg/L during post-monsoon season. The acceptable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 2012). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, 55% sample exceeds the maximum permissible limit of calcium as 200 mg/L and 8% sample exceeds the maximum permissible limit of magnesium as 100 mg/L in pre-monsoon season during the year 2018-19 while 25% sample exceeds the maximum permissible limit of calcium as 200 mg/L and 10% sample exceeds the maximum permissible limit of magnesium as 100 mg/L in pre-monsoon season during the year 2019-20. The variation of calcium and magnesium in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(b) & 8(b). The calcium and magnesium distribution maps for the pre- and post-monsoon seasons are shown in Fig. 12(a-d) & 13(a-d) respectively.

The concentration of sodium in the study area varies from 8.4 to 274 mg/L during pre-monsoon season and 7.8 to 1275 mg/L during post-monsoon season of the year 2018-19 and from 7.7 to 2694 mg/L during pre-monsoon season and 9 to 362 mg/L during post-monsoon season of the year 2019-20. The high sodium values in the study area may be attributed to base-exchange phenomenon causing sodium hazards. Groundwater with high value of sodium is not suitable for irrigation purpose. The concentration of potassium in ground water of the study area varies 1.2 to 163 mg/L during pre-monsoon season and 0.3 to 238 mg/L during post-monsoon season during the year 2018-19 and from 0.67 to 225 mg/L during pre-monsoon season and 0.15 to 316 mg/L during post-monsoon season during year2019-20.

The concentration of chloride varies from 10 to 388 mg/L during pre-monsoon season and 4.2 to 780 mg/L during post-monsoon season of the year 2018-19 and from 8 to 1080 mg/L during pre-monsoon season and 12 to 652 mg/L during post-monsoon season of the year 2019-20. More than 90% samples of the study area fall within the acceptable limit of 250 mg/L during both pre- and post-monsoon season during both year [Table 9(a) & (b)]. The variation of chloride in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(b) &8(b).

The sulphate content in groundwater generally occurs as soluble salts of calcium, magnesium and sodium. The concentration of sulphate in the study area varies from 4.0 to 2031 mg/L during pre-monsoon season and 4.9 to 3257 mg/L during post-monsoon season of the year 2018-19. Bureau of Indian standard has prescribed 200 mg/L as the acceptable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 52% of the samples analysed fall within the acceptable limit of 200 mg/L while 13% of the samples exceed the acceptable limit but are within the permissible limit of 400 mg/L and 34% of the samples exceed the maximum permissible limit of 400 mg/L during pre-monsoon season [Table 10(a)]. Almost similartrend was observed during post-monsoon season. During the year 2019-20, sulphate varies from 3.0 to 5735 mg/L during pre-monsoon season and 4.0 to 2002 mg/L during post-monsoon season. In the study area, 51% of the samples analysed fall within the acceptable limit of 200 mg/L while 19% of the samples exceed the acceptable limit but are within the permissible limit of 400 mg/L and 29% of the samples exceed the maximum permissible limit of 400 mg/L during pre-monsoon season [Table 10(b)]. Almost similar trend was observed during post-monsoon season. The variation of sulphate in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(c) & 8(c). The sulphate distribution map for the pre-monsoon season is shown in Fig. 14(a&c).

The nitrate content in the study area varies from 0.32 to 329 mg/L during pre-monsoon season and 0.0 to 215 mg/L during post-monsoon season of the year 2018-19. About 77% of the samples of the study area fall within the permissible limit of 45 mg/L and 23% of samples even cross the permissible limit during pre- monsoon season and about 85%of the samples of the study area fall within the permissible limit of 45 mg/L and 15% of samples even cross the permissible limit during post- monsoon season [Table 11(a)]. During the year 2019-20, nitrate varies from 0 to 193.6 mg/L during pre-monsoon season and 0 to 569 mg/L during post-monsoon season. About 92% of the samples of the study area fall within the permissible limit of 45 mg/L and 8% of samples even cross the permissible limit during pre- monsoon season and about 67% of the samples of the study area fall within the permissible limit of 45 mg/L and 33% of samples even cross the permissible limit during post-monsoon season [Table 11(b)]. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. The variation of nitrate in groundwater of study area for pre- and post-monsoon seasons is shown in Fig. 7(c) & 8(c). The nitrate distribution map for the pre-monsoon season is shown in Fig. 15(a&c).

The fluoride content in the ground water of the study area varies from 0.07 to 1.03 mg/L during pre-monsoon season and 0.07 to 1.5 mg/L during post-monsoon season of the year 2018-19 and from 0.06 to 2.4 mg/L during pre-monsoon season and 0.05 to 1.04 mg/L during post-monsoon season of the year 2019-20. Almost all the samples of the study area fall within the acceptable limit of 1.0 mg/L during pre- as well as post-monsoon season [Table

12(a) & (b)]. The fluoride distribution map for the pre- monsoon season is shown in Fig. 16(a&c).

From the above discussion, it is revealed that in the Maniyari shell formation region of Chhattisgarh state, the concentration of total dissolved solids exceeds the acceptable limit of 500 mg/L in about 84% samples but falls within the permissible limit during the pre-monsoon of the year 2018-19 and 61% samples exceed the acceptable limit but falls within permissible limit during the pre-monsoon of year 2019-20. The alkalinity values also exceed the acceptable limit in more than 48% of the samples in pre-monsoon season of the year 2018-19 and 53% of the samples in pre-monsoon season during the year 2019-20. From the hardness point of view,about 55% samples exceed the acceptable limit but within permissible limit and 45% samples even exceeds the permissible limit during pre-monsoon season during the year 2018-19 and about 53% samples exceed the acceptable limit but within permissible limit and 37% samples even exceeds the permissible limit during pre- monsoon season during the year 2019-20. The chloride contents are within the acceptable limits in almost all the samples. About 13% samples exceed the acceptable limit of sulphate but within permissible limit and 34% samples even exceeds the permissible limit during pre- monsoon season of the year 2018-19 and about 19% samples exceed the acceptable limit of sulphate but within permissible limit and 29% samples even exceeds the permissible limit during pre-monsoon season of the year 2019-20. The nitrate content in about 77% samples is well within the permissible limit during the year 2018-19 and about 92% samples is well within the permissible limit during the year 2019-20. The concentration of fluoride is well within the desirable limit in almost all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking waterspecifications.

Table 1(a). Details of sampling locations in the study area (Pre- & Post-monsoon 2018-19)

S. No.	Sample Code	Location	Block	District	Source	Lat.	Long.	Pre-monsoon		Post-monsoon	
						(^{0}N)	(^{0}E)	DTWL(m)	Ht. of MP(m)	DTWL(m)	Ht. of MP(m)
1	BMT-1	Berla	Berla	Bemetara	BW	21.523	81.479	10.1	0.38	7	0.38
2	BMT-1(Pz)	Berla	Bemetara	Bemetara	PzW	21.523	81.479	Not Collected	0.58	22.5	0.58
3	BMT-2	Beejabhat	Bemetara	Bemetara	BW	21.659	81.553	7.4	0.65	5.98	0.65
4	BMT-3	Balsamund	Bemetara	Bemetara	OW	21.724	81.650	37.34	0.2	Dry	0.2
5	BMT-3(Pz)	Balsamund	Bemetara	Bemetara	PzW	21.721	81.650	Not Collected	0.2	30.45	0.2
6	BMT-4	Pindri	Nawagarh	Bemetara	OW	21.729	81.640	4.7	0.5	3.42	0.5
7	BMT-5	Bemetara	Nawagarh	Bemetara	OW	21.707	81.605	0.9	0.14	0.88	0.14
8	BMT-6	Sambalpur	Nawagarh	Bemetara	OW	21.911	81.743	Dry	Dry	Dry	Dry
9	BMT-7	Kunra	Nawagarh	Bemetara	OW	21.822	81.781	9.4	0.59	7.78	0.59
10	BMT-7(Pz)	Kunra	Nawagarh	Bemetara	PzW	21.823	81.782	Not Collected	0.63	31.75	0.63
11	BMT-8	Murra	Bemetara	Bemetara	OW	21.800	81.815	Dry	Dry	Dry	Dry
12	BMT-9	Nawagarh	Bemetara	Bemetara	OW	21.906	81.609	4.1	0.65	3.4	0.65
13	BMT-10	Jhal	Bemetara	Bemetara	OW	21.945	81.613	Dry	0.6	Dry	0.6
14	BMT-11	Andhiyarkhor	Bemetara	Bemetara	OW	21.838	81.598	12.15	0.15	12.25	0.15
15	BMT-12	Jhal	Bemetara	Bemetara	OW	21.795	81.549	9.75	0.2	8.5	0.2
16	BMT-13	Sagona	Bemetara	Bemetara	OW	21.803	81.467	3.8	0.55	2.95	0.55
17	BMT-14	Kanhera	Bemetara	Bemetara	OW	21.827	81.456	6.38	0	4.95	Nil
18	BMT-15	Chilphi	Bemetara	Bemetara	OW	21.876	81.466	5.6	0.42	6.08	0.42
19	BMT-16	Dadhi	Bemetara	Bemetara	OW	21.894	81.473	6.1	0	5.97	Nil
20	BMT-17	Bahera	Bemetara	Bemetara	OW	21.776	81.501	4.25	0	2.97	Nil
21	BMT-18	Baiji	Bemetara	Bemetara	OW	21.763	81.515	4.23	0.5	2.95	0.5
22	BMT-19	Jhalam	Bemetara	Bemetara	OW	21.820	81.584	8.5	0	8.4	Nil
23	BMT-20	Baba Mohtara	Bemetara	Bemetara	OW	21.715	81.589	6.6	0.55	2.65	0.55
24	BMT-21	Kusmi	Bemetara	Bemetara	OW	21.699	81.623	9.7	0.5	8.69	0.5
25	BMT-22	Bitkuli	Bemetara	Bemetara	OW	21.775	81.668	Dry	0	Dry	0.28
26	BMT-23	Khilora	Bemetara	Bemetara	OW	21.714	81.534	6.95	0.25	4.3	0.25
27	BMT-24	Jeori	Bemetara	Bemetara	OW	21.641	81.539	14.96	0.44	13.4	0.44
28	BMT-25	Amora	Bemetara	Bemetara	OW	21.649	81.553	7.83	0.45	6.4	0.45
29	BMT-26	Farri	Bemetara	Bemetara	OW	21.667	81.543	14.4	0.6	13.7	0.6
30	BMT-27	Bhurki	Berla	Bemetara	OW	21.712	81.485	9.5	0.4	6.98	0.4
31	BMT-28	Dunra	Berla	Bemetara	OW	21.690	81.485	13.2	0.25	12.2	0.25
32	BMT-29	Ninwa	Berla	Bemetara	OW	21.682	81.464	8.42	0.24	7.95	0.24
33	BMT-30	Deorbija	Berla	Bemetara	OW	21.667	81.408	Dry	0	7.7	0.5
34	BMT-31	Rampur(Bhand)	Berla	Bemetara	OW	21.257	81.631	3.65	0.38	5.37	0.38
35	BMT-32	Deori	Berla	Bemetara	OW	21.568	81.571	Dry	0	Dry	0
36	BMT-33	Anandgaon	Berla	Bemetara	OW	21.506	81.566	Dry	0	Dry	0
37	BMT-34	Pirda	Berla	Bemetara	OW	21.414	81.580	4.6	0.25	2.56	0.25
38	BMT-35	Ufra	Berla	Bemetara	OW	21.375	81.556	5.2	0.6	5.07	0.6
39	BMT-36	Sankra	Saja	Bemetara	OW	21.478	81.501	Dry	0	7.1	Nil
40	BMT-37	Sondh	Saja	Bemetara	OW	21.539	81.437	3.65	0.5	3.15	0.5
41	BMT-38	Kodwa	Saja	Bemetara	BW	21.619	81.369	7.69	0.58	6.45	0.58
42	BMT-39	Saja	Saja	Bemetara	OW	21.657	81.315	Dry	0	Dry	0.25
43	BMT-40	Jata	Saja	Bemetara	OW	21.668	81.306	Dry	0	7.72	0.4
44	BMT-41	Saja	Saja	Bemetara	OW	21.668	81.306	61	0	7.72	0.4
45	BMT-42	Rakhi Joba	Saja	Bemetara	OW	21.586	81.346	Dry	0	Dry	0
46	BMT-43	Deokar	Saja	Bemetara	HP	21.563	81.320	Dry	0	6.85	0.55
47	BMT-44	Mohgaon	Saja	Bemetara	OW	21.602	81.292	Dry	0	7.7	0.5
48	BMT-45	Mouha Bhata	Saja	Bemetara	OW	21.608	81.291	Dry	0	Dry	0
49	BMT-46	Beltara(HP)	Saja	Bemetara	HP	21.727	81.294	45.75	0		0
50	BMT-47	Beltara(0W)	Saja	Bemetara	OW	21.730	81.293	8.68	0.28	9.28	0.28
51	BMT-48	Thelka	Saja	Bemetara	OW	21.726	81.317	Dry	0	Abandone	0
52	BMT-49	Thankamariya	Saja	Bemetara	OW	21.795	81.338	Dry	0	8.6	Nil
53	BMT-50	Keotara	Saja	Bemetara	OW	21.664	81.264	21.97	0.6	39.6	Nil
54	BMT-50(Pz)	Keotara	Kabirdham	Kabirdham	PzW	21.664	81.264	Not Collected	0.6	17.49	0.6
55	BMT-51	Bortara	Kabirdham	Kabirdham	OW	21.645	81.221	10.59	0.67	6.76	0.6
56	BMT-52	Sawartala	Kabirdham	Kabirdham	OW	21.667	81.241	12.56	0.34	11.45	0.34
57	BMT-53	Parpodi	Mungeli	Mungeli	OW	21.587	81.206	4.55	0.4	7.27	0.4
58	BMT-54(Pz)	Khandesra	Mungeli	Mungeli	PzW	21.818	81.522	Not Collected	0.58	30.4	0.58
59	KBD-1	Indori	Mungeli	Mungeli	OW	21.931	81.347	3.42	0.7	2.55	0.7
60	KBD-2	Dasranghpur	Mungeli	Mungeli	BW	21.889	81.378	5.55	0.45	4.9	0.45

61	KBD-3	Gourmati	Mungeli	Mungeli	OW	21.780	81.290	Dry	0	Dry	0
62	MNG-1	Moungeli	Mungeli	Mungeli	HP	22.060	81.681	Dry	0	Dry	0
63	MNG-2	Dharampura	Mungeli	Mungeli	OW	22.100	81.751	Dry	0	Dry	0
64	MNG-3	Chhatona	Mungeli	Mungeli	OW	22.110	81.810	11.32	0.45	8.3	0.45
65	MNG-4	Pathariya	Mungeli	Mungeli	OW	22.032	81.847	63.6	0	66.1	0
66	MNG-5	Pandarbhata	Mungeli	Mungeli	OW	21.958	81.733	5.98	0.49	5.98	0.49
67	MNG-6	Pandarbhata	Mungeli	Mungeli	HP	21.958	81.733	5.98	0.49	5.98	0.49
68	MNG-7	Sargaov	Mungeli	Mungeli	OW	21.905	81.983	Not Collected	0	Dry	0
69	MNG-8	Bhojpuri	Mungeli	Mungeli	OW	21.912	81.996	Not Collected	Nil	5.9	Nil
70	MNG-9	Sanwa	Mungeli	Mungeli	OW	21.894	81.965	Not Collected	Nil	7.9	Nil
71	MNG-10	Bavli	Mungeli	Mungeli	OW	21.941	81.914	Not Collected	Nil	9.6	Nil
72	MNG-11	Padiyain	Mungeli	Mungeli	OW	21.991	81.868	Not Collected	0	Dry	0

Table 1(b). Details of sampling locations in the study area (Pre- & Post-monsoon 2019-20)

S. No.	Sample Code	Location	Block	District	Source	Lat.	Long.	Pre-monsoon		Post-monsoon	
						(^{0}N)	(^{0}E)	DTWL(m)	Ht. of MP(m)	DTWL(m)	Ht. of MP(m)
1	BMT-1	Berla	Berla	Bemetara	BW	21.523	81.479	8.95	0.38	5.05	0.38
2	BMT-1(Pz)	Berla	Bemetara	Bemetara	PzW	21.523	81.479	42.6	0.58	18.6	0.58
3	BMT-2	Beejabhat	Bemetara	Bemetara	BW	21.659	81.553	9.5	0.65	4.35	0.65
4	BMT-3	Balsamund	Bemetara	Bemetara	OW	21.724	81.650	11.2	0.2	11.3	0.2
5	BMT-3(Pz)	Balsamund	Bemetara	Bemetara	PzW	21.721	81.650	-	0.2	18.55	0.2
6	BMT-4	Pindri	Nawagarh	Bemetara	OW	21.729	81.640	5.9	0.5	2.65	0.5
7	BMT-5	Bemetara	Nawagarh	Bemetara	OW	21.707	81.605	1.4	0.14	0.85	0.14
8	BMT-6	Sambalpur	Nawagarh	Bemetara	OW	21.911	81.743	10.65	0.5	8.54	0.5
9	BMT-7	Kunra	Nawagarh	Bemetara	OW	21.822	81.781	8.5	0.59	8.05	0.59
10	BMT-7(Pz)	Kunra	Nawagarh	Bemetara	PzW	21.823	81.782	34.3	0.63	20	0.63
11	BMT-8	Murra	Bemetara	Bemetara	OW	21.800	81.815	11.8	0	8.6	0
12	BMT-9	Nawagarh	Bemetara	Bemetara	OW	21.906	81.609	4.5	0.65	2.7	0.65
13	BMT-10	Jhal	Bemetara	Bemetara	OW	21.945	81.613	6.90(Dry)	0.6	9.1	0.6
14	BMT-11	Andhiyarkhor	Bemetara	Bemetara	OW	21.838	81.598	12.2	0.15	8.2	0.15
15	BMT-12	Jhal	Bemetara	Bemetara	OW	21.795	81.549	8.25	0.2	Dry	0.2
16	BMT-13	Sagona	Bemetara	Bemetara	OW	21.803	81.467	3.6	0.55	0.8	0.55
17	BMT-14	Kanhera	Bemetara	Bemetara	OW	21.827	81.456	6.3	Nil	3.05	Nil
18	BMT-15	Chilphi	Bemetara	Bemetara	OW	21.876	81.466	6.3	0.42	4.95	0.42
19	BMT-16	Dadhi	Bemetara	Bemetara	OW	21.894	81.473	6.7	Nil	Abondoned	Nil
20	BMT-17	Bahera	Bemetara	Bemetara	OW	21.776	81.501	4.1	Nil	2.2	Nil
21	BMT-18	Baiji	Bemetara	Bemetara	OW	21.763	81.515	4.7	0.5	3.4	0.5
22	BMT-19	Jhalam	Bemetara	Bemetara	OW	21.820	81.584	8.4	Nil	6.3	Nil
23	BMT-20	Baba Mohtara	Bemetara	Bemetara	OW	21.715	81.589	6.6	0.55	6.1	0.55
24	BMT-21	Kusmi	Bemetara	Bemetara	OW	21.699	81.623	9.70(Dry)	0.5	6.85	0.5
25	BMT-22	Bitkuli	Bemetara	Bemetara	OW	21.775	81.668	9.20(Dry)	0.28	9.3	0.28
26	BMT-23	Khilora	Bemetara	Bemetara	OW	21.714	81.534	7.35	0.25	3.85	0.25
27	BMT-24	Jeori	Bemetara	Bemetara	OW	21.641	81.539	14.8	0.44	4.95	0.44
28	BMT-25	Amora	Bemetara	Bemetara	OW	21.649	81.553	9.9	0.45	4.33	0.45
29	BMT-26	Farri	Bemetara	Bemetara	OW	21.667	81.543	15.40(Dry)	0.6	9.7	0.6
30	BMT-27	Bhurki	Berla	Bemetara	OW	21.712	81.485	7.5	0.4	5.85	0.4
31	BMT-28	Dunra	Berla	Bemetara	OW	21.690	81.485	12.5	0.25	10.8	0.25
32	BMT-29	Ninwa	Berla	Bemetara	OW	21.682	81.464	10.2	0.24	8.7	0.24
33	BMT-30	Deorbija	Berla	Bemetara	OW	21.667	81.408	7.9	0.5	1.3	0.5
34	BMT-31	Rampur(Bhand)	Berla	Bemetara	OW	21.257	81.631	6.2	0.38	5.85	0.38
35	BMT-32	Deori	Berla	Bemetara	OW	21.568	81.571	11.60(Dry)	0.62	11.6	0.62
36	BMT-33	Anandgaon	Berla	Bemetara	OW	21.506	81.566	5.20(Dry)	0.6	1.95	0.6
37	BMT-34	Pirda	Berla	Bemetara	OW	21.414	81.580	4.85	0.25	2.55	0.25
38	BMT-35	Ufra	Berla	Bemetara	OW	21.375	81.556	6.9	0.6	3	0.6
39	BMT-36	Sankra	Saja	Bemetara	OW	21.478	81.501	8.60(Dry)	Nil	3.9	Nil
40	BMT-37	Sondh	Saja	Bemetara	OW	21.539	81.437	3.45	0.5	3.2	0.5
41	BMT-38	Kodwa	Saja	Bemetara	BW	21.619	81.369	6.3	0.58	6.4	0.58
42	BMT-39	Saja	Saja	Bemetara	OW	21.657	81.315	Dry	0.25	Dry	0.25
43	BMT-40	Jata	Saja	Bemetara	OW	21.668	81.306	9.4	0.4	0.4	0.4
44	BMT-41	Saja	Saja	Bemetara	OW	21.668	81.306	Abondoned	0.4	Abondoned	0.4
45	BMT-42	Rakhi Joba	Saja	Bemetara	OW	21.586	81.346	14.7(Dry)	0.7	14.7(Dry)	0.7
46	BMT-43	Deokar	Saja	Bemetara	HP	21.563	81.320	10.80(Dry)	0.55	6.4	0.55

47	BMT-44	Mohgaon	Saja	Bemetara	OW	21.602	81.292	Abondoned	0.5	5.6	0.5
48	BMT-45	Mouha Bhata	Saja	Bemetara	OW	21.608	81.291	7.9	0.5	6.5	0.5
49	BMT-46	Beltara(HP)	Saja	Bemetara	HP	21.727	81.294	45.75	0	45.75	0
50	BMT-47	Beltara(0W)	Saja	Bemetara	OW	21.730	81.293	9.7	0.28	9.3	0.28
51	BMT-48	Thelka	Saja	Bemetara	OW	21.726	81.317	Abondoned	0	Abondoned	0
52	BMT-49	Thankamariya	Saja	Bemetara	OW	21.795	81.338	8.5	Nil	8.5	Nil
53	BMT-50	Keotara	Saja	Bemetara	OW	21.664	81.264	19.60(Dry)	0.5	19.60(Dry)	0.5
54	BMT-50(Pz)	Keotara	Kabirdham	Kabirdham	PzW	21.664	81.264	23.25	0.6	15.6	0.6
55	BMT-51	Bortara	Kabirdham	Kabirdham	OW	21.645	81.221	9.3	0.6	0.6	0.6
56	BMT-52	Sawartala	Kabirdham	Kabirdham	OW	21.667	81.241	13.1	0.34	8.95	0.34
57	BMT-53	Parpodi	Mungeli	Mungeli	OW	21.587	81.206	7.75(Dry)	0.4	0.4	0.4
58	BMT-54(Pz)	Khandesra	Mungeli	Mungeli	PzW	21.818	81.522	38.1	0.58	12.6	0.58
59	KBD-1	Indori	Mungeli	Mungeli	OW	21.931	81.347	4.4	0.7	2.3	0.7
60	KBD-2	Dasranghpur	Mungeli	Mungeli	BW	21.889	81.378	5.35	0.45	4.6	0.45
61	KBD-3	Gourmati	Mungeli	Mungeli	OW	21.780	81.290	Abondoned	0	Abondoned	0
62	MNG-1	Moungeli	Mungeli	Mungeli	HP	22.060	81.681	7.8(Dry)	0.45	7.8(Dry)	0.45
63	MNG-2	Dharampura	Mungeli	Mungeli	OW	22.100	81.751	Abondoned	0	Abondoned	0
64	MNG-3	Chhatona	Mungeli	Mungeli	OW	22.110	81.810	11.3	0.45	8.8	0.45
65	MNG-4	Pathariya	Mungeli	Mungeli	OW	22.032	81.847	Abondoned	0	Abondoned	0
66	MNG-5	Pandarbhata	Mungeli	Mungeli	OW	21.958	81.733	10.3	0.49	5.15	0.49
67	MNG-6	Pandarbhata	Mungeli	Mungeli	HP	21.958	81.733	46.42	0.49	46.42	0.49
68	MNG-7	Sargaov	Mungeli	Mungeli	OW	21.905	81.983	Dry	0.3	Dry	0.3
69	MNG-8	Bhojpuri	Mungeli	Mungeli	OW	21.912	81.996	6.1	Nil	5.4	Nil
70	MNG-9	Sanwa	Mungeli	Mungeli	OW	21.894	81.965	7.5	Nil	7.05	Nil
71	MNG-10	Bavli	Mungeli	Mungeli	OW	21.941	81.914	8.1	Nil	8.4	Nil
72	MNG-11	Padiyain	Mungeli	Mungeli	OW	21.991	81.868	5.10(Dry)	0.44	5.10(Dry)	0.44

Table 2(a). Source and depth wise distribution of sampling sites of the study area for the year 2018-19.

Source structure	Sample numbers of pre-monsoon 2018-19				Sample numbers of post-monsoon 2018-19			
	Depth range			Total number	Depth range			Total number
	<20 m	21-40 m	>40 m		<20 m	21-40 m	>40 m	
Hand Pumps	-	-	46,62	2	49,67,69	-	-	3
BoreWells/ TubeWells	1	3	41,60	4	1,4,44,54,65,68, 70,72	2,5,10,58	-	12
Open Wells	2,4,5,6,7,8,9, 10,11,12,13, 14,15,16,17, 18,19,20,21, 22,23,24,25, 26,27,28,29, 30,31,32,33, 34,35,36,37, 38,39,40,42, 43,44,45,47, 48,49,51,52, 53,54,55,56, 57,58,59,61	50	-	56	3,6,7,8,9,10,11, 12,13,14,15,16, 17,18,19,20,21, 22,23,24,25,26, 27,28,29,30,31, 32,33,34,35,36, 37,38,39,40,41, 42,,43,45,46,47, 48,50,51,52,53, 55,56,57,59,60, 61,62,63,64,65, 66,67,68,71	53	-	57
Total	56	2	4	62	67	5	-	72

Table 2(b). Source and depth wise distribution of sampling sites of the study area for the year 2019-20.

Source structure	Sample numbers of pre-monsoon 2019-20				Sample numbers of post-monsoon 2019-20			
	Depth range			Total number	Depth range			Total number
	<20 m	21-40 m	>40 m		<20 m	21-40 m	>40 m	
Hand Pumps	-	-	49,67	2	-	-	49,67	2
BoreWells/ TubeWells	1,3,41,60	-	-	4	1,3,41,60	-	-	4
Open Wells	4,5,6,7,8,9,11 ,12,13,14,15, 16,17,18,19, 20,21,22,23, 24,25,26,27, 28,29,30,31, 32,33,34,35, 36,37,38,39, 40,42,43,44, 45,46,47,48, 50,51,52,53, 55,56,57,59, 61,62,63,64, 65,66,68,69, 70,71,72	10,54, 58	2	66	2,4,5,6,7,8,9, 10,11,12,13,14, 15,16,17,18,19, 20,21,22,23,24, 25,26,27,28,29, 30,31,32,33,34, 35,36,37,38,39, 40,42,43,45,46, 47,48,50,51,52, 53,54,55,56,57, 58,59,61,62,63, 64,65,66,68,69, 70,71,72	-	-	66
Total	66	3	3	72	70	-	2	72

Table 3(a). Hydro-chemical data of groundwater samples collected during pre- and post-monsoon season (2018-19).

S. No.	Parameters	Minimum	Maximum	Average
1.	pH	6.6 (6.4)	8.7 (7.4)	7.9 (6.9)
2.	EC(μS/cm)	570 (364)	4898 (8944)	1591 (1515)
3.	TDS (mg/L)	399 (255)	3429 (6261)	1114 (1061)
4.	Alkalinity (mg/L)	61 (75)	412 (460)	202 (244)
5.	Hardness (mg/L)	182 (119)	2098 (1983)	687 (609)
6.	Na (mg/L)	8.43 (7.81)	274 (1275)	62 (71)
7.	K (mg/L)	1.21 (0.33)	163 (238)	16 (15)
8.	Ca (mg/L)	54 (28)	587 (601)	184 (168)
9.	Mg (mg/L)	7.32 (8.46)	201 (144)	55 (46)
10.	HCO_3 (mg/L)	74 (92)	503 (561)	247 (298)
11.	Cl (mg/L)	10 (4.2)	388 (780)	96 (86)
12.	SO_4 (mg/L)	3.99 (4.9)	2031 (3257)	379 (336)
13.	NO_3 (mg/L)	0.32 (0.00)	329 (215)	37 (29)
14.	F (mg/L)	0.07 (0.07)	1.03 (1.50)	0.38 (0.44)

***Values given in parenthesis represent post-monsoon values of different parameters.**

Table 3(b). Hydro-chemical data of groundwater samples collected during pre- and post-monsoon season (2019-20).

S. No.	Parameters	Minimum	Maximum	Average
1.	pH	6.2 (6.1)	7.7 (7.2)	7.1 (6.7)
2.	EC(μS/cm)	357 (413)	14914 (5118)	1636 (1485)
3.	TDS (mg/L)	250 (289)	10440 (3583)	1145 (1039)
4.	Alkalinity (mg/L)	83 (52)	354 (415)	189 (223)
5.	Hardness (mg/L)	119 (116)	3267 (2125)	650 (610)
6.	Na (mg/L)	7.7 (9)	2694 (362)	96 (68)
7.	K (mg/L)	0.67 (0.15)	225 (316)	18 (29)
8.	Ca (mg/L)	26 (26)	569 (648)	164 (165)
9.	Mg (mg/L)	10 (9)	488 (259)	58 (48)
10.	HCO_3 (mg/L)	101 (63)	432 (506)	231 (272)
11.	Cl (mg/L)	8 (12)	1080 (652)	85 (106)
12.	SO_4 (mg/L)	3 (4)	5735 (2002)	461 (293)
13.	NO_3 (mg/L)	0 (0)	194 (569)	24 (52)
14.	F (mg/L)	0.06 (0.05)	2.4 (1.04)	0.46 (0.45)

***Values given in parenthesis represent post-monsoon values of different parameters.**

Table 4(a). TDS distribution in groundwater of the study area for the year 2018-19

S. No.	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-500	0-20	1,35,37,52,53	8,9,15,24,28,37,38,40,54,56,57	8.06	15.27
		20-40	-	-		
		>40	-	-		
2.	501-2000	0-20	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,24,25,26,27,29,30,31,32,33,34,36,38,39,40,41,42,43,44,45,46,47,48,49,51,54,55,56,57,58,59,60	1,3,4,11,12,13,14,16,17,18,19,20,21,22,23,26,27,29,30,31,32,33,34,35,36,37,39,41,42,43,44,45,46,47,48,49,50,51,52,55,59,60,61,62,63,64,65,67,68,69,70	83.87	77.77
		20-40	50	2,53,58		
		>40	41,46,60	-		
3.	>2000	0-20	22,28,15,61	25,66,71	8.06	6.94
		20-40	-	5,10		
		>40	62	-		
Total number of samples			62	72	100	100

Table 4(b). TDS distribution in groundwater of the study area for the year 2019-20

S. No.	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-500	0-20	1,4,8,24,28,37,38,40,43,44,46,47,51,55,56,57,	1,2,4,15,17,24,28,29,34,36,37,38,40,42,57,59	25	22.22
		20-40	54	-		
		>40	2	-		
2.	501-2000	0-20	3,6,7,11,13,14,15,19,20,21,22,23,26,27,29,30,32,33,34,35,36,39,41,42,45,48,50,52,53,59,60,61,62,63,64,65,68,69,70,71,72	3,6,7,9,10,11,13,14,16,18,19,20,21,22,23,26,27,30,32,33,35,39,41,43,44,45,46,47,48,50,51,52,53,54,55,56,58,60,61,62,63, 64,66,68,69,70,71,72	61.11	69.44
		20-40	10,58	-		
		>40	49	49,67		
3.	>2000	0-20	5,9,12,16,17,18,25,31,66,67	5,8,12,25,31,65	13.88	8.33
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 5(a). Alkalinity distribution in groundwater of the study area for the year 2018-19

S. No.	Alkalinity, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	1,2,3,4,6,7,8,9,10,12,13,14,15,17,18,19,20,21,22,24,26,31,34,35,37,52,53,54,55,56	1,3,4,8,9,15,16,20,23,24,25,28,36,37,38,40,54,56,57	51.61	29.16
		20-40	-	5,10		
		>40	60,62	-		
2.	201-600	0-20	5,11,16,23,25,27,28,29,30,32,33,36,38,39,40,42,43,44,45,47,48,49,50,51,57,58,59	6,7,11,12,13,14,17,18,19,21,22,26,27,29,30,31,32,33,34,35,39,41,42,43,44,45,46,47,48,49,50,51,52,53,55,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72	48.38	70.83
		20-40	50	2,53,58		
		>40	41,46	-		
3.	>600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 5(b). Alkalinity distribution in groundwater of the study area for the year 2019-20

S. No.	Alkalinity, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	1,4,5,8,10,11,12,13,14,15,16,17,20,22,24,26,28,29,32,34,37,38,40,42,45,50,51,54,56,59,60,65, 71,72	1,2,3,4,15,17,19,22,23,24,28,29,32,33,34,35,36,37,38,39,40,43,56,57,59,65	47.22	36.11
		20-40	-	-		
		>40	-	-		
2.	201-600	0-20	2,3,6,7,9,18,19,21,23,25,27,30,31,33,35,36,39,41,43,44,46,47,48,52,53,55,57,58,61,62,63,64, 66,68,69,70	5,6,7,8,9,10,11,12,13,14,16,17,18,20,21,25,27,30,31,41,42,44,45,46,47,48,50,51,52,53,54,55,58,60,,61,62,63,64,65,66,68,69,70,71,72	52.77	63.88
		21-40	-	-		
		>40	49,67	49,67		
3.	>600	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 6(a). Hardness distribution in groundwater of the study area for the year 2018-19

S. No.	Hardness range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	-	8,9,28	-	4.16
		20-40	-	-		
		>40	-	-		
2.	201-600	0-20	1,2,16,20,21,23,24,25,26,29,31,32,33,34,35,36,37,38,39,40,42,43,44,45,52,53,54,57,58,59	1,3,7,13,14,15,19,22,23,24,27,29,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,54,55,56,57,61,62,63,64,67,68,69,72	54.83	65.27
		20-40	50	2,53,58		
		>40	41,46	-		
3.	>600	0-20	3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,22,27,28,30,48,49,51,55,56	4,6,11,12,16,17,18,20,21,25,26,30,51,52,59,60,65,66,70,71	45.16	30.55
		20-40	-	5,10		
		>40	60,62	-		
Total number of samples			62	72	100	100

Table 6(b). Hardness distribution in groundwater of the study area for the year 2019-20

S. No.	Hardness range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	4,8,29,37,38,51,56	4,28,40	9.72	4.16
		20-40	-	-		
		>40	-	-		
2.	201-600	0-20	1,2,3,5,14,19,23,24,32,33,34,35,36,38,39,40,41,42,43,44,46,47,48,50,53,54,55,57,59,60,61,62 ,63, 64,68,69,72	1,2,3,9,10,15,17,19,21,22,23,24,27,29,32,33,34,35,36,37,38,39,41,42,43,44,45,46,47,48,50,51,53,54,55,56,57,58,59,62,63,64,69,72	52.77	63.88
		21-40	-	-		
		>40	49	49,67		
3.	>600	0-20	6,7,9,10,11,12,13,15,16,17,18,20,21,22,25,26,27,28,30,31,52,58,65,66,70, 71	5,6,7,8,11,12,13,14,16,18,20,25,26,30,31,52,60,61,65,66, 68,70,71	37.5	31.94
		20-40	-	-		
		>40	67	-		
Total number of samples			72	72	100	100

Table 7(a). Calcium distribution in groundwater of the study area for the year 2018-19

S. No.	Calcium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-75	0-20	1,24,37,43,52,53,58,59	8,9,15,24,28,37,38,40, 46,54,56	12.90	16.67
		20-40	-	2		
		>40	-	-		
2.	76-200	0-20	2,3,5,11,16,17,20,21,23 ,25,26,29,30,31,32,33, 34,35,36,38,39,40,42, 44,45,47,48,51,54,56, 57	1,3,7,13,14,19,22,23,26 ,27,29,31,32,33,34,35, 36,39,41,42,43,44,45, 47,48,49,50,51,55,57, 59,61,62,63,64,67,68, 69	32.26	56.94
		20-40	50	53,58		
		>40	41,46	-		
3.	>200	0-20	4,6,7,8,9,10,12,13,14, 15,18,19,22,27,28,49, 55,61	4,6,11,12,16,17,18,20,2 1,25,30,52,60,65,66,70, 70,71	54.84	26.39
		20-40	-	5,10		
		>40	60,62	-		
Total number of samples			62	72	100	100

Table 7(b). Calcium distribution in groundwater of the study area for the year 2019-20

S. No.	Calcium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-75	0-20	1,2,4,8,24,28,37,38,40, 43,44,46,47,51,54,55, 56,57,59,62,63,64,69	1,2,4,15,17,24,28,29,36 ,37,38,40,55, 57,59	31.94	20.83
		20-40	-	-		
		>40	-	-		
2.	76-200	0-20	3,6,7,11,13,14,19,21,23 ,26,27,29,32,33,34,35, 36,39,41,42,45,48,50, 53,58,60,61,68,71,72	3,6,7,9,10,11,14,16,19, 21,22,23,26,27,32,33, 34,35,39,41,42,43,44, 45,46,47,48,50,51,53, 54,56,58,60,61,63,64, 68,69, 72	43.05	56.94
		20-40	-	-		
		>40	49	49,67		
3.	>200	0-20	5,9,10,12,15,16,17,18, 20,22,25,30,31,52,65, 66,70	5,8,12,13,18,20,25,30, 3152,62,65,66 ,70,71	25	22.22
		20-40	-	-		
		>40	67	-		
Total number of samples			72	72	100	100

Table 8(a). Magnesium distribution in groundwater of the study area for the year 2018-19

S. No.	Magnesium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-30	0-20	1,34,35,36,37,42,43, 52,53,54,59	3,8,9,15,22,24,28,34,37 ,38,39,40,45,54,56,57, 72	17.74	23.61
		20-40	-	-		
		>40	-	-		
2.	31-100	0-20	2,3,4,5,6,7,9,10,11,12, 13,14,16,17,18,19,20, 21,23,24,25,26,27,29, 30,31,32,33,38,44,45, 47,48,51,55,56,57,58, 61	1,4,6,7,11,12,13,14,16, 17,18,19,20,21,23,26, 27,29,30,31,32,33,35, 36,41,42,43,44,46,47, 48,49,50,51,52,55,59, 60,61,62,63,64,65,66, 67,68,69,70,71	74.19	73.61
		20-40	50	2,10,53,58		
		>40	41,46,60,62	-		
3.	>100	0-20	8,15,22,28,49	25	8.06	2.77
		20-40	-	5		
		>40	-	-		
Total number of samples			62	72	100	100

Table 8(b). Magnesium distribution in groundwater of the study area for the year 2019-20

S. No.	Magnesium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-30	0-20	1,4,8,24,28,37,38,40, 42,44,46,51,54,55,56, 57,59	1,2,3,4,17,19,21,22,23, 24,28,29,36,37,38,39, 40,55,56,57,59,64,72	23.61	33.33
		20-40	-	-		
		>40	-	67		
2.	31-100	0-20	2,3,6,7,11,12,13,14,15 ,16,17,19,20,21,22,23, 26,27,29,32,33,34,35, 36,39,41,43,45,47,48, 49,50,52,53,58,60,61, 62,63,64,65,66,67,68, 69,70,71,72	6,7,8,9,10,11,13,14,15, 16,18,20,26,27,30,32, 33,34,35,41,42,43,44, 45,46,47,48,50,51,52, 53,54,58,60,61,62,63, 65, 66,68,69,70,71	66.66	61.11
		20-40	-	-		
		>40	49,67	49		
3.	>100	0-20	5,9,10,18,25,30,31	5,12,25,31	9.72	5.55
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 9(a). Chloride distribution in groundwater of the study area for the year 2018-19

S. No.	Chloride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-250	0-20	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,18,19,20,21,22,23,24,25,26,27,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,47,48,49,50,51,52,53,54,56,57,58,59,61	1,3,4,7,8,9,10,11,12,13,14,15,16,17,18,19,21,22,23,24,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,72	93.55	94.44
		20-40	50	2,5,53,58		
		>40	41,46,60,62	-		
2.	251-1000	0-20	7,17,28,55	6,20,26	6.45	5.56
		20-40	-	10		
		>40	-	-		
3.	>1000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 9(b). Chloride distribution in groundwater of the study area for the year 2019-20

S. No.	Chloride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-250	0-20	1,2,3,4,5,6,8,11,12,13,14,15,16,18,19,21,22,23,24,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,47,48,50,51,52,53,54,56,57,58,59,61,62,63,64,65,66,68,69,70,71,72	1,2,3,4,7,8,9,10,11,12,13,14,15,16,17,18,19,21,22,23,24,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,50,51,52,53,54,55,56,57,58,59,61,62,63,64,65,66,68,69,70, 71,72	94.44	95.83
		20-40	-	-		
		>40	49,67	49,67		
2.	251-1000	0-20	9,20,26	20,26,60	4.16	4.16
		20-40	-	-		
		>40	-	-		
3.	>1000	0-20	-	-	1.38	-
		20-40	10	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 10(a). Sulphate distribution in groundwater of the study area for the year 2018-19

S. No.	Sulphate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	1,2,16,17,21,23,24,25, 26,31,32,33,34,35,36, 37,38,39,40,42,43,44, 45,47,52,53,54,57,58, 59	1,3,6,8,9,13,15,19,22, 23,24,26,28,32,34,35, 36,37,38,39,40,41,42, 43,44,45,46,47,48,49, 50,54,55,56,57,61,62, 63,64,67,68,69,72	52.23	62.50
		20-40	50	2,53,58		
		>40	41,46	-		
2.	201-400	0-20	4,5,11,20,27,29,51,55	7,14,20,27,29,31,59	12.90	9.72
		20-40	-	-		
		>40	-	-		
3.	>400	0-20	3,6,7,8,9,10,12,13,14, 15,18,19,22,28,30,48, 49,56,61	4,11,12,16,17,18,20,21, 25,30,33,51,52,60,65, 66,70,71	33.87	27.77
		20-40	-	5,10		
		>40	60,62	-		
Total number of samples			62	72	100	100

Table 10(b). Sulphate distribution in groundwater of the study area for the year 2019-20

S. No.	Sulphate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-200	0-20	1,2,3,4,8,19,23,24,26 ,28,34,35,36,37,38,39, 40,41,43,44,46,47,48, 50,51,53,54,55,56,57, 58,60, 62,63,64,69	1,2,3,4,6,7,15,19,20,21, 24,26,28,29,32,34,35, 36,37,38,39,40,41,42, 43,44,45,46,47,48,50, 51,53,54,55,56,57,58, 59,61,62,63,64,67,69, 72	51.38	63.88
		20-40	-	-		
		>40	49	49,67		
2.	201-400	0-20	5,6,14,20,21,27,29,32, 33,42,61,59,68, 72	7,9,10,14,22,23,27,33, 60,61,68	19.44	15.27
		20-40	-	-		
		>40	-	-		
3.	>400	0-20	7,9,11,12,13,15,16,17, 18,22,25,30,31,45,52, 65,66,70,71	5,8,11,12,13,16,18,25, 30,31,52,65,66, 70,71	29.16	20.83
		20-40	10	-		
		>40	67	-		
Total number of samples			72	72	100	100

Table 11(a). Nitrate distribution in groundwater of the study area for the year 2018-19

S. No.	Nitrate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-45	0-20	1,3,5,6,10,11,12,13,14, 16,18,19,20,22,23,24, 25,26,27,28,29,30,31, 32,33,35,37,39,40,42, 43,44,45,47,48,49,50, 51,52,53,54,56,57,58, 59	1,4,7,8,9,11,13,14,15, 16,17,19,21,22,23,24, 25,26,27,28,29,31,32, 33,34,35,36,38,39,40, 41,42,43,44,45,46,47, 48,49,50,51,52,54,55, 56,57,59,60,61,62,63, 64,65,67,68,69,70,71, 72	77.42	84.72
		20-40	-	2,5,10		
		>40	41,46,60,62	-		
2.	>45	0-20	2,4,7,8,9,15,17,21,34, 36,38,55,61	3,6,12,18,20,30,37,63, 66	22.58	15.28
		20-40	50	53,58		
		>40	-	-		
Total number of samples			62	72	100	100

Table 11(b). Nitrate distribution in groundwater of the study area for the year 2019-20

S. No.	Nitrate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-45	0-20	1,2,3,4,5,7,8,10,11,12, 13,14,15,16,17,18,19, 20,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,48, 49,50,51,52,54,55,56, 57,58,59,60,61,62,63, 64,65,68,69,70,71,72	1,2,3,4,5,7,8,9,11,13,15 ,16,17,19,21,22,24,25 ,26,27,28,32,33,34,38, 40,41,42,43,44,46,47, 48,51,52,55,57,58,59, 64,65,68,69,70,71,72	91.66	66.24
		20-40	-	-		
		>40	49	49,67		
2.	>45	0-20	6,9,21,53,66	6,10,12,14,18,20,23,29, 30,31,35,36,37,39,45, 50,53,54,56,60,61,62, 63,66	8.33	33.33
		20-40	-	-		
		>40	67	-		
Total number of samples			72	72	100	100

Table 12(a). Fluoride distribution in groundwater of the study area for the year 2018-19

S. No.	Fluoride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-1.0	0-20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,40,42,43,44,45,47,48,49,50,51,52,53,54,55,56,57,58,59,61	1,3,4,6,7,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72	98.38	98.61
		20-40	-	2,5,53,58		
		>40	41,46,60,62	-		
2.	1.1-1.5	0-20	39	-	1.62	-
		20-40	-	-		
		>40	-	-		
3.	>1.5	0-20	-	-	-	1.38
		20-40	-	10		
		>40	-	-		
Total number of samples			62	72	100	100

Table 12(b). Fluoride distribution in groundwater of the study area for the year 2019-20

S. No.	Fluoride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-1.0	0-20	1,2,3,4,5,6,7,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,68,69,70,71,72	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,68,69, 70, 71,72	98.38	98.61
		20-40	-	-		
		>40	49,67	49,67		
2.	1.1-1.5	0-20	-	5	-	1.38
		20-40	-	-		
		>40	-	-		
3.	>1.5	0-20	-	-	1.38	-
		20-40	10	-		
		>40	-	-		
Total number of samples			72	72	100	100

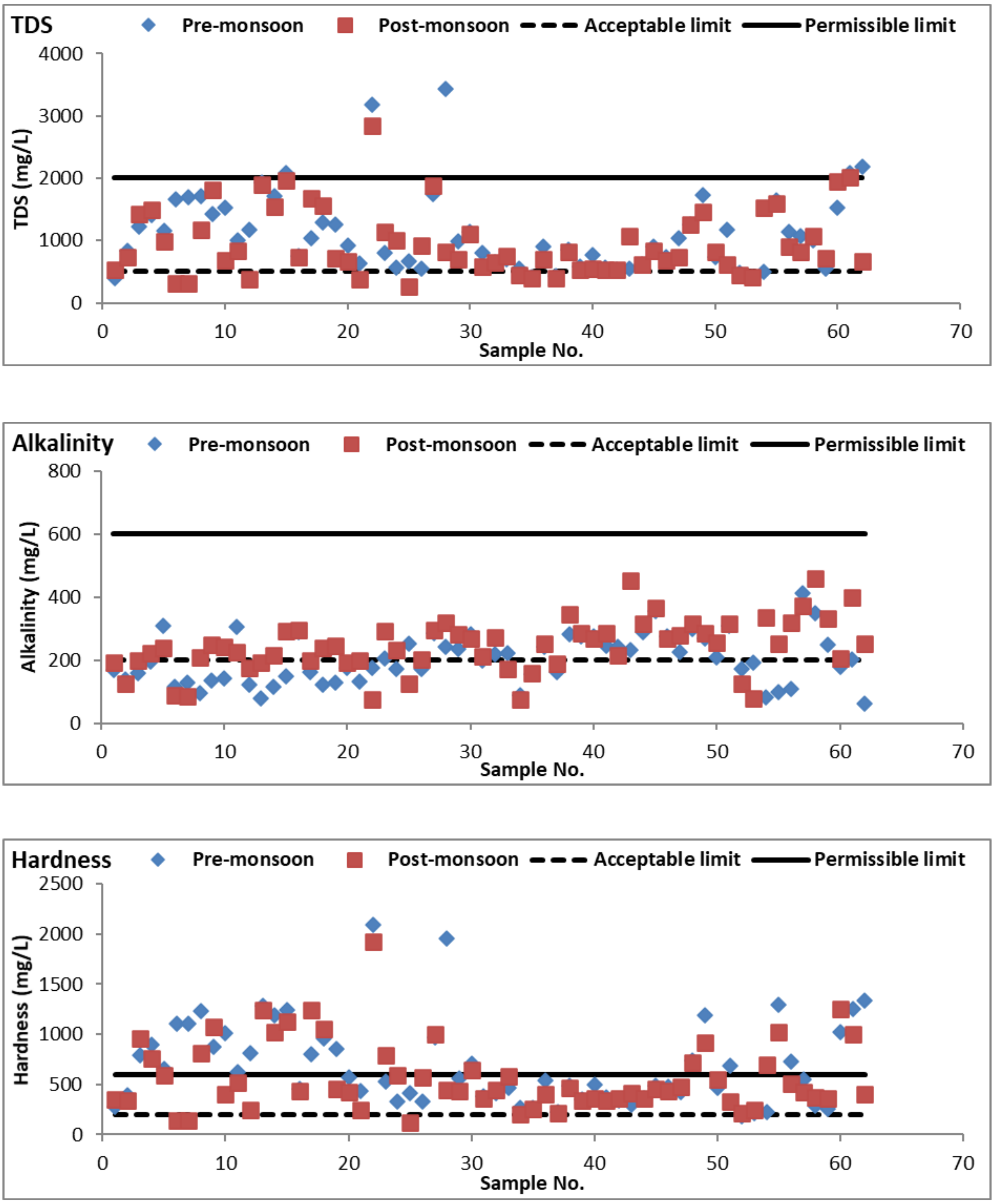


Fig. 7(a). Variation of TDS, Alkalinity and Hardness in groundwater of the study area for the year 2018-19

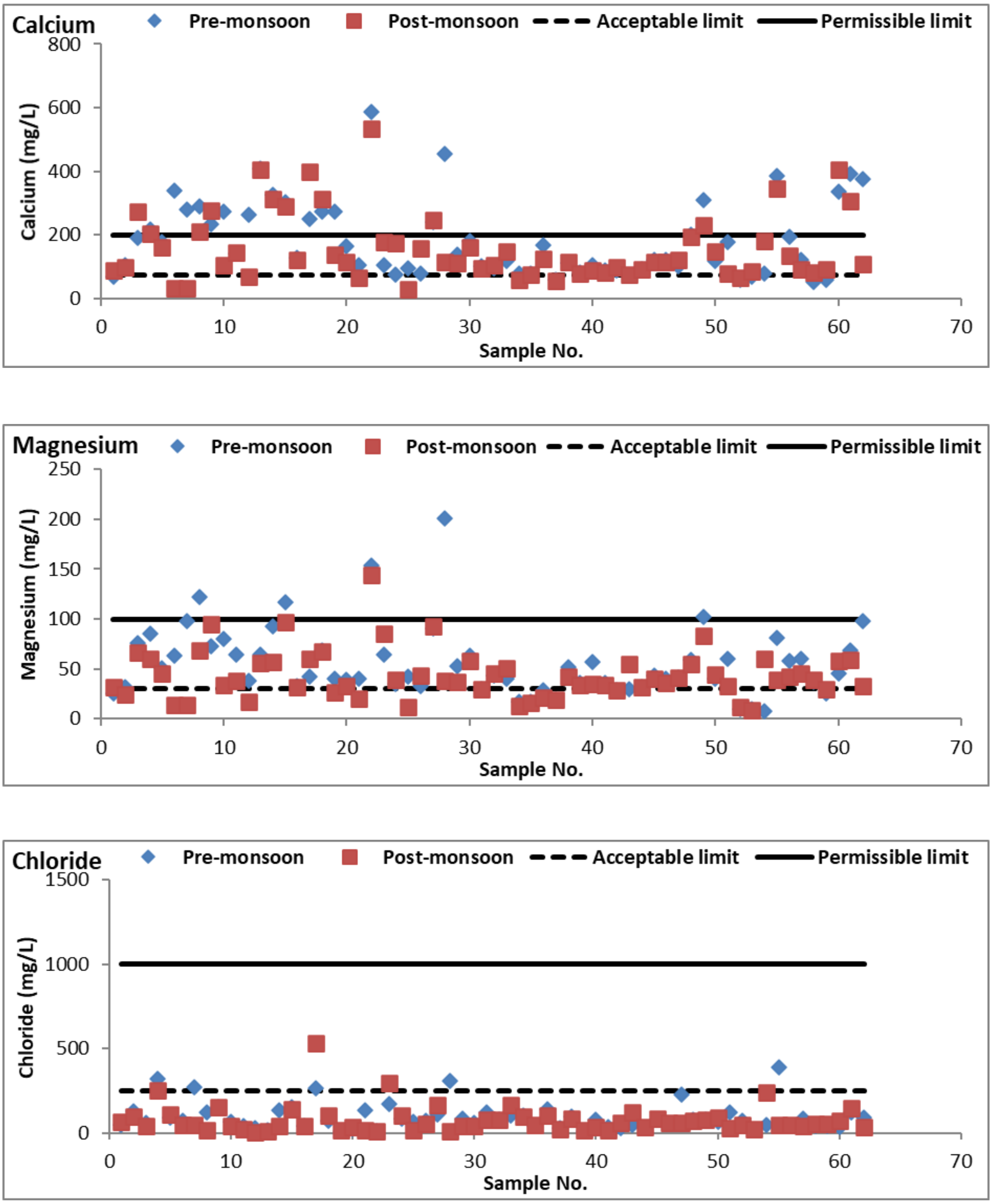


Fig. 7(b). Variation of Calcium, Magnesium and Chloride in groundwater of the study area for the year 2018-19

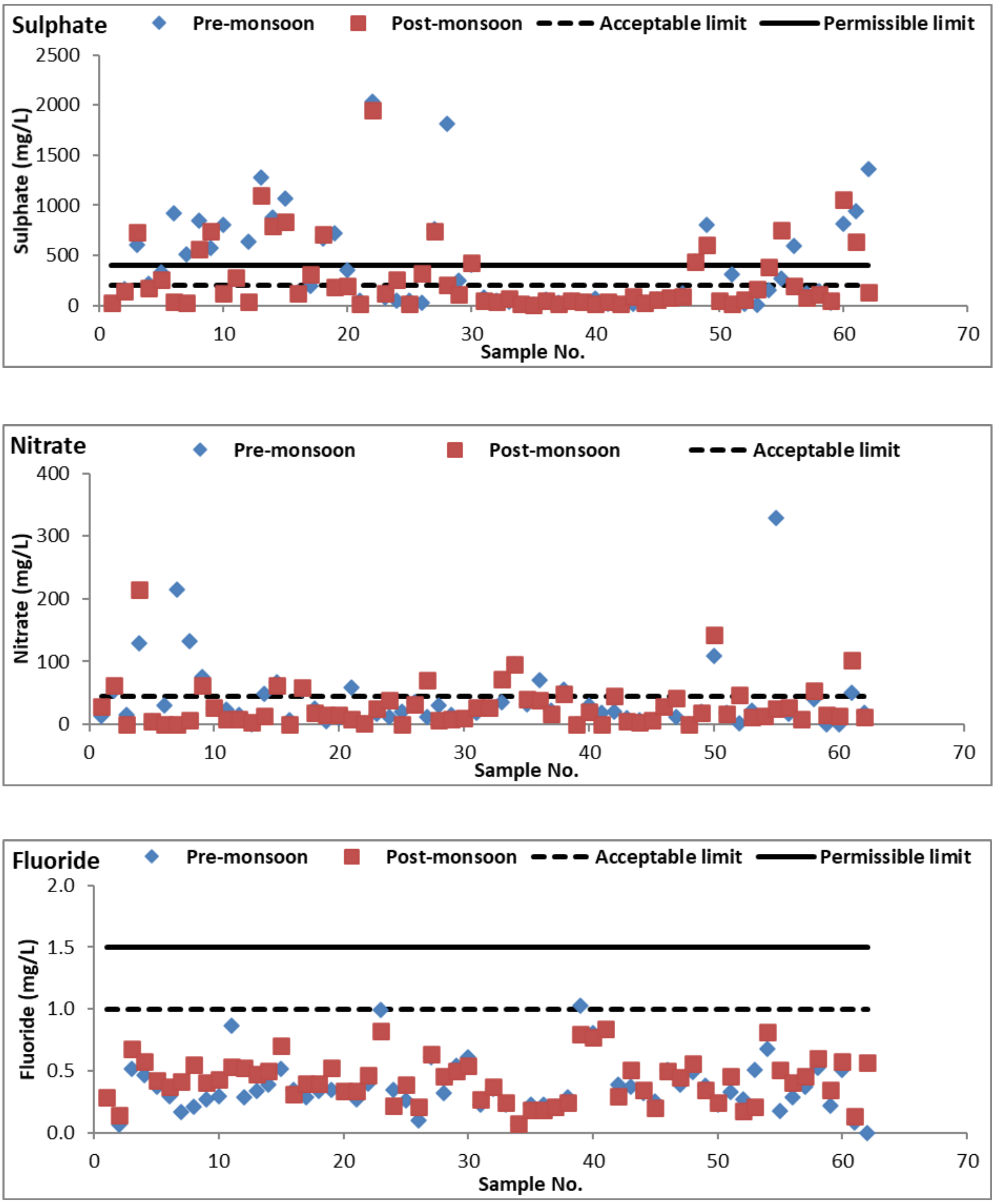


Fig. 7(c). Variation of Sulphate, Nitrate and Fluoride in groundwater of the study area for the year 2018-19

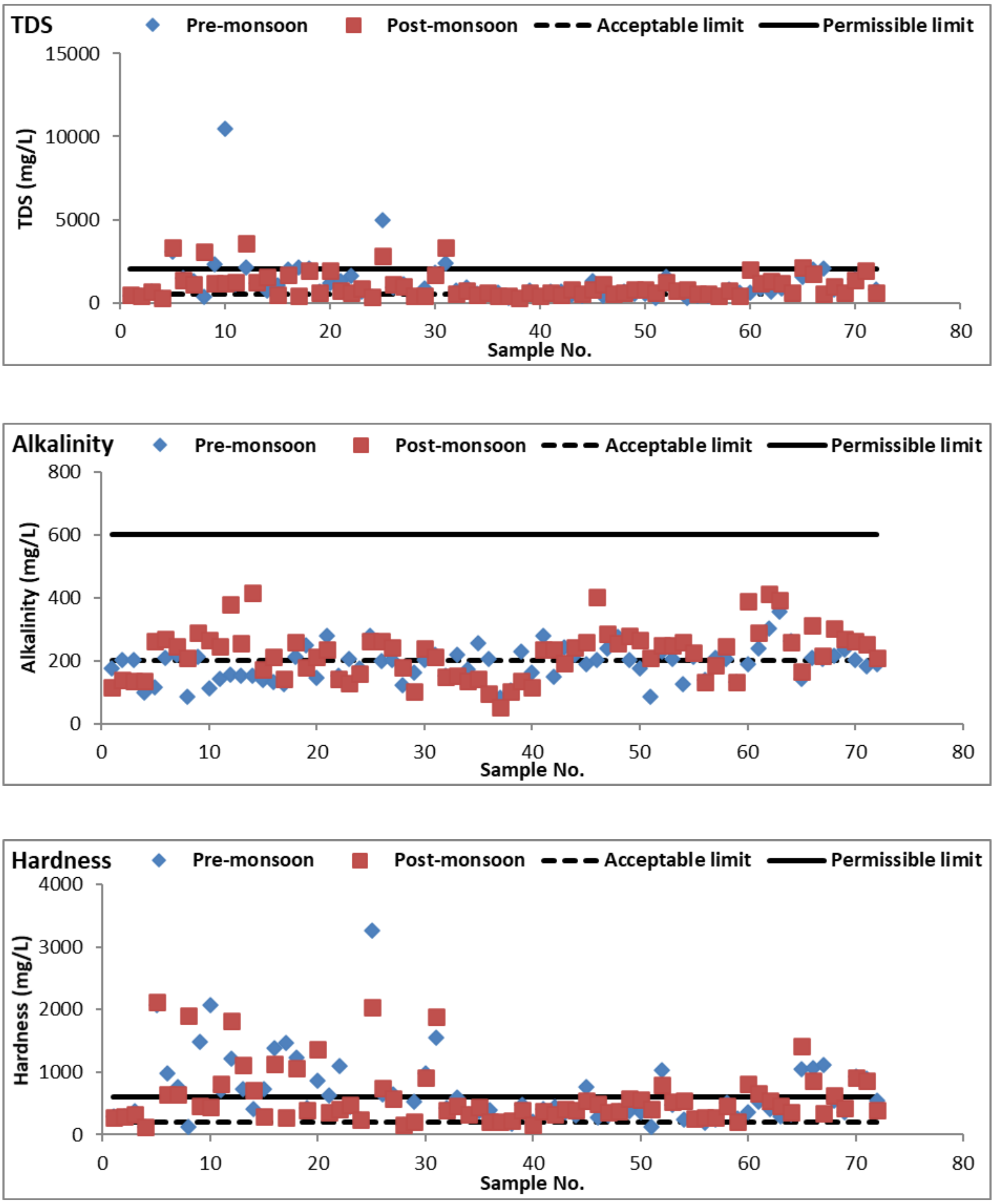
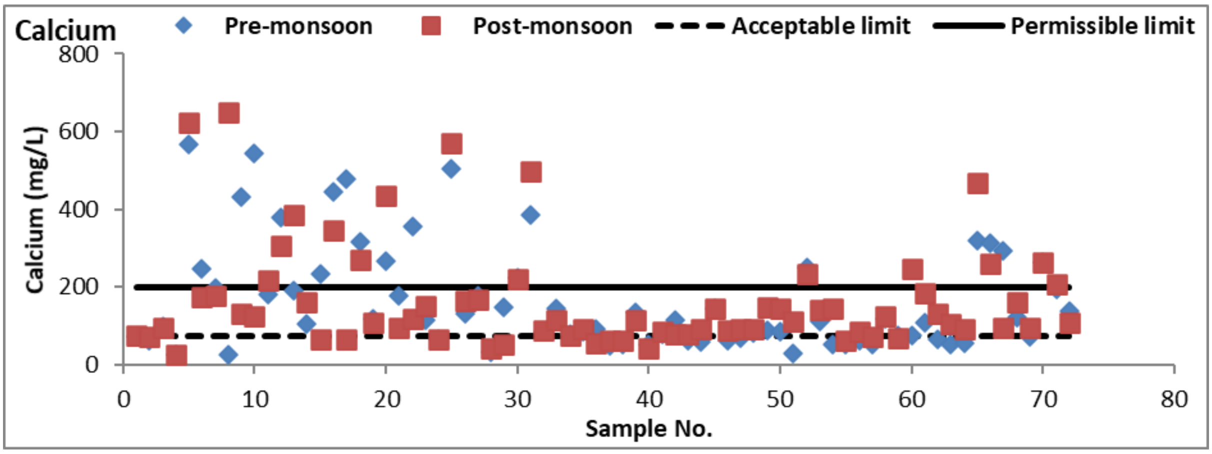
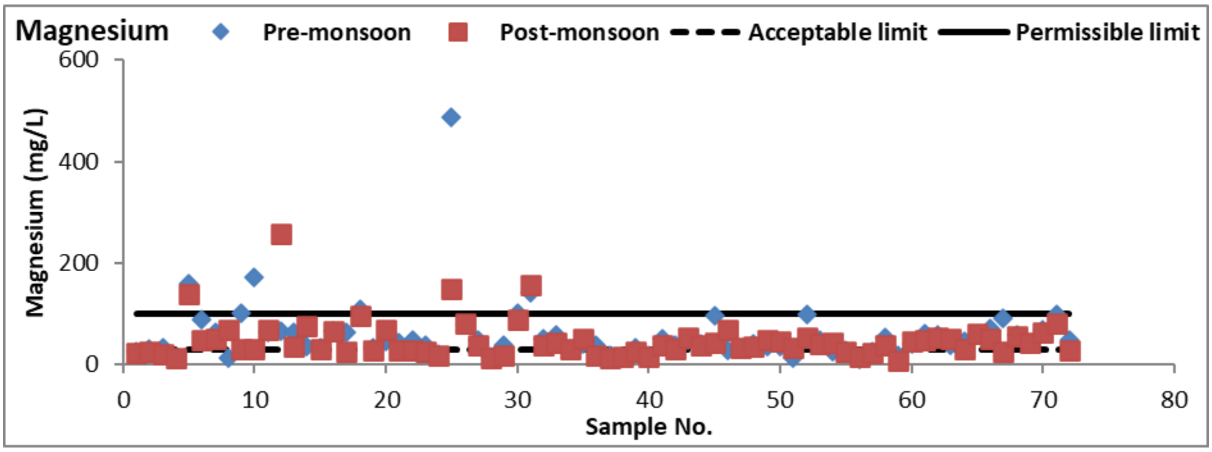


Fig. 8(a). Variation of TDS, Alkalinity and Hardness in groundwater of the study area during the year 2019-20.





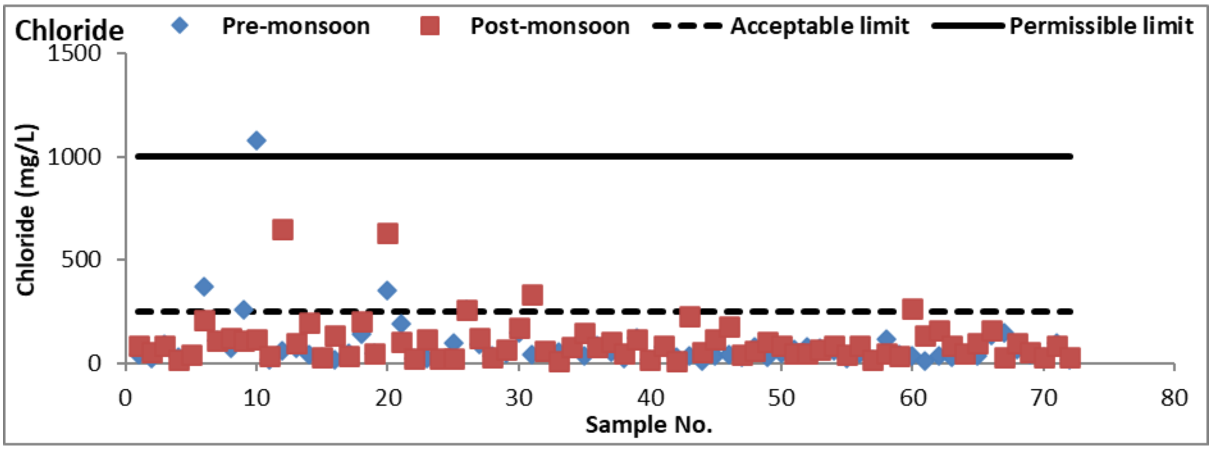


Fig. 8(b). Variation of Calcium, Magnesium and Chloride in groundwater of the study area during the year 2019-20.

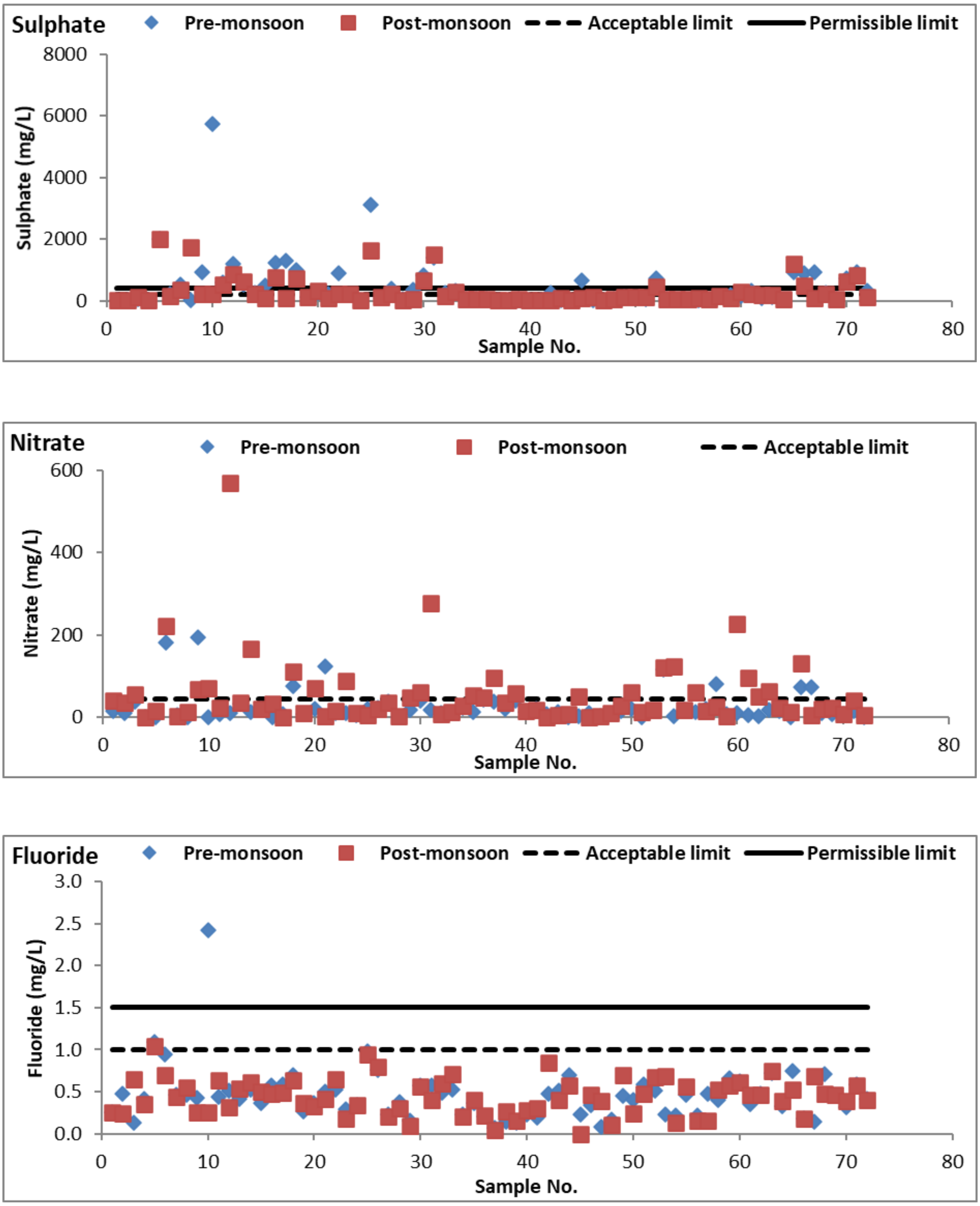


Fig. 8(c). Variation of Sulphate, Nitrate and Fluoride in groundwater of the study area during the year 2019-20.

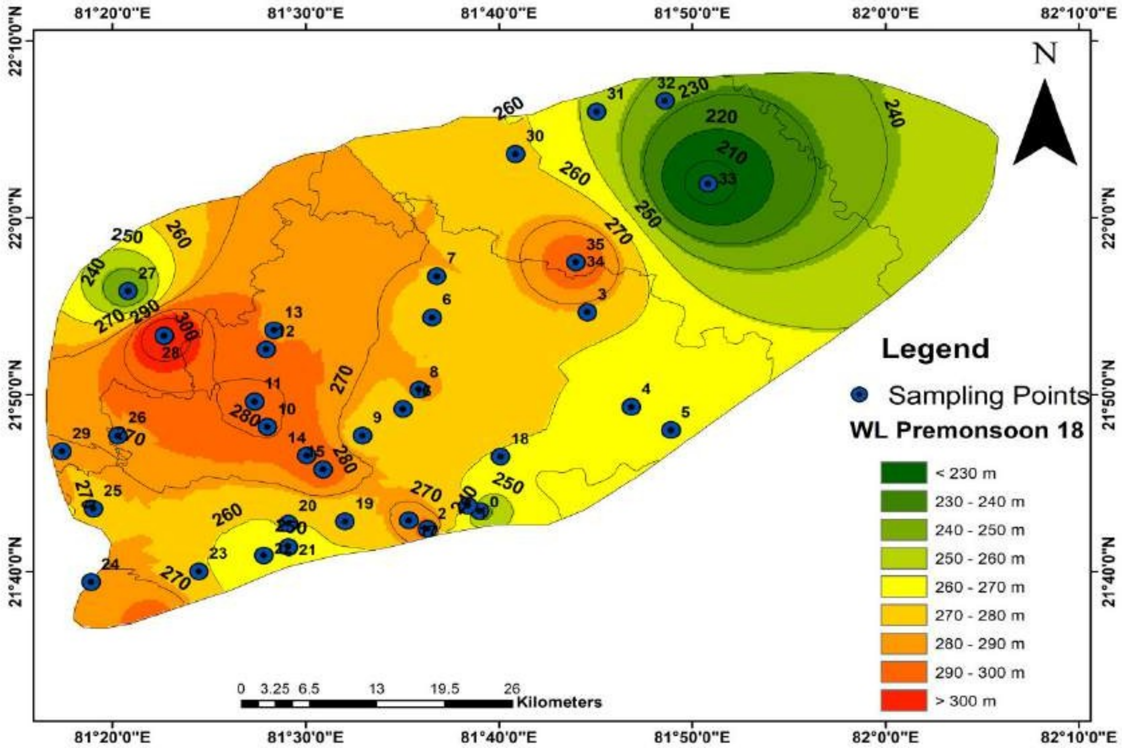


Fig. 9(a). Map showing groundwater level in the study area (Pre-monsoon 2018-19).

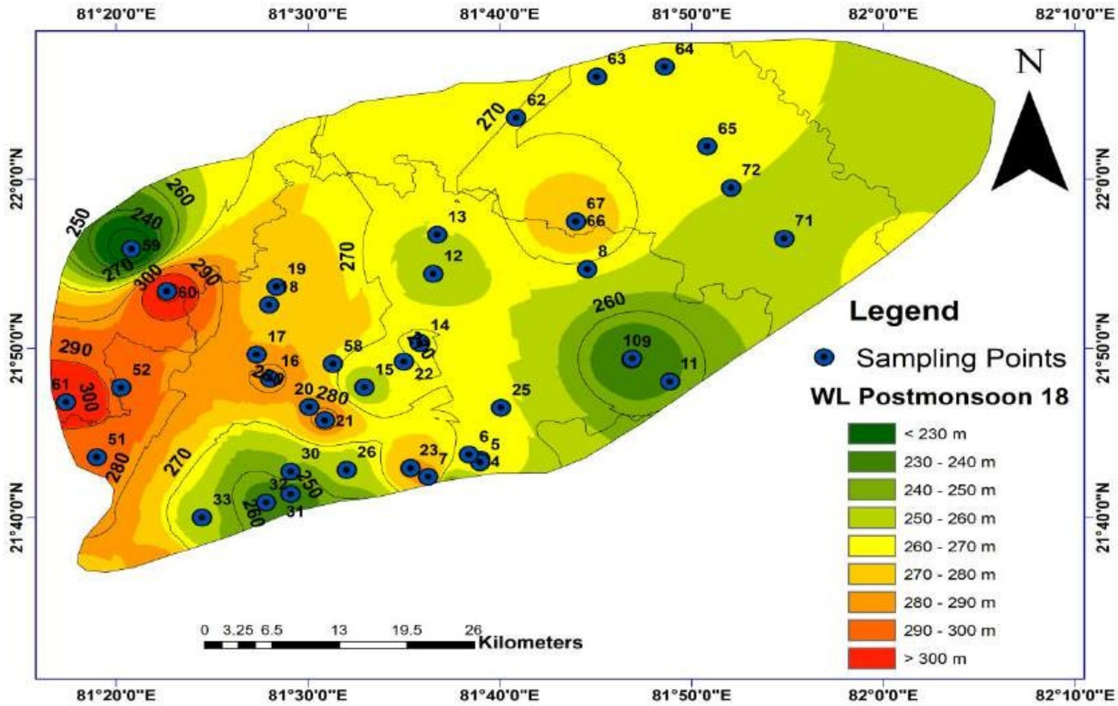


Fig. 9(b). Map showing groundwater level in the study area (Post-monsoon 2018-19)

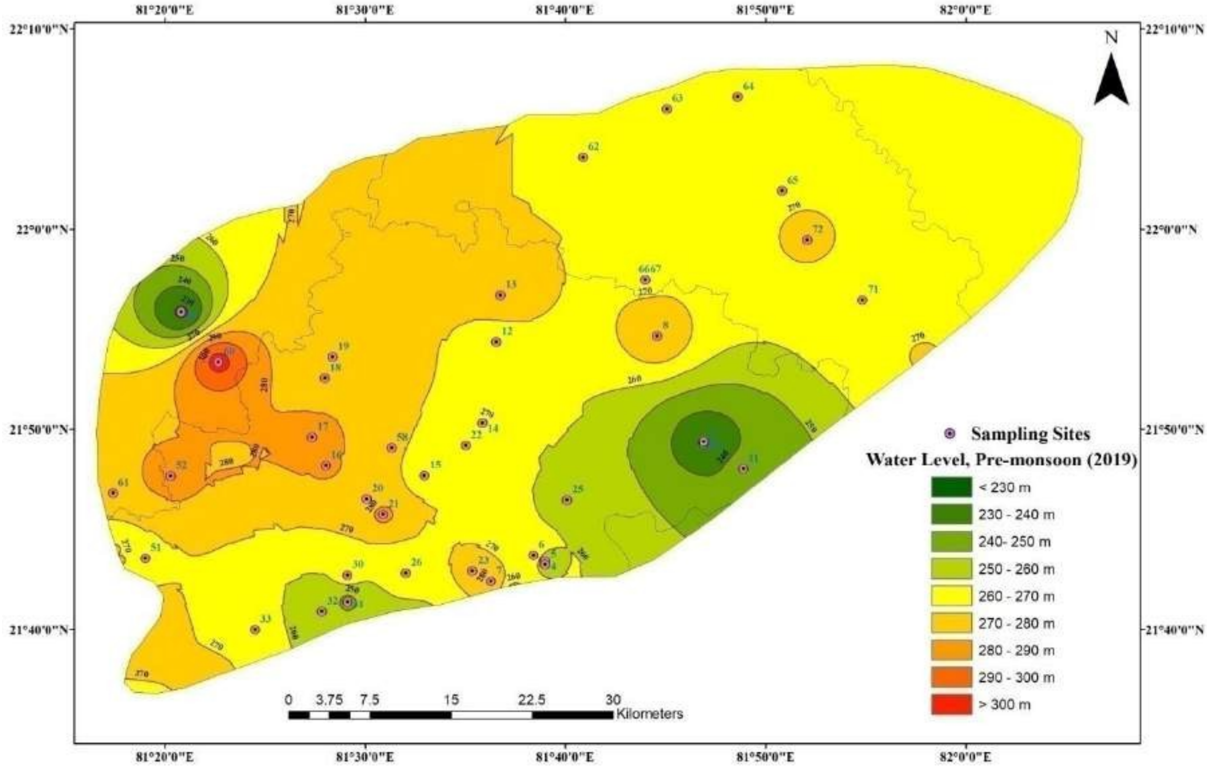


Fig. 9(c). Map showing groundwater level in the study area (Pre-monsoon 2019-20)

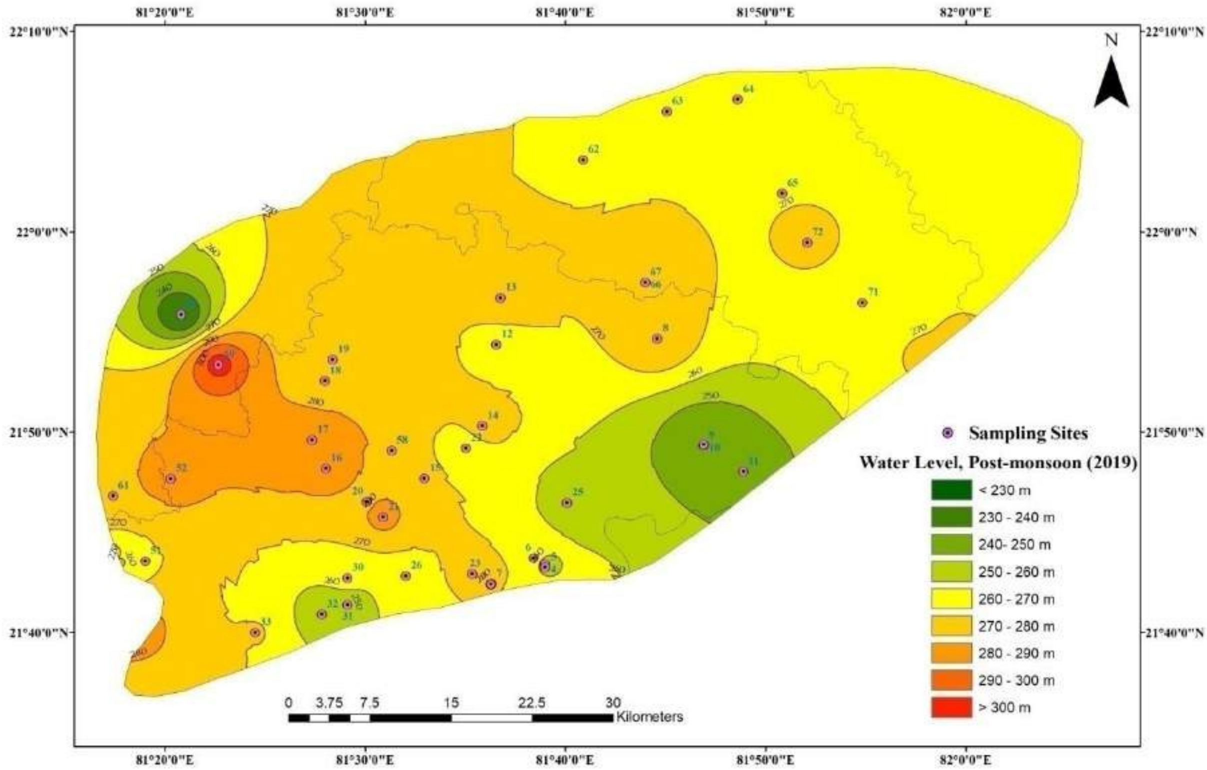


Fig. 9(d). Map showing groundwater level in the study area (Post-monsoon 2019-20)

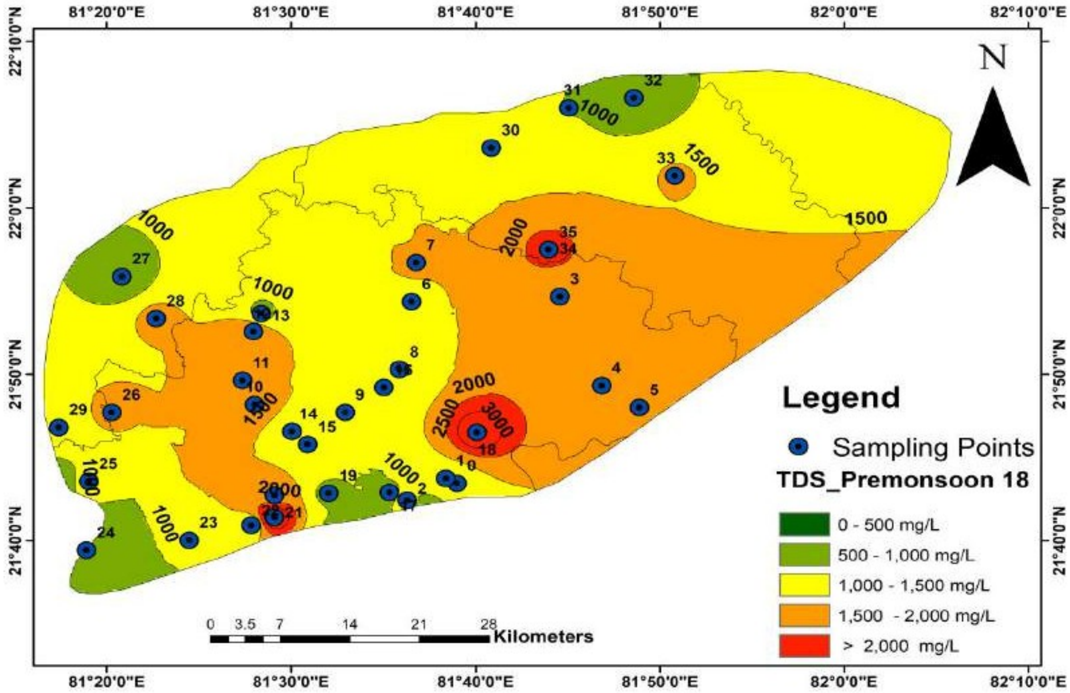


Fig. 10(a). Spatial distribution of TDS in groundwater of the study area (Pre- monsoon 2018-19)

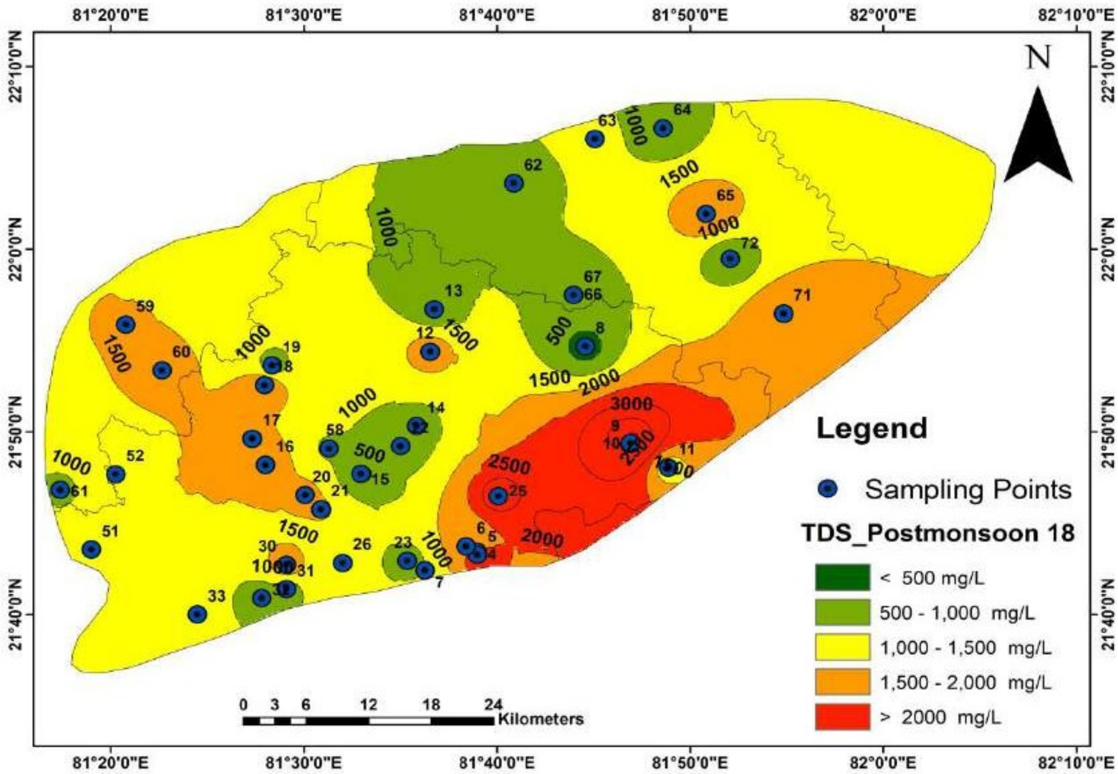


Fig. 10(b). Spatial distribution of TDS in groundwater of the study area (Post-monsoon 2018-19)

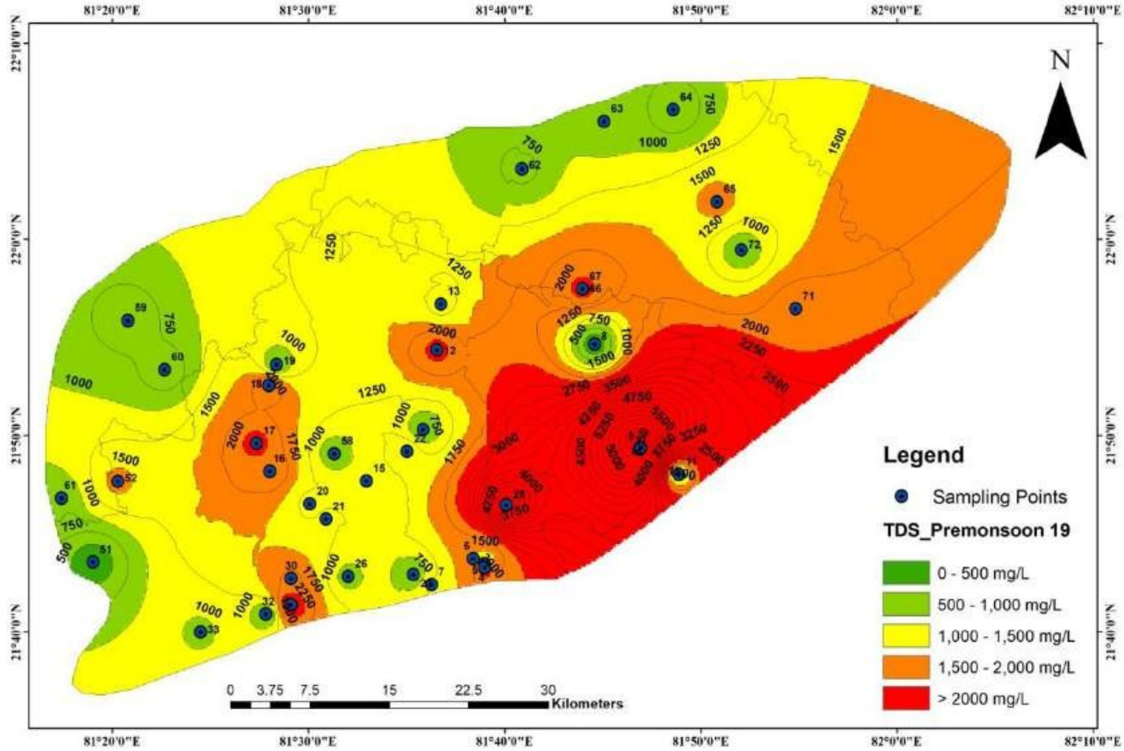


Fig. 10(c). Spatial distribution of TDS in groundwater of the study area (Pre-monsoon 2019-20)

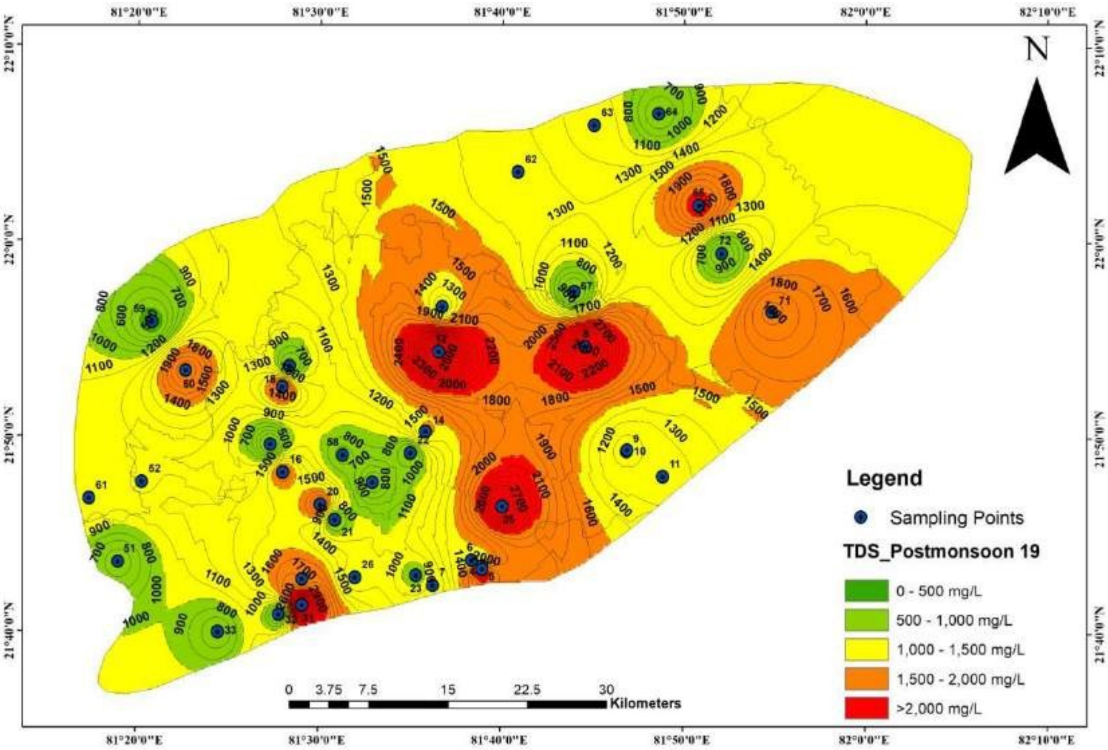


Fig. 10(d). Spatial distribution of TDS in groundwater of the study area (Post-monsoon 2019-20)

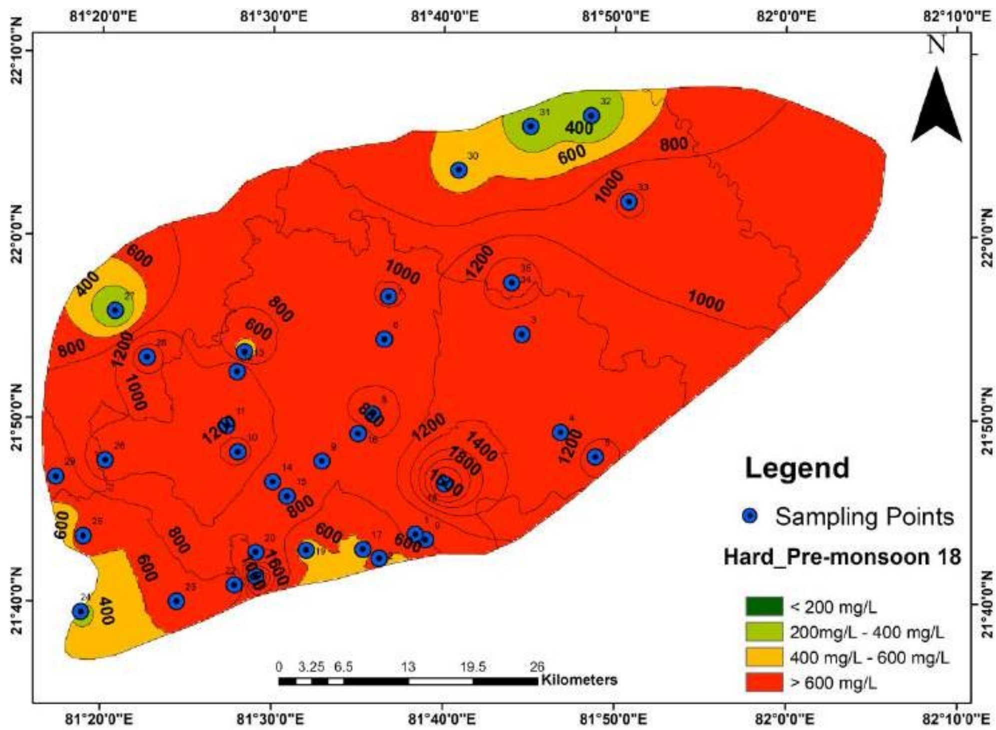


Fig. 11(a). Spatial distribution of Hardness in groundwater of the study area (Pre-monsoon2018-19)

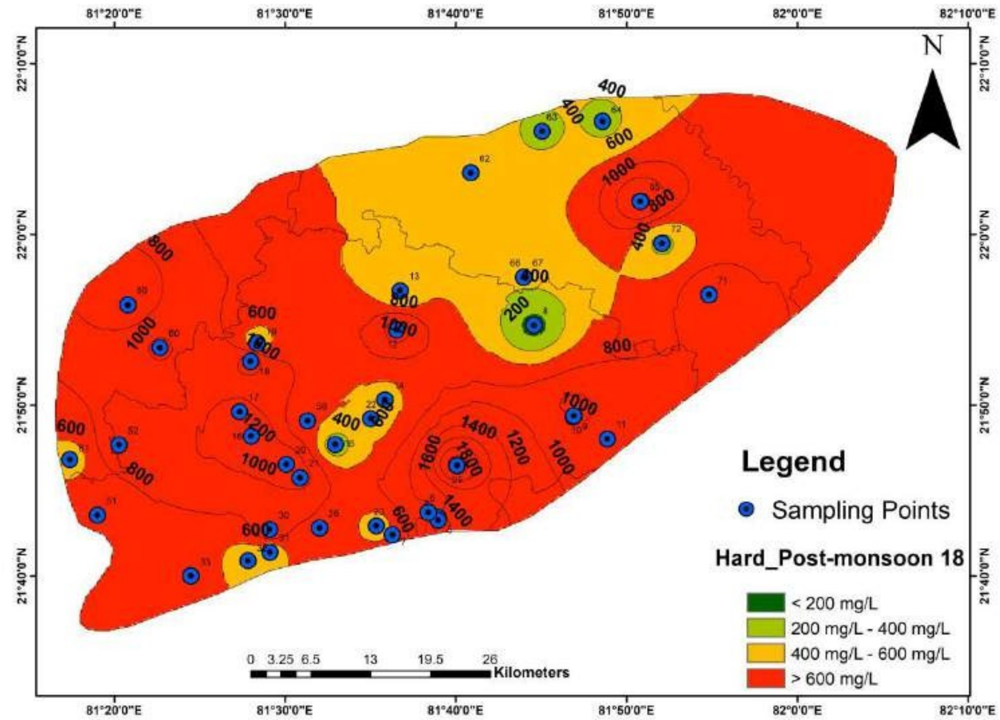


Fig. 11(b). Spatial distribution of Hardness in groundwater of the study area (Post-monsoon2018-19)

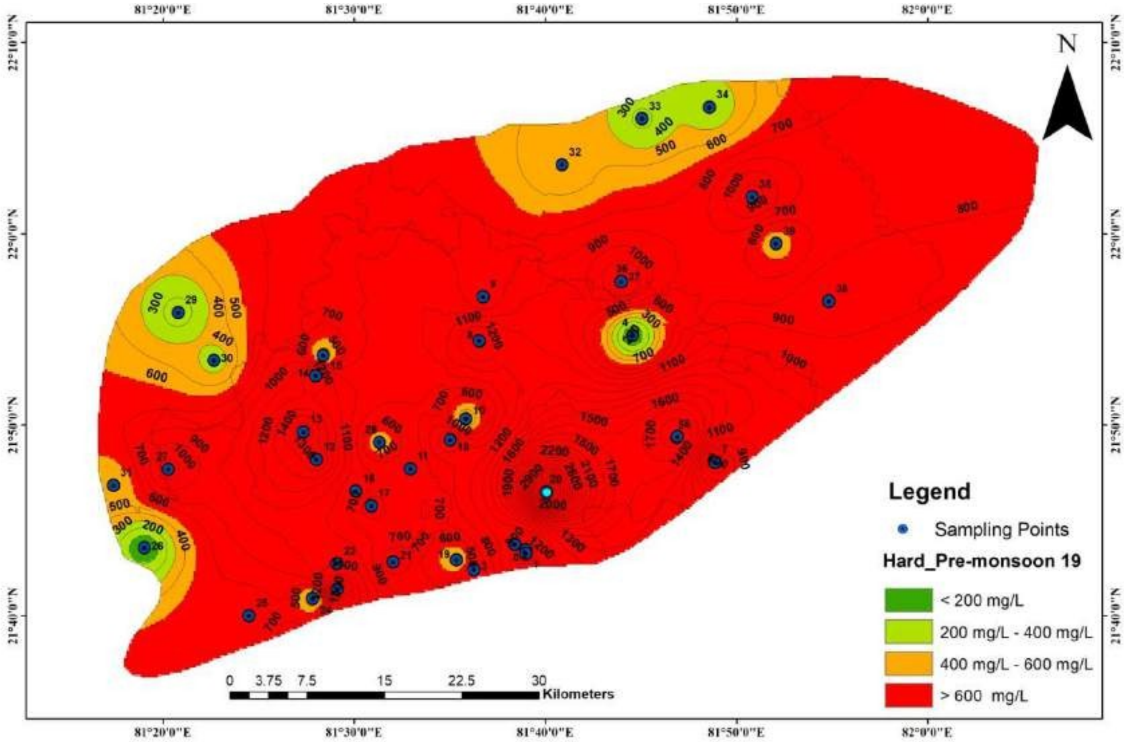


Fig. 11(c). Spatial distribution of Hardness in groundwater of the study area (Pre-monsoon2019-20)

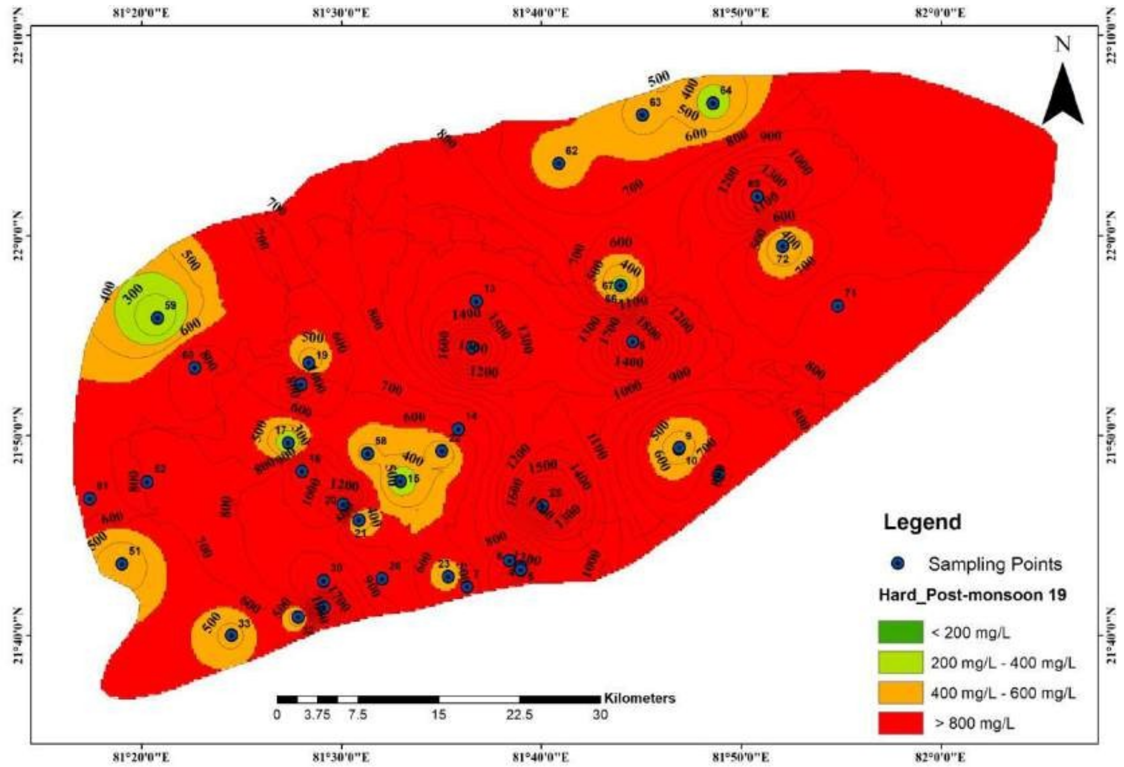


Fig. 11(d). Spatial distribution of Hardness in groundwater of the study area (Post-monsoon2019-20)

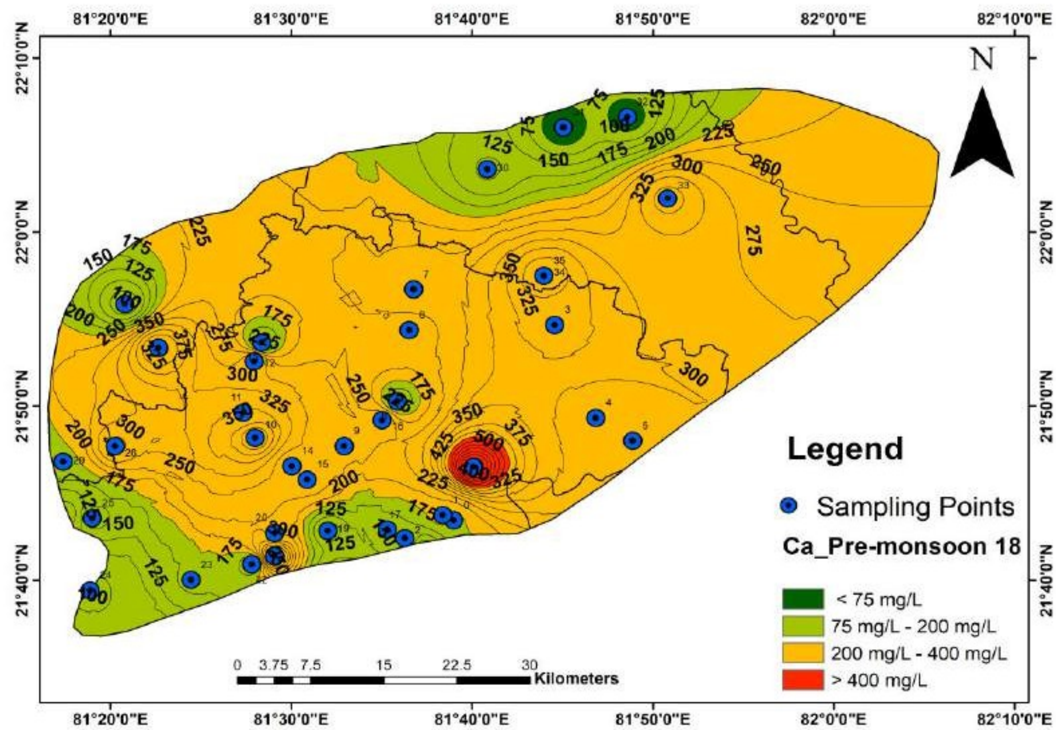


Fig. 12(a). Spatial distribution of Calcium in groundwater of the study area (Pre-monsoon2018-19)

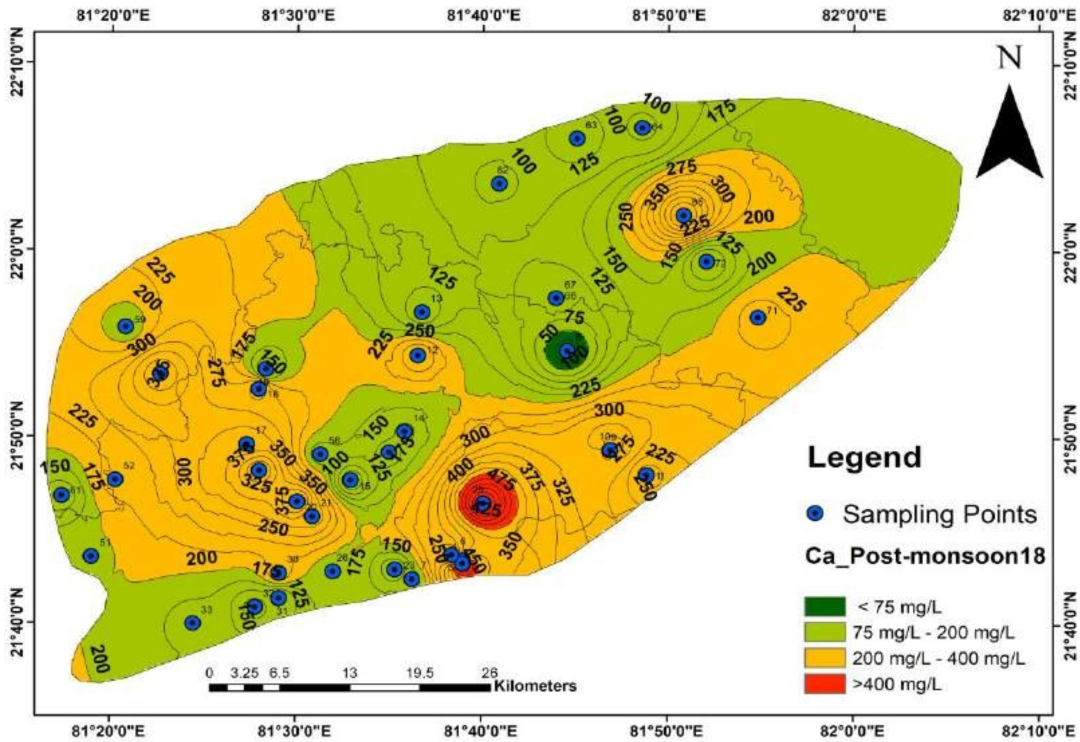


Fig. 12(b). Spatial distribution of Calcium in groundwater of the study area (Post-monsoon2018-19)

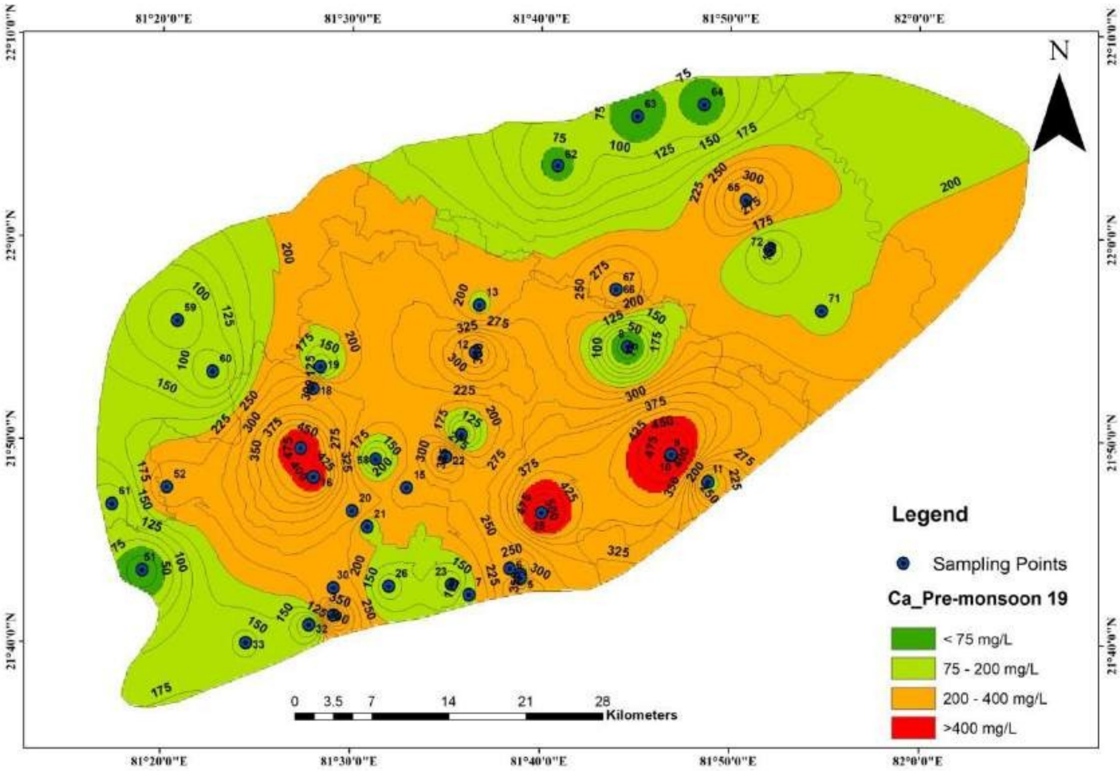


Fig. 12(c). Spatial distribution of Calcium in groundwater of the study area (Pre-monsoon2019-20)

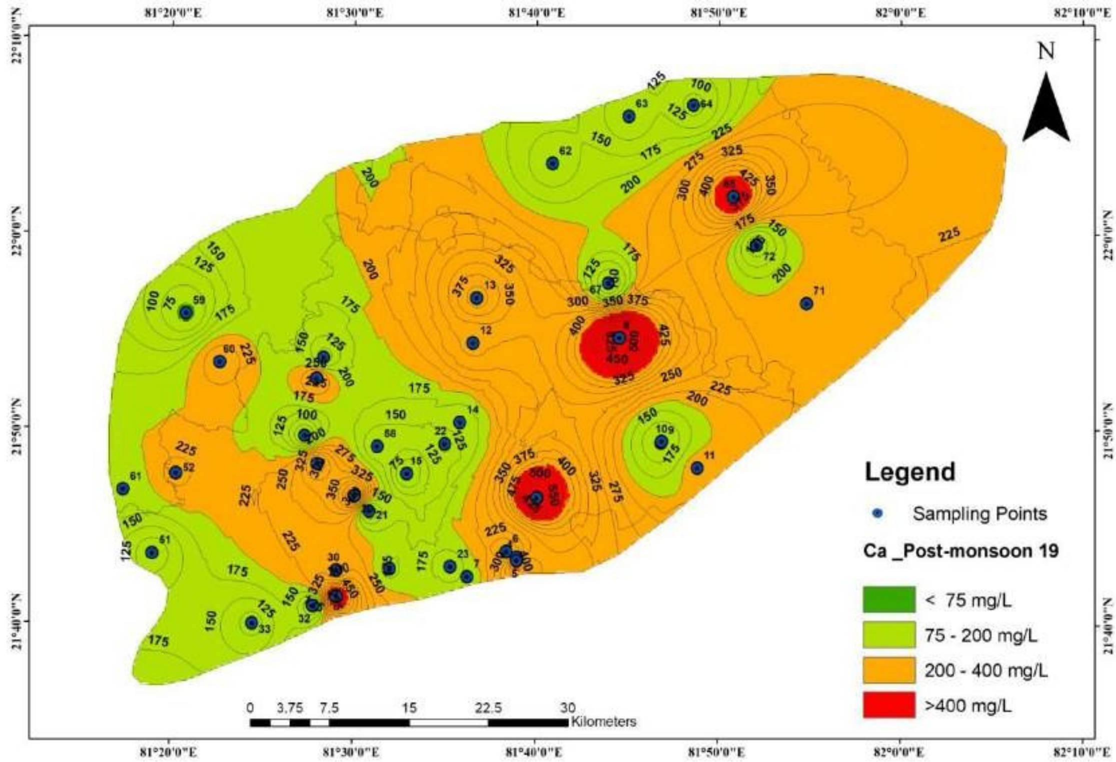


Fig. 12(d). Spatial distribution of Calcium in groundwater of the study area (Post-monsoon2019-20)

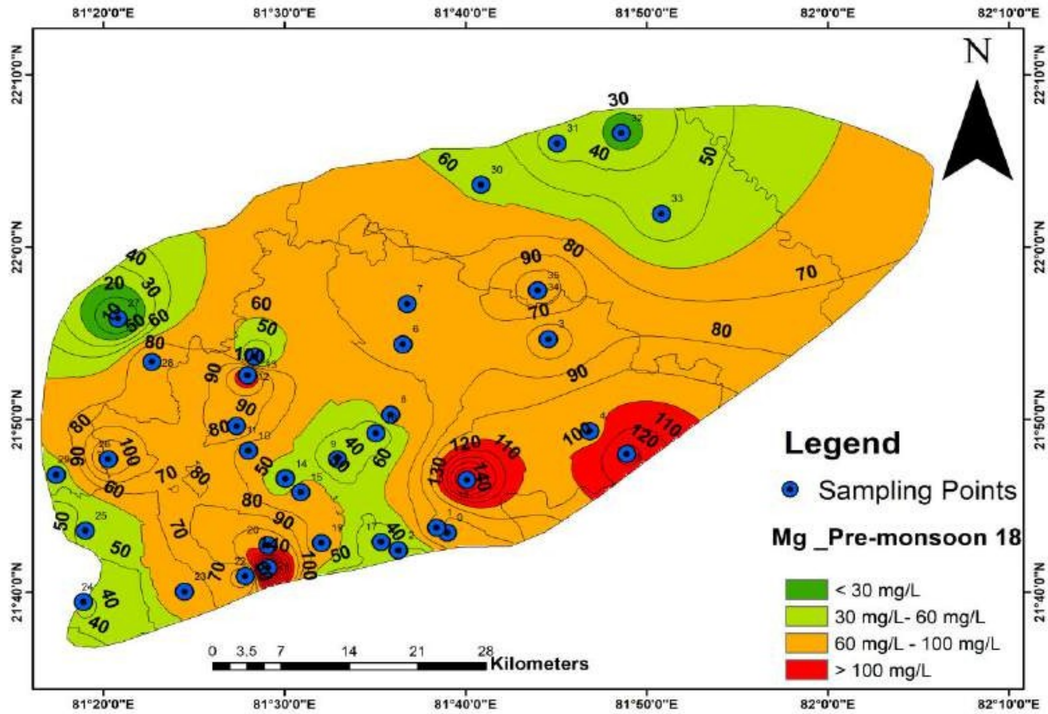


Fig. 13(a). Spatial distribution of Magnesium in groundwater of the study area (Pre-monsoon2018-19)

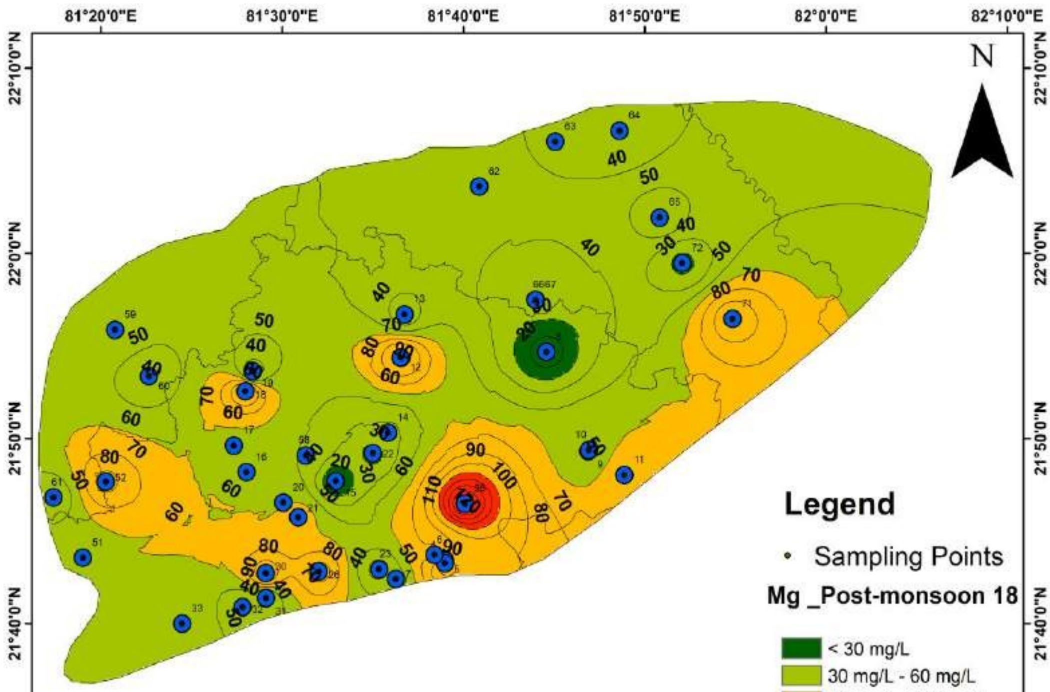


Fig. 13(b). Spatial distribution of Magnesium in groundwater of the study area (Post-monsoon 2018-19)

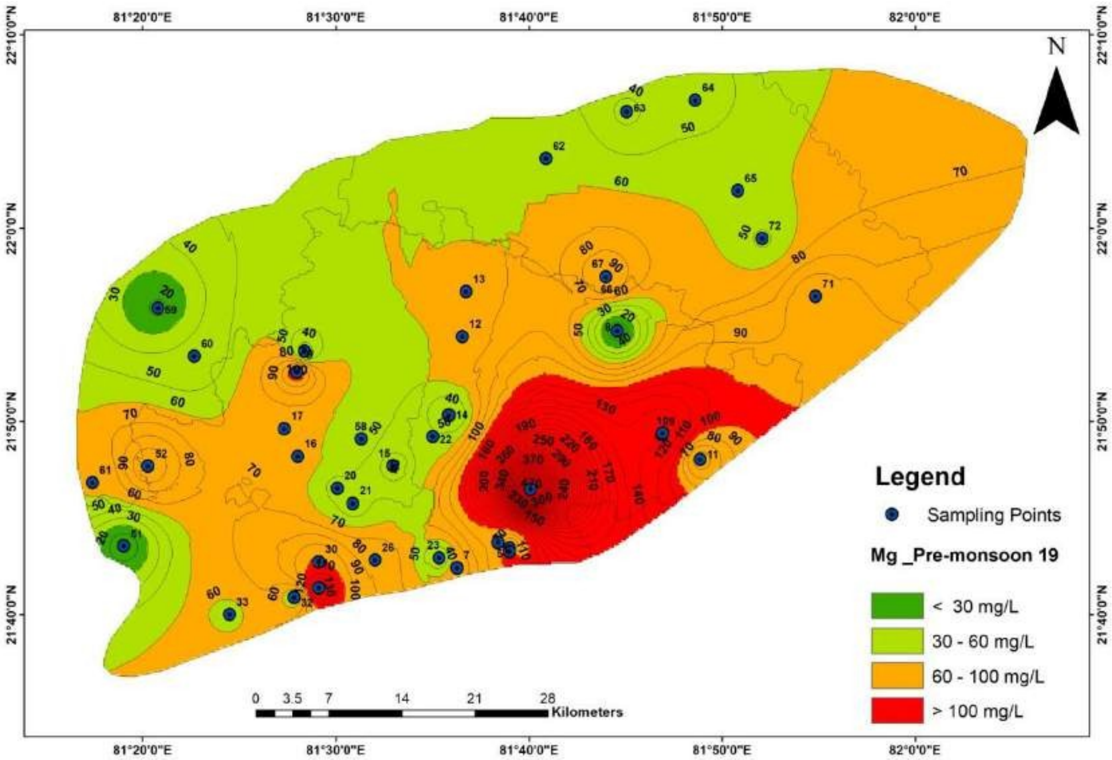


Fig. 13(c). Spatial distribution of Magnesium in groundwater of the study area (Pre-monsoon2019-20)

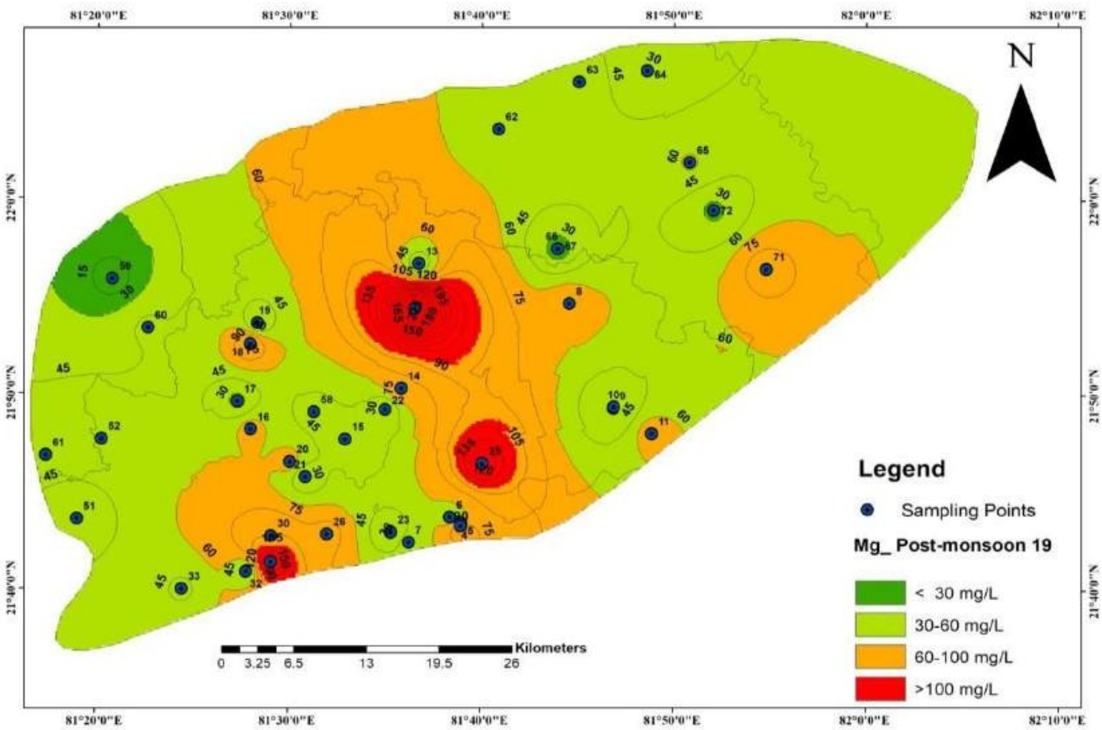


Fig. 13(d). Spatial distribution of Magnesium in groundwater of the study area (Post-monsoon2019-20)

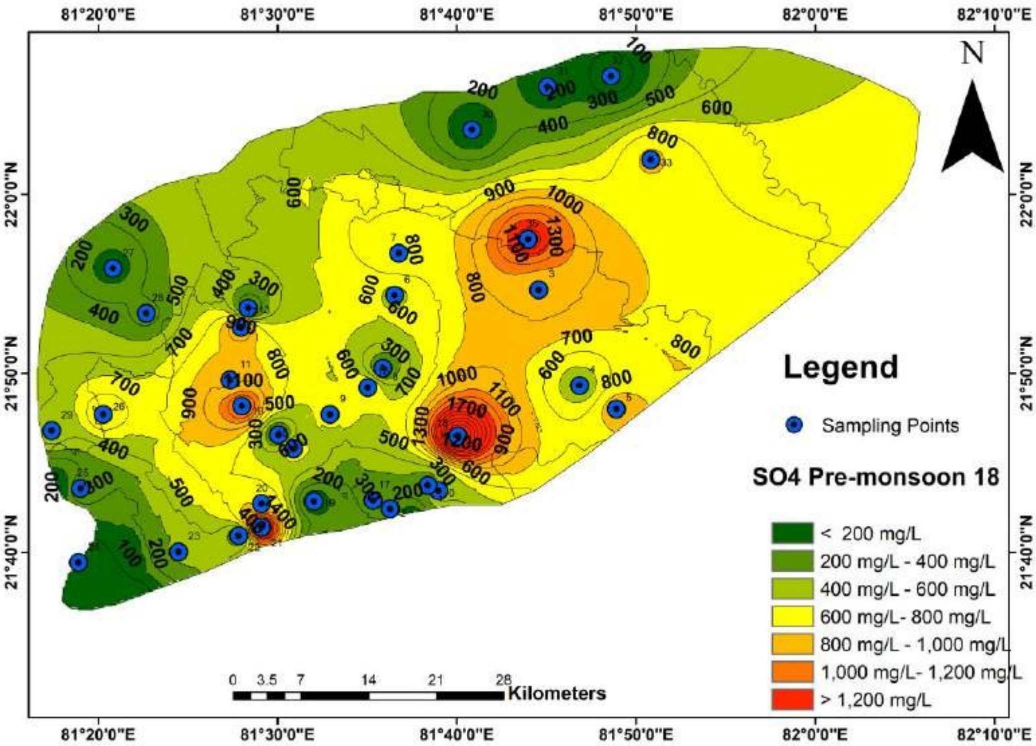


Fig. 14(a). Spatial distribution of Sulphate in groundwater of the study area (Pre-monsoon2018-19)

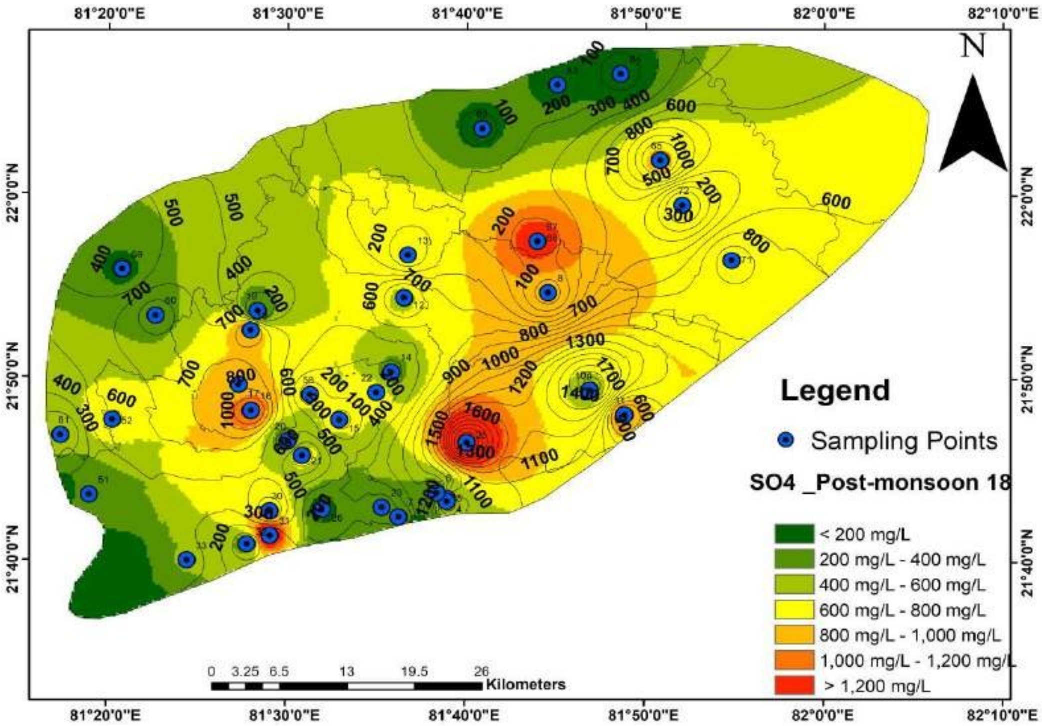


Fig. 14(b). Spatial distribution of Sulphate in groundwater of the study area (Post-monsoon2018-19)

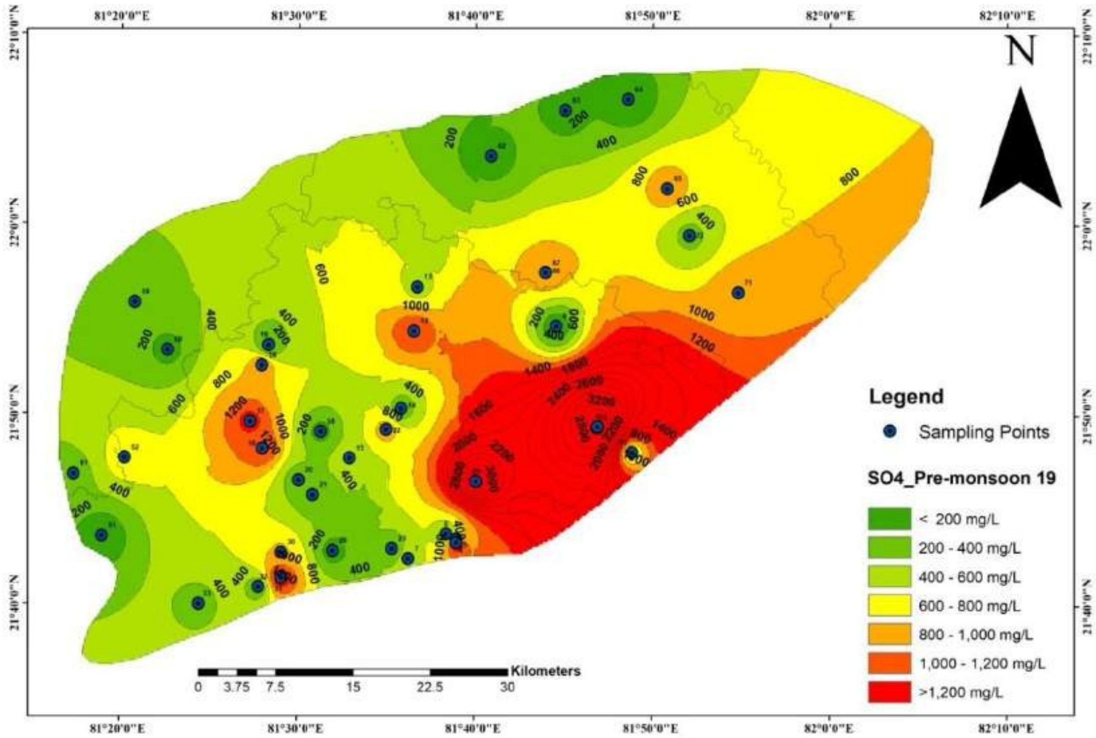


Fig. 14(c). Spatial distribution of Sulphate in groundwater of the study area (Pre-monsoon2019-20)

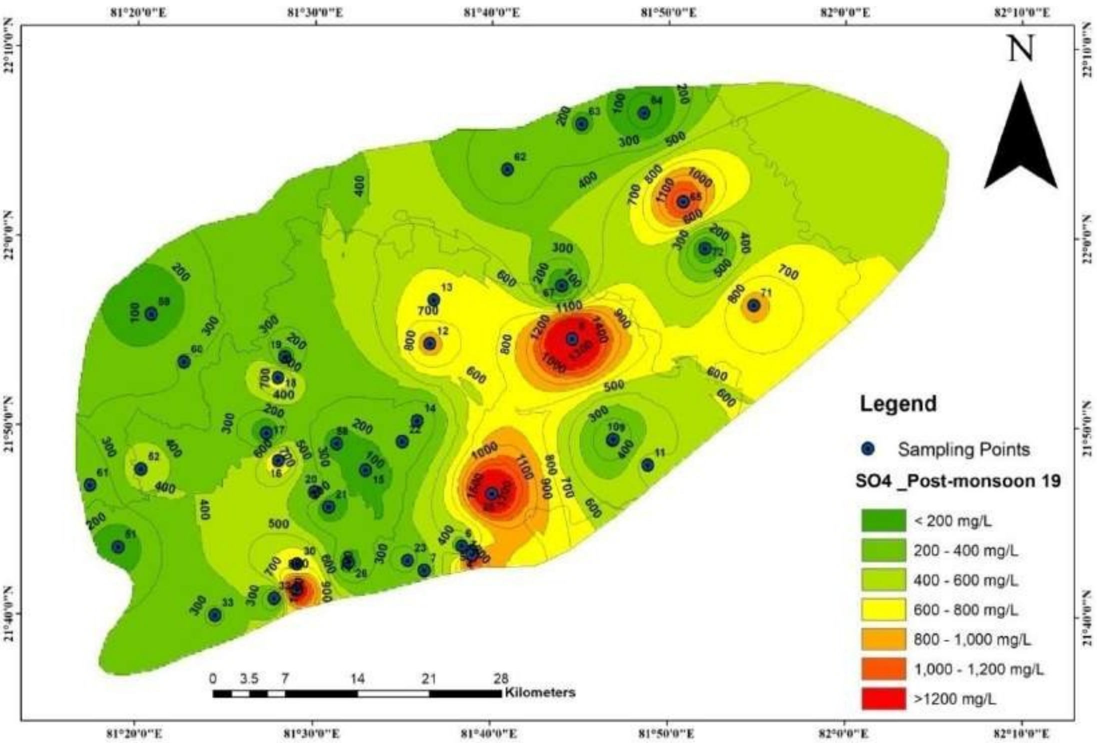


Fig. 14(d). Spatial distribution of Sulphate in groundwater of the study area (Post-monsoon2019-20)

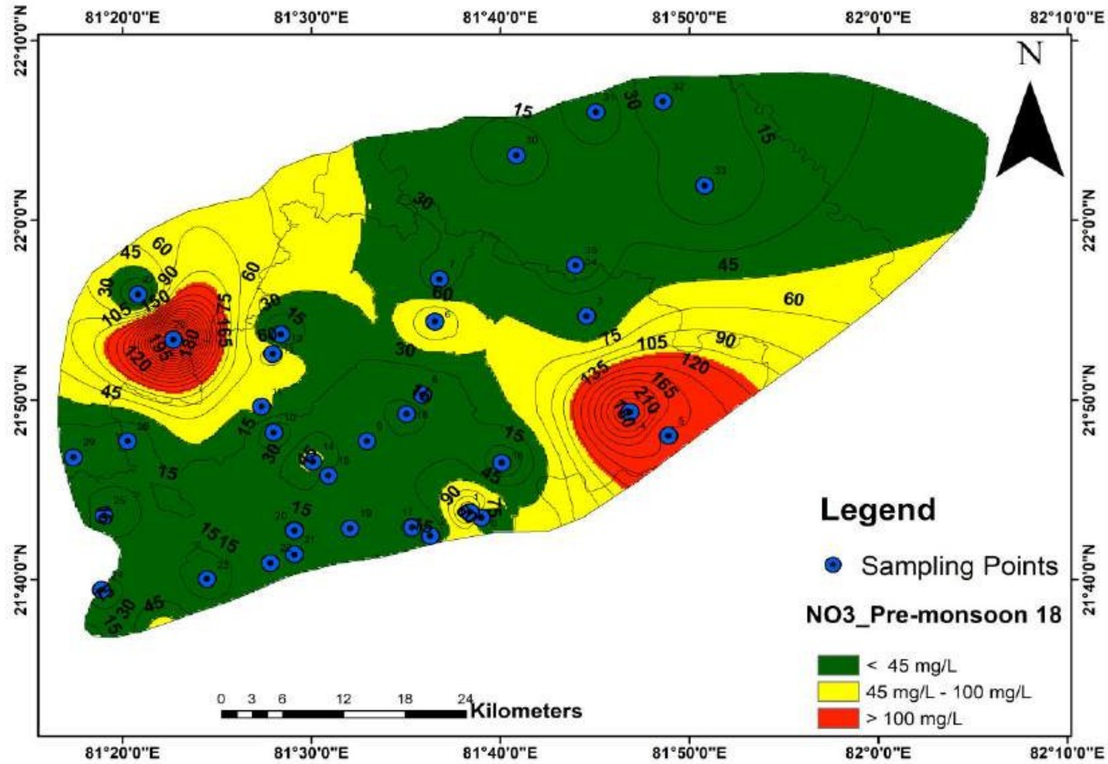


Fig. 15(a). Spatial distribution of Nitrate in groundwater of the study area (Pre-monsoon2018-19)

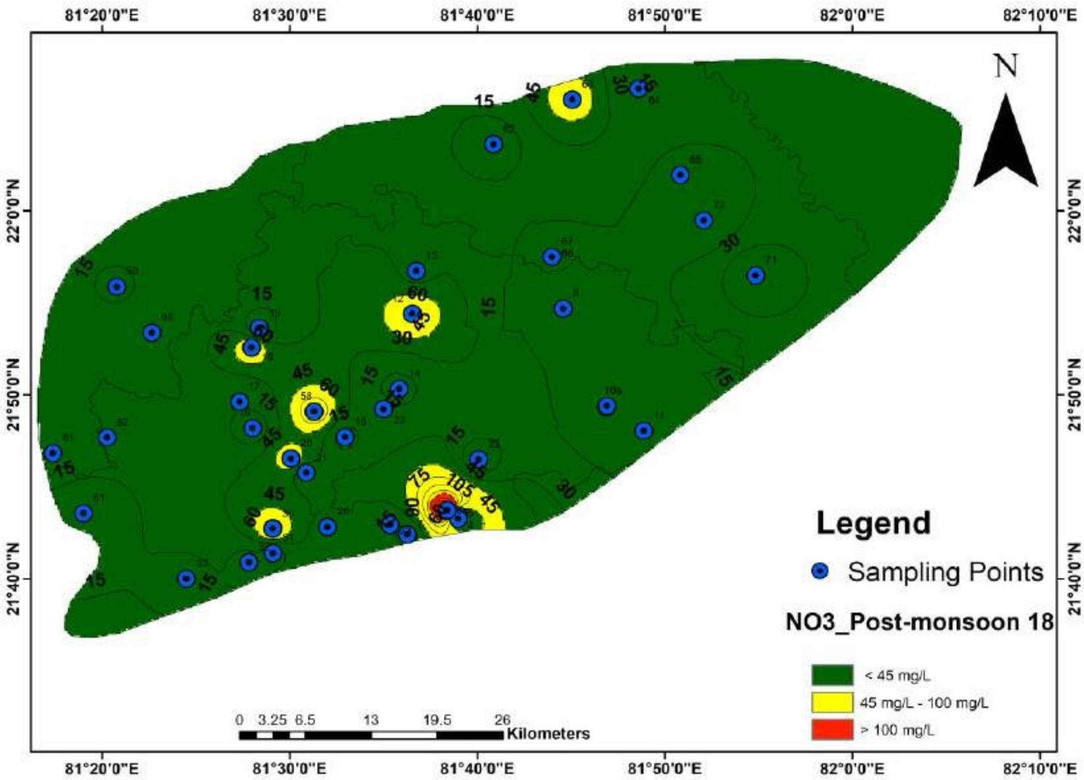


Fig. 15(b). Spatial distribution of Nitrate in groundwater of the study area (Post-monsoon2018-19)

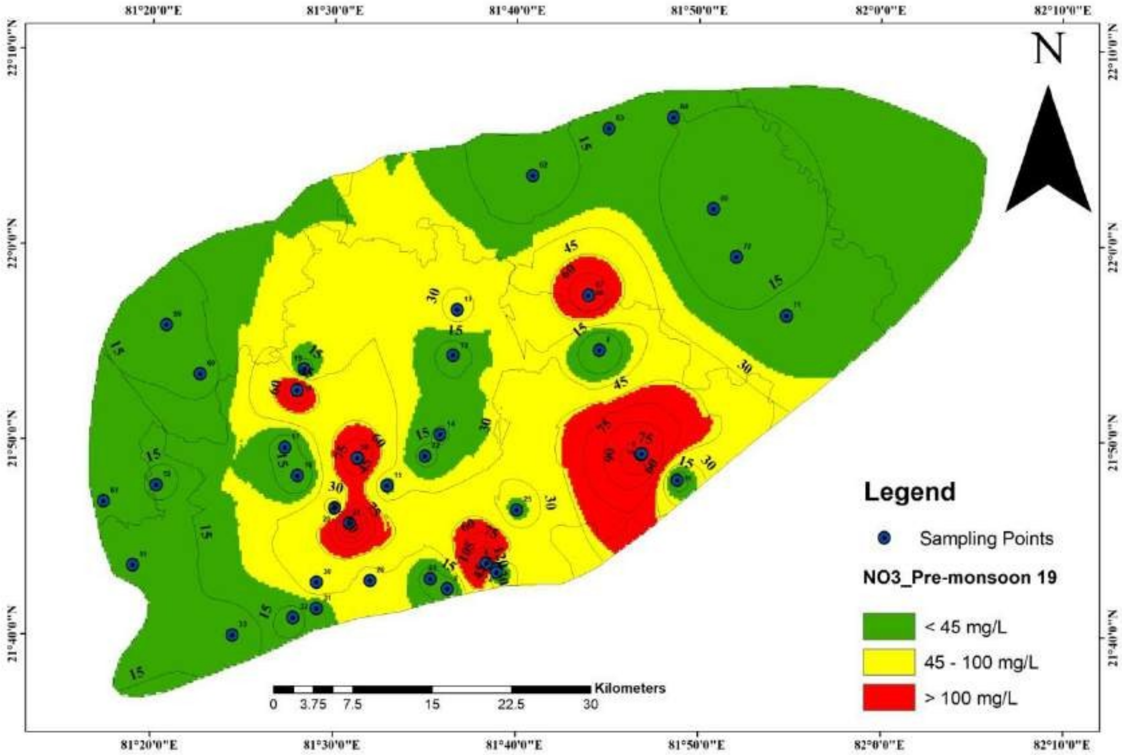


Fig. 15(c). Spatial distribution of Nitrate in groundwater of the study area (Pre-monsoon2019-20)

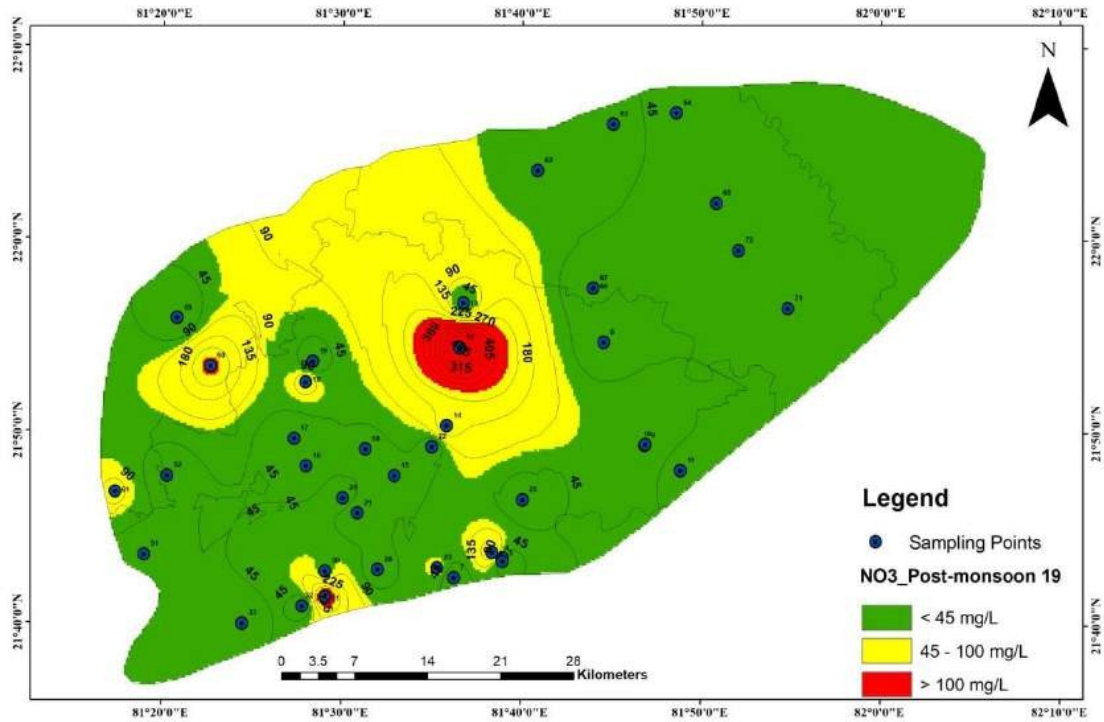


Fig. 15(d). Spatial distribution of Nitrate in groundwater of the study area (Post-monsoon2019-20)

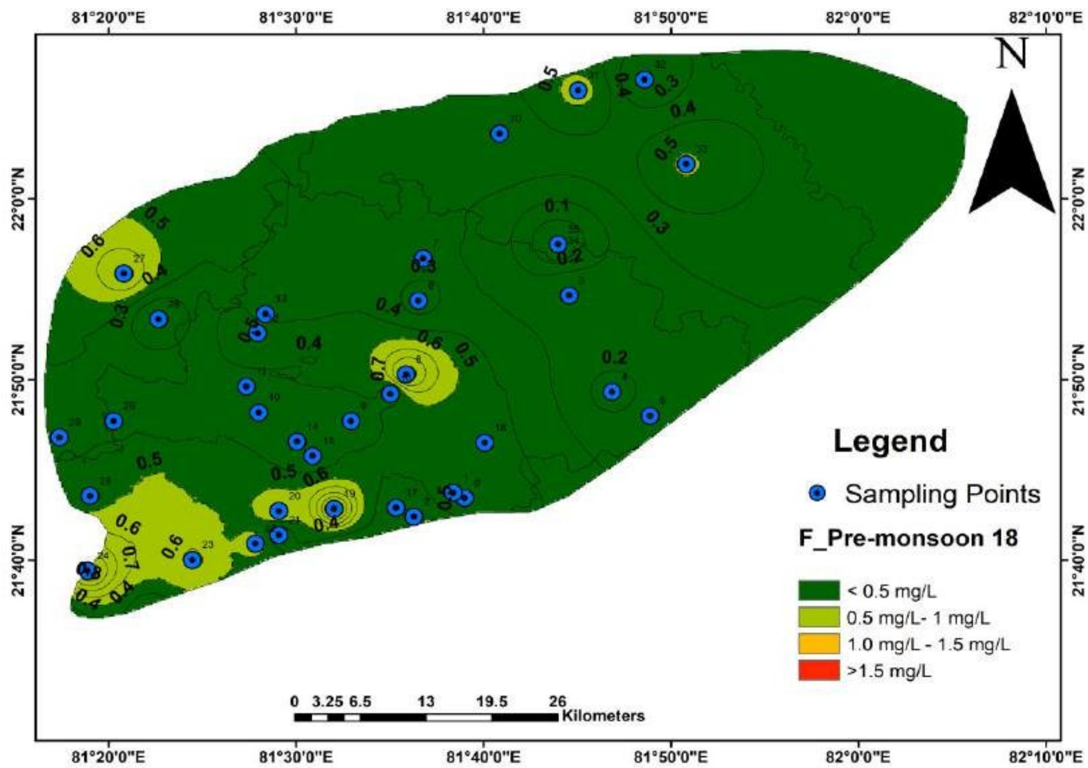


Fig. 16(a). Spatial distribution of Fluoride in groundwater of the study area (Pre-monsoon2018-19)

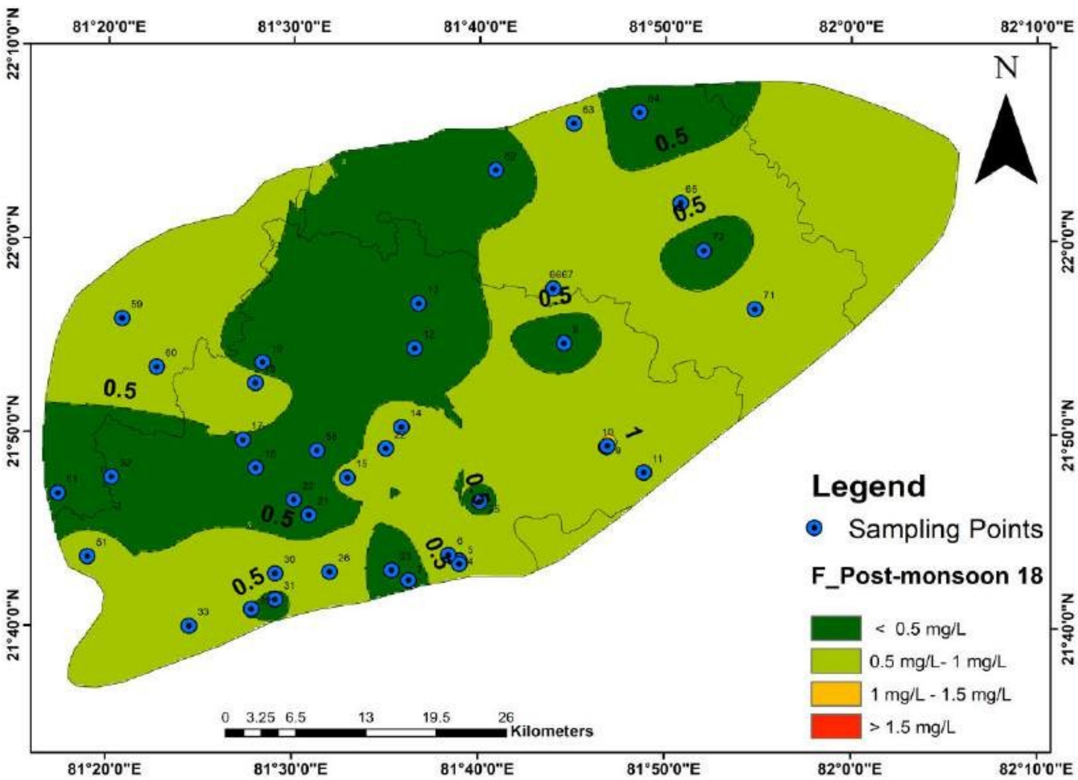


Fig. 16(b). Spatial distribution of Fluoride in groundwater of the study area (Post-monsoon2018-19)

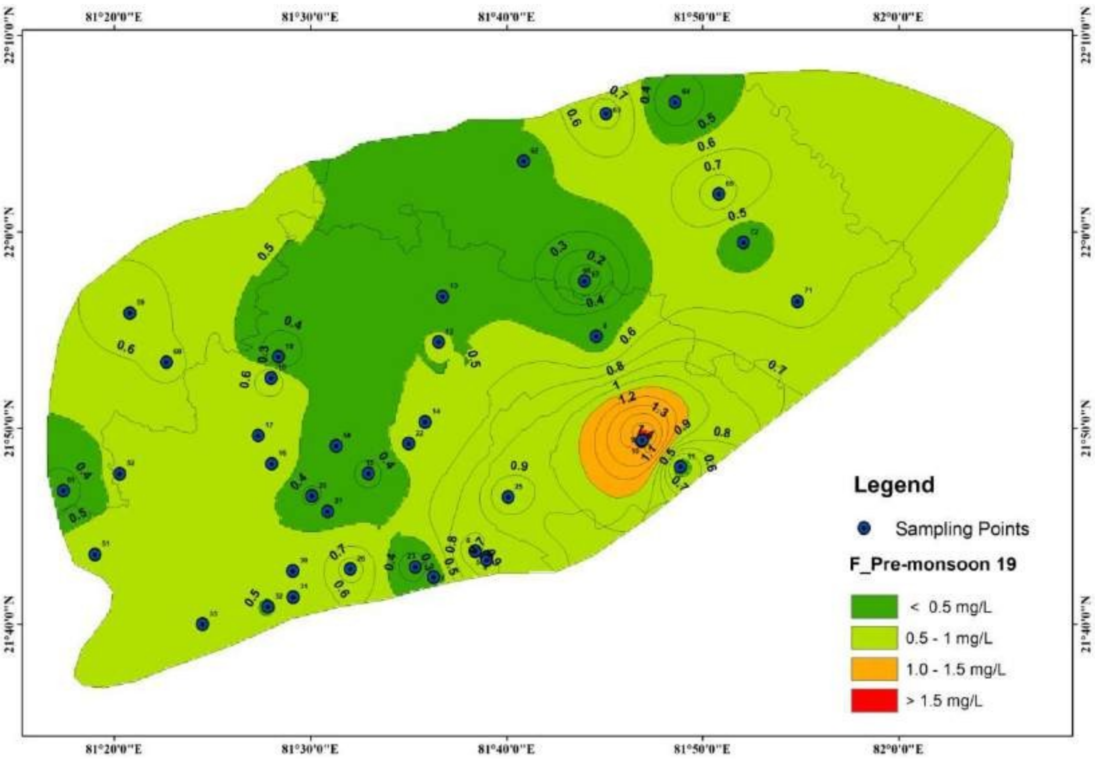


Fig. 16(c). Spatial distribution of Fluoride in groundwater of the study area (Pre-monsoon2019-20)

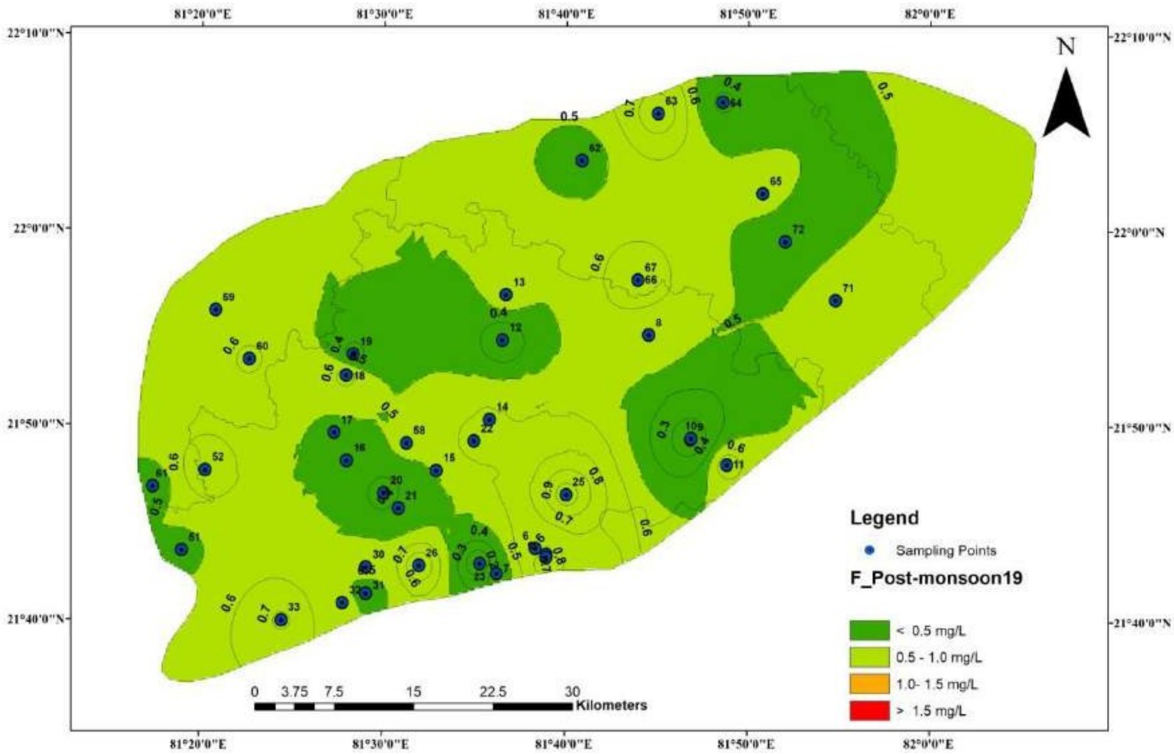


Fig. 16(d). Spatial distribution of Fluoride in groundwater of the study area (Post-monsoon2019-20)

Metal Concentrations

The quality of water is an indispensable concern for mankind since it is directly linked with human welfare. The accumulation of various kinds of pollutants and nutrients through sewage, industrial effluents and agricultural runoff into the water bodies bring about a series of changes in the physicochemical characteristics of water (Raghav and Shrivastava, 2016). The pollutants of living environment are “Hazardous Metals” also termed as “Toxic metals”, are of serious concern that the whole world is facing today because they are not readily degradable in nature and often accumulate through tropic level, aggregate in the animal as well as human bodies. Heavy metals are getting importance for causing a deleterious biological effect and create environmental problems (Praveena et al., 2010). These toxic heavy metals entering the environment may lead to bioaccumulation and biomagnifications. After entering to water bodies, metals accumulate in water, sediments, and biota (Pandey and Singh, 2017). Higher concentrations of heavy metals can form harmful complex compounds, which critically effect different biological functions (Rajbanshi, 2009). Because of their high water solubility, heavy metals can be easily absorbed by living organisms and, due to their mobility in natural water ecosystems and their toxicity to living forms, have been ranked as major inorganic contaminants in surface and ground waters (CWC Report, 2019).Some of the heavy metals are extremely essential to humans, for examples cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in lowconcentrations.

Groundwater samples collected from the study area were filtered immediately through 0.45µm membrane filter by hand operated vacuum pump and preserved with conc. HNO_3 for dissolved metals analysis. All the samples are stored in sampling kits maintained at 4ºC. The concentrations of trace metals (Fe, Mn, Cu, Cr, Ni, Zn, Pb, Cd and As) were analysed using inductively coupled plasma-atomic emission spectrometry (ICP-OES).

The metal concentrations of Fe, Mn, Cu, Cr, Ni, Zn, Pb, Cd and As in groundwater of study area for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 13(a)&(b). Distribution of metal concentrations with depth and season are given in Table 14(a-b) to 22(a-b) and variation of different metal concentrations in pre- and post-monsoon seasons during the year 2018-19 and 2019-20 are given in Fig. 17(a-b) and 18(a-b) respectively.

Table 13(a). Metal concentrations in groundwater samples collected during pre- and post-monsoon season (2018-19).

S. No.	Metals	Minimum	Maximum	Average	Permissible limit
1.	Fe (µ g/L)	76(16)	12220(12215)	989(827)	300
2.	Mn (µg/L)	4.4(2.3)	1293(1397)	72(60)	300
3.	Cu (µg/L)	1.1(1.1)	104(101)	7.9(5.4)	1500
4.	Cr (µ g/L)	3.1(0.7)	31(12)	5.6(4)	50
5.	Ni (µ g/L)	ND(4.4)	12(22)	8.6(8.4)	20
6.	Zn (µg/L)	1.7(ND)	4888(4790)	491(273)	15000
7.	Pb (µg/L)	0.8(0.8)	39(22)	5.7(7.7)	10
8.	Cd (µg/L)	0.3(0.3)	1.2(33)	0.5(2.8)	3
9.	As (µ g/L)	ND(ND)	ND(67.5)	ND(1.44)	50

Table 13(b). Metal concentrations in groundwater samples collected during pre- and post-monsoon season (2019-20).

S. No.	Metals	Minimum	Maximum	Average	Permissible limit
1.	Fe (µ g/L)	30(1)	20090(2540)	834(254)	300
2.	Mn (µg/L)	5.3(ND)	4229(581)	158(39)	300
3.	Cu (µg/L)	ND(ND)	95(29)	8.5(3.5)	1500
4.	Cr (µ g/L)	ND(ND)	339(5.1)	7.9(0.14)	50
5.	Ni (µ g/L)	ND(ND)	212(7)	9.6(0.19)	20
6.	Zn (µg/L)	ND(13)	1313(1278)	59(183)	15000
7.	Pb (µg/L)	ND(ND)	17(338)	2.6(5.7)	10
8.	Cd (µg/L)	ND(0.01)	2.8(2.7)	0.8(0.54)	3
9	As (µ g/L)	ND(ND)	9.8(41)	0.38(8.0)	50

Iron an essential element in human nutrition, is an integral component of cytochromes, porphyrins and metalloenzymes. Iron is an essential constituent in plant metabolism. Deficiency of iron in plants causes chlorosis. The iron values in the ground water of the study area fall within range of 76 to 12220 µg/L during pre-monsoon season and 16 to 12215 µg/L during post-monsoon season of the year 2018-19 and in the range 30 to 20090 µg/L during pre-monsoon season and 1 to 2540 µg/L during post-monsoon season of the year 2019-20. The Bureau of Indian Standards has recommended 300 µg/L as the acceptable limit for iron in drinking water (BIS 2012). It is evident from the results that 54.84% samples of the study area below the acceptable limit of 300 µg/L and 45.16% of the samples exceed the maximum acceptable limit in pre-monsoon season of the year 2018-19. While in post-monsoon season, 61.11% of the samples fall within the acceptable limit and 38.89% of the samples even exceed the maximum acceptable limit [Table 14(a)]. For the year 2019-20, 31% samples fall below the acceptable limit and 69% samples crosses the 300 µg/L as the acceptable limit in pre-monsoon season whereas about 81% samples are below the limit of 300 µg/L in the post-monsoon season [Table 14(b)]. High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soilstrata.

It is a known fact that iron in trace amounts is essential for nutrition. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity. The objection to iron in the distribution system is not due to health reason but to staining of laundry and plumbing fixtures and appearance. Taste and order problems may be caused by filamentous organism that prey on iron compounds (frenothrix, gallionella and leptothrix are called iron bacteria), originating another consumer’s objection (redwater).

Manganese (Mn) is one of the important micronutrient that uptakes by aquatic flora and fauna as well as human being for their proper growth. It occurs naturally in surface but human activities are also responsible for Mn pollution in water (Singh and Kumar, 2017). The concentration of manganese ranges from 4.4 to 1293 µg/L during pre-monsoon season and 2.3 to 1397µg/L during post-monsoon season of the year 2018-19 whereas the concentration of manganese ranges from 5.3 to 4229 µg/L during pre-monsoon season and ND to 581 µg/L during post-monsoon season of the year 2019-20 [Table 15(a-b)]. A concentration of 100 µg/L has been recommended as acceptable limit and 300 µg/L as the permissible limit for drinking water (BIS 2012). It is evident from the results that about 89% of the samples of the study area fall within the acceptable limit 100 µg/L and about 5% of the samples exceed the maximum permissible limit 300 µg/L during pre-monsoon season where as only 1.38% sample crosses the maximum permissible limit of 300 µg/L during post-monsoon season during the year 2018-19 [Table 15(a)]. For the year 2019-20, 88% samples fall below the acceptable limit and 6% samples crosses the permissible limit in pre-monsoon whereas about 93% samples are below the acceptable limit 100 μg/L in the post-monsoon season [Table 15(b)]. Manganese is an essential trace nutrient for plants and animals, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water. In general concentration of manganese in ground water is less than that of iron.

Copper is both essential and toxic to living systems. As an essential metal, copper is required for adequate growth, cardiovascular integrity, lung elasticity, neovascularization, and iron metabolism. Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomachaches, vomiting and diarrhea. Intentionally high uptakes of copper may cause liver and kidney damage and even death. There are scientific articles that indicate a link between long-term exposure to high concentrations of copper and a decline in intelligence with young adolescents. The Bureau of Indian Standards has recommended 50 μg/L as the acceptable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS 2012). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 2011). The concentration of copper ranges from 1.1 to 104 μg/L during pre- monsoon season and 1.1 to 101 μg/L during post-monsoon season of the year 2018-19 whereas it ranges from ND to 95 μg/L during pre-monsoon season and ND to 29 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. It is evident from the results that about 98% of the samples of the study area fall within the acceptable limit of 50 μg/L and none of the samples exceed the maximum permissible limit of 1500 μg/L during pre- monsoon season whereas about 99% samples fall within the acceptable limit during post- monsoon season [Table 16(a)]. Almost, similar trend is observed for the year2019-20.

Chromium (Cr) exists in two forms (III) and (VI). Cr (III) is of low toxicity and the hexavalent form is toxic. After breathing in, chromium (VI) can cause nose irritations, nosebleeds, weakened immune systems, respiratory problems, kidney and liver damage, alteration of genetic material and lung cancer. A concentration of 50 μg/L has been recommended as acceptable limit for drinking water (BIS, 2012). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 2011). The concentration of chromium ranges from 3.1 to 31 μg/L during pre-monsoon season and 0.7 to 12 μg/L during post-monsoon season of the year 2018-19 whereas the concentration of chromium ranges from ND to 339 μg/L during pre-monsoon season and ND to 5.1 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. All the samples of the study area have chromium concentration below 50 μg/L for drinking purpose (BIS, 2012) for both the season of the year 2018-19. But during the year 2019 -20, only 3 % samples crossed the 50 μg/L limit during pre-monsoon season [Table 17(a-b)].

Nickel is released into the environment from a variety of natural and anthropogenic sources. Wastewater from municipal sewage treatment plants also contributes to environmental metal accumulation. In small quantities nickel is essential, but when the uptake is too high it can be a danger to human health. Humans may be exposed to nickel by breathing air, drinking water, eating food or smoking cigarettes. A concentration of 20 μg/L has been recommended as acceptable limit for drinking water (BIS, 2012). The concentration of Nickel ranges from ND to 12 μg/L during pre-monsoon season and 4.4 to 22 μg/L during post-monsoon season of the year 2018-19 whereas it ranges from ND to 212 μg/L during pre-monsoon season and ND to 7 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. About 97% of the samples of the study area have Nickel concentration below 20 μg/L for pre-monsoon season and 99 % during post-monsoon season of the year 2018-19.

Almost same trend is observed in the year 2019-20 [Table 18(a-b)].

Zinc (Zn) is an essential element for both animals and man which is necessary for the functioning of various enzyme systems. The largest natural emission of zinc to water results from erosion. The main anthropogenic sources of zinc are mining, zinc production facilities, iron and steel production, corrosion of galvanized structures, coal and fuel combustion, waste disposal and incineration, and the use of zinc-containing fertilizers and pesticide. Symptoms of zinc toxicity in humans include vomiting dehydration, electrolyte imbalance, abdominal pain, nausea lethargyness, dizziness and lack of muscular co-ordination The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the acceptable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 2012). The concentration of zinc ranges from 1.7 to 4888 μg/L during pre-monsoon season and ND to 4790 μg/L during post-monsoon season of the year 2018-19 whereas the concentration of zinc ranges from ND to 1313 μg/L during pre-monsoon season and 13 to 1278 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. All the samples of the study area have zinc concentration well within 5000 μg/L (acceptable limit) for both of the year [Table 19(a-b)].

Lead (Pb) is known as one of the systemic poisons because it affects various organs and tissues. Pb poisoning is also manifested by muscle aches and joint pain, lung damage, difficulty in breathing, and diseases such as asthma, bronchitis, and pneumonia. Pb poisoning can also damage the immune system, interfering with cell maturation and skeletal growth. The Bureau of Indian Standards has prescribed 10 μg/L lead as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 10 μg/L as guideline value for drinking water (WHO, 2011). The concentration of lead ranges from 0.8 to 39 μg/L during pre-monsoon season and 0.8 to 22 μg/L during post-monsoon season of the year 2018-19 whereas the concentration of lead ranges from ND to 17 μg/L during pre-monsoon season and ND to 338 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. For the year 2018-19, almost all samples fall within the acceptable limit 10 μg/L . In case of year 2019-20, the only 1% samples above the BIS limit for the pre-monsoon and about 6% samples crossed the BIS limit for post-monsoon season [Table20(a-b)].

Cadmium is an element that occurs naturally in the earth's crust. Cadmium is toxic to humans, animals, micro-organisms and plants, however only a small amount of cadmium intake is absorbed by the body and will be stored mainly in bones, liver and, in case of chronic exposure, in kidneys. BIS has prescribed 3 μg/L cadmium as the acceptable limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has also prescribed 3 μg/L as the guideline value for Cd for drinking water (WHO, 2011). The concentration of cadmium ranges from 0.3 to 1.2 μg/L during pre-monsoon season and 0.3 to 33 μg/L during post-monsoon season of the year 2018-19 whereas the concentration ranges from ND to 2.8 μg/L during pre-monsoon season and 0.01 to 2.7 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. For the year 2018-19, almost all samples in the pre-monsoon and 88 % samples in the post-monsoon season fall within the acceptable limit 3 μg/L. In case of year 2019-20, all samples fall within the BIS limit for both the seasons [Table21(a-b)].

Ground water is expected to contain higher arsenic concentrations than surface water. Because of its presence in geological materials, arsenic can be traced in water as originated by natural processes or by industrial activities – industrial waste, arsenical pesticides and smelting operations. Generally, arsenic found in two state – As(+3) and As(+5) in ground water. As(+3) compounds are more toxic than As(+6) compounds. Arsenic compounds are skin and lung carcinogens in humans. The Bureau of Indian Standards has prescribed 10 μg/L arsenic as the acceptable limit and 50 μg/L as permissible limit for drinking water (BIS, 2012). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 2011).The concentration of arsenic was not detected during pre-monsoon season and ND to 67.54 μg/L during post-monsoon season of the year 2018-19 whereas the concentration ranges from ND to 9.78 μg/L during pre-monsoon season and ND to 40.68 μg/L during post-monsoon season of the year 2019-20 [Table 13(a-b)]. During the year 2018-19, only 3% samples for the pre-monsoon season above the permissible limit and all samples fall within the acceptable limit of 10 μg/L in the post-monsoon season. In case of year 2019-20, all samples fall within the acceptable limit during the pre-monsoon season and 74% samples were observed within the acceptable limit but 26% samples were above the acceptable limit but within the permissible limit and no sample exceeded the permissible limit during the post-monsoon season [Table 22(a-b)]..

It is inferred from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron in 69% samples, manganese in 5.6% samples, nickel in 3.2% samples, chromium in 2.8% samples, lead in 5.6% samples, cadmium in 12.5% samples and arsenic in 3.2% samples during the study period.

Table 14(a). Iron distribution in groundwater of the study area for the year 2018-19

S. No.	Fe range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-300	0-20	1,6,7,8,9,10,11,12,13, 14,15,16,18,19,21,23, 27,29,34,37,38,39,40, 43,44,47,49,53,54,57, 61	1,3,4,9,11,13,14,15,16, 17,18,21,23,24,25,26, 27,29,30,32,37,41,42, 43,44,46,50,52,53,56, 57,59,60,61,62,63,64, 65,66,67,68,69,70,72	54.84	61.11
		20-40	50	53		
		>40	41,60,62	-		
2.	>300	0-20	2,3,4,5,17,20,22,24,25, 26,28,30,31,32,33,35, 36,42,45,48,51,52,55, 56,58,59	6,7,8,12,19,20,22,28,31 ,33,34,35,36,38,39,40, 45,47,48,49,51,54,55, 71	45.16	38.89
		20-40	-	2,5,10,58		
		>40	46	-		
Total number of samples			62	72	100	100

Table 14(b). Iron distribution in groundwater of the study area for the year 2019-20.

S. No.	Fe range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-300	0-20	2,3,4,5,8,9,10,20,33,36, 44,83,54,55,56,58,59, 63,69,71,72	3,4,5,6,7,9,10,11,12,13, 14,15,16,17,21,22,23, 24,25,26,27,29,30,31, 32,33,34,35,36,37,38, 42,43,44,45,47,49,51, 52,53,54,55,56,57,59, 61,64,65,66,67,68,70, 71,72	30.55	80.55
		20-40	-	50		
		>40	46	41,60,62		
2.	>300	0-20	1,6,7,11,12,13,14,15,16 ,17,18,19,21,22,23,24, 25,26,27,28,29,30,31, 32,34,35,37,38,39,40, 42,43,45,47,48,49,51, 52,53,57,61,64,65,66, 67,68,70	1,2,8,18,19,20,28,39,40 ,48,58,63, 69	69.44	19.44
		20-40	50	-		
		>40	41,60,62	46		
Total number of samples			72	72	100	100

Table 15(a). Manganese distribution in groundwater of the study area for the year 2018-19.

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Mn range, μg/L</th><th rowspan="2">Depth range, m</th><th colspan="2">Sample numbers</th><th colspan="2">Areal distribution, %</th></tr>
<tr><th>Pre-monsoon</th><th>Post-monsoon</th><th>Pre-monsoon</th><th>Post-monsoon</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">0-100</td><td>0-20</td><td>1,2,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,20,21,23,24,25,26,29,30,31,32,33,34,35,37,38,39,40,42,43,44,45,47,48,49,50,51,53,54,55,56,57,58,59,61</td><td>1,3,4,6,9,10,11,12,13,14,15,17,18,20,21,22,23,24,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,43,44,45,46,47,48,49,50,51,52,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72</td><td rowspan="3">88.71</td><td rowspan="3">87.50</td></tr>
<tr><td>20-40</td><td>50</td><td>2,53,58</td></tr>
<tr><td>>40</td><td>41,46,60,62</td><td>-</td></tr>
<tr><td rowspan="3">2.</td><td rowspan="3">101-300</td><td>0-20</td><td>13,22,27,36</td><td>8,16,19,25,42,54</td><td rowspan="3">6.45</td><td rowspan="3">11.11</td></tr>
<tr><td>20-40</td><td>-</td><td>5,10</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">3.</td><td rowspan="3">>300</td><td>0-20</td><td>5,28,52</td><td>7</td><td rowspan="3">4.84</td><td rowspan="3">1.38</td></tr>
<tr><td>20-40</td><td>-</td><td>-</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td colspan="3">Total number of samples</td><td>62</td><td>72</td><td>100</td><td>100</td></tr>
</table>

Table 15(b). Manganese distribution in groundwater of the study area for the year 2019-20.

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Mn range, μg/L</th><th rowspan="2">Depth range, m</th><th colspan="2">Sample numbers</th><th colspan="2">Areal distribution, %</th></tr>
<tr><th>Pre-monsoon</th><th>Post-monsoon</th><th>Pre-monsoon</th><th>Post-monsoon</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">0-100</td><td>0-20</td><td>3,4,5,6,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,34,35,36,37,38,39,40,42,43,44,45,47,48,49,51,52,53,55,57,58,59,61,63,64,65,66,68,69,70,71,72</td><td>1,2,3,4,5,6,9,10,11,12,13,14,15,16,17,18,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,42,43,45,47,48,49,51,52,53,54,55,56,57,58,59,61,63,64,65,66,67,68,69,70,71, 72</td><td rowspan="3">87.5</td><td rowspan="3">93.05</td></tr>
<tr><td>20-40</td><td>50</td><td>50</td></tr>
<tr><td>>40</td><td>41,46,60,62</td><td>41,46,60,62</td></tr>
<tr><td rowspan="3">2.</td><td rowspan="3">101-300</td><td>0-20</td><td>7,32,54,56,67</td><td>19,20,44</td><td rowspan="3">6.94</td><td rowspan="3">4.17</td></tr>
<tr><td>20-40</td><td>-</td><td>-</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">3.</td><td rowspan="3">>300</td><td>0-20</td><td>1,2,10,33</td><td>7,8</td><td rowspan="3">5.55</td><td rowspan="3">2.77</td></tr>
<tr><td>20-40</td><td>-</td><td>-</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td colspan="3">Total number of samples</td><td>72</td><td>72</td><td>100</td><td>100</td></tr>
</table>

Table 16(a). Copper distribution in groundwater of the study area for the year 2018-19.

S. No.	Cu range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-50	0-20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,47,48,49,51,52,53,54,56,57,58,59,61	1,3,4,6,7,8,9,11,12,13,14,15,16,17,18,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72	96.77	98.61
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	51-1500	0-20	25,55	19	3.23	1.38
		20-40	-	-		
		>40	-	-		
3.	>1500	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 16(b). Copper distribution in groundwater of the study area for the year2019-20.

S. No.	Cu range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-50	0-20	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,47,48,49,50,51,52,53,54,55,56,57,58,59,61,63,64,65,66,67,68,69,70,71,72	1,3,4,6,7,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72	98.61	100
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	51-1500	0-20	7	-	1.38	-
		20-40	-	-		
		>40	-	-		
3.	>1500	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 17(a). Chromium distribution in groundwater of the study area for the year 2018-19.

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Cr range, µg/L</th><th rowspan="2">Depth range, m</th><th colspan="2">Sample numbers</th><th colspan="2">Areal distribution, %</th></tr>
<tr><th>Pre-monsoon</th><th>Post-monsoon</th><th>Pre-monsoon</th><th>Post-monsoon</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">0-50</td><td>0-20</td><td>1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,47,48,49,51,52,53,54,55,56,57,58,59,61</td><td>1,3,4,6,7,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72</td><td rowspan="3">100</td><td rowspan="3">100</td></tr>
<tr><td>20-40</td><td>50</td><td>2,5,10,53,58</td></tr>
<tr><td>>40</td><td>41,46,60,62</td><td>-</td></tr>
<tr><td rowspan="3">2.</td><td rowspan="3">>50</td><td>0-20</td><td>-</td><td>-</td><td rowspan="3">-</td><td rowspan="3">-</td></tr>
<tr><td>20-40</td><td>-</td><td>-</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td colspan="3">Total number of samples</td><td>62</td><td>72</td><td>100</td><td>100</td></tr>
</table>

Table 17(b). Chromium distribution in groundwater of the study area for the year 2019-20.

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Cr range, µg/L</th><th rowspan="2">Depth range, m</th><th colspan="2">Sample numbers</th><th colspan="2">Areal distribution, %</th></tr>
<tr><th>Pre-monsoon</th><th>Post-monsoon</th><th>Pre-monsoon</th><th>Post-monsoon</th></tr>
<tr><td rowspan="3">1.</td><td rowspan="3">0-50</td><td>0-20</td><td>1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,42,43,44,45,47,48,49,51,52,53,54,55,56,57,58,59,61,63,64,65,66,67,68,69,70,71,72</td><td>1,3,4,6,7,8,9,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71,72</td><td rowspan="3">97.22</td><td rowspan="3">100</td></tr>
<tr><td>20-40</td><td>50</td><td>2,5,10,53,58</td></tr>
<tr><td>>40</td><td>41,46,60,62</td><td>-</td></tr>
<tr><td rowspan="3">2.</td><td rowspan="3">>50</td><td>0-20</td><td>72</td><td>-</td><td rowspan="3">2.77</td><td rowspan="3">-</td></tr>
<tr><td>20-40</td><td>10</td><td>-</td></tr>
<tr><td>>40</td><td>-</td><td>-</td></tr>
<tr><td colspan="3">Total number of samples</td><td>72</td><td>72</td><td>100</td><td>100</td></tr>
</table>

Table 18(a). Nickel distribution in groundwater of the study area for the year 2018-19.

S. No.	Ni range, μg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-20	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,49, 50,51,52,54,55,56,57, 59,60,61,62,63,64,65, 66,67,68,69,70,71,72	96.77	98.61
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	>20	0-20	-	48	3.23	1.38
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 18(b). Nickel distribution in groundwater of the study area for the year 2019-20.

S. No.	Ni range, μg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-20	0-20	1,2,3,4,5,6,7,8,9,11,12, 13,14,15,16,17,18,19, 20,21,22,23,24,25,26, 27,28,29,30,31,32,33, 34,35,36,37,38,39,40, 42,43,44,45,47,48,49, 51,52,53,54,55,56,57, 58,59,61,63,64,65,66, 67,68,69,70, 71,72	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,48, 49,50,51,52,54,55,56, 57,59,60,61,62,63,64, 65,66,67,68,69,70,71, 72	98.61	100
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	>20	0-20	10	-	1.38	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 19(a). Zinc distribution in groundwater of the study area for the year 2018-19.

S. No.	Zn range, μg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-5000	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,48, 49,50,51,52,54,55,56, 57,59,60,61,62,63,64, 65,66,67,68,69,70,71, 72	100	100
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	5001-15000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>15000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 19(b). Zinc distribution in groundwater of the study area for the year 2019-20.

S. No.	Zn range, μg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-5000	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61,63,64,65, 66,67,68,69,70,71,72	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,48, 49,50,51,52,54,55,56, 57,59,60,61,62,63,64, 65,66,67,68,69,70,71, 72	100	100
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	5001-15000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>15000	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 20(a). Lead distribution in groundwater of the study area for the year 2018-19.

S. No.	Pb range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-10	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,49, 50,51,52,54,55,56,57, 59,60,61,62,63,64,65, 66,67,68,69,70,71,72	100	98.61
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	>10	0-20	-	48	-	1.39
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 20(b). Lead distribution in groundwater of the study area for the year 2019-20.

S. No.	Pb range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-10	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,29,30,31,32,33, 34,35,36,37,38,39,40, 42,43,44,45,47,48,49, 51,52,53,54,55,56,57, 58,59,61,63,64,65,66, 67,68,69,70, 71,72	3,4,6,7,8,9,11,12,13,14, 15,16,17,18,19,20,21, 22,23,24,25,26,27,28, 29,30,31,32,33,34,35, 36,38,39,41,42,43,44, 45,46,47,48,49,50,51, 52,54,55,56,57,60,61, 62,63,64,65,66,67,68, 69,70,71,72	98.61	94.44
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	>10	0-20	28	1,37,40,59	1.38	5.55
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 21(a). Cadmium distribution in groundwater of the study area for the year 2018-19.

S. No.	Cd range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-3	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61	1,3,4,6,7,8,9,11,12,14, 15,16,17,19,20,21,22, 23,24,26,28,29,30,32, 33,34,35,36,37,38,39, 40,41,43,44,45,46,47, 49,51,52,54,55,56,57, 59,60,61,62,63,64,65, 66,67,68,69,70,71,72	100	87.5
		20-40	50	2,5,10,58		
		>40	41,46,60,62	-		
2.	>3	0-20	-	13,18,25,27,31,42,48, 50	-	12.5
		20-40	-	53		
		>40	-	-		
Total number of samples			62	72	100	100

Table 21(b). Cadmium distribution in groundwater of the study area for the year 2019-20.

S. No.	Cd range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-3	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 40,42,43,44,45,47,48, 49,51,52,53,54,55,56, 57,58,59,61,63,64,65, 66,67,68,69,70,71,72	1,3,4,6,7,8,9,11,12,13, 14,15,16,17,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33,34, 35,36,37,38,39,40,41, 42,43,44,45,46,47,48, 49,50,51,52,54,55,56, 57,59,60,61,62,63,64, 65,66,67,68,69,70,71, 72	100	100
		20-40	50	2,5,10,53,58		
		>40	41,46,60,62	-		
2.	>3	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

Table 22(a). Arsenic distribution in groundwater of the study area for the year 2018-19.

S. No.	As range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-10	0-20	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18, 19,20,21,22,23,24,25, 26,27,28,29,30,31,32, 33,34,35,36,37,38,39, 42,44,45,47,48,49,51, 52,53,54,55,56, 57,58, 59,61	1,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19, 20,21,22,23,24,25,26, 27,28,29,30,31,32,33, 34,35,36,37,38,39,40, 41,42,43,44,45,46,47, 48,49,50,51,52,53,54, 55,56,57,59,60,61,62, 63,64,65,66,67,68,69, 70,71, 72	96.78	100
		20-40	50	2,58		
		>40	41,46,60,62	-		
2.	11-50	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
3.	>50	0-20	40,43	-	3.22	-
		20-40	-	-		
		>40	-	-		
Total number of samples			62	72	100	100

Table 22(b). Arsenic distribution in groundwater of the study area for the year 2019-20.

S. No.	As range, µg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	0-10	0-20	1,2,3,4,5,6,7,8,9,11,12, 13,14,15,16,17,18,19, 20,21,22,23,24,25,26, 27,28,29,30,31,32,33, 34,35,36,37,38,39,40, 42,43,44,45,47,48,49, 51,52,54,55,56,57,59, 60,61,62,63,64,65,66, 67,68,69,70,71, 72	1,3,4,6,7,8,9,11,12,13, 14,15,17,18,19,23,24, 25,26,27,28,29,30,32, 33,34,36,37,38,39,40, 41,42,43,44,45,47,48, 49,51,52,54,56,57,58, 59,60,62,63,65,66,68, 69,71,72	100	73.61
		20-40	50	2,58		
		>40	41,46,60,62	-		
2.	11-50	0-20	-	5,7,8,9,10,16,20,21,22, 31,35,50,53,55,61,64, 67,70	-	26.38
		20-40	-	-		
		>40	-	46		
3.	>50	0-20	-	-	-	-
		20-40	-	-		
		>40	-	-		
Total number of samples			72	72	100	100

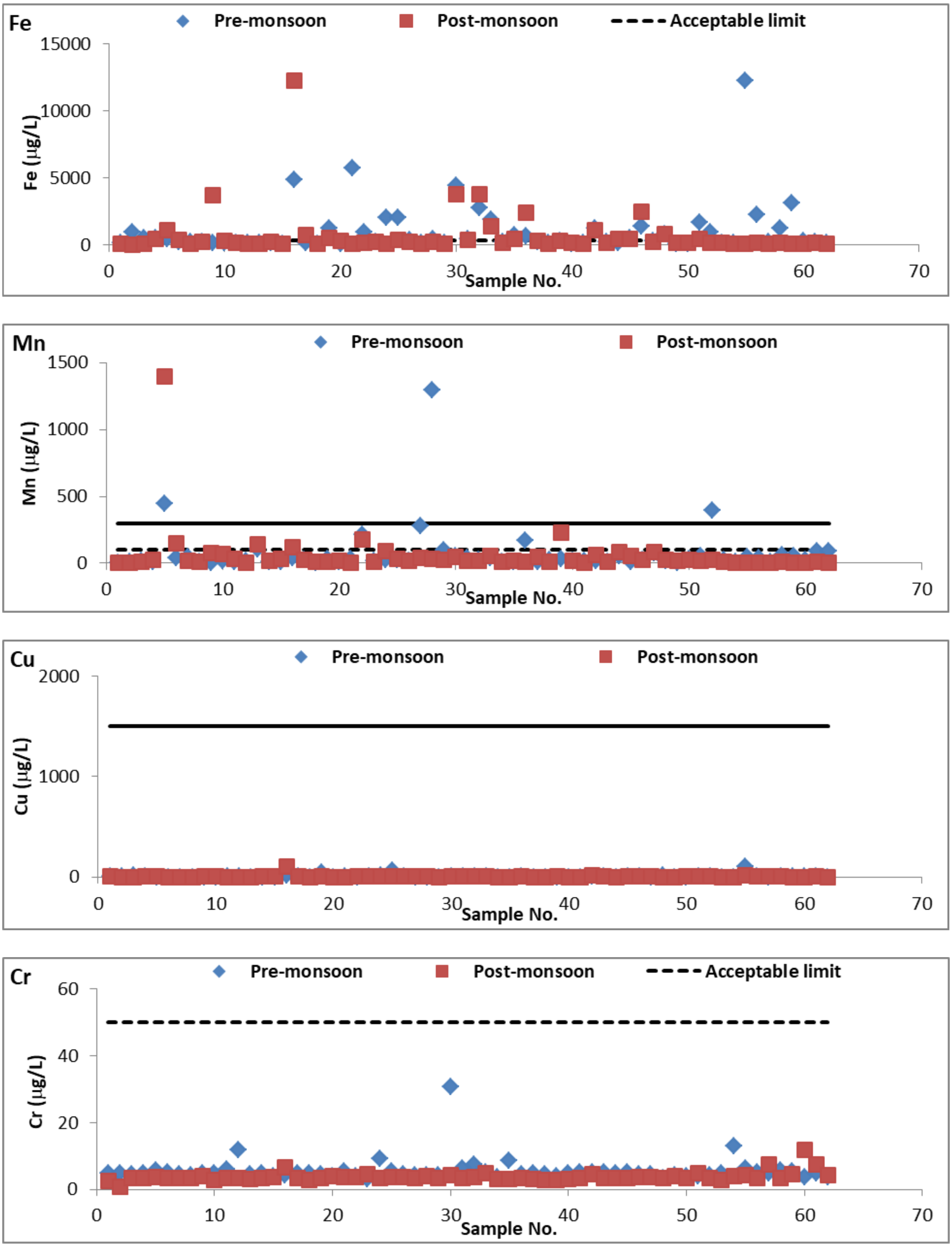


Fig. 17(a). Variation of Fe, Mn, Cu and Cr in groundwater of the study area for the year2018-19

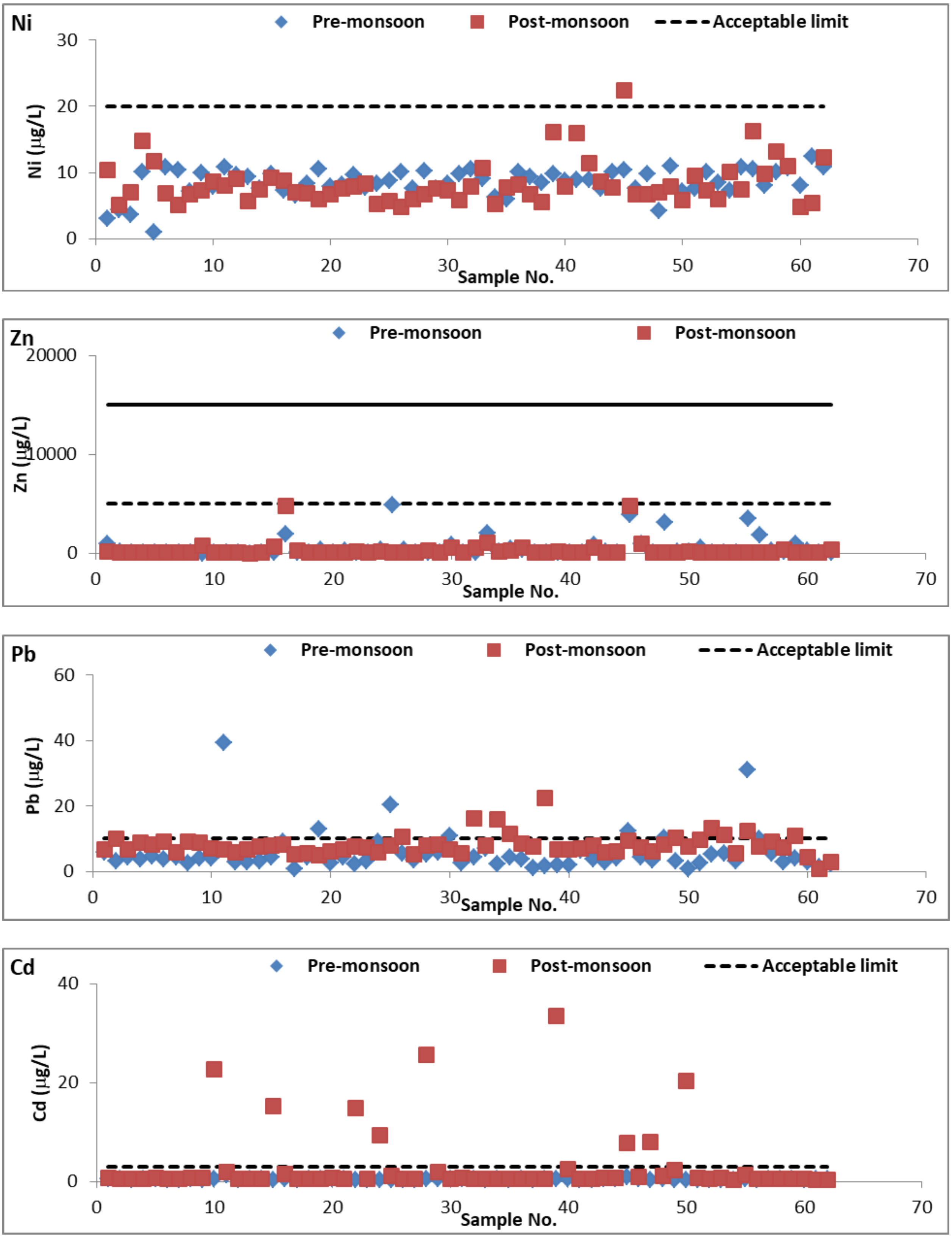


Fig. 17(b). Variation of Ni, Zn, Pb and Cd in groundwater of the study area for the year 2018-19

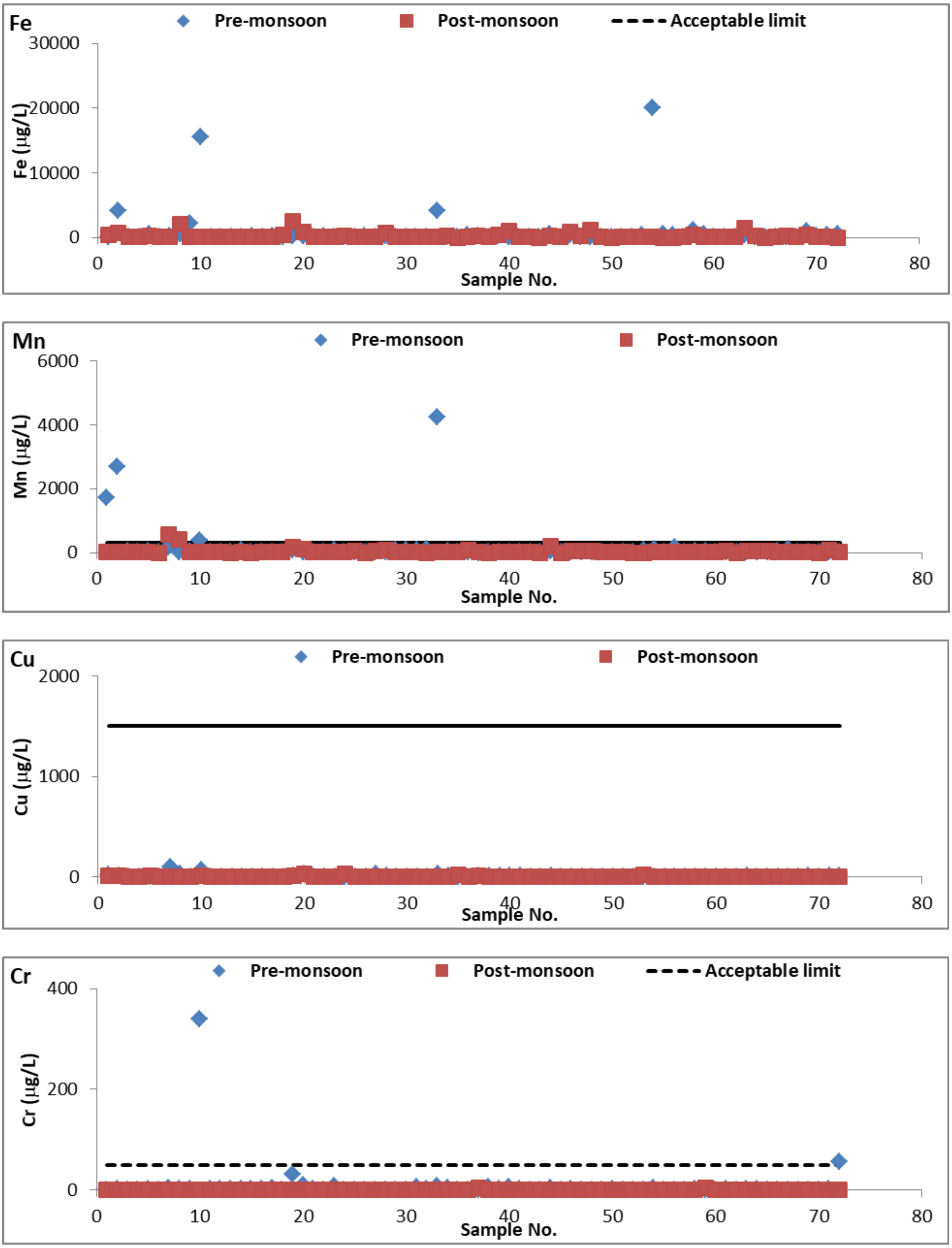


Fig. 18(a). Variation of Fe, Mn, Cu and Cr in groundwater of the study area for the year2019-20

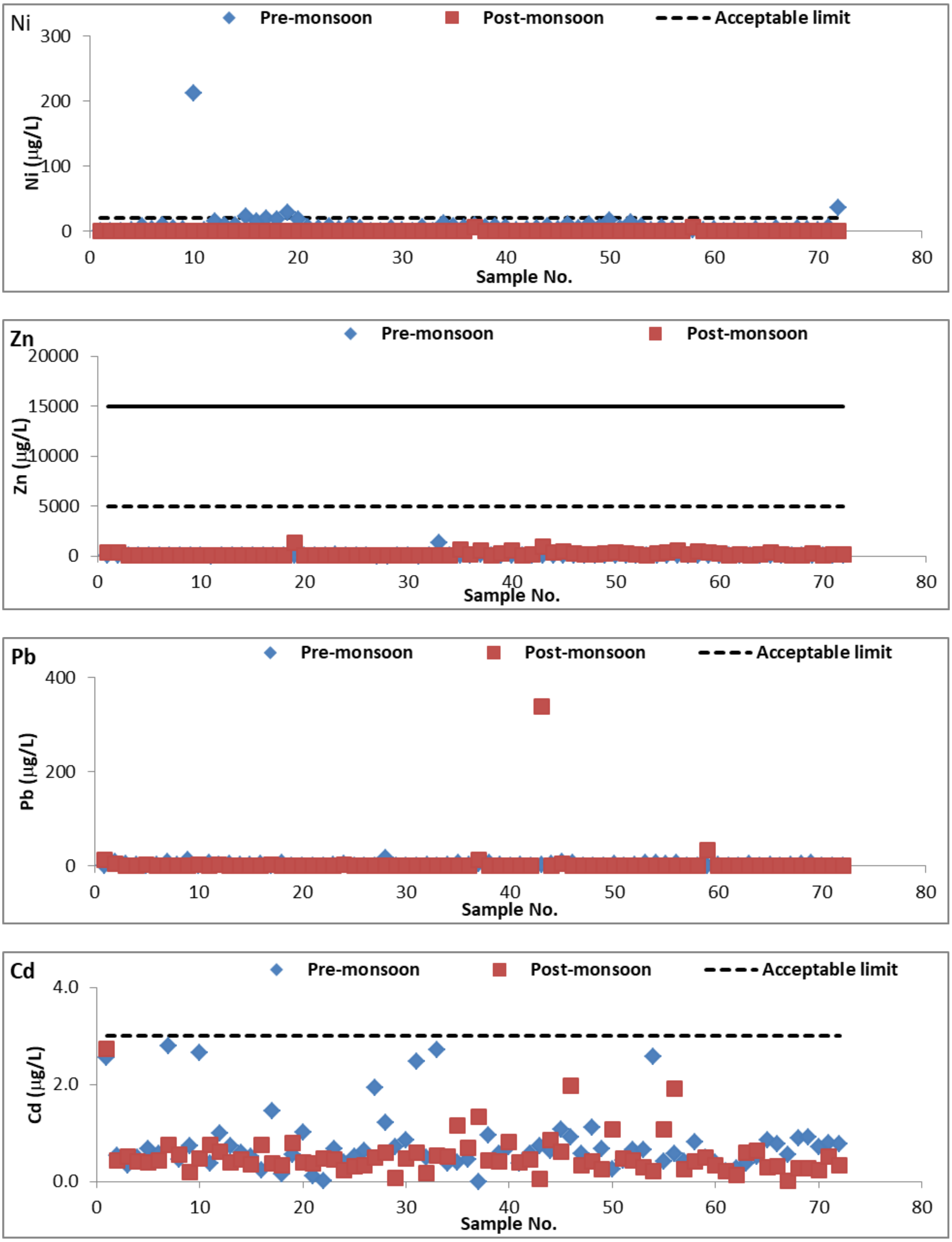


Fig. 18(b). Variation of Ni, Zn, Pb and Cd in groundwater of the study area for the year 2019-20

5.2 Water Quality Evaluation for IrrigationPurpose

Water quality plays an important role in irrigated agriculture. Many problems arise during inefficient management of water for agriculture use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Under good soil and water management practices, good quality water has the ability to cause maximum yield. The quality of irrigation water is assessed by the following characteristics:

- Salinity
- Relative Proportion of Sodium to other Cations(SAR)
- Residual Sodium Carbonate(RSC)
- Heavymetals

Salinity

Salinity is expressed in terms of total dissolved solids (TDS) and thereby electrical conductivity (EC). If the salt concentration in water increases, the soil salinity also increases, it is difficult for plants to extract water. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solid content of the residual water in the root zone also has to be maintained within limits by proper leaching. The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 23. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinitylevels.

Table .23. Safe limits of electrical conductivity for irrigation water

S.No.	Nature of soil	Crop growth	Upper permissible safe limit ofEC, µS/cm
1.	Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately welldrained	Semi-tolerant	1500
		Tolerant	2000
2.	Having textured soils having clay contents of 20-30% soils that arewell drained internally and have good surface drainagesystem	Semi-tolerant	2000
		Tolerant	4000
3.	Medium textured soils having clay 10-20%internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4.	Light textured soils having clay less than 10% soil that have excellent internally and surface drainagesystem	Semi-tolerant	6000
		Tolerant	8000

Source: CGWB and CPCB (2000).

Relative Proportion of Sodium to other Cations

The clay minerals in the soil absorb divalent cations, like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conductive for plant growth. Sodium reacts with soil to reduce its permeability. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards,1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} x100$$

Where all ionic concentrations are expressed in milliequivalent per liter.Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

Residual Sodium Carbonate

Water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate, changing the residual water to high sodium water with sodium bicarbonate in solution. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe forirrigation.

The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 24. The values of sodium percentage (Na%), SAR and RSC were calculated for ground water samples collected from different sources in the different seasons and are given in Table 25(a-b). The electrical conductivity values in the study area varies widely from 570 to 4898 μS/cm during pre-monsoon season and 364 to 8944 μS/cm during post-monsoon season of the year 2018-19 and from 357 to14914 μS/cm during pre-monsoon season and 413 to 5118 μS/cm during post-monsoon season of the year 2019-20. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

The values of SAR in the ground water of the study area ranged from 0.19 to 4.26 during pre-monsoon season and 0.18 to 3.69 during post-monsoon season of the year 2018-19 and from 0.20 to 25.76 during pre-monsoon season and 0.25 to 3.75 cm during post-monsoon season of the year 2019-20. The sodium percentage in the study area was found to vary from from 4.48 to 55.76 during pre-monsoon season and 6.89 to 49.17 during post-monsoon season of the year 2018-19 and from 6.12 to 74.04 during pre-monsoon season and 5.89to 46.12 during post-monsoon season of the year 2019-20. Only one sample exceeds the recommended value of percentage of sodium of 60% for irrigation during pre-monsoon seasonandisnotsuitableforirrigationpurpose.Almost all samples have SAR values below 10 indicating excellent quality for irrigation purpose. Almost all of the samples were observed having RSC value below 1.25 suggesting suitability for irrigation purpose.

Table 24. Guidelines for evaluation of irrigation water quality

Water class	Na, %	EC, μS/cm	SAR	RSC, meq/l
Excellent	< 20	< 250	< 10	< 1.25
Good	20-40	250-750	10-18	1.25-2.0
Medium	40-60	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	> 26	2.5-3.0
Very bad	> 80	> 4000	> 26	> 3.0

Source: CGWB and CPCB (2000).

5.3 Classification ofGroundwater

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram and U.S. Salinity Laboratory classification have been used in the present study to classify the ground water of the study area. Piper trilinear diagram (Piper, 1944) and Chadha's diagram (Chadha, 1999) are used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) has been used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop.

Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. The chemical analysis data of ground water samples of the study area have been plotted on trilinear diagram for both the surveys for the year 2018-19 and 2019-20 [Fig. 19(a-d)]. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-Cl-SO_4 or Ca-Mg-CO_3-HCO_3 hydrochemical facies in both pre- and post-monsoon seasons during the study peroid.

Chadha's diagram

Modified version of the piper trilinear diagram is developed by Chadha (1999). In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plottings from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1. Alkaline earth exceeds alkalimetals.
2. Alkali metals exceed alkalineearth.
3. Weak acidic anions exceed strong acidicanions.
4. Strong acidic anions exceed weak acidicanions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. The position of data pointsin the diagram represent Ca^{2+} -Mg^{2+}-HCO_3^- type, Ca^{2+} -Mg^{2+}- dominant HCO_3^- type, or HCO_3^- - dominant Ca^{2+} -Mg^{2+}- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram representsCa^{2+} -Mg^{2+}-Cl^- type, Ca^{2+} -Mg^{2+}- dominant Cl^- - type or Cl^- - dominant Ca^{2+} -Mg^{2+}- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent Na^+-Cl^-- type, Na_2SO_4-type, Na^+-dominant Cl^- -type, or Cl^--dominant Na^+-typewaters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent Na^+- HCO_3^- -type,Na^+-dominantHCO_3^--type,orHCO_3^--dominantNa^+-typewaters.

The chemical analysis data of ground water samples of the study area have been plotted using Chadha's diagram for both the surveys for the year 2018-19 and 2019-20 [Fig. 20(a-d)]. It is evident from the results that majority of the samples of the study area belong to Ca-Mg-Cl-SO_4 or Ca-Mg-CO_3-HCO_3 hydrochemical facies in both pre- and post-monsoon seasons during the study peroid.

U. S. Salinity Laboratory Classification

Sodium concentration plays an important role in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The U.S. Regional Salinity Laboratory has developed a diagram for use in studying the suitability of ground water for irrigation purposes with reference to sodium adsorption ratio (SAR) as an index for sodium hazard S and electrical conductivity (EC) of water expressed in µS/cm as an index of salinity hazardC.

The chemical analysis data of ground water samples of the study area has been analysed as per U.S. Salinity Laboratory classification for the groundwater quality data [Fig. 21(a-d)]. It is evident from the results that the majority of ground water samples of the study area falls under water types C3-S1 followed by C2-S1 in pre-and post-monsoon seasons [Table 26(a-b)]. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. The C2-S1 type water (medium salinity and low SAR) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

Table 25(a). SAR, Na% and RSC values in ground water of the study area (Pre- and Post-monsoon 2018-19)

S.No.	Sample Code	Location	Source	Pre-monsoon			Post-monsoon		
				SAR	Na (%)	RSC	SAR	Na (%)	RSC
1	BMT-1	Berla	BW	0.39	11.31	-2.10	0.50	13.14	-3.17
2	BMT-1(Pz)	Berla	PzW				0.86	20.53	-1.58
3	BMT-2	Beejabhat	OW	1.34	32.62	-5.17	1.34	35.09	-4.36
4	BMT-3	Balsamund	BW	1.15	17.31	-12.58	0.89	12.97	-15.21
5	BMT-3(Pz)	Balsamund	PzW				1.10	11.31	-37.12
6	BMT-4	Pindri	OW	1.04	24.85	-13.96	1.32	31.21	-10.80
7	BMT-5	Bemetara	OW	1.38	24.38	-7.00	1.43	25.40	-7.06
8	BMT-6	Sambalpur	OW	1.08	14.25	-19.94	1.33	38.03	-1.11
9	BMT-7	Kunra	OW	1.26	20.61	-19.44	1.37	39.51	-1.00
10	BMT-7(Pz)	Kunra	PzW				12.78	59.77	-34.18
11	BMT-8	Murra	OW	0.92	11.97	-22.66	0.78	12.42	-12.10
12	BMT-9	Nawagarh	OW	1.98	25.42	-14.88	1.96	23.75	-16.60
13	BMT-10	Jhal	OW	1.33	17.59	-17.47	1.18	23.00	-3.26
14	BMT-11	Andhiyarkhor	OW	1.42	22.46	-6.31	1.16	20.73	-5.87
15	BMT-12	Jhal	OW	0.55	9.22	-13.95	0.38	11.51	-1.39
16	BMT-13	Sagona	OW	0.77	10.03	-24.26	0.69	9.31	-21.04
17	BMT-14	Kanhera	OW	0.92	12.05	-21.51	0.63	9.25	-16.16
18	BMT-15	Chilphi	OW	1.77	23.15	-21.81	1.72	22.90	-16.60
19	BMT-16	Dadhi	OW	0.90	17.76	-3.38	0.89	17.90	-2.76
20	BMT-17	Bahera	OW	0.46	7.83	-12.72	0.83	10.74	-20.88
21	BMT-18	Baiji	OW	0.40	6.48	-16.81	0.61	9.73	-16.39
22	BMT-19	Jhalam	OW	0.61	9.78	-14.46	0.63	13.44	-4.15
23	BMT-20	Baba Mohtara	OW	0.51	10.30	-7.96	0.53	12.39	-4.73
24	BMT-21	Kusmi	OW	0.51	11.32	-5.94	0.33	10.38	-0.87
25	BMT-22	Bitkuli	OW	0.88	9.01	-38.46	0.88	9.36	-37.06
26	BMT-23	Khilora	OW	0.62	12.47	-6.49	0.75	12.57	-10.09
27	BMT-24	Jeori	OW	0.49	19.37	-3.14	0.85	21.70	-7.21
28	BMT-25	Amora	OW	0.45	12.67	-3.21	0.96	32.57	0.13
29	BMT-26	Farri	OW	0.44	15.99	-3.21	0.81	15.70	-7.36
30	BMT-27	Bhurki	OW	2.22	26.48	-13.79	2.47	28.30	-14.11
31	BMT-28	Dunra	OW	2.69	24.23	-34.35	1.23	23.04	-2.41
32	BMT-29	Ninwa	OW	0.90	19.01	-6.59	0.71	15.21	-2.97
33	BMT-30	Deorbija	OW	1.18	18.48	-8.58	1.06	17.45	-7.52
34	BMT-31	Rampur(Bhand)	OW	0.45	31.54	-3.58	0.30	16.27	-2.99
35	BMT-32	Deori	OW	0.49	11.83	-3.93	0.31	7.33	-3.56
36	BMT-33	Anandgaon	OW	0.46	10.95	-4.76	0.51	10.76	-8.15
37	BMT-34	Pirda	OW	1.10	32.46	-3.59	1.07	36.33	-2.51
38	BMT-35	Ufra	OW	0.29	8.82	-2.27	0.30	9.12	-1.91
39	BMT-36	Sankra	OW	0.66	15.46	-6.00	0.65	18.96	-3.04
40	BMT-37	Sondh	OW	0.63	22.46	-1.29	0.51	20.22	-0.51
41	BMT-38	Kodwa	OW	1.09	20.47	-4.17	1.08	21.05	-2.38
42	BMT-39	Saja	OW	0.36	9.40	-1.63	0.34	9.22	-1.00
43	BMT-40	Jata	OW	0.73	14.82	-4.38	0.18	6.89	-1.91
44	BMT-41	Saja	BW	0.19	7.71	-2.49	0.33	8.78	-1.19
45	BMT-42	Rakhi Joba	OW	0.30	8.04	-2.06	0.36	9.16	-2.89
46	BMT-43	Deokar	OW	0.91	21.14	-1.39	3.20	44.70	0.78
47	BMT-44	Mohgaon	OW	0.57	13.64	-1.37	0.72	16.42	-0.89
48	BMT-45	Mouha Bhata	OW	1.00	23.08	-2.55	0.95	22.66	-1.76
49	BMT-46	Beltara	HP	0.43	9.55	-3.98	0.45	10.19	-3.39
50	BMT-47	Beltara	OW	2.48	42.85	-3.94	0.47	11.43	-4.00
51	BMT-48	Thelka	OW	1.79	25.14	-8.84	1.70	24.53	-7.97
52	BMT-49	Thankamariya	OW	0.94	12.31	-18.52	1.04	14.87	-12.67
53	BMT-50	Keotara	OW	0.44	10.55	-5.11	0.41	9.19	-5.94
54	BMT-50(Pz)	Keotara	OW				0.29	9.03	-1.51
55	BMT-51	Bortara	OW	1.50	22.56	-7.62	1.05	22.72	-0.35
56	BMT-52	Sawartala	OW	1.75	42.03	-0.24	1.13	30.33	-1.83
57	BMT-53	Parpodi	OW	0.67	19.23	-0.39	0.61	16.51	-3.30
58	BMT-54(Pz)	Khandesra	OW				0.78	14.16	-7.04
59	KBD-1	Indori	OW	1.40	33.02	-2.90	3.36	40.33	-7.24
60	KBD-2	Dasranghpur	OW	0.77	9.95	-24.04	0.77	11.85	-15.47
61	KBD-3	Gaurmati	OW	1.49	21.99	-12.37	1.10	20.14	-3.81
62	MNG-1	Mungeli	OW	1.52	24.86	-2.71	1.33	24.98	-0.95
63	MNG-2	Dharampura	OW	4.26	55.76	1.21	3.69	49.17	1.85
64	MNG-3	Chhatona	OW	1.23	28.59	-0.16	1.55	29.71	-0.46
65	MNG-4	Pathariya	BW	0.82	11.68	-16.88	0.91	11.78	-20.92

66	MNG-5	Pandarbhata(OW)	OW	1.10	24.30	-21.08	1.36	30.01	-12.16
67	MNG-6	Pandarbhata(HP)	HP	1.43	17.06	-25.59	0.78	16.94	-2.99
68	MNG-7	Sargaov	OW				0.68	13.32	-4.32
69	MNG-8	Bhojpuri	OW				1.22	23.27	-1.58
70	MNG-9	Sanwa	OW				0.70	10.43	-14.02
71	MNG-10	Bavli	OW				0.99	32.51	-12.13
72	MNG-11	Padiyain	OW				0.79	18.36	-1.33

Table 25(b). SAR, Na% and RSC values in ground water of the study area(Pre- and Post-monsoon 2019-20)

S.No.	Sample Code	Location	Source	Pre-monsoon			Post-monsoon		
				SAR	Na (%)	RSC	SAR	Na (%)	RSC
1	BMT-1	Berla	BW	0.405058	11.68422	-1.40575	0.713234	19.0067	-2.79444
2	BMT-1(Pz)	Berla	PzW	0.651687	16.80902	-0.81453	0.426962	11.12233	-2.4676
3	BMT-2	Beejabhat	BW	0.787975	24.58117	-2.59951	1.220328	35.83196	-3.16095
4	BMT-3	Balsamund	OW	1.588006	44.51631	-0.01856	1.789496	46.11735	0.98883
5	BMT-3(Pz)	Balsamund	PzW	1.04967	10.6423	-38.7572	1.707621	15.99541	-36.1648
6	BMT-4	Pindri	OW	0.914614	17.64471	-14.583	1.543259	35.77783	-6.21723
7	BMT-5	Bemetara	OW	1.386245	23.07909	-9.84723	1.316849	23.63133	-7.04952
8	BMT-6	Sambalpur	OW	1.990677	49.58118	-0.43386	1.732739	16.92042	-32.9591
9	BMT-7	Kunra	OW	1.093646	15.50033	-24.5786	1.020598	44.13533	-2.10022
10	BMT-7(Pz)	Kunra	PzW	25.75589	74.04183	-38.6425	1.019756	45.05727	-2.42093
11	BMT-8	Murra	OW	0.841374	14.02	-10.8141	0.795741	13.33799	-10.4498
12	BMT-9	Nawagarh	OW	1.914182	22.14382	-20.5829	3.683883	33.8884	-27.2312
13	BMT-10	Jhal	OW	1.283924	19.54483	-10.9827	0.384707	5.894861	-15.9487
14	BMT-11	Andhiyarkhor	OW	1.434242	26.58465	-4.50797	3.566245	40.29535	-4.1506
15	BMT-12	Jhal	OW	0.497109	8.899456	-11.1079	1.060984	24.20963	-1.74082
16	BMT-13	Sagona	OW	0.752222	9.5553	-24.4782	0.945124	12.54951	-17.6318
17	BMT-14	Kanhera	OW	0.692795	8.596038	-26.1958	0.440833	15.74815	-1.85533
18	BMT-15	Chilphi	OW	1.603032	21.18782	-19.6224	2.231605	27.18535	-14.9582
19	BMT-16	Dadhi	OW	0.948844	18.96312	-2.59257	0.803364	17.1743	-3.32347
20	BMT-17	Bahera	OW	0.688416	10.98343	-13.6634	1.143692	13.65289	-22.0741
21	BMT-18	Baiji	OW	2.314766	35.33791	-5.69713	1.807458	36.24289	-1.39211
22	BMT-19	Jhalam	OW	0.560102	8.24277	-18.1833	0.677343	15.05278	-4.82572
23	BMT-20	Baba Mohtara	OW	0.559088	12.73702	-3.97027	0.974537	25.38587	-6.45101
24	BMT-21	Kusmi	OW	0.430118	13.16284	-0.59892	0.361571	11.47472	-0.98336
25	BMT-22	Bitkuli	OW	2.780566	20.08026	-58.4628	1.001301	10.08314	-34.4847
26	BMT-23	Khilora	OW	0.715759	12.76796	-8.17074	0.771638	13.27986	-8.51844
27	BMT-24	Jeori	OW	1.041171	22.8226	-7.84143	0.82736	21.5885	-5.70515
28	BMT-25	Amora	OW	1.366793	38.0511	-0.04078	0.69037	43.50356	1.11986
29	BMT-26	Farri	OW	1.140917	20.25515	-6.6955	0.783075	33.8909	-1.72994
30	BMT-27	Bhurki	OW	2.50559	28.98907	-14.6426	2.481023	29.41513	-12.5089
31	BMT-28	Dunra	OW	1.305415	14.47177	-25.5197	2.780456	24.86721	-32.4791
32	BMT-29	Ninwa	OW	0.980885	23.04952	-4.7214	0.763672	16.72197	-4.08257
33	BMT-30	Deorbija	OW	1.23334	20.43117	-6.54296	0.93721	17.95583	-5.5666
34	BMT-31	Rampur(Bhand)	OW	0.346253	18.87176	-2.29328	0.257058	13.00649	-3.08689
35	BMT-32	Deori	OW	0.390555	10.20082	-1.33863	0.494921	10.80872	-5.39538
36	BMT-33	Anandgaon	OW	0.538881	14.18406	-2.81684	0.872535	31.77104	-1.90879
37	BMT-34	Pirda	OW	0.40024	17.53887	-1.8974	0.972353	34.27272	-3.06786
38	BMT-35	Ufra	OW	0.249035	8.861831	-1.06367	0.252799	8.105502	-2.02032
39	BMT-36	Sankra	OW	0.623467	17.16869	-3.92674	0.676016	17.65782	-4.51447
40	BMT-37	Sondh	OW	0.536316	19.95007	-0.20525	0.486789	19.20863	-0.45876
41	BMT-38	Kodwa	BW	1.384766	26.8179	-1.20616	1.255733	25.61021	-1.58724
42	BMT-39	Saja	OW	0.633139	13.66345	-5.28699	0.322968	8.771317	-0.68437
43	BMT-40	Jata	OW	0.202855	6.118227	-1.29609	2.002938	35.11615	-3.60998
44	BMT-41	Saja	OW	0.327659	9.13397	-0.82695	0.336843	8.831613	-1.97762
45	BMT-42	Rakhi Joba	OW	1.647103	23.24814	-10.6532	0.682106	13.85515	-4.6305
46	BMT-43	Deokar	HP	0.947081	22.80054	-0.52174	3.468309	44.35038	-0.18698
47	BMT-44	Mohgaon	OW	0.558441	14.40877	-0.33022	0.663939	15.04316	-0.36079
48	BMT-45	Mouha Bhata	OW	1.031755	26.32957	-0.74581	0.699647	18.1319	-1.25789
49	BMT-46	Beltara	HP	0.587292	14.0109	-2.47884	0.522768	10.18585	-4.56804
50	BMT-47	Beltara	OW	0.508649	13.68587	-2.87503	0.512147	12.47263	-4.66571
51	BMT-48	Thelka	OW	1.839496	48.91415	-0.5377	0.950898	19.45641	-3.04718
52	BMT-49	Thankamariya	OW	1.081116	14.74869	-15.1367	1.05285	15.96346	-9.98838
53	BMT-50	Keotara	OW	0.417842	9.991586	-4.59301	0.40436	9.323616	-4.47935
54	BMT-50(Pz)	Keotara	OW	0.276055	8.870798	-1.67961	0.403625	9.137186	-4.51244
55	BMT-51	Bortara	OW	1.028858	24.88619	0.101629	1.263409	34.64699	0.18604

56	BMT-52	Sawartala	OW	1.07316	31.09743	-0.57099	1.475953	32.64167	-2.34509
57	BMT-53	Parpodi	OW	1.045634	25.90838	0.373126	0.582218	14.9391	-1.10668
58	BMT-54(Pz)	Khandesra	OW	0.943669	17.72409	-5.36927	1.068215	20.32446	-3.34498
59	KBD-1	Indori	OW	2.244947	41.25408	-2.05706	1.372938	32.82536	-0.94252
60	KBD-2	Dasranghpur	BW	1.017976	21.87792	-2.53911	1.402738	42.82478	-6.65104
61	KBD-3	Gourmati	OW	1.27839	22.29838	-4.58527	1.648589	25.52132	-6.03097
62	MNG-1	Moungeli	HP	1.20758	23.64887	-0.79077	3.747292	44.6234	-0.87352
63	MNG-2	Dharampura	OW	3.845477	53.37623	2.942409	3.59204	45.48407	0.19238
64	MNG-3	Chhatona	OW	1.316878	27.08336	-0.10843	1.236988	25.00233	-0.75656
65	MNG-4	Pathariya	OW	0.820205	11.70097	-17.3486	0.908371	11.12579	-24.3598
66	MNG-5	Pandarbhata	OW	1.192999	27.44613	-16.3485	1.444353	32.91391	-9.53926
67	MNG-6	Pandarbhata	HP	1.207404	27.49368	-17.1634	0.73183	16.80066	-1.73172
68	MNG-7	Sargaov	OW	0.673178	14.28228	-5.64967	0.896092	17.11752	-5.27949
69	MNG-8	Bhojpuri	OW	0.858032	19.09791	-1.27071	0.715196	15.01968	-1.83727
70	MNG-9	Sanwa	OW	0.73028	11.25309	-13.7672	0.666536	10.29359	-11.8795
71	MNG-10	Bavli	OW	1.342603	35.42933	-13.3621	1.1495	37.95318	-10.9914
72	MNG-11	Padiyain	OW	0.642881	12.5556	-6.4078	0.655369	15.0244	-2.62639

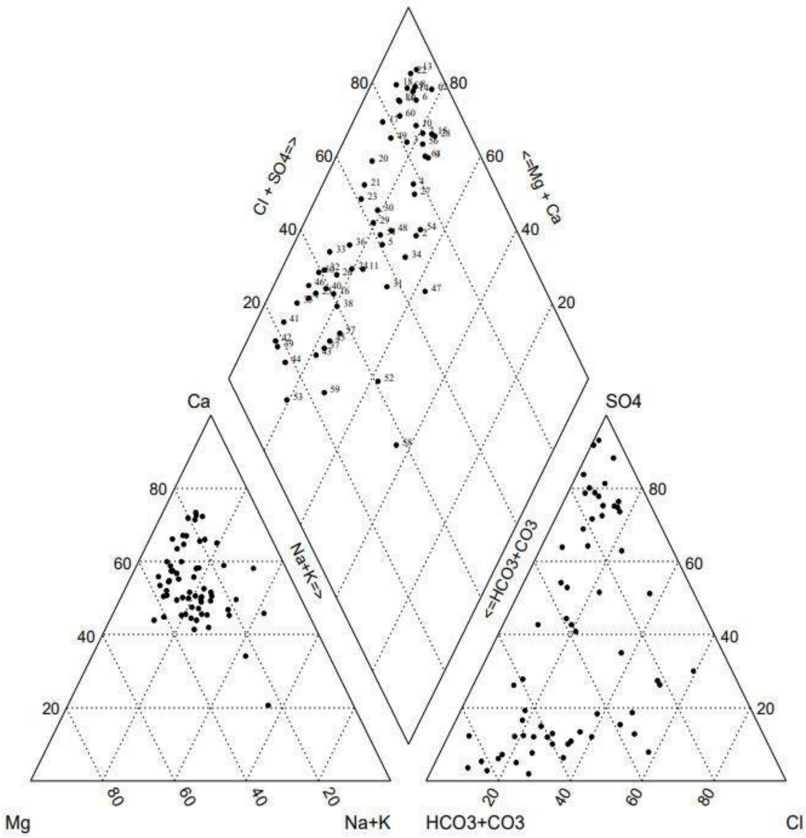


Fig. 19(a). Piper Trilinear Diagram (Pre-monsoon 2018-19)

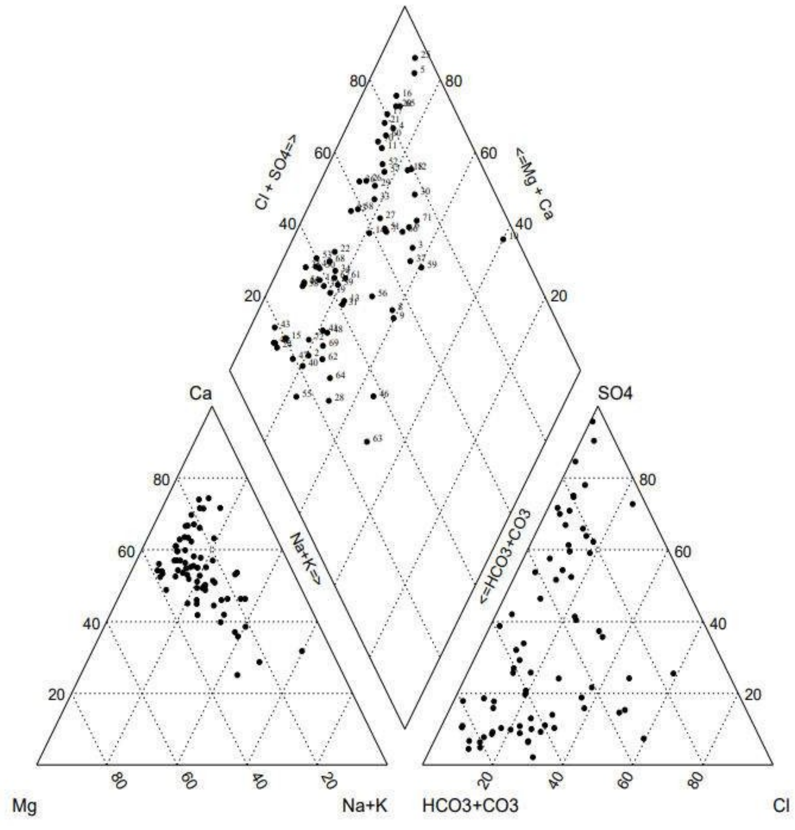


Fig. 19(b). Piper Trilinear Diagram (Post-monsoon 2018-19)

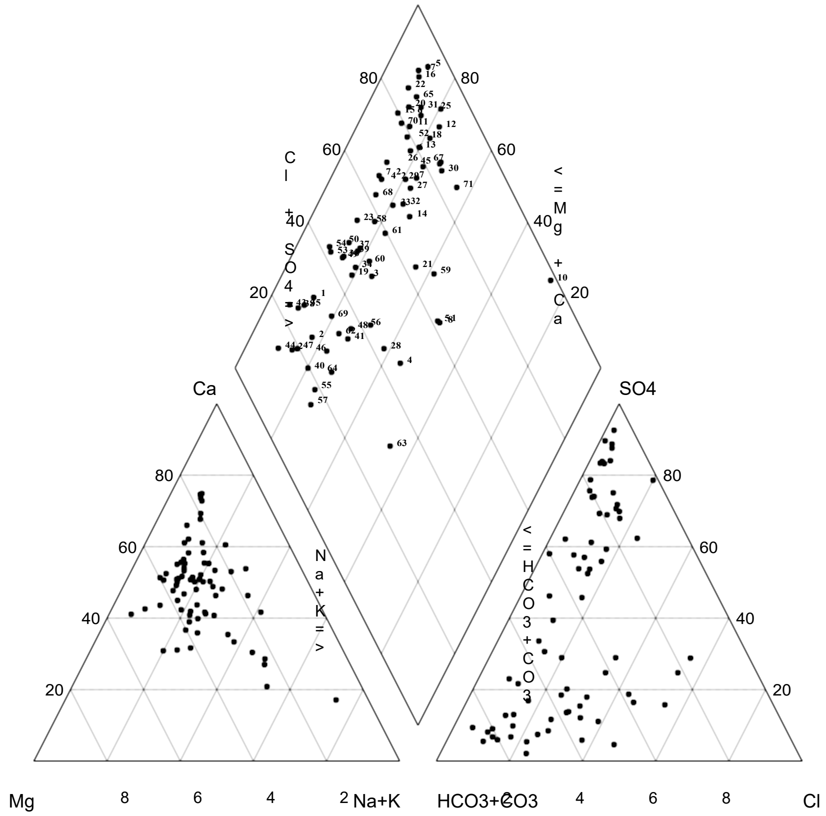


Fig. 19(c). Piper Trilinear Diagram (Pre-monsoon 2019-20)

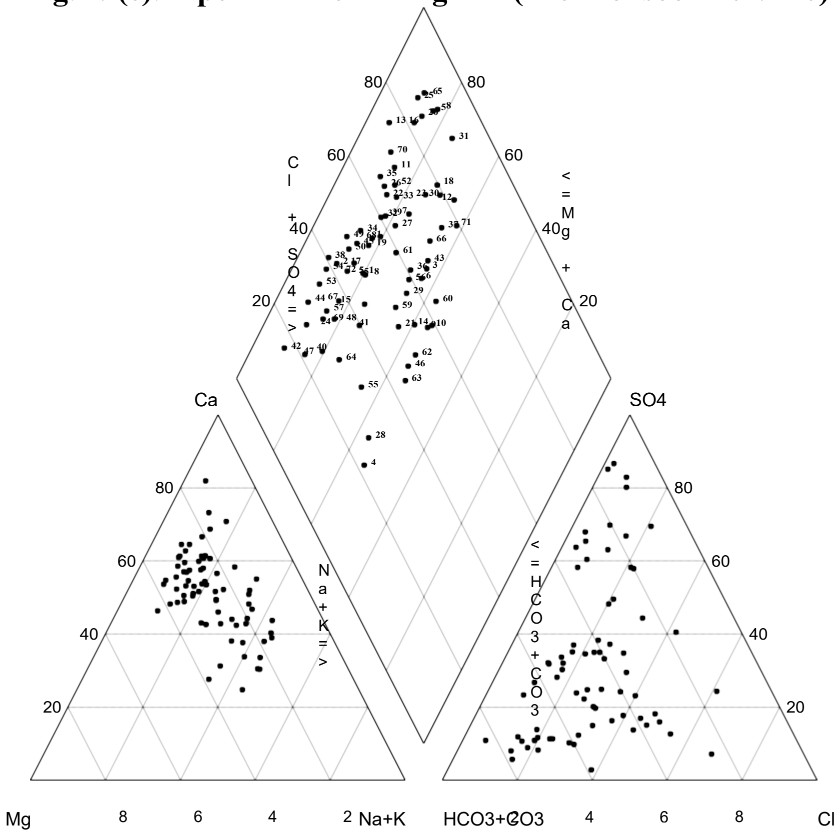


Fig. 19(d). Piper Trilinear Diagram (Post-monsoon 2019-20)

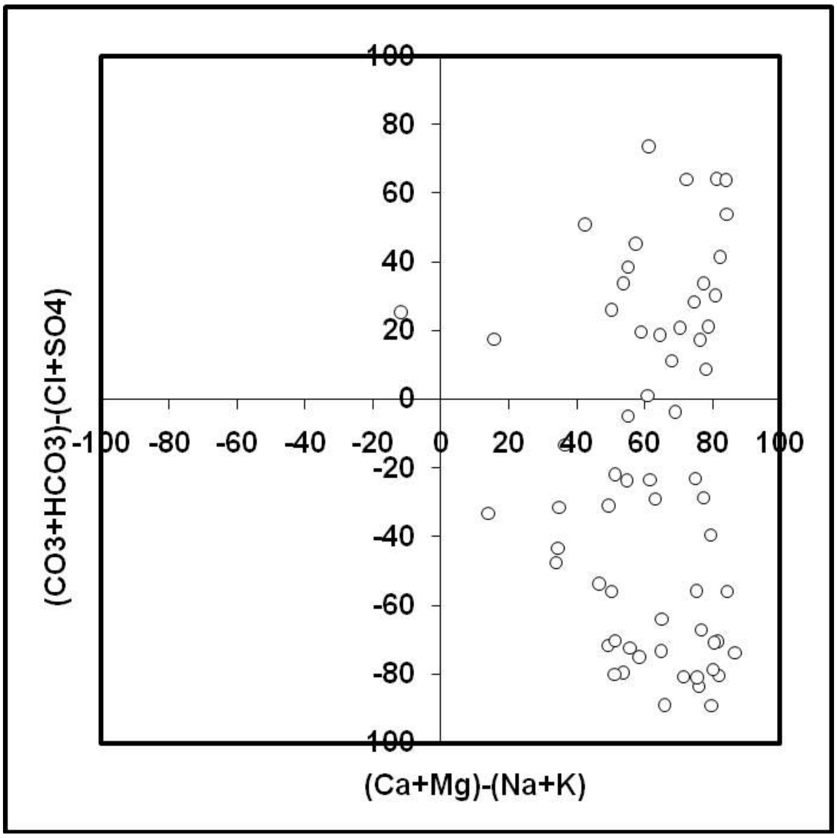


Fig. 20(a). Chadha's Diagram (Pre-monsoon 2018-19)

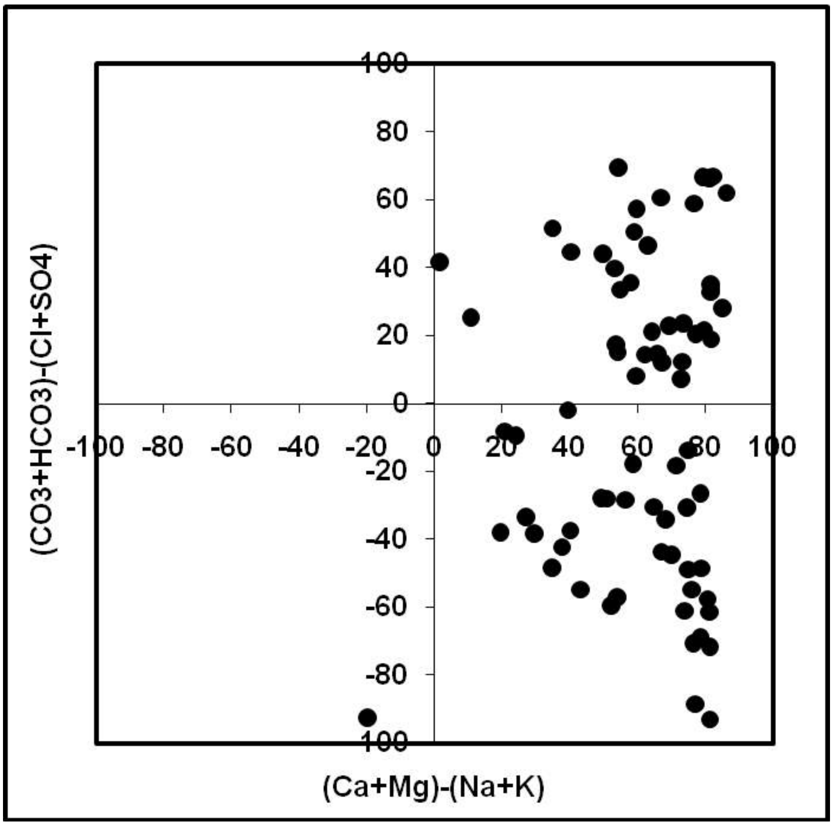


Fig. 20(b). Chadha's Diagram (Post-monsoon 2018-19)

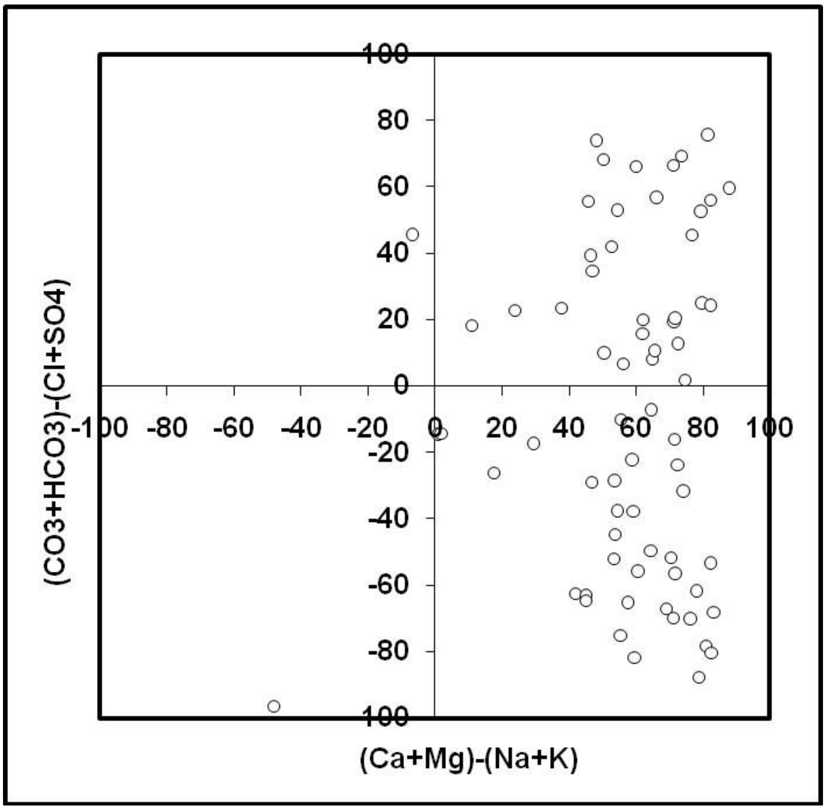


Fig. 20(c). Chadha's Diagram (Pre-monsoon 2019-20)

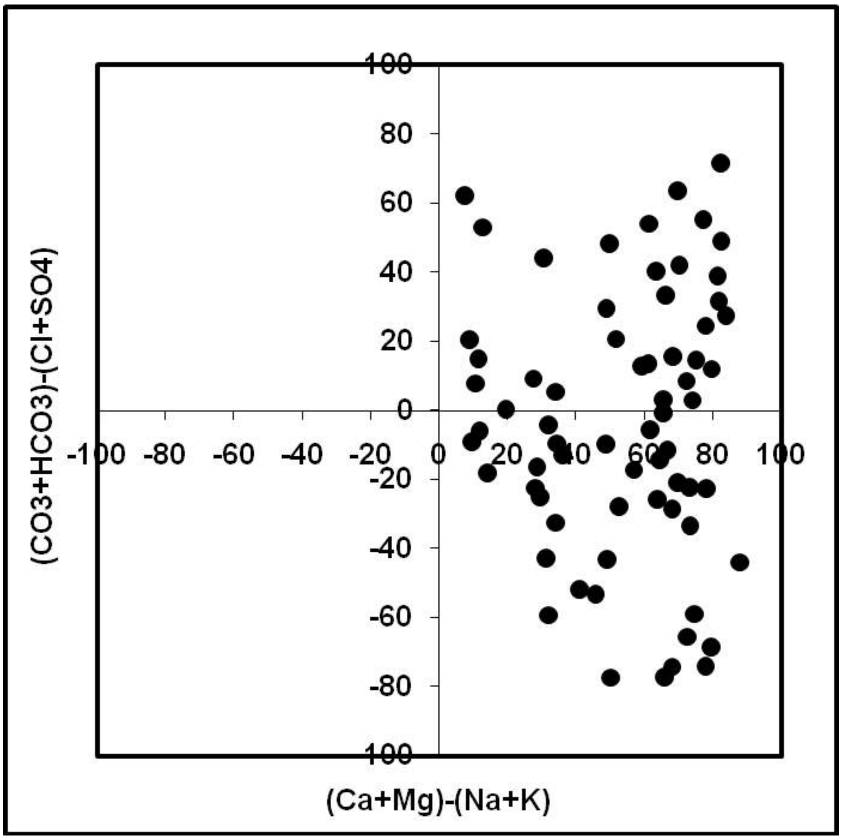


Fig. 20(d). Chadha's Diagram (Post-monsoon 2019-20)

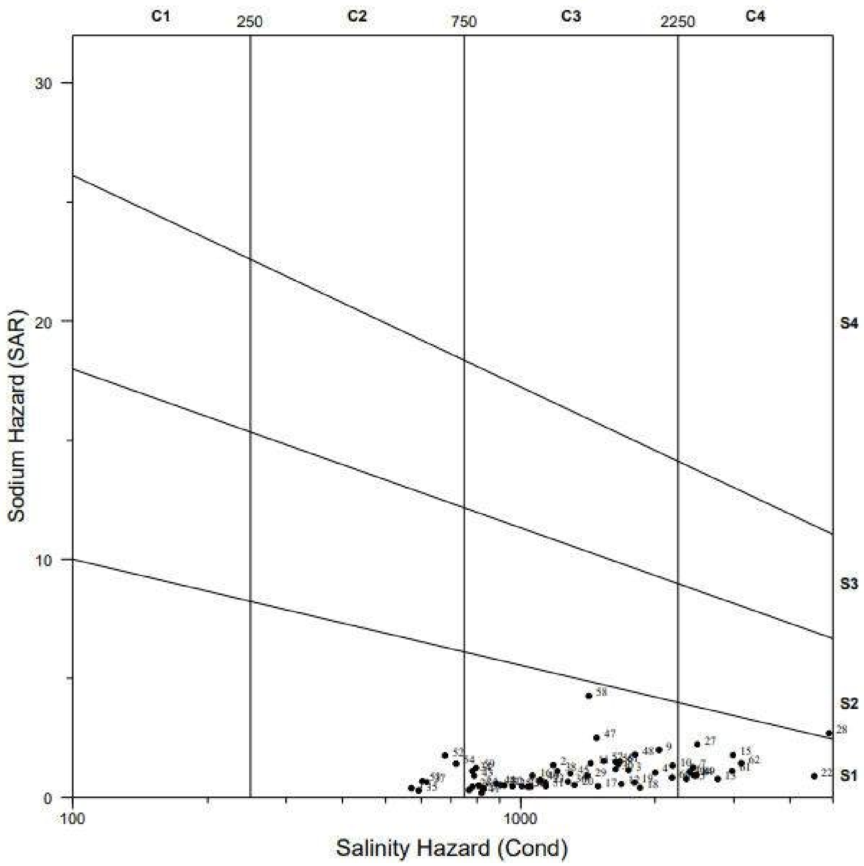


Fig. 21(a). U.S. Salinity Laboratory Classification (Pre-monsoon 2018-19)

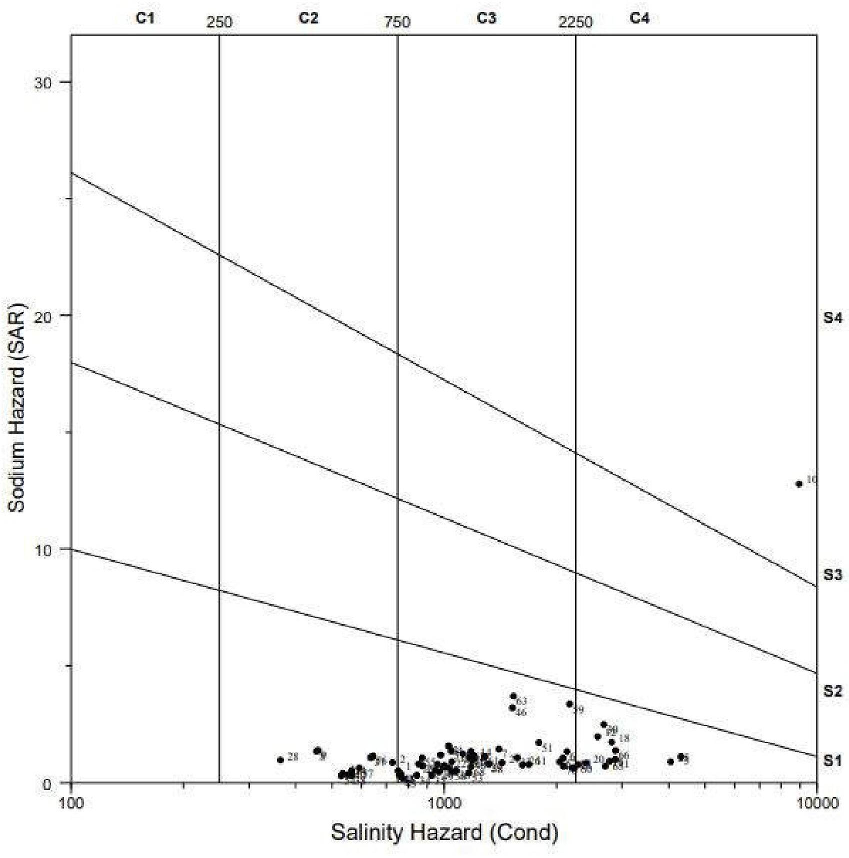


Fig. 21(b). U.S. Salinity Laboratory Classification (Post-monsoon 2018-19)

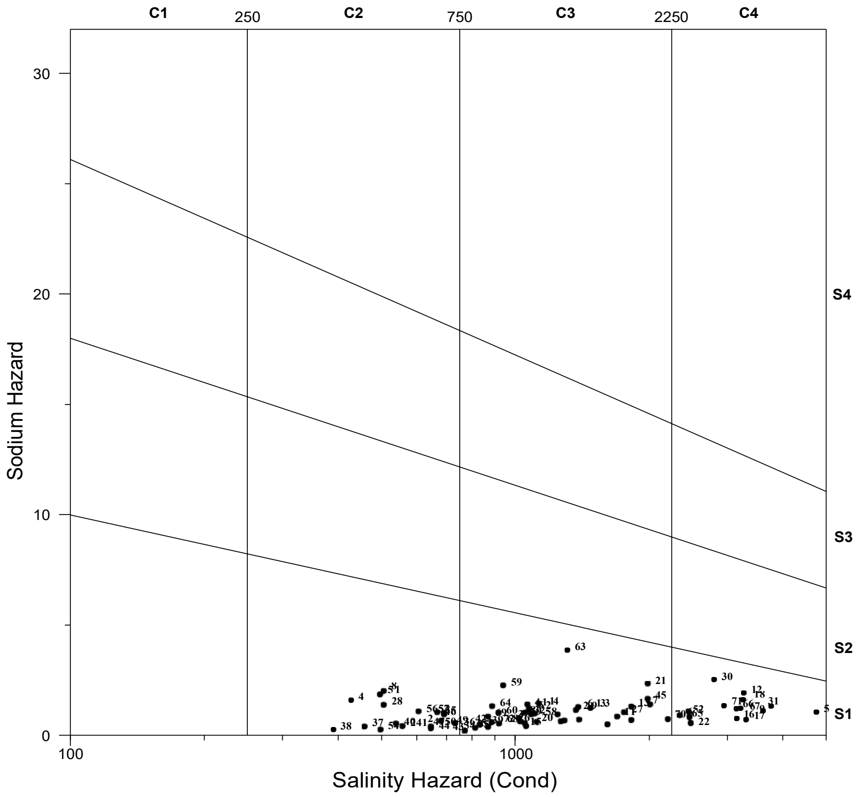


Fig. 21(c). U.S. Salinity Laboratory Classification (Pre-monsoon 2019-20)

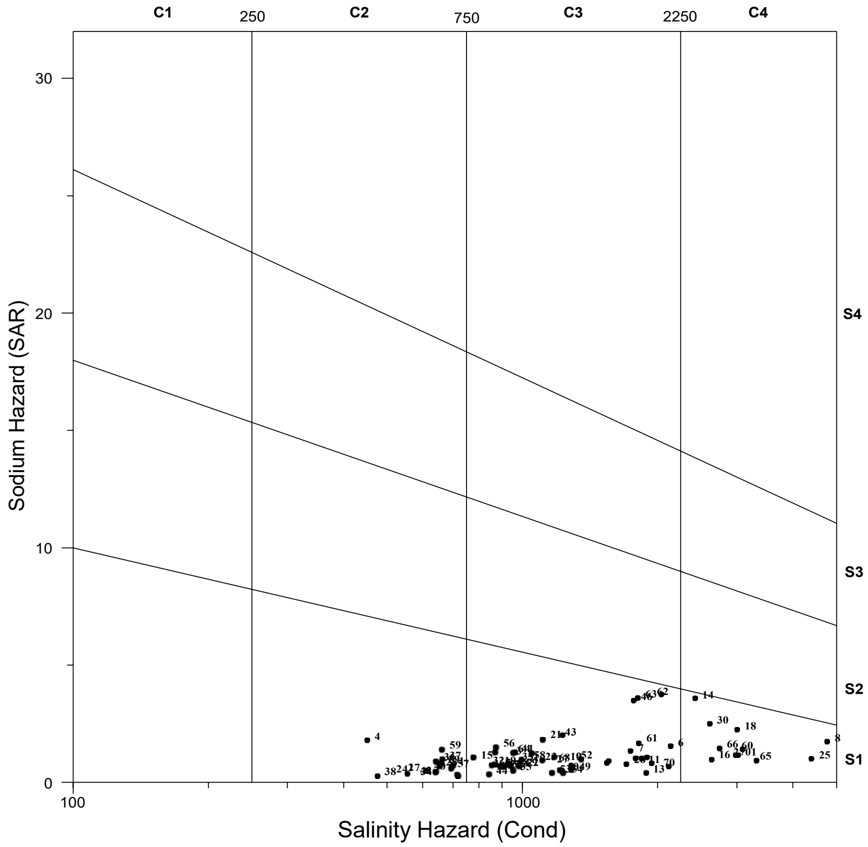


Fig. 21(d). U.S. Salinity Laboratory Classification (Post-monsoon 2019-20)

Table. 26(a) Summarized results of water classification for the year 2018-19

Classification/Type	Sample numbers	
	Pre-monsoon 2018-19	Post-monsoon 2018-19
Piper Trilinear Classification		
Ca-Mg-HCO_3 (Group 5)	1,16,25,26,32,33,35,37,38,39,40, 41,42,43,44,45,46,50,52,53,57,59,	1,2,13,15,19,22,24,28,31,32,34 35,38,39,40,41,42,43,44,45,46, 47,48,49,50,53,54,55,61,62,63, 64,67,68,69,72
Ca-Mg-Cl-SO_4 (Group 6)	2,3,4,5,6,7,8,9,10,11,12,13,14,15, 17,18,19,20,21,22,23,24,27,28,29, 30,31,34,36,47,48,49,51,54,55,56, 60,61,62	3,4,5,6,7,8,9,11,12,14,16,17,18 20,21,23,25,26,27,29,30,33,36, 37,51,52,56,57,58,59,60,65,66, 70,71
Na-K- Cl-SO_4 (Group 7)	-	10
Na-K-HCO_3 (Group 8)	58	-
Chadha's Diagram		
Ca-Mg-HCO_3 (Group 5)		
Ca-Mg-Cl-SO_4 (Group 6)		
Na-K- Cl-SO_4 (Group 7)	-	-
Na-K-HCO_3 (Group 8)	-	-
U. S. Salinity Laboratory Classification		
C1-S1	-	-
C2-S1	1,35,37,52,53,54	2,8,9,15,24,28,37,38,40,54,56, 57
C2-S2	-	-
C2-S3	-	-
C2-S4	-	-
C3-S1	2,3,4,5,9,10,11,12,16,17,18,19,20, 21,23,24,25,26,29,30,31,32,33,34, 36,38,39,40,41,42,43,44,45,46,47, 48,50,51,56,57,58,59,60	1,3,4,6,7,11,13,14,17,19,21,22, 23,26,27,29,31,32,33,34,35,36, 39,41,42,43,44,45,46,47,48,49, 50,51,52,53,55,58,59,61,62,63, 64,67,68,69,70,72
C3-S2	-	-
C3-S3	-	-
C3-S4	-	-
C4-S1	6,7,8,11,13,14,15,22,27,49,55, 61,62	5,12,16,18,20,25,30,60,65,66, 71
C4-S2	28	10
C4-S3	-	-
C4-S4	-	-

Table. 26(b) Summarized results of water classification for the year 2019-20

Classification/Type	Sample numbers	
	Pre-monsoon 2019-20	Post-monsoon 2019-20
Piper Trilinear Classification		
Ca-Mg-HCO_3 (Group 5)	1,2,3,4,19,24,28,34,35,36,37,38,39 40,41,43,44,46,47,48,49,50,53,54, 55,56,57,60,62,64,69	2,4,15,17,21,24,38,40,41,42,44 46,47,48,49,50,51,53,54,55,57 58,64,67,69,72
Ca-Mg-Cl-SO_4 (Group 6)	5,6,7,8,9,11,12,13,14,15,16,17,18, 20,21,22,23,25,26,27,29,30,31,32, 33,42,45,51,52,58,59,61,65,66,67, 68,70,71,72	1,3,5,6,7,8,9,10,11,12,13,14,16 18,19,20,22,23,25,26,27,28,29, 30,31,32,33,34,35,36,37,39,43, 45,52,56,59,60,61,62,63,65,66 68,70,71
Na-K- Cl-SO_4 (Group 7)	10	
Na-K-HCO_3 (Group 8)	63	-
Chadha's Diagram		
Ca-Mg-HCO_3 (Group 5)		
Ca-Mg-Cl-SO_4 (Group 6)		
Na-K- Cl-SO_4 (Group 7)	-	-
Na-K-HCO_3 (Group 8)	-	-
U. S. Salinity Laboratory Classification		
C1-S1	-	-
C2-S1	1,35,37,52,53,54	1,2,4,15,17,24,28,29,34,36,37, 38,40,42,57,59
C2-S2	-	-
C2-S3	-	-
C2-S4	-	-
C3-S1	2,3,4,5,9,10,11,12,16,17,18,19,20, 21,23,24,25,26,29,30,31,32,33,34, 36,38,39,40,41,42,43,44,45,46,47, 48,50,51,56,57,58,59,60	3,6,7,9,10,11,12,13,14,19,21, 22,23,26,27,32,33,35,39,41,43, 44,45,46,47,48,49,50,51,52,53, 54,55,56,58,61,62,63,64,67,68, 69,70,72
C3-S2		
C3-S3	-	-
C3-S4	-	-
C4-S1		5,8,16,18,20,25,30,60,65,66,71
C4-S2	-	31
C4-S3	-	-
C4-S4	-	-

5.4 Hydrogeochemistry of Groundwater

Geo-environmental conditions have a marked influence on the groundwater quality. Hydrogeochemical studies relevant to the water quality explain the relationship of water chemistry to aquifer lithology. Such relationship would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry. Gibbs (1970) proposed a hypothesis to elucidate the major natural mechanisms controlling world water chemistry. Three mechanisms – atmospheric precipitation, rock dominance and the evaporation-crystallization process – are the major factors controlling the composition of dissolved salts of the world waters. Other second-order factors, such as relief, vegetation and composition of material in the basin dictate only minor deviations within the zones dominated by the three primefactors.

Gibbs plot is a diagrammatic representation of the mechanisms responsible for controlling the chemical composition of various bodies of water on the surface of the earth. The major cations that characterize the end-member of the world surface waters are Ca for freshwater bodies and Na for high-saline water bodies. Gibbs plotted the weight ratio Na/(Na+Ca) on the x-axis and the variation in total salinity on the y-axis [Fig. 22(a)]. This ordered arrangement can serve as a basis for discussion of the several mechanisms that control world waterchemistry.

The first of these mechanisms is the atmospheric precipitation. The chemical compositions of low-salinity waters are controlled by the amount of dissolved salts furnished by precipitation. These waters consist mainly of the rivers having sources in thoroughly leached areas of low relief in which the rate of supply of dissolved salts to the rivers is very low and the amount of rainfall is high – much greater in proportion to the low amount of dissolved salts supplied from the rocks. In addition, the composition of this precipitation differs from that of rock-derived dissolved salts.

The second mechanism is the rock dominance controlling world water chemistry. The waters of these rock-dominated end-members are more or less in partial equilibrium with the materials in their basins. Their positions within this grouping are dependent on the relief and climate of each basin and the composition of each basin.

The third major mechanism that controls the chemical composition of the earth's surface waters is the evaporation-fractional crystallization process. This mechanism produces a series extending from the Ca-rich, medium-salinity (freshwater), 'rock source' end-member grouping to the opposite, Na-rich, high-salinityend-member.

Almost all collected groundwater samples from study area in both seasons for the year 2018-19 and 2019-20 fall in rock dominance zone suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals. Few samples are away from this zone reflecting the contribution of anthropogenic activity responsible for chemical composition of ground water of the study area [Fig. 22(b)].

Scatter Plots between Ions

The scatter plot of (Ca+Mg) vs TZ^+ shows that all the points fall above 1:1 equiline[Fig. 23(a-b)]. The relatively high contribution of (Ca+Mg) to the total cations (TZ^+) and high (Ca+Mg)/(Na+K) ratio indicate that carbonate weathering is a major source of dissolved ions in the groundwater of the study area [Fig. 23(a-b)] .

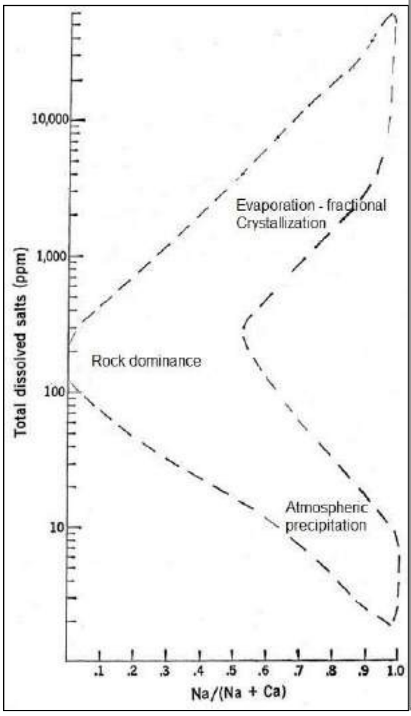
The scatter plot of (Na+K) vs TZ+ shows that all the points fall above 1:1 equiline with a low ratio indicating a relatively low contribution of dissolved ions from silicate weathering [Fig. 23(a-b)]. Na^+, K^+ and dissolved silica in the drainage basin are mainly derived from the weathering of silicate minerals, with clay minerals asby-products.

The plot of (Ca+Mg) vs HCO_3 for most of the samples in the study area indicates an excess of Ca+Mg over HCO_3 suggesting an extra source of Ca and Mg. This requires that a portion of the (Ca+Mg) has to be balanced by other anions like SO_4 and/or Cl.

The plot of (Ca+Mg) vs $HCO_3+SO_4$is a major indicator to identify the ion exchange process activated in the study area. If ion exchange is the process, the points shift to right side of the plot due to excess of HCO_3+SO_4. If reverse ions exchange is the process, points shiftleft due to excess Ca+Mg. Plot of (Ca+Mg) vs HCO_3+SO_4 shows that most of the plotted points clusters around the 1:1 equiline and fall in Ca+Mg indicating the reverse ion exchange process which may be due to the excess of Ca+Mg [Fig.23(a-b)].

The plot of Na vs Cl indicates most of the points lie below the 1:1 equiline reflecting contribution of silicate weathering through the release of Na [Fig. 23(a-b)].

Further, SO_4 plotted against the Ca, Mg, Na and K [Fig. 24] and best relationship was observed between Ca and SO_4 (maximum r^2) further supporting the fact that the source of sulphate in the groundwater of the study area may be $CaSO_4$ i.e. Gypsum, which is present in Maniyari shale formation of the region.



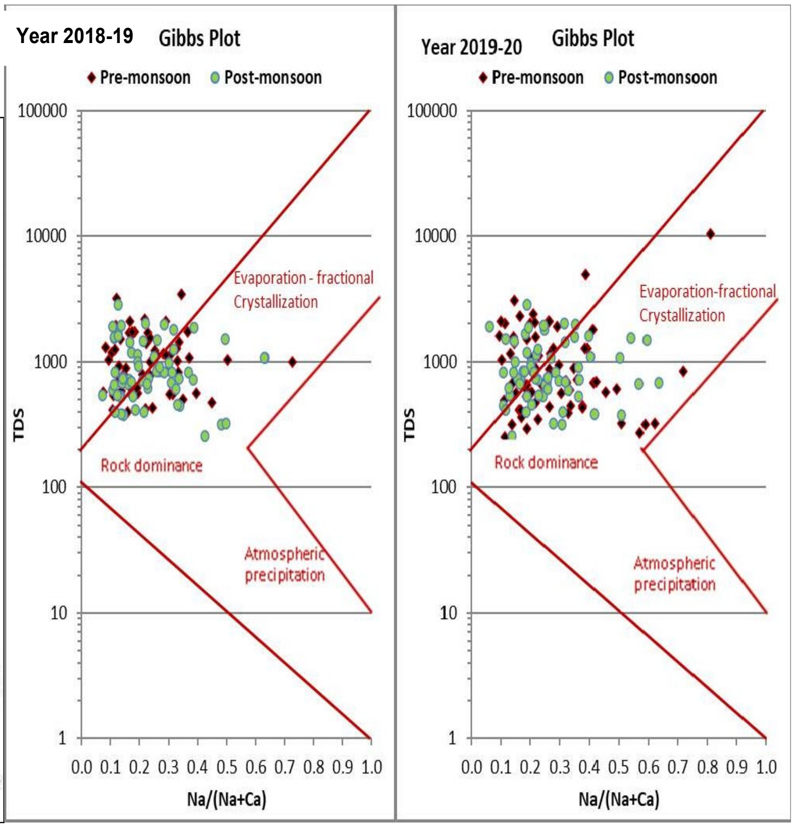


Fig. 22(a). Gibbs plot (Source: Gibbs, 1970) **Fig. 22(b). Gibbs plot for mechanism controlling the groundwater chemistry during the year 2018-19 and 2019-20.**

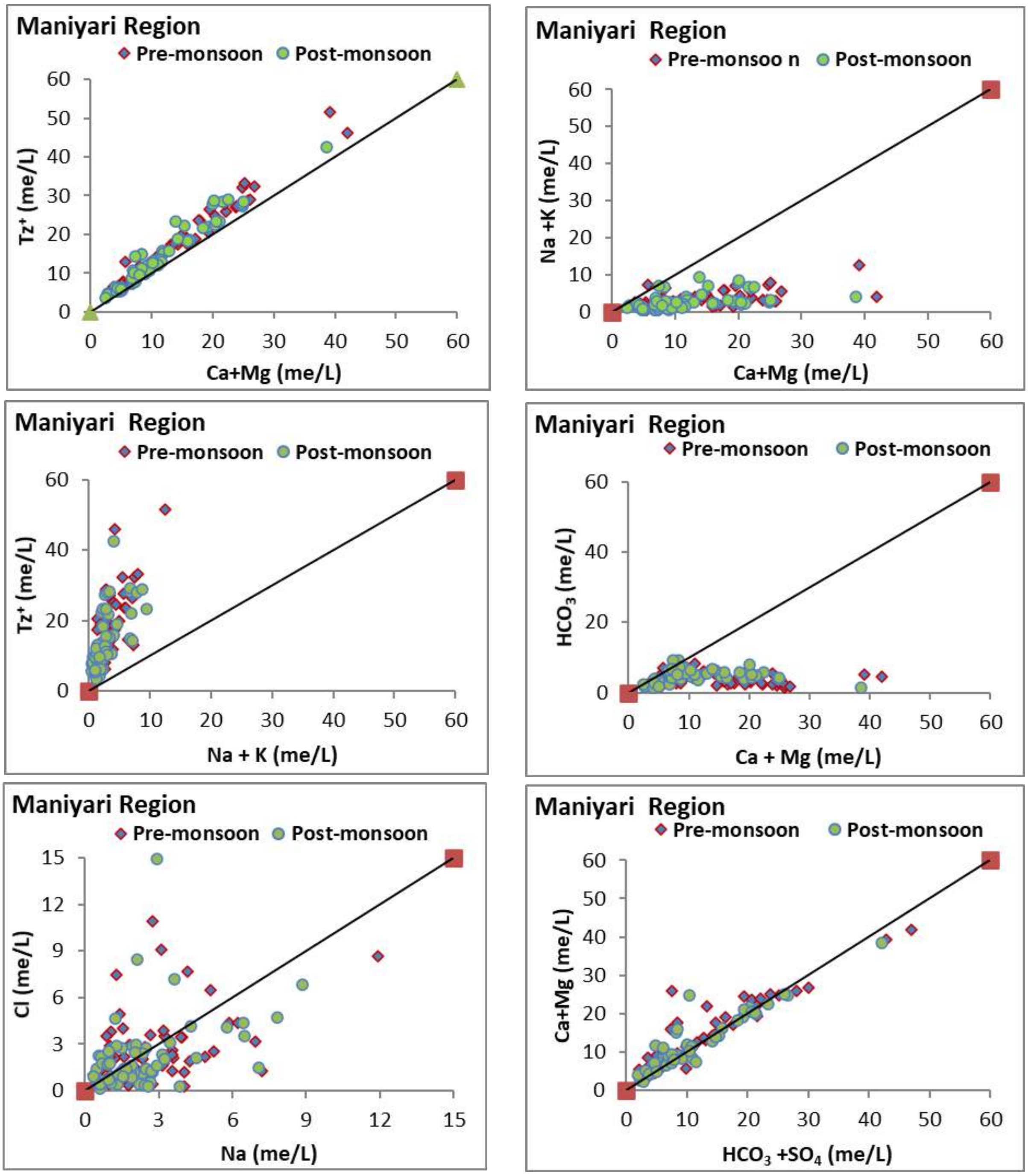


Fig. 23 (a). Scatter Plots for the year 2018-19

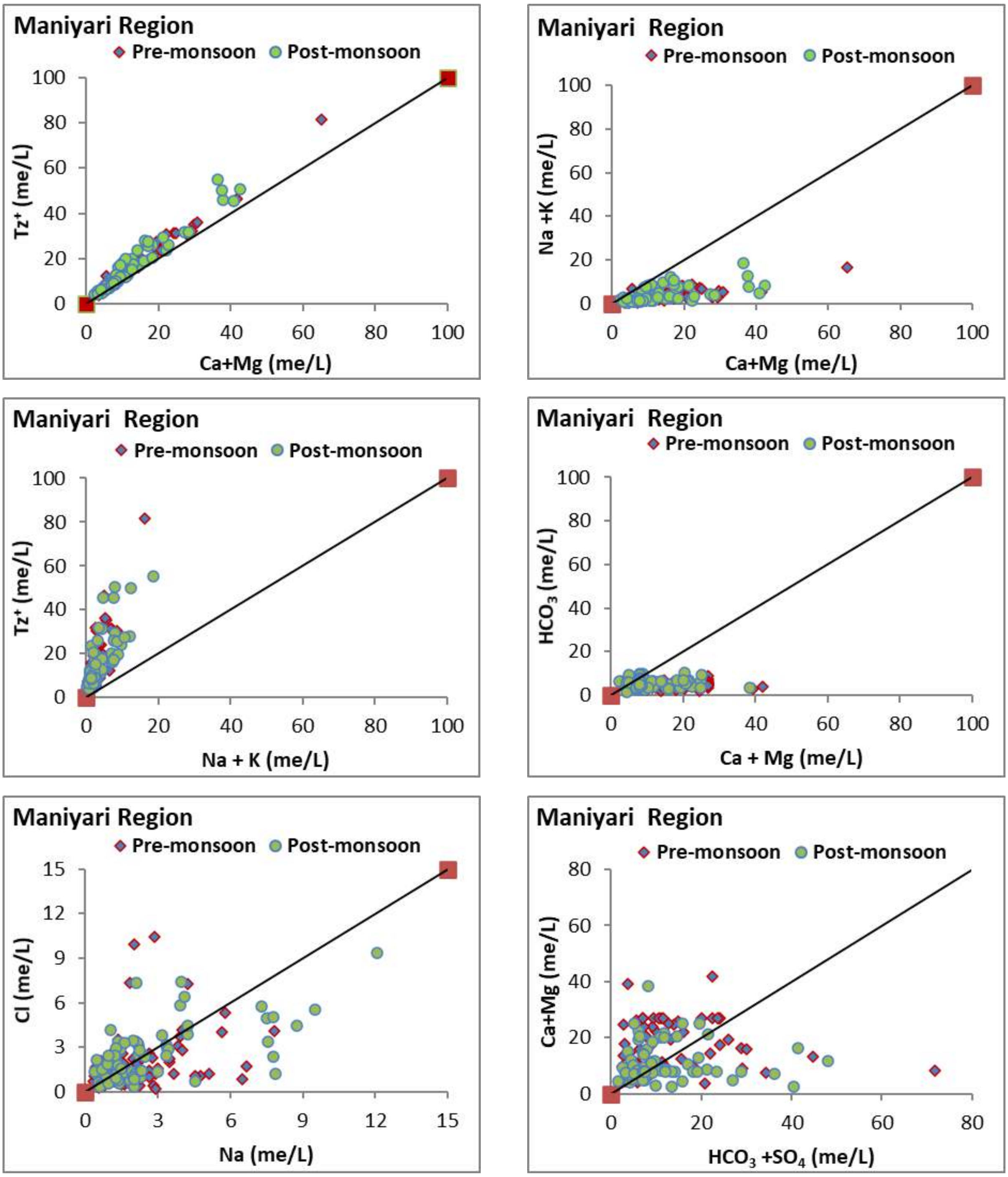
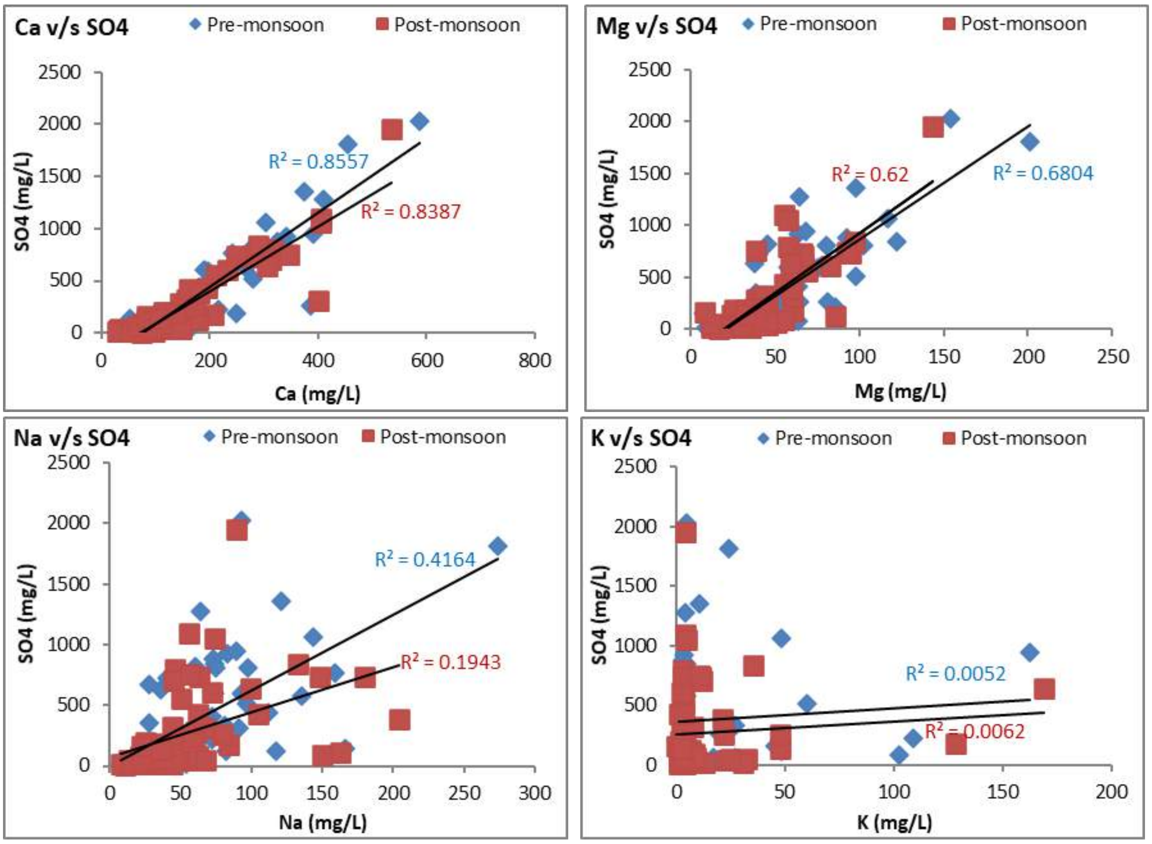


Fig. 23(b). Scatter Plots for the year 2019-20.

Year2018-19



Year2019-20

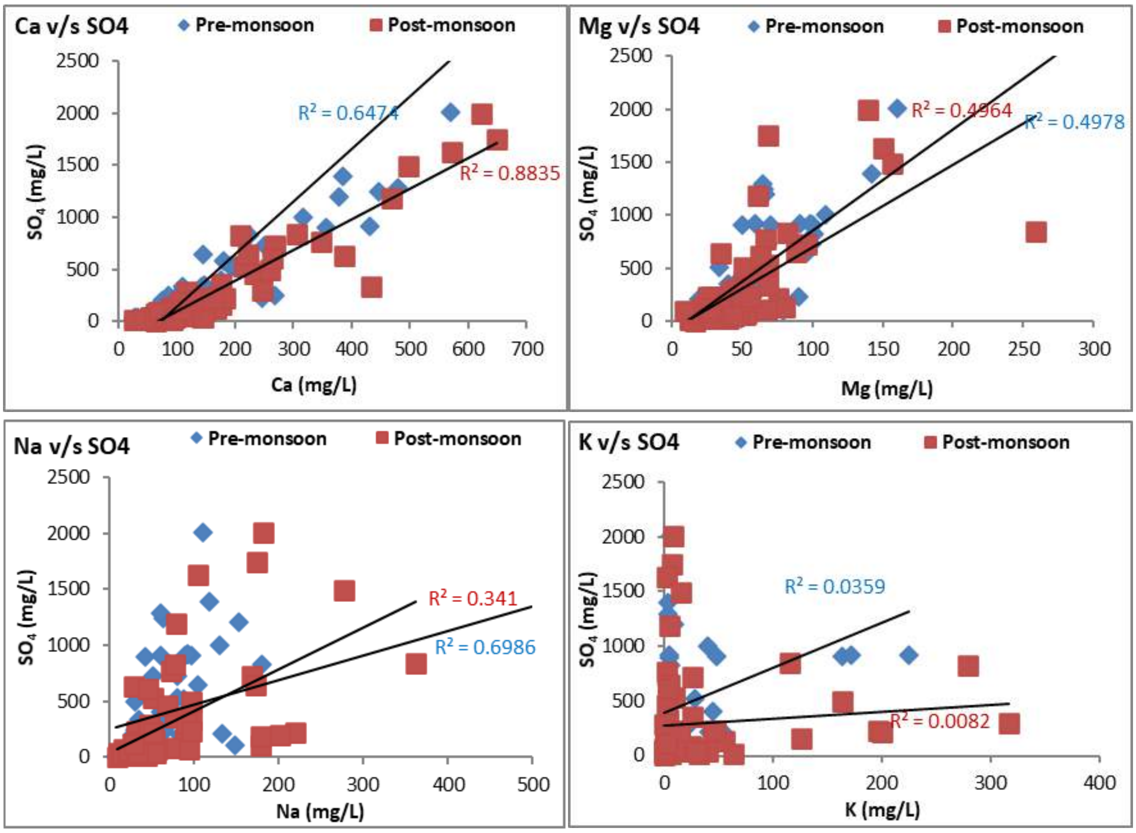


Fig. 24. Relationship of SO_4 with other cations

5.5 Water Quality Index of Groundwater

Water Quality Index (WQI) is an important parameter for demarcating groundwater quality and its suitability for drinking purposes (Subba Rao, 1997; Mishra and Patel, 2001; Avvannavar and Shrihari, 2008; Khan and Jhariya, 2017). The standards for drinking purposes as recommended by BIS (2012) and WHO (2011) have been considered for the calculation of WQI. For computing WQI, three steps are followed. In the first step, each of the 10 parameters (TDS, HCO_3, Cl, SO_4, NO_3, F, Ca, Mg, Na and K) has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes.

The maximum weight of 5 has been assigned to the parameters like nitrate, total dissolved solids, chloride, fluoride and sulphate due to their major importance in water quality assessment (Srinivasamoorthy et al., 2008; Vasanthavigar et al., 2010). Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, magnesium, sodium and potassium were assigned weight between 1 and 5 depending on their importance in water quality determination. In the second step, the relative weight (W_i) is computed from the followingequation:

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

Where
W_i = relative weight
w_i= weight of each parameter
n = number of parameters

Calculated relative weight (W_i) values of each parameter are given in Table 27.

Table .27. Relative Weight of Chemical Parameters

Chemical parameters	Indian Standard (BIS 10500, 2012)	Weight (wi)	Relative weight $W_i = w_i / \sum_{i=1}^{n} w_i$
Total dissolved solids (mg/L)	500	5	0.131
Bicarbonate (mg/L)	244	1	0.026
Chloride (mg/L)	250	5	0.131
Sulphate (mg/L)	200	5	0.131
Nitrate (mg/L)	45	5	0.131
Fluoride (mg/L)	1.0	5	0.131
Calcium (mg/L)	75	3	0.079
Magnesium (mg/L)	30	3	0.079
Sodium (mg/L)	200	4	0.105
Potassium (mg/L)	10	2	0.053

In the third step, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS (2012) and the result multiplied by 100.

$$q_i = \left(\frac{C_i}{S_i}\right) x100$$

Where

q_i = quality rating

C_i = Concentration of each chemical parameter in each water sample (mg/L)

S_i = Indian drinking water standard for each chemical parameter (mg/L) according to the guidelines of the BIS 10500 (2012)

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i x q_i$$

$$\boldsymbol{WQI} = \sum_{i=1}^{n} \boldsymbol{SI_i}$$

Where

SI_i = Sub-index of ith parameter

q_i= rating based on concentration of ith parameter

n = number of parameters

Water quality types can be determined on the basis of WQI. The WQI range and type of water can be classified as

Range	Type ofwater
<50	Excellentwater
50-100.1	Goodwater
100-200.1	Poorwater
200-300.1	Very poorwater
>300	Water unsuitable for drinkingpurposes

Water quality indices for different ground water sources in the study area were calculated for pre- and post-monsoon season (2018-19 & 2019-20), the type of water was classified and given in Table 28(a&b) and Fig. 25(a-b) and Fig. 26(a-b) respectively. It was observed that most of the ground waters fall between poor to good type. In post-monsoon season, the quality of ground water at some locations was observed to be improved.

Table 28(a). Water Quality Index of ground water of study area (Pre- and Post-monsoon 2018-19)

S.No.	Sample Code	Location	Source	Depth (m)	Pre-monsoon		Post-monsoon	
					WQI	Type of Water	WQI	Type of Water
1	BMT-1	Berla	BW	8.95	34.32	**Excellent water**	66.08	**Good water**
2	BMT-1(Pz)	Berla	PzW	42.6	Not Collected		86.95	**Good water**
3	BMT-2	Beejabhat	BW	9.5	88.26	**Good water**	108.71	**Poor water**
4	BMT-3	Balsamund	OW	11.2	94.50	**Good water**	159.41	**Poor water**
5	BMT-3(Pz)	Balsamund	PzW	18.55	Not Collected		382.92	**Water unsuitable for drinking purpose**
6	BMT-4	Pindri	OW	5.9	145.15	**Poor water**	266.33	**Very poor water**
7	BMT-5	Bemetara	OW	1.4	116.08	**Poor water**	242.08	**Very poor water**
8	BMT-6	Sambalpur	OW	10.65	119.34	**Poor water**	60.99	**Good water**
9	BMT-7	Kunra	OW	8.5	158.26	**Poor water**	42.59	**Excellent water**
10	BMT-7(Pz)	Kunra	PzW	34.3	Not Collected		785.19	**Water unsuitable for drinking purpose**
11	BMT-8	Murra	OW	11.8	134.36	**Poor water**	139.34	**Poor water**
12	BMT-9	Nawagarh	OW	4.5	103.24	**Poor water**	301.49	**Water unsuitable for drinking purpose**
13	BMT-10	Jhal	OW	6.9	105.88	**Poor water**	142.81	**Poor water**
14	BMT-11	Andhiyarkhor	OW	12.2	100.95	**Poor water**	100.36	**Poor water**
15	BMT-12	Jhal	OW	8.25	84.00	**Good water**	48.65	**Excellent water**
16	BMT-13	Sagona	OW	3.6	133.37	**Poor water**	210.45	**Very Poor water**
17	BMT-14	Kanhera	OW	6.3	119.54	**Poor water**	174.07	**Poor water**
18	BMT-15	Chilphi	OW	6.3	155.21	**Poor water**	273.70	**Very Poor water**
19	BMT-16	Dadhi	OW	6.7	169.13	**Poor water**	383.07	**Water unsuitable for drinking purpose**
20	BMT-17	Bahera	OW	4.1	75.20	**Good water**	203.94	**Very Poor water**
21	BMT-18	Baiji	OW	4.7	91.94	**Good water**	172.69	**Poor water**
22	BMT-19	Jhalam	OW	8.4	122.03	**Poor water**	90.06	**Good water**
23	BMT-20	Baba Mohtara	OW	6.6	59.21	**Good water**	83.96	**Good water**
24	BMT-21	Kusmi	OW	9.7	191.68	**Poor water**	46.34	**Excellent water**
25	BMT-22	Bitkuli	OW	9.2	233.47	**Very Poor water**	365.65	**Water unsuitable for drinking purpose**
26	BMT-23	Khilora	OW	7.35	61.57	**Good water**	136.24	**Poor water**
27	BMT-24	Jeori	OW	14.8	100.10	**Poor water**	157.23	**Poor water**
28	BMT-25	Amora	OW	9.9	107.18	**Poor water**	45.90	**Excellent water**
29	BMT-26	Farri	OW	15.4	54.49	**Good water**	112.34	**Poor water**
30	BMT-27	Bhurki	OW	7.5	130.75	**Poor water**	209.64	**Very Poor water**
31	BMT-28	Dunra	OW	12.5	321.54	**Water unsuitable for drinking purpose**	151.05	**Poor water**
32	BMT-29	Ninwa	OW	10.2	76.30	**Good water**	82.32	**Good water**
33	BMT-30	Deorbija	OW	7.9	192.38	**Poor water**	212.24	**Very Poor water**
34	BMT-31	Rampur(Bhand)	OW	6.2	86.01	**Good water**	88.06	**Good water**
35	BMT-32	Deori	OW	11.6	113.88	**Poor water**	172.65	**Poor water**
36	BMT-33	Anandgaon	OW	5.2	98.13	**Good water**	140.45	**Poor water**
37	BMT-34	Pirda	OW	4.85	57.60	**Good water**	93.79	**Good water**
38	BMT-35	Ufra	OW	6.9	50.51	**Good water**	67.34	**Good water**
39	BMT-36	Sankra	OW	8.6	90.86	**Good water**	145.50	**Poor water**
40	BMT-37	Sondh	OW	3.45	37.49	**Excellent water**	61.45	**Good water**
41	BMT-38	Kodwa	BW	6.3	58.63	**Good water**	101.02	**Poor water**
42	BMT-39	Saja	OW	Dry	47.28	**Excellent water**	165.76	**Poor water**
43	BMT-40	Jata	OW	9.4	56.21	**Good water**	77.05	**Good water**
44	BMT-41	Saja	OW	Abondon ed	48.51	**Excellent water**	65.44	**Good water**
45	BMT-42	Rakhi Joba	OW	14.7	66.17	**Good water**	100.72	**Poor water**
46	BMT-43	Deokar	HP	10.8	39.78	**Excellent water**	99.52	**Good water**
47	BMT-44	Mohgaon	OW	Abondon ed	43.18	**Excellent water**	74.76	**Good water**
48	BMT-45	Mouha Bhata	OW	7.9	74.32	**Good water**	124.53	**Poor water**
49	BMT-46	Beltara	HP	45.75	82.26	**Good water**	139.44	**Poor water**
50	BMT-47	Beltara	OW	9.7	83.00	**Good water**	115.73	**Poor water**
51	BMT-48	Thelka	OW	Abondon	99.68	**Good water**	148.72	**Poor water**

				ed				
52	BMT-49	Thankamariya	OW	8.5	113.03	**Poor water**	165.10	**Poor water**
53	BMT-50	Keotara	OW	19.6	59.79	**Good water**	169.54	**Poor water**
54	BMT-50(Pz)	Keotara	OW	23.25	Not Collected		219.45	**Very Poor water**
55	BMT-51	Bortara	OW	9.3	113.03	**Poor water**	77.04	**Good water**
56	BMT-52	Sawartala	OW	13.1	83.27	**Good water**	71.61	**Good water**
57	BMT-53	Parpodi	OW	7.75	36.44	**Excellent water**	57.52	**Good water**
58	BMT-54(Pz)	Khandesra	OW	38.1	Not Collected		135.86	**Poor water**
59	KBD-1	Indori	OW	4.4	42.37	**Excellent water**	161.08	**Poor water**
60	KBD-2	Dasranghpur	BW	5.35	470.85	**Water unsuitable for drinking purpose**	180.25	**Poor water**
61	KBD-3	Gourmati	OW	Abondon ed	139.25	**Poor water**	100.76	**Poor water**
62	MNG-1	Moungeli	HP	7.8	62.70	**Good water**	82.36	**Good water**
63	MNG-2	Dharampura	OW	Abondon ed	89.46	**Good water**	110.84	**Poor water**
64	MNG-3	Chhatona	OW	11.3	112.33	**Poor water**	76.42	**Good water**
65	MNG-4	Pathariya	OW	Abondon ed	103.18	**Poor water**	208.02	**Very poor water**
66	MNG-5	Pandarbhata	OW	10.3	181.78	**Poor water**	282.78	**Very poor water**
67	MNG-6	Pandarbhata	HP	-	148.20	**Poor water**	74.54	**Good water**
68	MNG-7	Sargaov	OW	Dry	Not collected		84.33	**Good water**
69	MNG-8	Bhojpuri	OW	6.1	Not Collected		79.23	**Good water**
70	MNG-9	Sanwa	OW	7.5	Not Collected		153.40	**Poor water**
71	MNG-10	Bavli	OW	8.1	Not Collected		330.82	**Water unsuitable for drinking purpose**
72	MNG-11	Padiyain	OW	5.1	Not Collected		57.52	**Good water**

Table 28(b). Water Quality Index of ground water of study area (Pre- and Post-monsoon 2019-20)

S.No.	Sample Code	Location	Source	Depth (m)	Pre-monsoon		Post-monsoon	
					WQI	Type of Water	WQI	Type of Water
1	BMT-1	Berla	BW	8.95	40.91	Excellent water	53.11	Good water
2	BMT-1(Pz)	Berla	PzW	42.6	44.29	Excellent water	46.31	Excellent water
3	BMT-2	Beejabhat	BW	9.5	81.08	Good water	104.9	Poor water
4	BMT-3	Balsamund	OW	11.2	30.04	Excellent water	25.64	Excellent water
5	BMT-3(Pz)	Balsamund	PzW	18.55	340.9	Water unsuitable for drinking purpose	358.9	Water unsuitable for drinking purpose
6	BMT-4	Pindri	OW	5.9	223.0	Very Poor water	237.2	Very Poor water
7	BMT-5	Bemetara	OW	1.4	141.3	Poor water	118.6	Poor water
8	BMT-6	Sambalpur	OW	10.65	36.54	Excellent water	313.7	Water unsuitable for drinking purpose
9	BMT-7	Kunra	OW	8.5	301.1	Water unsuitable for drinking purpose	208.0	Very Poor water
10	BMT-7(Pz)	Kunra	PzW	34.3	1001.6	Water unsuitable for drinking purpose	207.9	Very Poor water
11	BMT-8	Murra	OW	11.8	117.4	Poor water	135.6	Poor water
12	BMT-9	Nawagarh	OW	4.5	218.9	Very Poor water	538.6	Water unsuitable for drinking purpose
13	BMT-10	Jhal	OW	6.9	129.0	Poor water	152.8	Poor water
14	BMT-11	Andhiyarkhor	OW	12.2	77.01	Good water	177.4	Poor water
15	BMT-12	Jhal	OW	8.25	111.0	Poor water	54.18	Good water
16	BMT-13	Sagona	OW	3.6	214.8	Very Poor water	179.4	Poor water
17	BMT-14	Kanhera	OW	6.3	227.0	Very Poor water	46.32	Excellent water
18	BMT-15	Chilphi	OW	6.3	252.4	Very Poor water	229.31	Very Poor water
19	BMT-16	Dadhi	OW	6.7	63.07	Good water	58.01	Good water
20	BMT-17	Bahera	OW	4.1	122.6	Poor water	203.7	Very Poor water
21	BMT-18	Baiji	OW	4.7	162.7	Poor water	73.53	Good water
22	BMT-19	Jhalam	OW	8.4	165.6	Poor water	71.29	Good water
23	BMT-20	Baba Mohtara	OW	6.6	67.3	Good water	121.8	Poor water
24	BMT-21	Kusmi	OW	9.7	34.01	Excellent water	35.71	Excellent water

25	BMT-22	Bitkuli	OW	9.2	573.6	Water unsuitable for drinking purpose	305.8	Water unsuitable for drinking purpose
26	BMT-23	Khilora	OW	7.35	101.6	Poor water	115.3	Poor water
27	BMT-24	Jeori	OW	14.8	135.6	Poor water	119.0	Poor water
28	BMT-25	Amora	OW	9.9	33.20	Excellent water	63.74	Good water
29	BMT-26	Farri	OW	15.4	88.58	Good water	66.54	Good water
30	BMT-27	Bhurki	OW	7.5	193.3	Poor water	181.4	Poor water
31	BMT-28	Dunra	OW	12.5	258.2	Very Poor water	407.3	Water unsuitable for drinking purpose
32	BMT-29	Ninwa	OW	10.2	84.42	Good water	61.44	Good water
33	BMT-30	Deorbija	OW	7.9	96.99	Good water	79.25	Good water
34	BMT-31	Rampur(Bhand)	OW	6.2	68.10	Good water	58.52	Good water
35	BMT-32	Deori	OW	11.6	53.50	Good water	75.60	Good water
36	BMT-33	Anandgaon	OW	5.2	66.21	Good water	61.67	Good water
37	BMT-34	Pirda	OW	4.85	40.33	Excellent water	76.14	Good water
38	BMT-35	Ufra	OW	6.9	26.24	Excellent water	37.32	Excellent water
39	BMT-36	Sankra	OW	8.6	81.69	Good water	73.07	Good water
40	BMT-37	Sondh	OW	3.45	36.29	Excellent water	34.25	Excellent water
41	BMT-38	Kodwa	BW	6.3	64.46	Good water	59.44	Good water
42	BMT-39	Saja	OW	Dry	70.47	Good water	46.80	Excellent water
43	BMT-40	Jata	OW	9.4	51.70	Good water	82.09	Good water
44	BMT-41	Saja	OW	Abondoned	43.02	Excellent water	54.74	Good water
45	BMT-42	Rakhi Joba	OW	14.7	131.7	Poor water	85.08	Good water
46	BMT-43	Deokar	HP	10.8	41.43	Excellent water	98.76	Good water
47	BMT-44	Mohgaon	OW	Abondoned	38.19	Excellent water	48.44	Excellent water
48	BMT-45	Mouha Bhata	OW	7.9	68.51	Good water	56.25	Good water
49	BMT-46	Beltara	HP	45.75	58.65	Good water	86.08	Good water
50	BMT-47	Beltara	OW	9.7	59.18	Good water	93.79	Good water
51	BMT-48	Thelka	OW	Abondoned	40.69	Excellent water	63.75	Good water
52	BMT-49	Thankamariya	OW	8.5	166.1	Poor water	125.6	Poor water
53	BMT-50	Keotara	OW	19.6	92.95	Poor water	103.5	Poor water
54	BMT-50(Pz)	Keotara	OW	23.25	30.99	Excellent water	99.59	Good water
55	BMT-51	Bortara	OW	9.3	44.42	Excellent water	66.84	Good water
56	BMT-52	Sawartala	OW	13.1	40.29	Excellent water	66.53	Good water
57	BMT-53	Parpodi	OW	7.75	42.77	Good water	40.57	Excellent water
58	BMT-54(Pz)	Khandesra	OW	38.1	97.21	Good water	76.95	Good water
59	KBD-1	Indori	OW	4.4	62.19	Good water	42.56	Excellent water
60	KBD-2	Dasranghpur	BW	5.35	63.12	Good water	375.4	Water unsuitable for drinking purpose
61	KBD-3	Gourmati	OW	Abondoned	86.98	Good water	133.2	Poor water
62	MNG-1	Moungeli	HP	7.8	64.01	Good water	121.2	Poor water
63	MNG-2	Dharampura	OW	Abondoned	74.06	Good water	114.6	Poor water
64	MNG-3	Chhatona	OW	11.3	52.66	Good water	57.43	Good water
65	MNG-4	Pathariya	OW	Abondoned	169.7	Poor water	224.3	Very Poor water
66	MNG-5	Pandarbhata	OW	10.3	288.7	Very Poor water	264.4	Very Poor water
67	MNG-6	Pandarbhata	HP	-	298.3	Very Poor water	54.34	Good water
68	MNG-7	Sargaov	OW	Dry	91.57	Good water	103.9	Poor water
69	MNG-8	Bhojpuri	OW	6.1	53.24	Good water	62.21	Good water
70	MNG-9	Sanwa	OW	7.5	146.0	Poor water	136.0	Poor water
71	MNG-10	Bavli	OW	8.1	300.6	Water unsuitable for drinking purpose	327.2	Water unsuitable for drinking purpose
72	MNG-11	Padiyain	OW	5.1	82.73	Good water	55.28	Good water

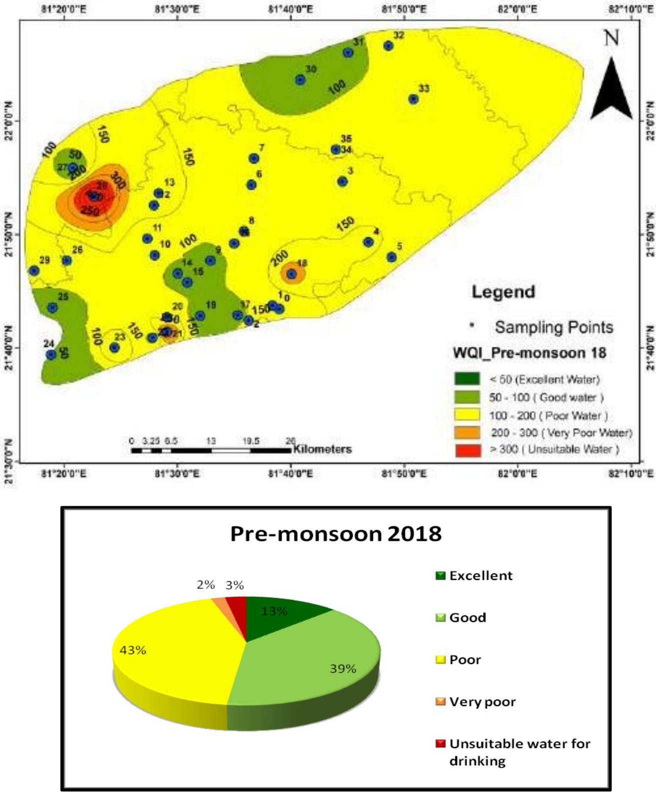


Fig. 25(a). Classification of ground water on the basis of Water Quality Index (Pre-monsoon 2018-19)

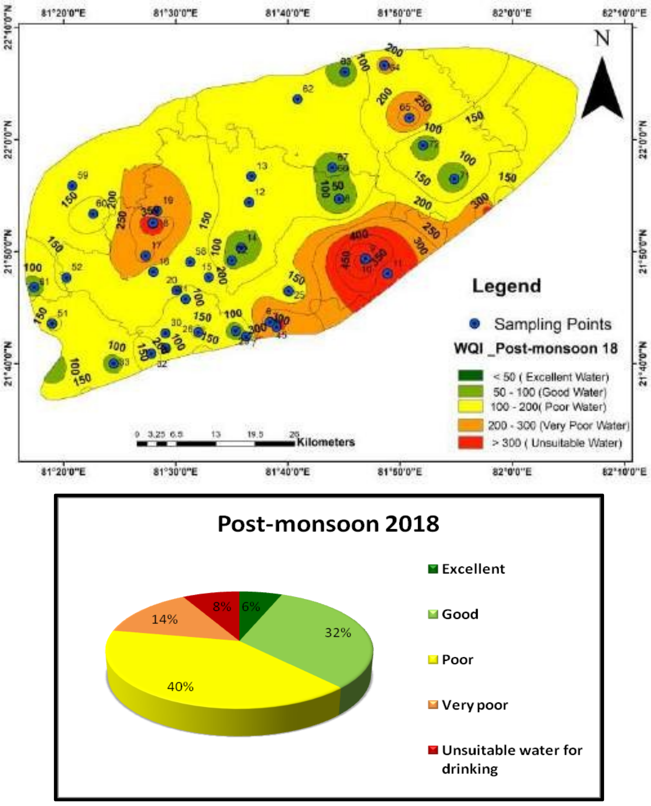


Fig.25(b). Classification of ground water on the basis of Water Quality Index (Post-monsoon 2018-19)

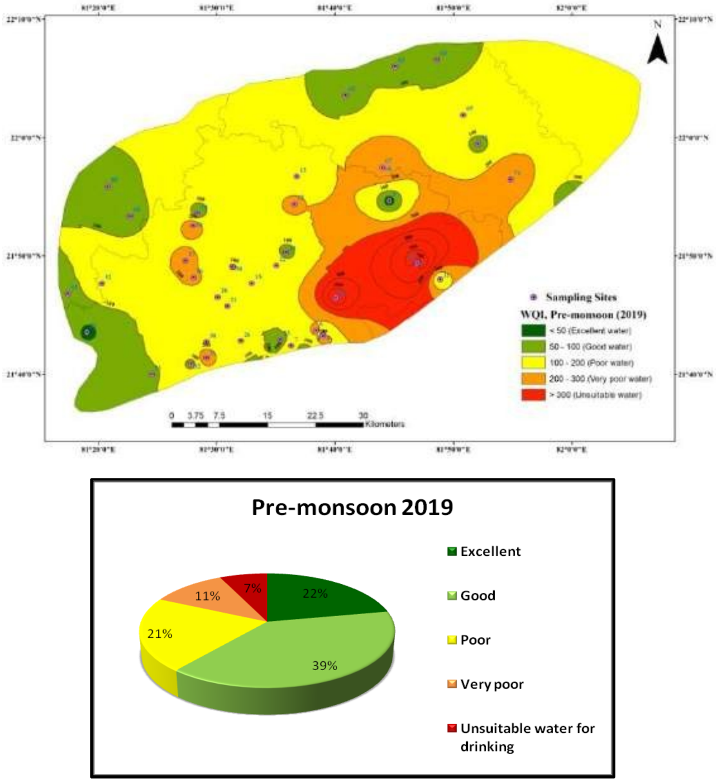


Fig. 26(a). Classification of ground water on the basis of Water Quality Index (Pre-monsoon 2019-20)

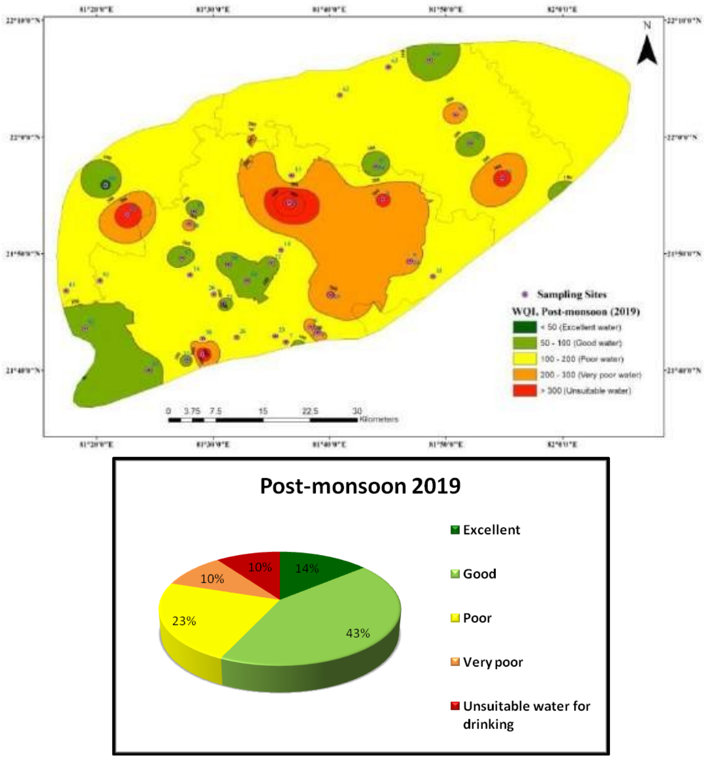


Fig. 26(b). Classification of ground water on the basis of Water Quality Index (Post-monsoon 2019-20)

5.6 Groundwater Flow Modelling

Processing of ground water data, aquifer parameter data and Litholog data

The groundwater level data of observation wells existing in the Maniyari shale formation region observed by Water Resources Department, Raipur, Chhattisgarh from 2000 to 2019 (Quarterly basis viz; May, August, November and January) were collected and processed. Geological formation, SWL, Discharge, Drawdown, Transmissivity and Storativity data of 49 locations in Maniyari Shell Formation Region were collected from CGWB, Raipur. Collected aquifer data has been processed and presented in Fig. 27 to 35. Total 33 Lithologs having depth 40-90 m are presented in Fig. 27-28. Lithologs variations in the study area are depicted in Fig. 29 to 32. Drawdown, Discharge and Transmissivity variation in Maniyari Shell Formation Region are shown in Fig. 33 to Fig.35.

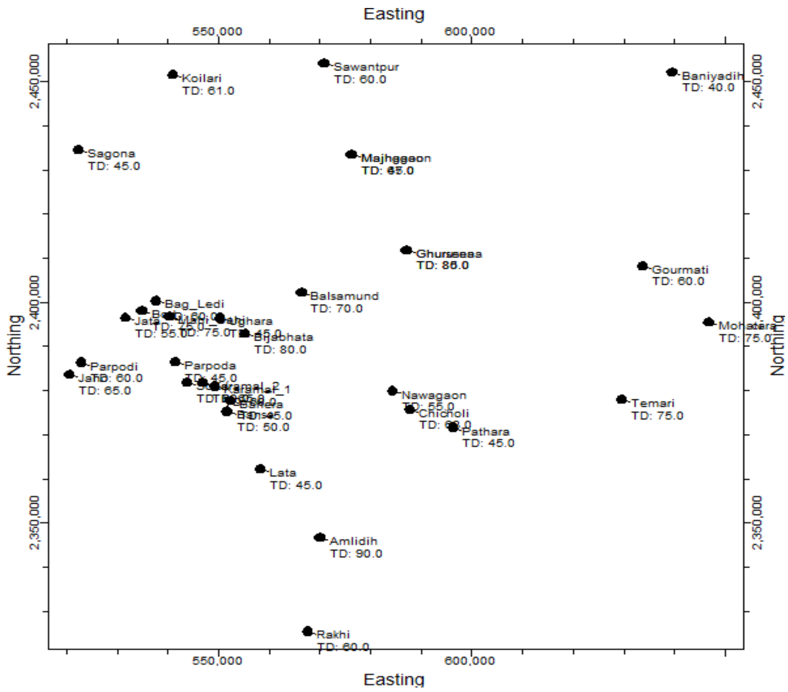


Fig. 27. Distribution of Lithologs with Total Depth (m)

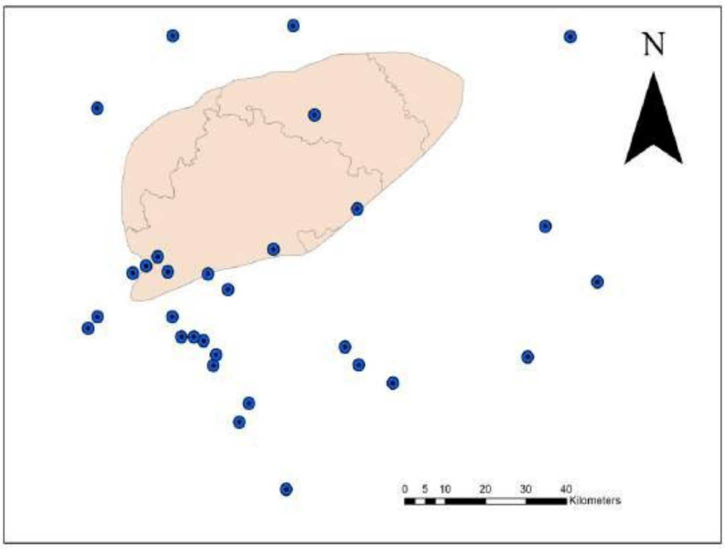


Fig. 28. Map showing location of Litholog data

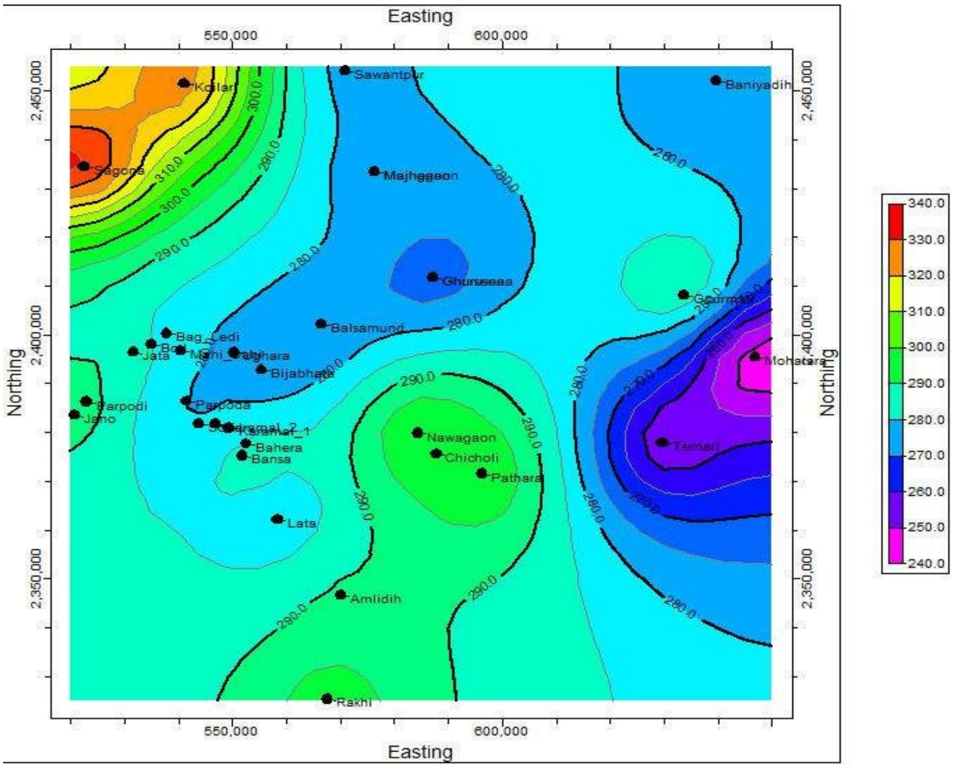


Fig. 29. Lithologs along with variation of Surface Topography

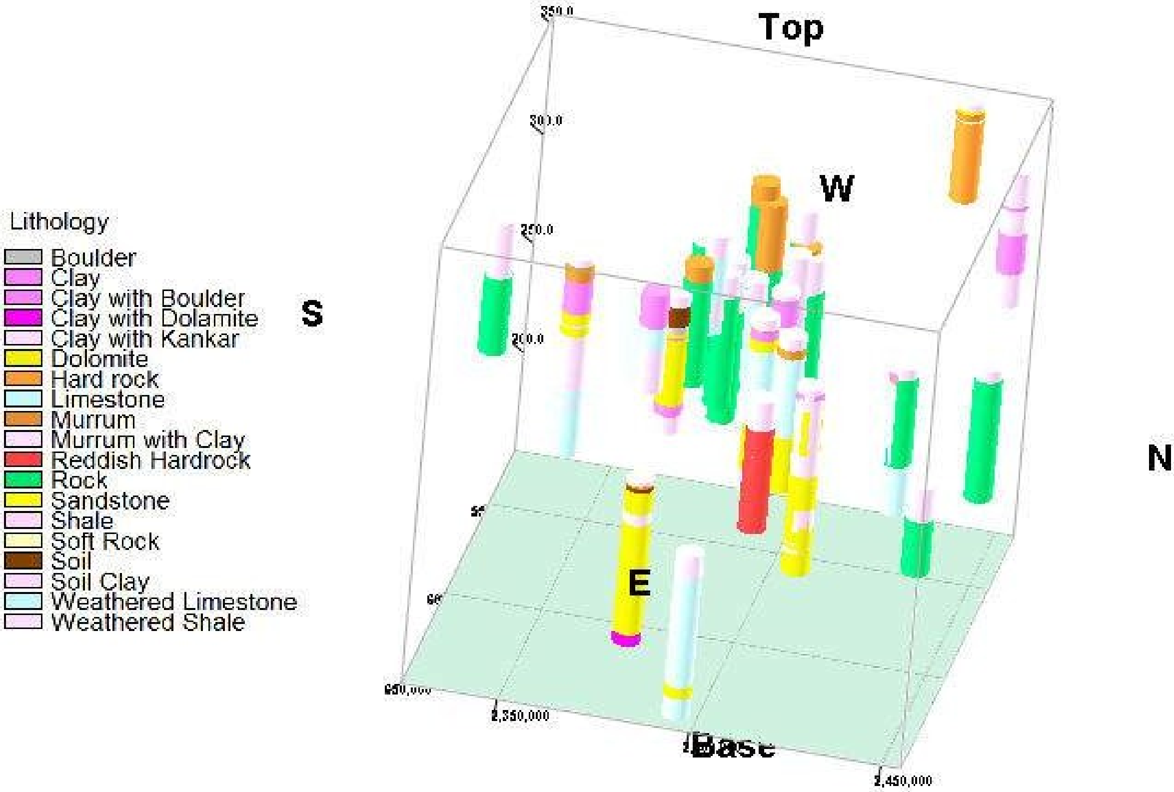


Fig. 30. Lithological Variation

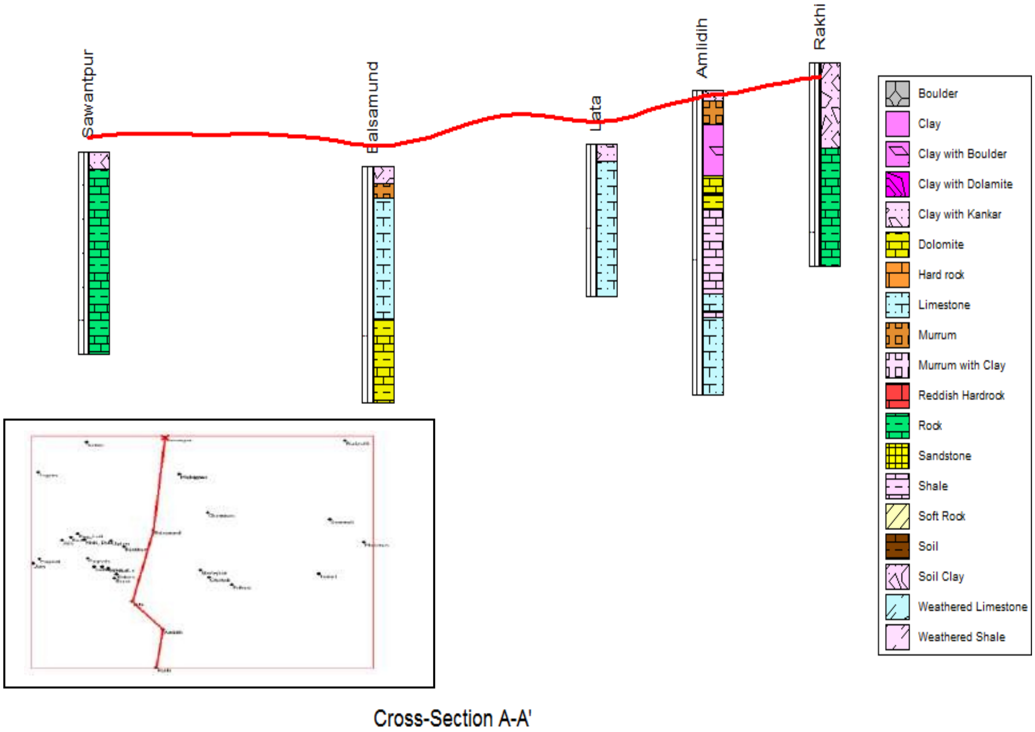


Fig. 31. Variation of Lithologs along SectionA-A'

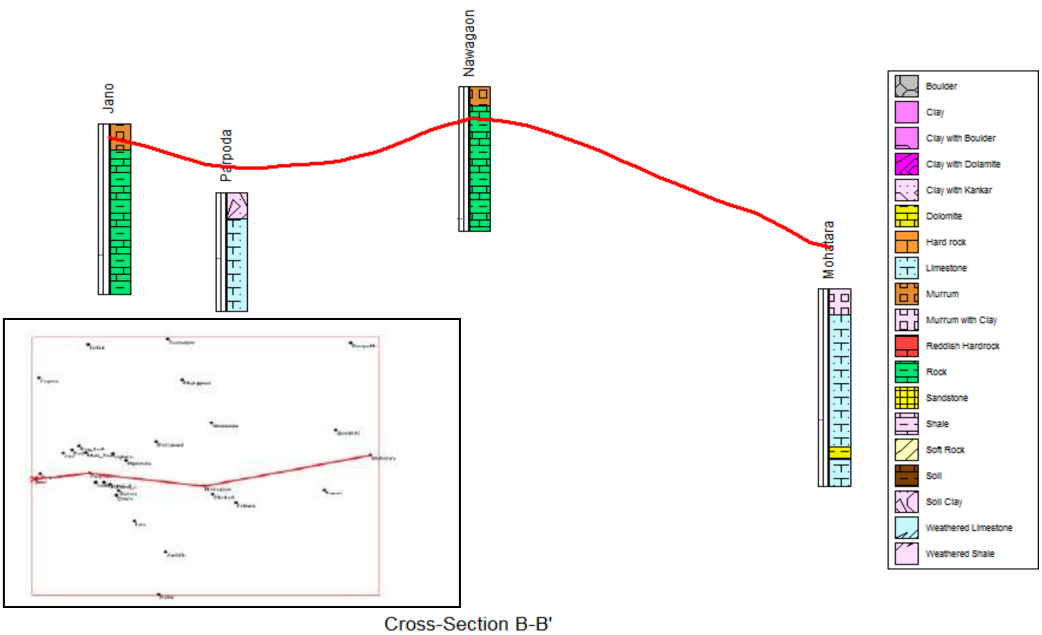


Fig. 32. Variation of Lithologs along SectionB-B'

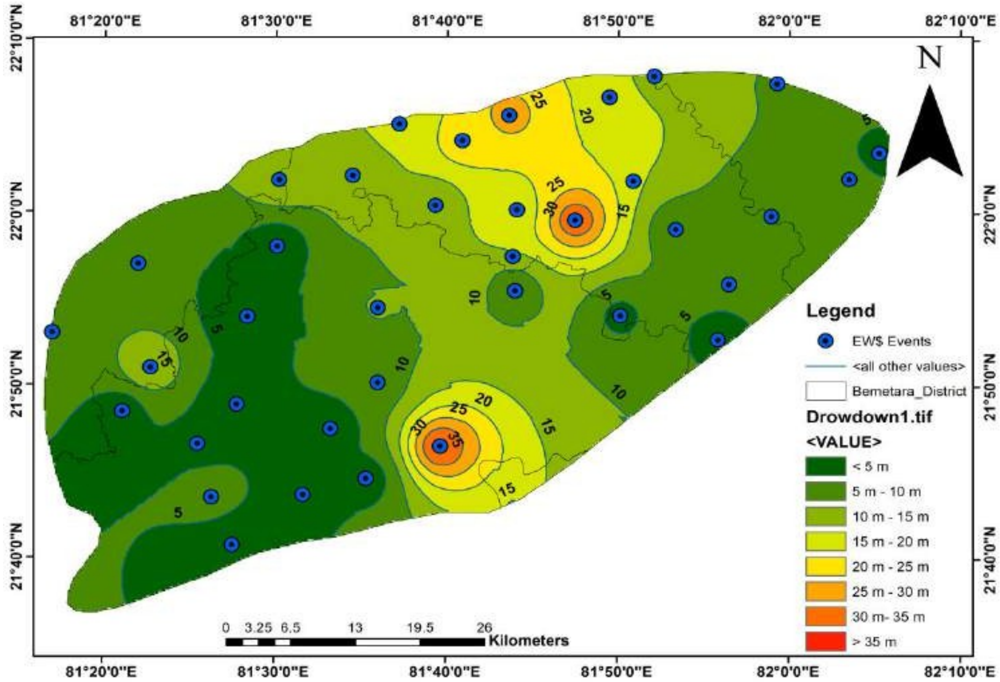


Fig. 33. Drawdown variation in Maniyari Region

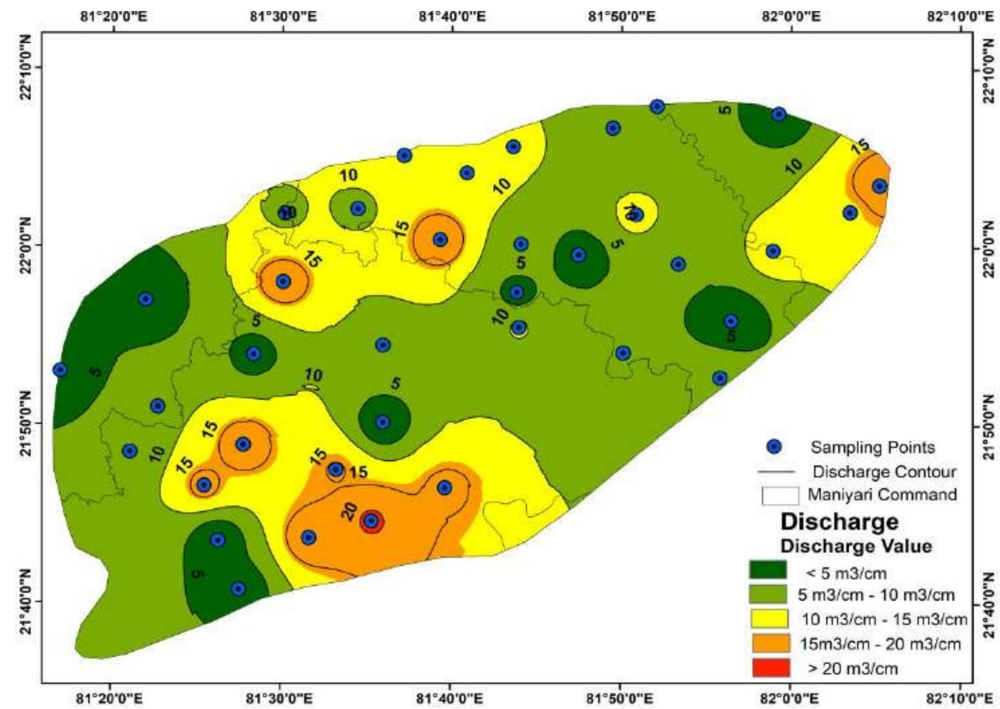


Fig. 34. Discharge variation in Maniyari Region

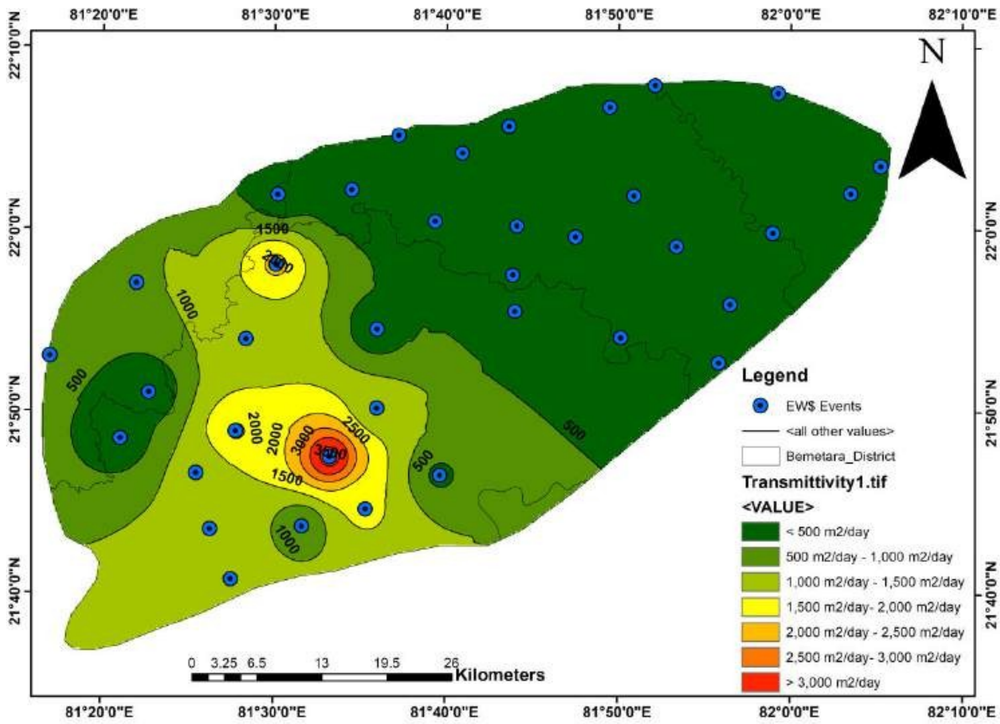


Fig. 35. Transmissivity variation in Maniyari Region

The above lithologs data and aquifer parameters has been used for development of groundwater model for estimating the artificial recharge in the identified degraded zones of sulphate contamination of the study area.

Groundwater Flow Model

The MODFLOW - a three-dimensional finite-difference flow model developed by USGS (Harbaugh, and McDonald, 1996; Harbaugh, 2005)- has a modular structure that allows to simulate steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can beconfined,unconfined,oracombinationofconfinedand unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. The governing partial differential equation for a confined aquifer used in the MODFLOW is as follows:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_S\frac{\partial h}{\partial t}\ldots \quad (1)$$

Where, K_{xx}, K_{yy} and $K_{zz}$are the values of hydraulic conductivities along the *x*, *y*, and *z* coordinate axes (L/T); h is the potentiometric head,(L); W is a volumetric flux per unit volume representing sources and/or sinks of water, where *negative* values are extractions and *positive* values are injections, (T^{-1}); $S_s$is the specific storage of the porous material (L^{-1}); and t is time(T).

Groundwater modelling using the MODFLOW is to develop a predictive model using the recharge to study the responses of the groundwater system and to determine responses of the aquifers for various management strategies.

In mathematical terms, the algebraic equation on discrete finite difference form in terms of potential head of water as solved by the MODFLOW (Harbaugh, and McDonald, 1996) is given by:

$$KZ_{i,j,k-\frac{1}{2}}h^{m}_{i,j,k-1}KX_{i-\frac{1}{2},j,k}h^{m}_{i-1,j,k} + KY_{i,j-\frac{1}{2},k}h^{m}_{i,j-1,k}$$
$$+ \left(-KZ_{i,j,k-\frac{1}{2}} - KX_{i-\frac{1}{2},j,k} - KY_{i,j-\frac{1}{2},k} - KY_{i,j+\frac{1}{2},k} - KX_{i+\frac{1}{2},j,k} - KZ_{i,j,k+\frac{1}{2}} + HCOF_{i,j,k}\right)h^{m}_{i,j,k} +$$
$$KY_{i,j+\frac{1}{2},k}h^{m}_{i,j+1,k} + KX_{i+\frac{1}{2},j,k}h^{m}_{i+1,j,k} + KZ_{i,j,k+\frac{1}{2}}h^{m}_{i,j,k+1} = RHS_{i,j,k}$$

…(2)

in which, $HCOF_{i,j,k} = P_{i,j,k} - \frac{SS_{i,j,k}\,\Delta X_i\,\Delta Y_j\,\Delta Z_k}{t^m - t^{m-1}}$

and, $RHS_{i,j,k} = -Q_{i,j,k} - SS_{i,j,k}\Delta X_i \Delta Y_j\,\Delta Z_k\frac{h^{m-1}_{i,j,k}}{t^m - t^{m-1}}$

Where,

- $h^{m}_{i,j,k}$is the hydraulic headat cell *i,j,k* at time step *m*, which is to becalculated;
- *KX, KY* and *KZ* are the hydraulic conductancebetween node *i,j,k* and a neighbouring node;
- $P_{i,j,k}$is the sum of coefficients of head from source and sink terms, such as aquifer recharge, $W_{rech.sh}$in the presentcase;
- $Q_{i,j,k}$is the sum of constants from source and sink terms, where $Q_{i,j,k} < 0$is flow out of the groundwater system (such as pumping), and $Q_{i,j,k} > 0$is flow in (such as injection), $Q_{w.sh}$and $Q_{w.dp}$in the presentcase;
- $SS_{i,j,k}$is the specificstorage;
- $\Delta X_i\ \Delta Y_j \Delta Z_k$are the dimensions of cell *i,j,k*, which, when multiplied, represent the volume of the cell;and
- $t^m$is the time at step*m.*

In matrix form, eq. (1) can be represented as:

$$[A][h] = [C] \qquad \dots \qquad (3)$$

where [A] is a matrix of the coefficients of head for all active nodes in the grid; [h] is a vector of heads at the end of time step m for all nodes in the grid; and [C] is a vector of the constant terms for all nodes in thegrid.
In eq. (3), which represents eq.(1) in matrix form, the elements of the matrices, [A] and [C] are known, the unknowns are the elements of matrix[h].

Setting of MODFLOW Model

Fig. 36 depicts the discretized domain map with position of active and inactive cells. The MODFLOW is setup for the area covering two districts viz. Bemetara and Mungeli with various databases. The total modeling area of these two districts is 5,639.29 sq.km comprising part of four administrative blocks namely Bemetara, Mungeli, Nawagarh and Patharia (Fig. 37). The Hamp river flows through southern boundary of the modeling area; Tesua river flows through the northern boundary; and Shivnath river flows through the eastern boundary, as shown in Fig. 38. The easting and northing distances of the modeling area vary from 546000 to 610000 and 2403000 to 2439000 m. To accommodate these distances, the study area was discretized into 64,000 m (X- (W-E) direction) and 36,000 m (Y- (N-S) direction) gridded network comprising of 11,088 cells with size of each cell of 445 mx470m.The model domain consists of 77 rows and 144 columns with an area of 2,304 km^2. The surface flow direction in the study area is largely towards south-east direction. All the cells inside the modeling domain are considered active and outside cells were considered inactive.

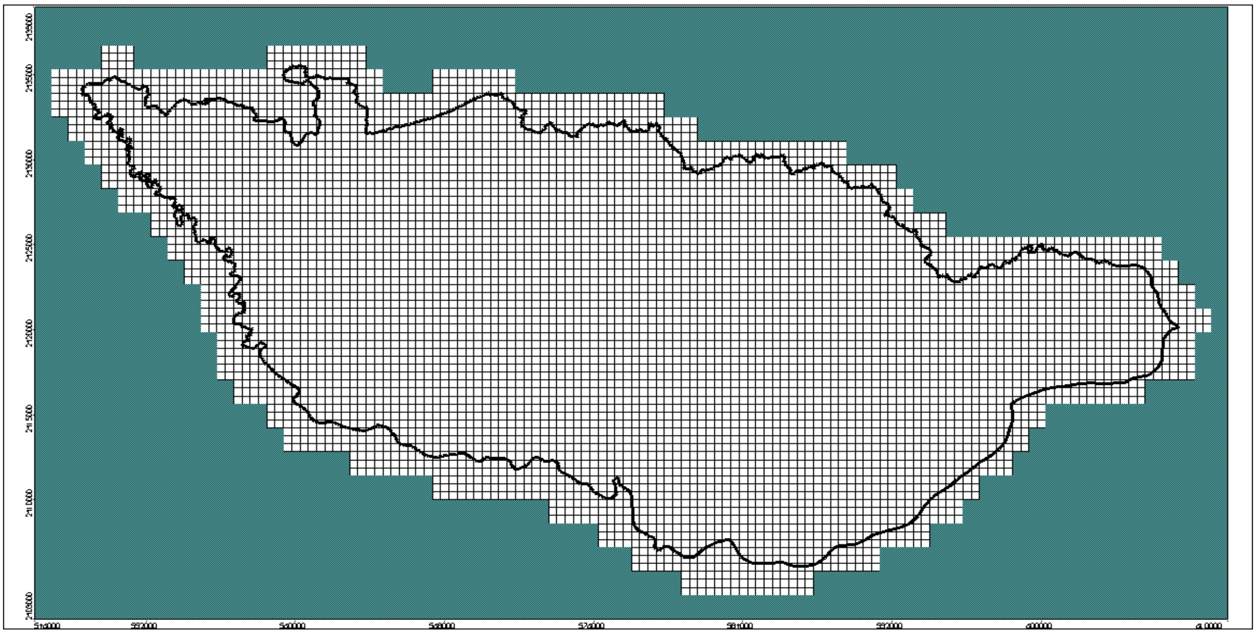


Fig. 36. Model domain showing discretisation of modelling area(cell size: 445m x470m)

The hydrogeological formations in the modelling domain with different geological strata representing formation of variable thickness were prepared in the Rockworks software. The underground formations comprise of alternate layers of aquifers and aquitards. Therefore, it was planned to consider a 4-layer model. The vertical cells below the active zone were considered active and inactive in the inactive zone. The vertical discretization of 4- layers represents the formations as top layer of variable thickness represent top soil having characteristics of aquitard, followed by an unconfined aquifer of varying thicknesses, then an aquitard of varying thicknesses, and then confined aquifer of variable thickness[Fig.39(a-b)].

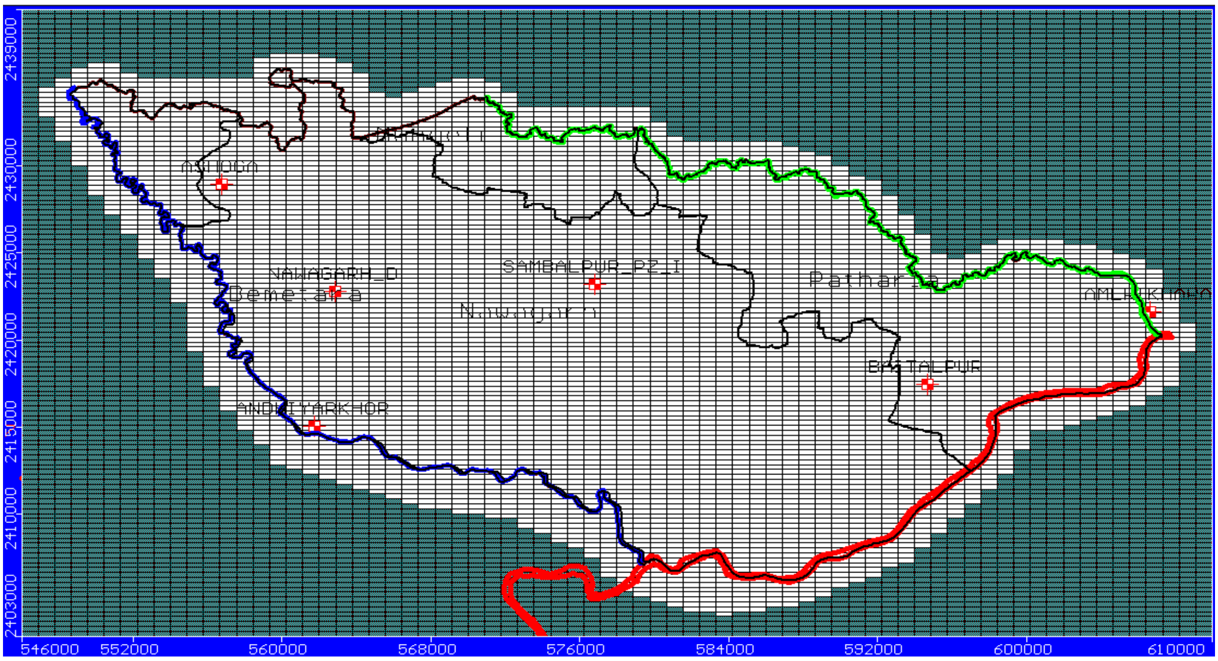


Fig. 37. Map showing administrative blocks, active and inactive cells

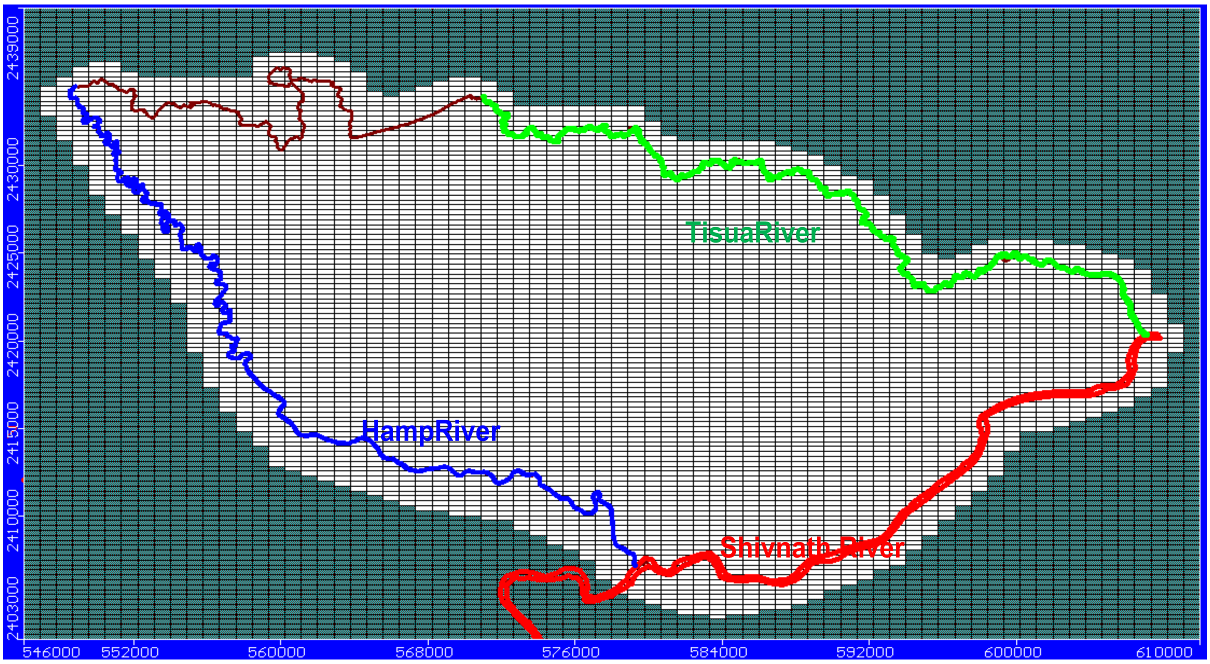


Fig. 38. **River and canals falling in the model area**

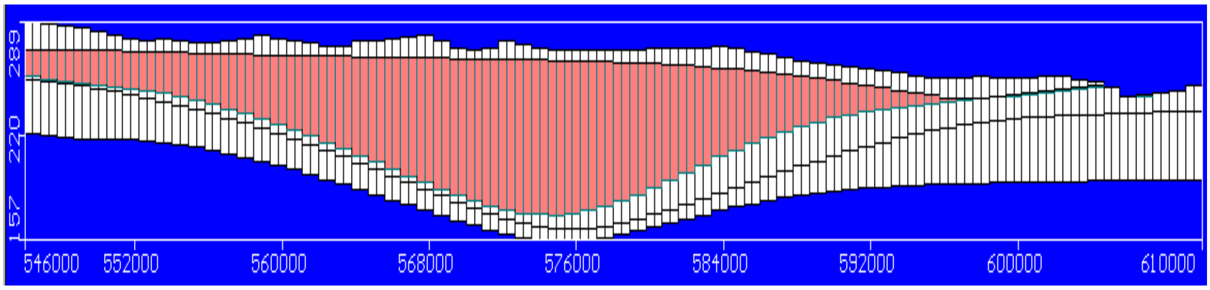


Fig. 39(a). **Sectional view of vertical discretization of model domain showing 4-layers of underground formations along middle of W-E direction (38th row).**

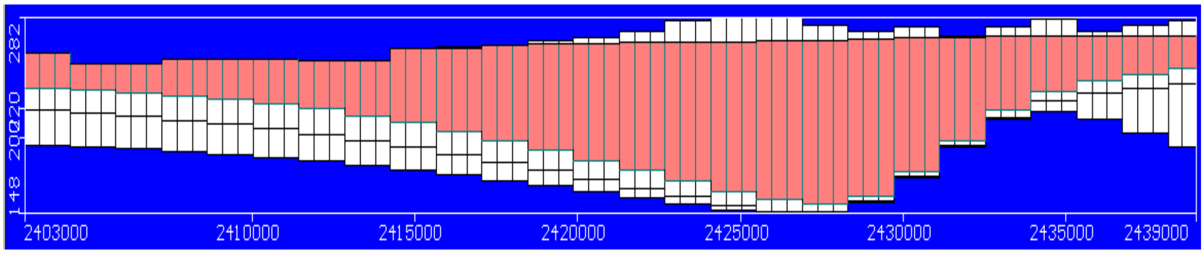


Figure 39(b). **Sectional view of vertical discretization of model domain showing 4-layers of underground formations along middle of N-S direction (72ndcolumn).**

Initial condition

The winter season water level data of the year 2014 was taken as the initial water table condition for simulation of the transient flow model. The rasterized map from point data of water level was then used as initial watertable for all active grids (Fig. 40).

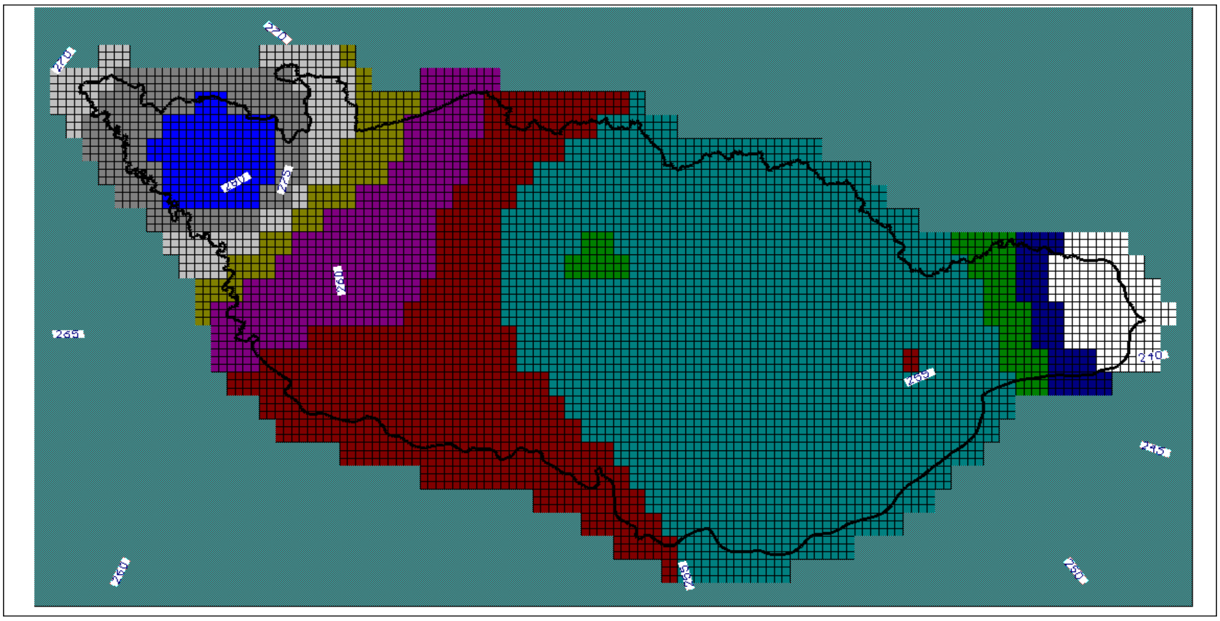


Fig. 40. Distribution of initial heads in the modelling area.

Boundary conditions

Ideally - a groundwater basin boundary should form the boundary condition. In the absence of a natural groundwater basin boundary, surface water hydrological features are considered as the boundary. In the present case, the Hamp river, Tesua river and and the Shivnath river are used as the constant head boundary conditions on the modelling area boundary. In a small portion, north-western boundary has been considered as no flow boundary. The groundwater level data of six observation wells (CGWB) for the year 2014 to 2018 was available and used for calibration and validation of the model. The location of these wells, falling in the modeling area, is shown in Fig. 41.

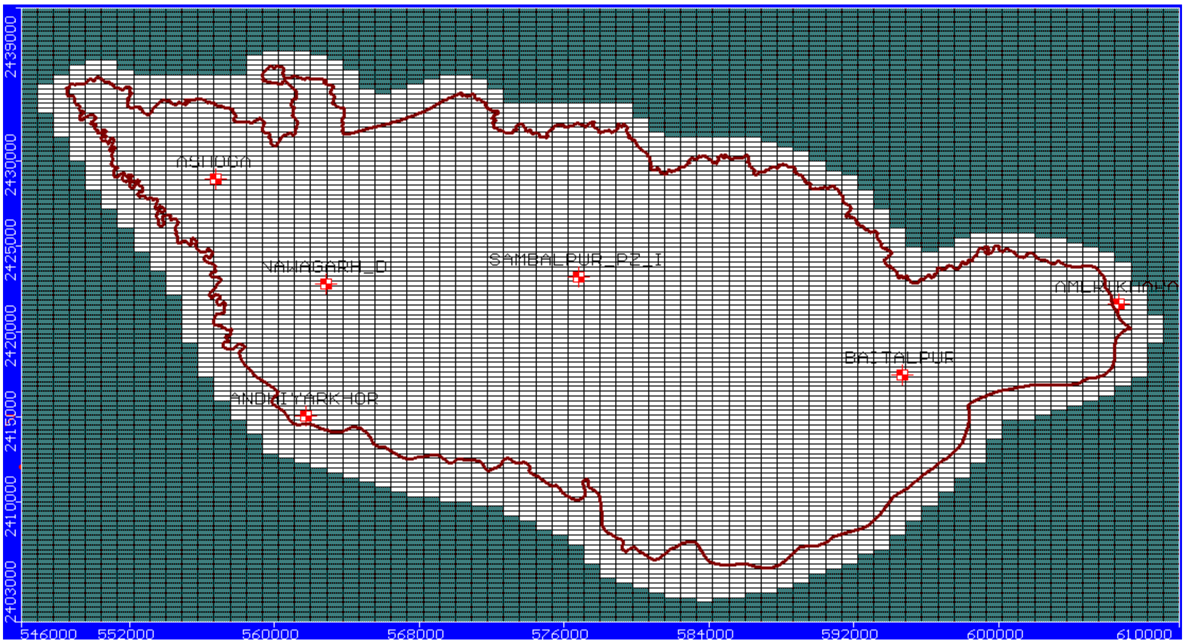


Fig. 41. Distributed locations of groundwater level observation points in the modeling area

Block-wise recharge and withdrawals were available for the area. Accordingly, the input minus output stresses were applied to the model and adjusted during the calibration process.

Calibration– MODFLOW Model

The MODFLOW model parameters were calibrated by the following ways:

(i) Firsthand calibration of the initial guess values of parameters (Table 29) considering steady-state condition of the domain, with initial groundwater levels at the top of the topographic elevations with no external stresses on the modelling domain, and allowing model run for a long duration till it reaches to steady statecondition;

(ii) Refinement of the firsthand calibrated values of the parameters considering transient state of the domain with a particular set of observed data and by considering all input stresses acting on thedomain;

The data period length of 5 years (2018), from January, 2014 to October, 2018was used for modeling; 2014 to 2016 for the calibration and 2017 to 2018 for the validation. For calibration of the model parameters, i.e., hydraulic conductivities, K_{xx}, K_{yy}, and K_{zz} and storage coefficients, S_{xx},S_{yy}, and S_{zz}, as indicated in (ii), input stresses namely, rainfall recharge, and groundwater withdrawal from both unconfined and confined aquifers were used for the above-mentioned period. For comparison of the simulated model's responses (in terms of heads) with the observed ones, data of 6 observation wells distributed within the modeling area were used. For performance evaluation of the simulated profiles corresponding to the calibrated model's parameters, few statistical measures viz. residual mean (RM), absolute residual mean (ARM), standard error of the estimate, root mean squared error (RMSE), normalized root mean squared error (NRMSE), correlation coefficient, were used.

Depending upon the data, there were total 24 stress periods. In each stress period, there were 10 time-steps with multiplier of 1.2. The simulation was carried out by setting a transient-state flow model.

MODFLOW simulation

To develop the MODFLOW simulation model, the parameters were calibrated from the transient state condition by comparing the computed heads with the observed heads. The acceptability of a model's parameters calibration is usually a subjective measure, and must be calibrated to different conditions. However, there are some generally accepted methods of evaluating and interpreting the model calibration using both qualitative and quantitative measures viz. residual mean (RM), absolute residual mean (ARM), standard error of the estimate (SE), root mean squared error (RMSE), normalized root mean squared error (NRMSE), correlation coefficient (CC), etc. If the responses of the model corresponding to the parameters assumed for calibration were found acceptable with these criteria, then the model's parameters and the setting of the model were said to be calibrated. The calibration of the model was thus a trial and error approach.

Model Calibration

Making use of the inputs stresses, boundary conditions and initial heads as explained above, the model parameters were calibrated employing the groundwater contours of January 2014 and groundwater levels for the period 2014 to 2016. Fig. 42 shows the comparison between the computed and the observed groundwater contours during 2014 to 2016.

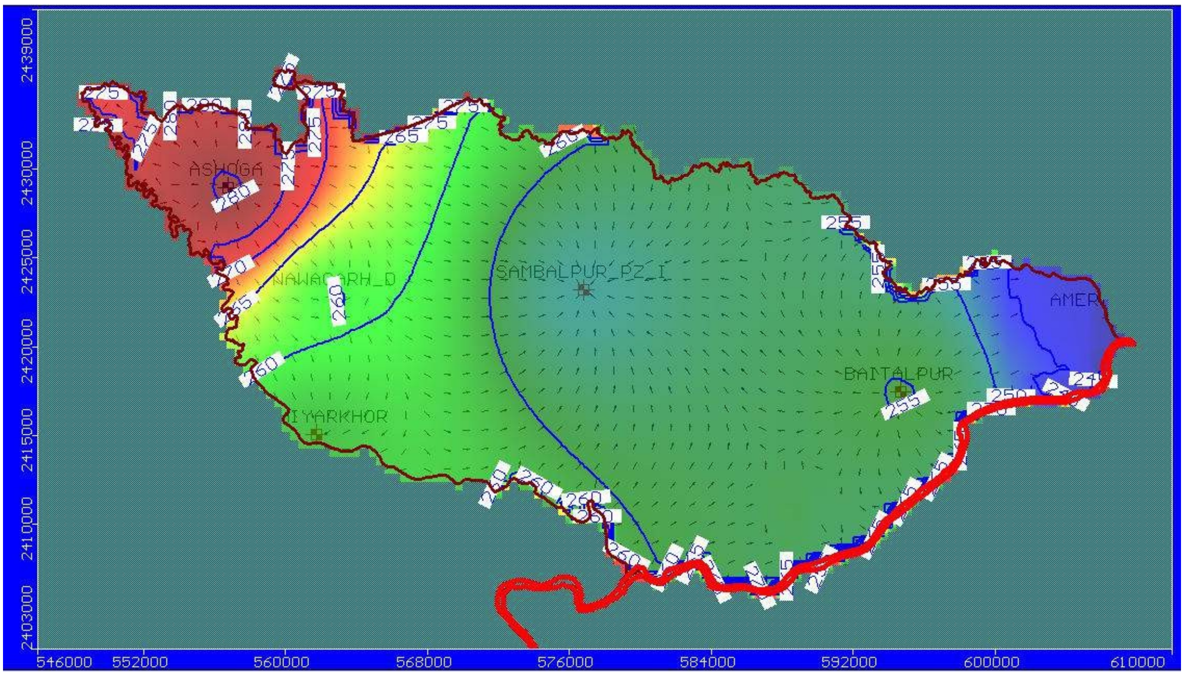


Fig. 42. Observed and simulated groundwater contours for January 2014 (observed in red colour; modeled in blue colour).

The 1:1 plots of the calculated heads versus observed heads of six wells in the modeling area for the calibration period of the first and last day are shown in Fig. 43 and 44, respectively. The statistical values of these plots namely, RM (residual mean) ranges between 0.988 and 0.992 m, ARM (absolute residual mean) ranges between 1.081 and 1.884 m, SE (std. error of the estimate) ranges between 0.849 and 1.166 m, RMSE ranges between 1.905 and 3.113 m, NRMSE ranges between 4.493 and 7.357 % and the correlation coefficient that ranges between 0.979 and 0.992 were also indicated in these figures. The histogram (Fig. 45) of residuals between the observed and computed heads for the calibration period showed a normal distribution, which implied a close agreement of error distribution.

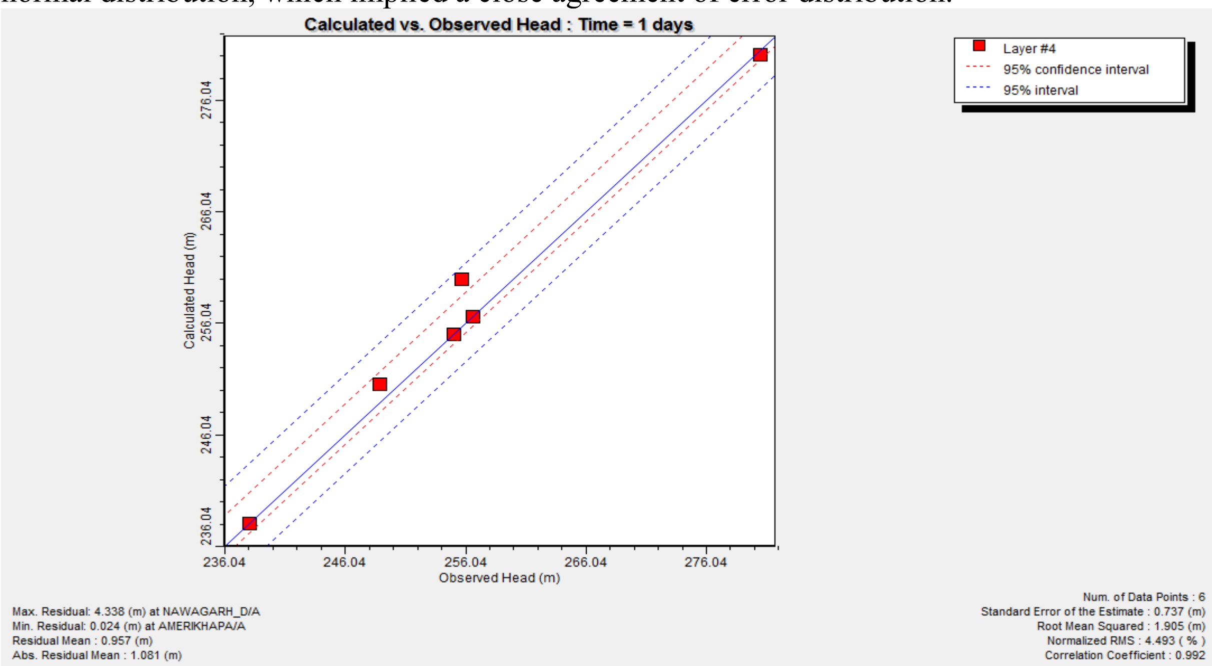


Fig. 43. 1:1 plot of Computed and observed heads for the calibration period for the first day of simulation

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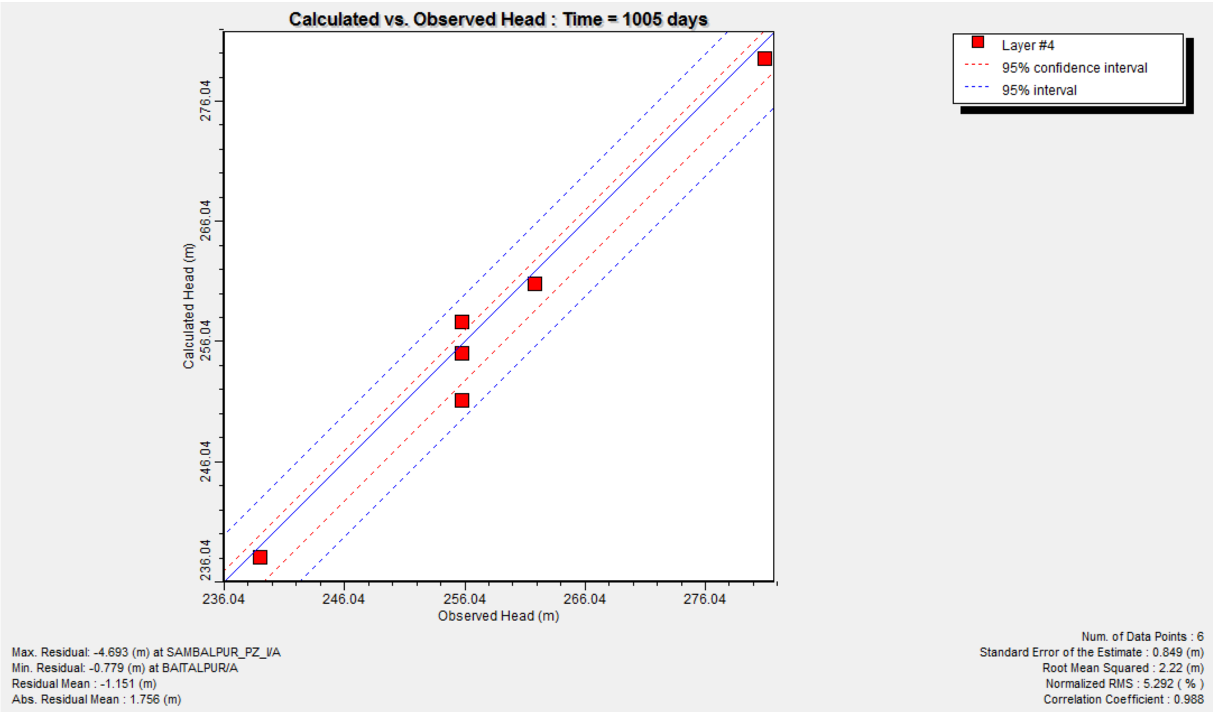


Fig. 44. 1:1 plot of Computed and observed heads for the calibration period for the last day of simulation, i.e., t=1005 days.

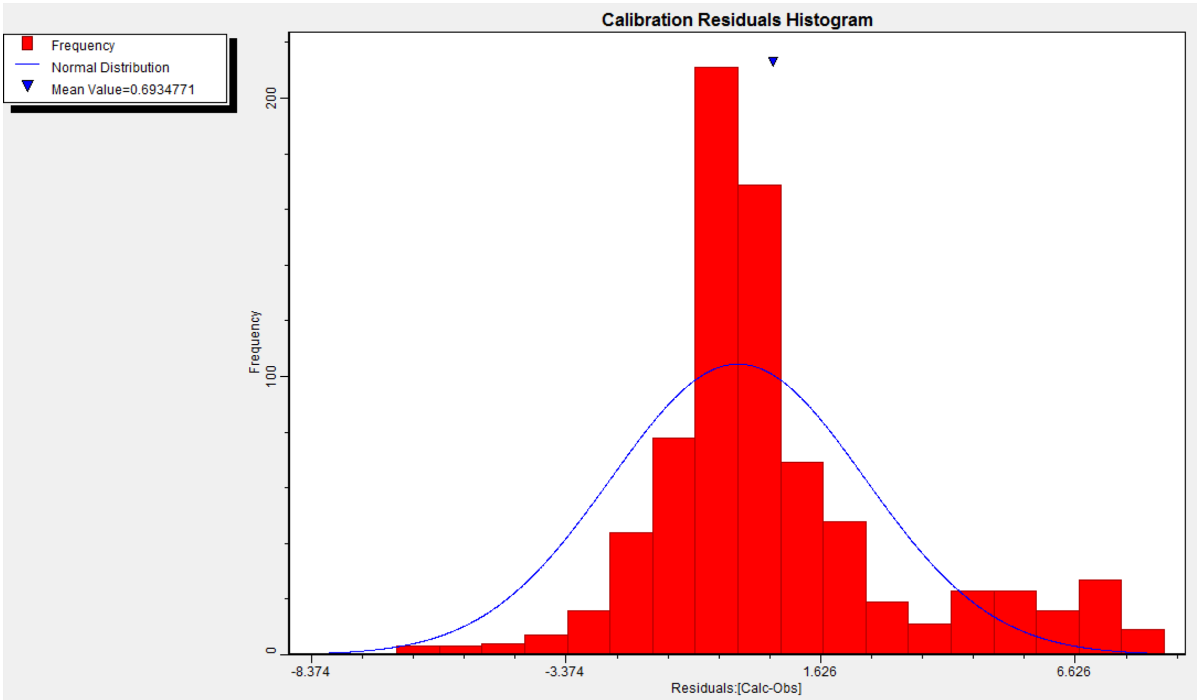


Fig. 45. Histogram of residuals for all times during the calibration period.

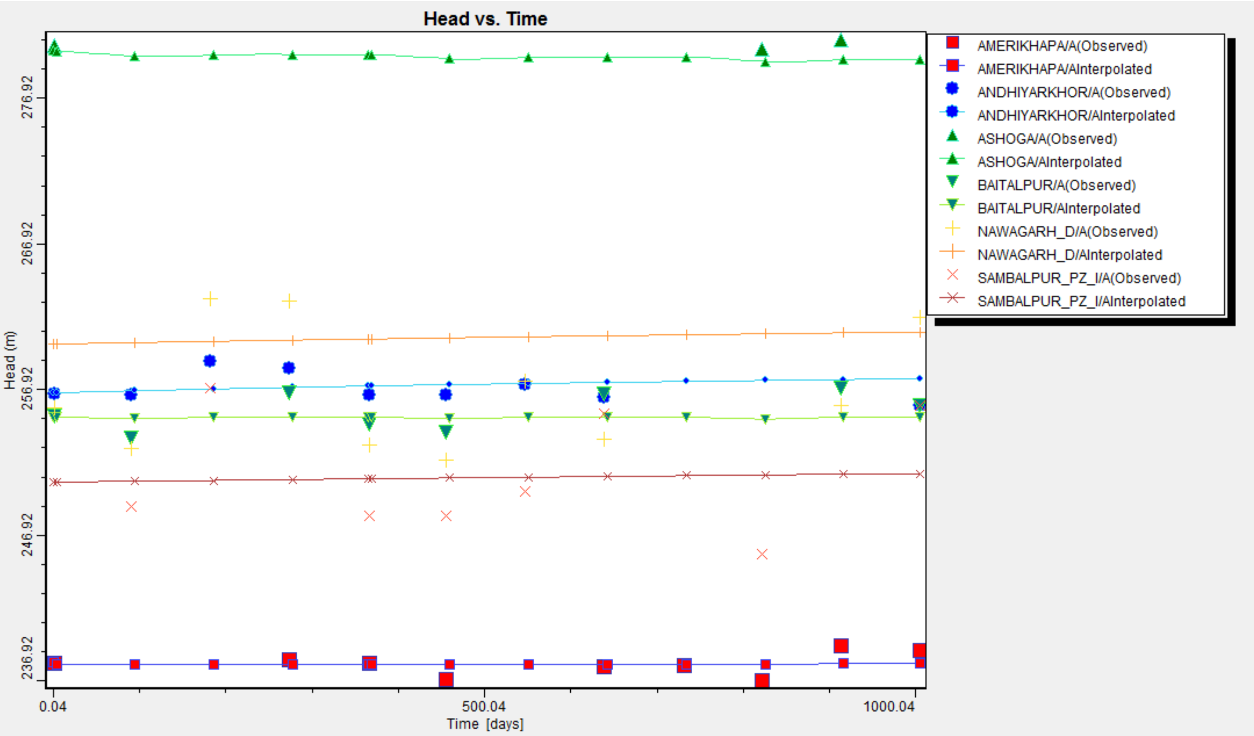


Fig. 46. Comparison of temporal variation of computed and observed heads of groundwater levels of various wells for the calibration period.

Fig. 42 to 46 demonstrated that the observed and the computed groundwater table profiles matched satisfactorily, which establishes the calibration of the developed model reasonably well. The hydraulic properties namely: hydraulic conductivity, specific yield and specific storage corresponding to these were initially taken as guess values (Table 29), which were optimized after a number of trial runs and finally obtained as the calibrated parameters of the aquifer. These calibrated parameters are given in Table 30 and 31. This calibrated model can now be used forvalidation.

Table 29. Initial guess values of hydraulic conductivity (m/day) zones.

Conductivity

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	15	15	1.5
2	30	30	3
3	5	5	0.5
4	20	20	2

Table 30. Calibrated hydraulic conductivity (m/day) values for various property zones.

Conductivity

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]
1	0.05	0.05	0.005
2	0.1	0.1	0.01
3	0.01	0.01	0.001
4	0.1	0.1	0.01

Table 31. Calibrated storage parameters for different model layers

Model Layer	Specific Storage (1/m)	Specific Yield (dimensionless)
Layer-1	-	0.001
Layer-2	3.3E-05	0.03
Layer-3	3.72E-06	0.001
Layer-4	5.96E-05	0.03

Model Validation

The above-mentioned calibrated groundwater flow model was validated using various inputs-output stresses and boundary conditions for the period 2017-2018 the groundwater levels for the period 2017 to 2018. The same hydraulic conductivity, specific yield and specific storage, as used in the calibration process, were used for the validation purpose. Fig. 47 shows the comparison between the computed and the observed groundwater contours during January2017.

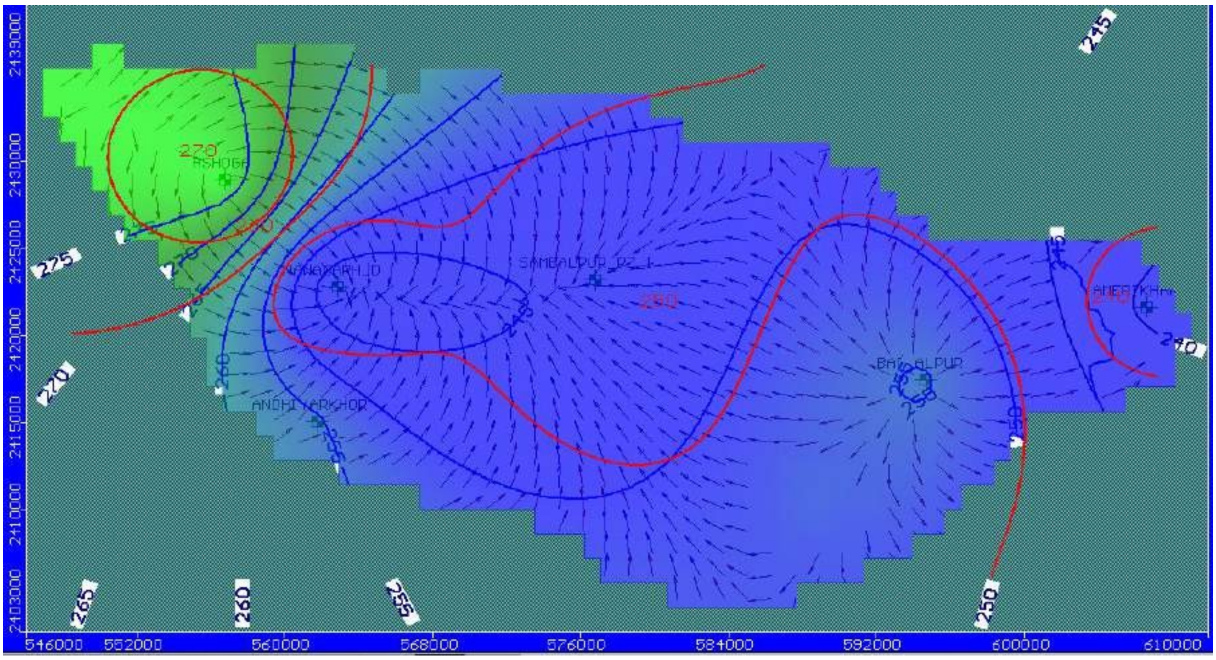


Fig. 47. Observed and simulated groundwater contours for January 2017 (observed in red colour; modeled in blue colour).

The 1:1 plots of the calculated heads versus observed heads of six wells in the modeling area for the validation period of the first and last day are shown in Fig. 48 and 49, respectively. The statistical values of these plots namely, RM (residual mean) rangesbetween -5.432and-0.077m,ARM(absoluteresidualmean)rangesbetween2.882and5.587m,SE (std. error of the estimate) ranges between 1.769 and 3.366 m, RMSE ranges between 3.955 and 9.283 m, NRMSE ranges between 8.831 and 23.028 % and the correlation coefficient that ranges between 0.82 and 0.97 were also indicated in these figures. The histogram(Fig. 50) of residuals between the observed and computed heads for the validation period showed a normal distribution, which implied a close agreement of error distribution.

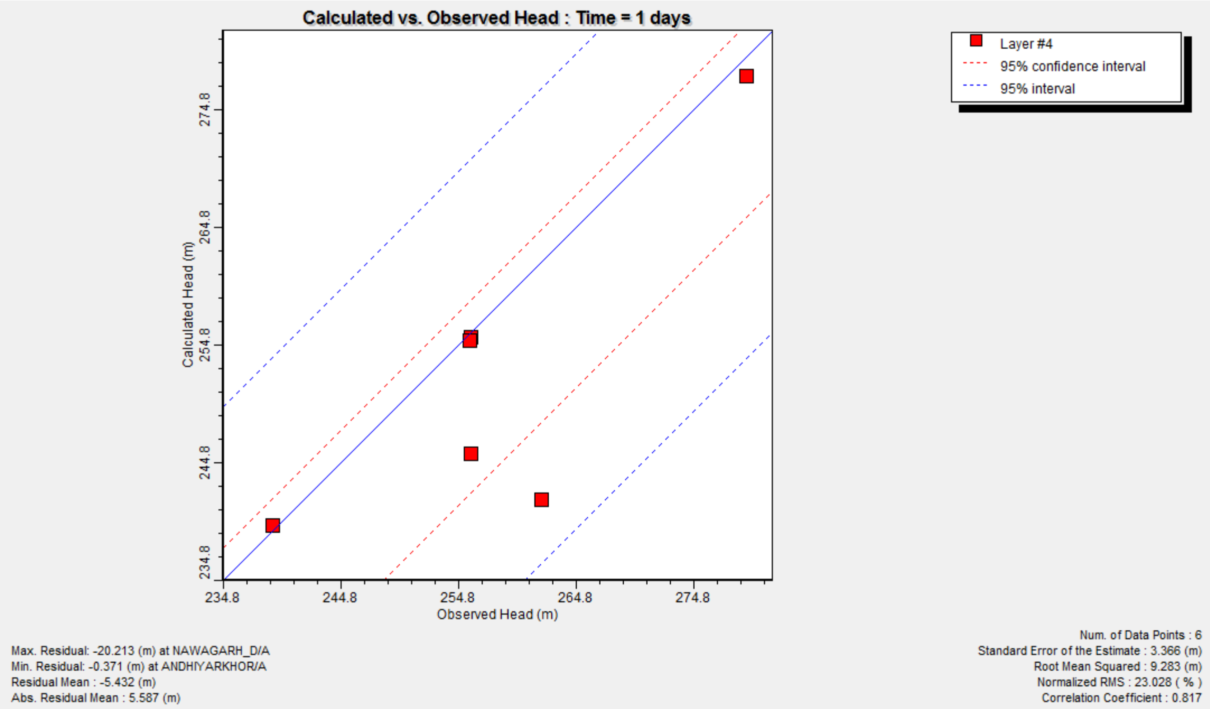


Fig. 48. 1:1 plot of Computed and observed heads for the validation period for the first day of simulation.

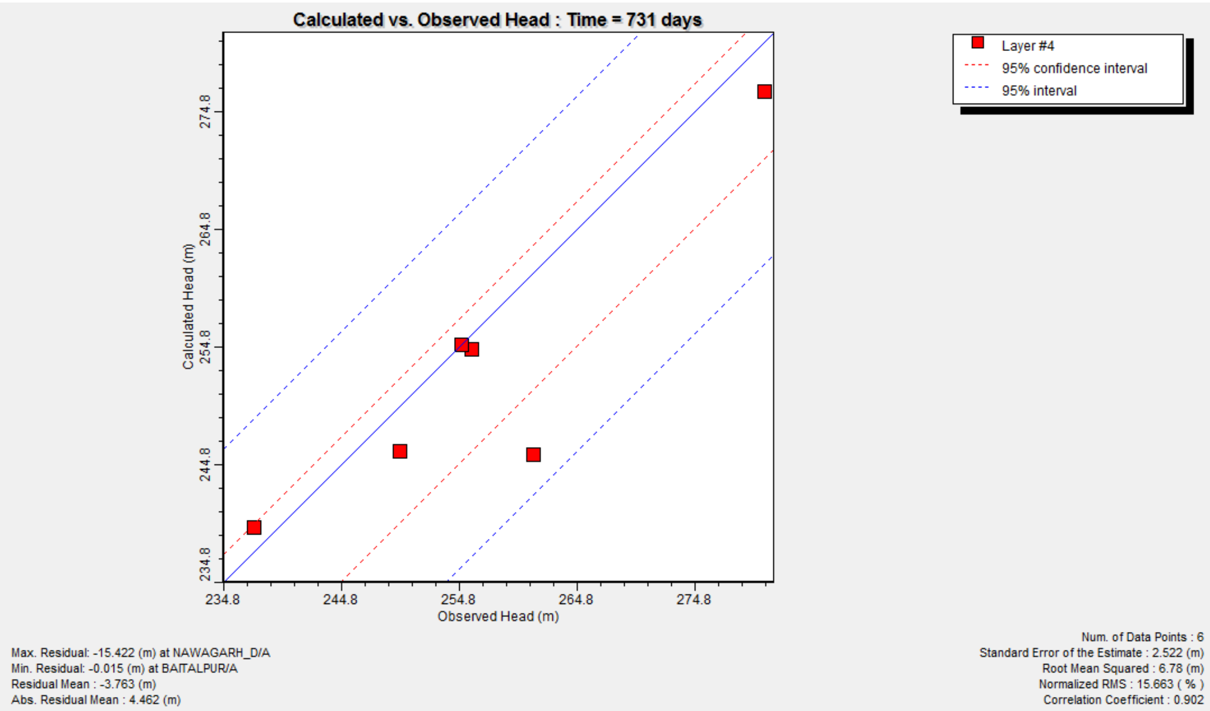


Fig. 49. 1:1 plot of Computed and observed heads for the validation period for the last day of simulation, i.e., t=731 days.

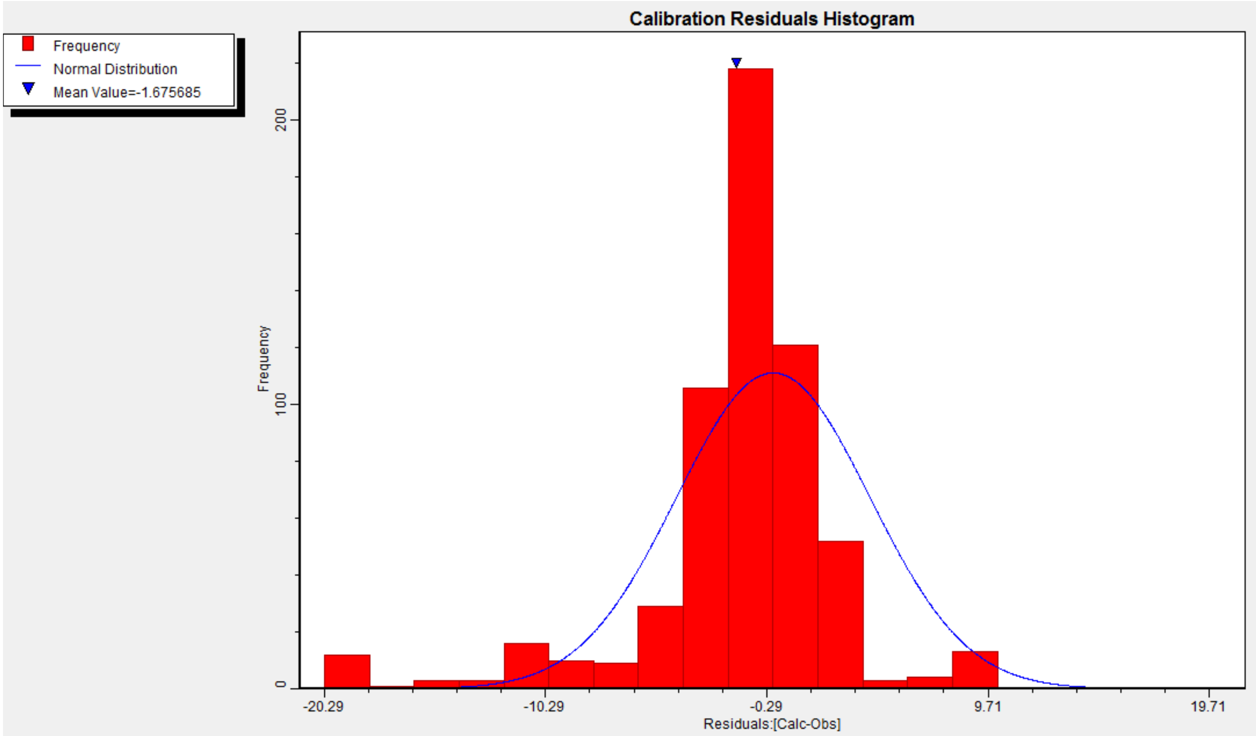


Fig. 50. Histogram of residuals for all times during the validation period

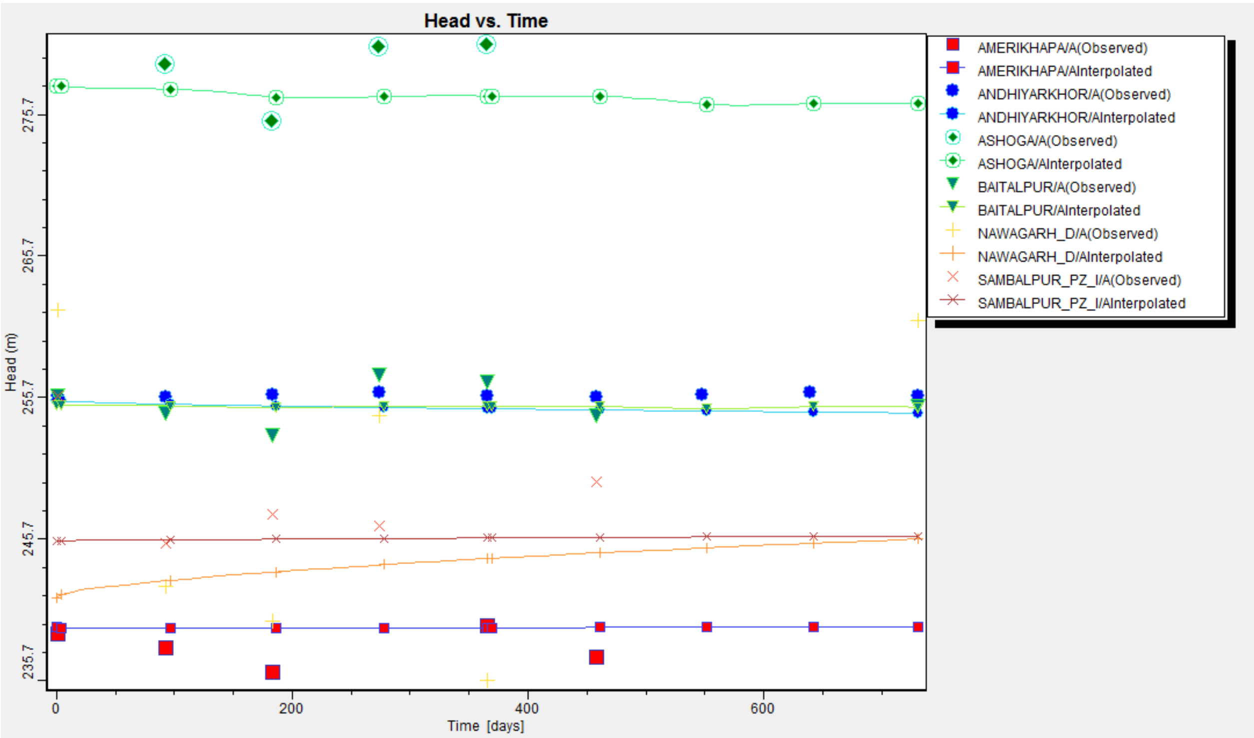


Fig. 51. Comparison of temporal variation of computed and observed heads of groundwater levels of few wells for the validation period.

Fig. 47 to 51 indicate that the observed and the computed groundwater table profiles matched reasonably well with acceptance of the validation with regards to various performance criteria found satisfactory except the NRMSE being little higher. The temporal variation of calculated and observed heads of groundwater levels for various locations corresponding to the calibrated and validated parameters is shown in Fig. 52. This MODFLOW model can now be used as a prediction or impact assessment model or any scenario analysis for the modeling area.The overall groundwater flow direction is observed towards the SE direction.The transient variations of groundwater table for individual observation and piezometer wells are shown in Fig. 52(a) to (f).

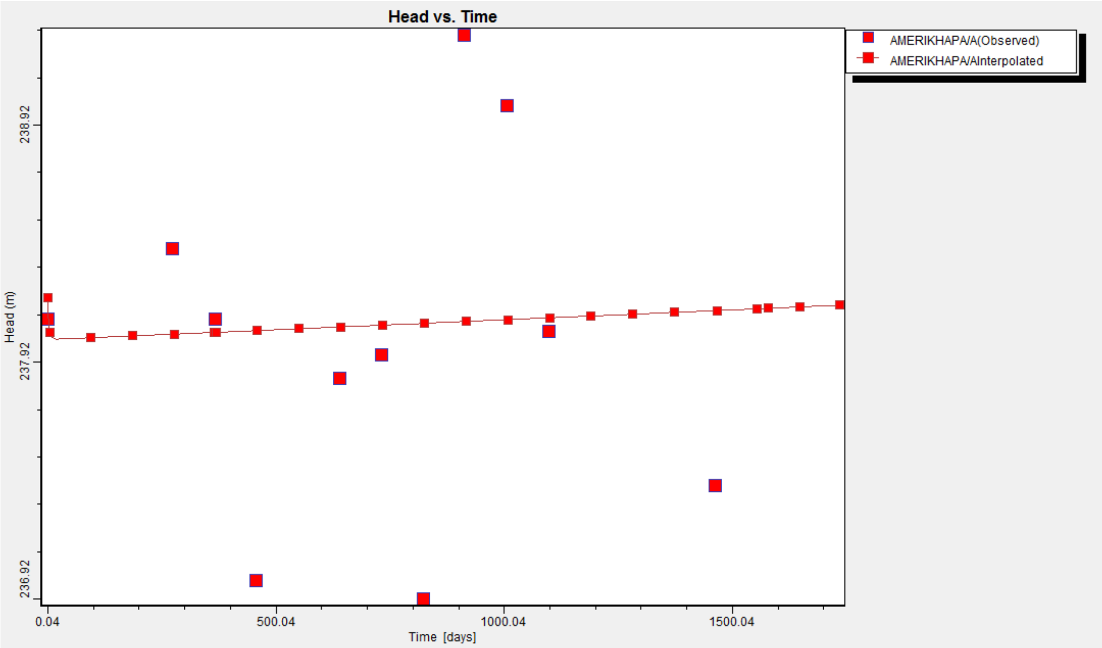


Fig. 52(a). Variation of groundwater table for the observation well located at Amerikhapa

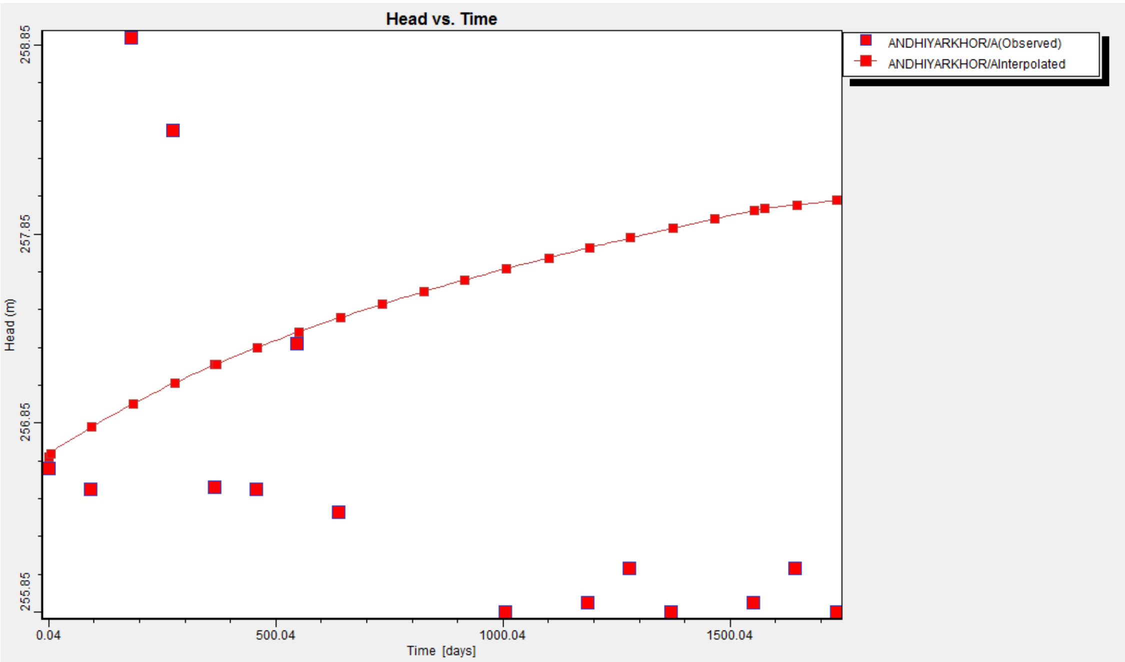


Fig. 52(b). Variation of groundwater table for the piezometer well located at Andhiyarkhore

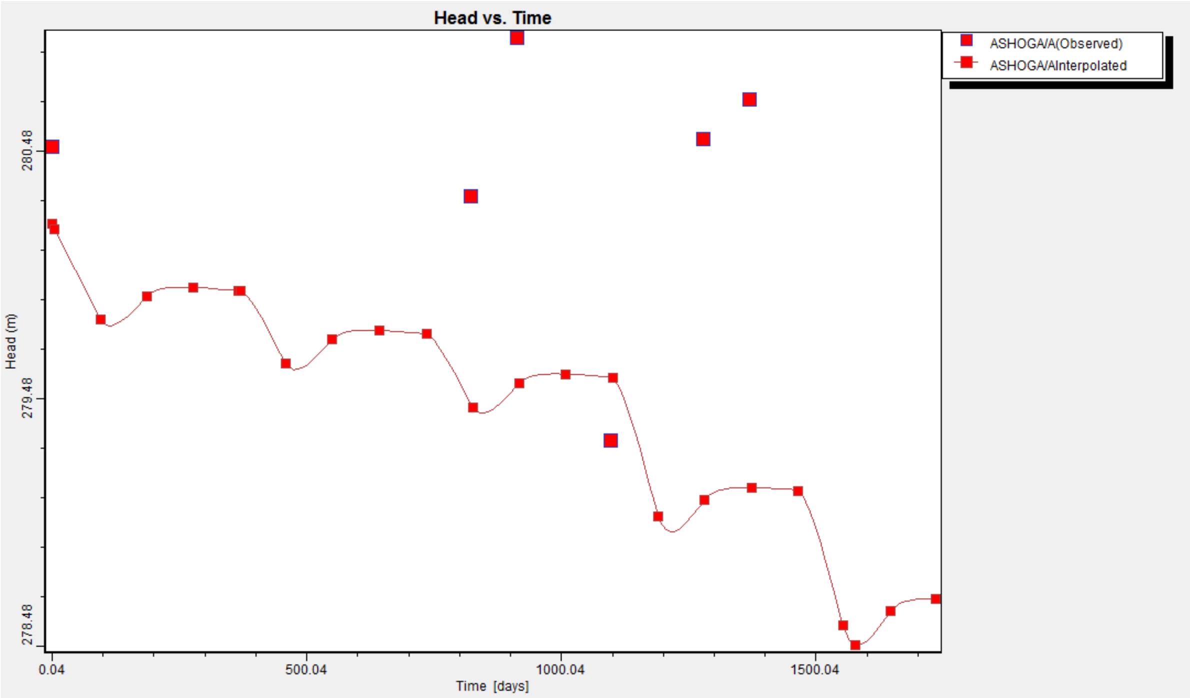


Fig. 52(c). Variation of groundwater table for the observation well located at Ashoga

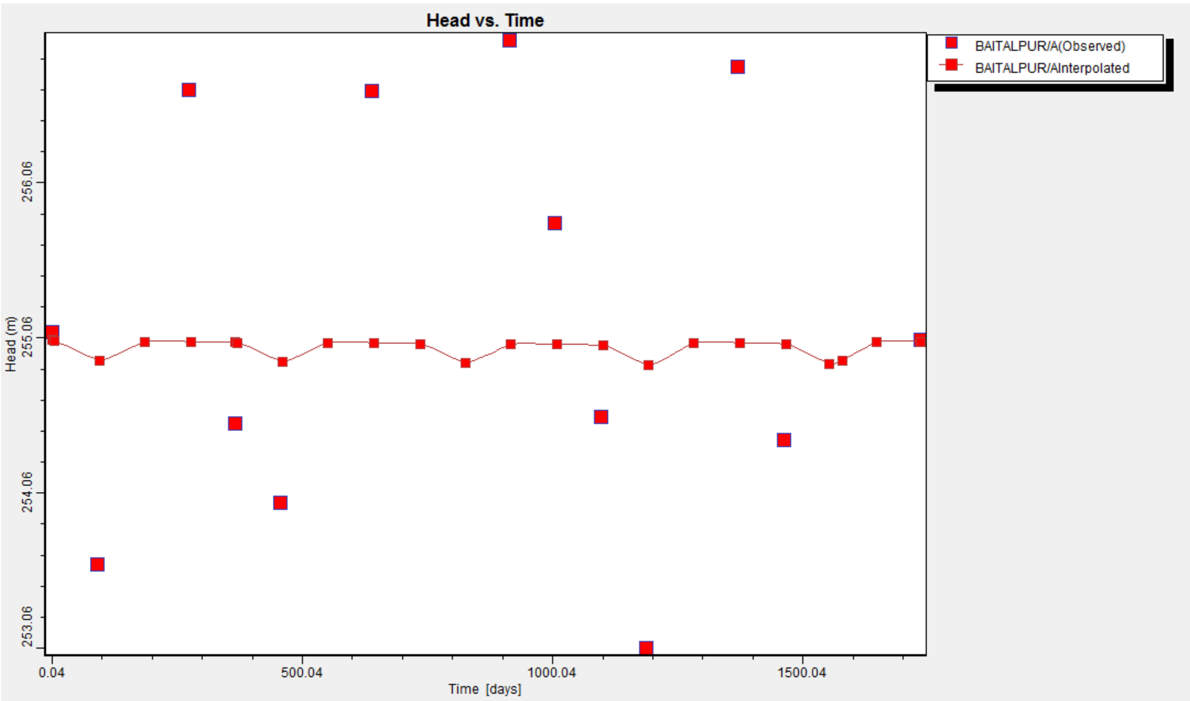


Fig. 52(d). Variation of groundwater table for the observation well located at Baitalpur

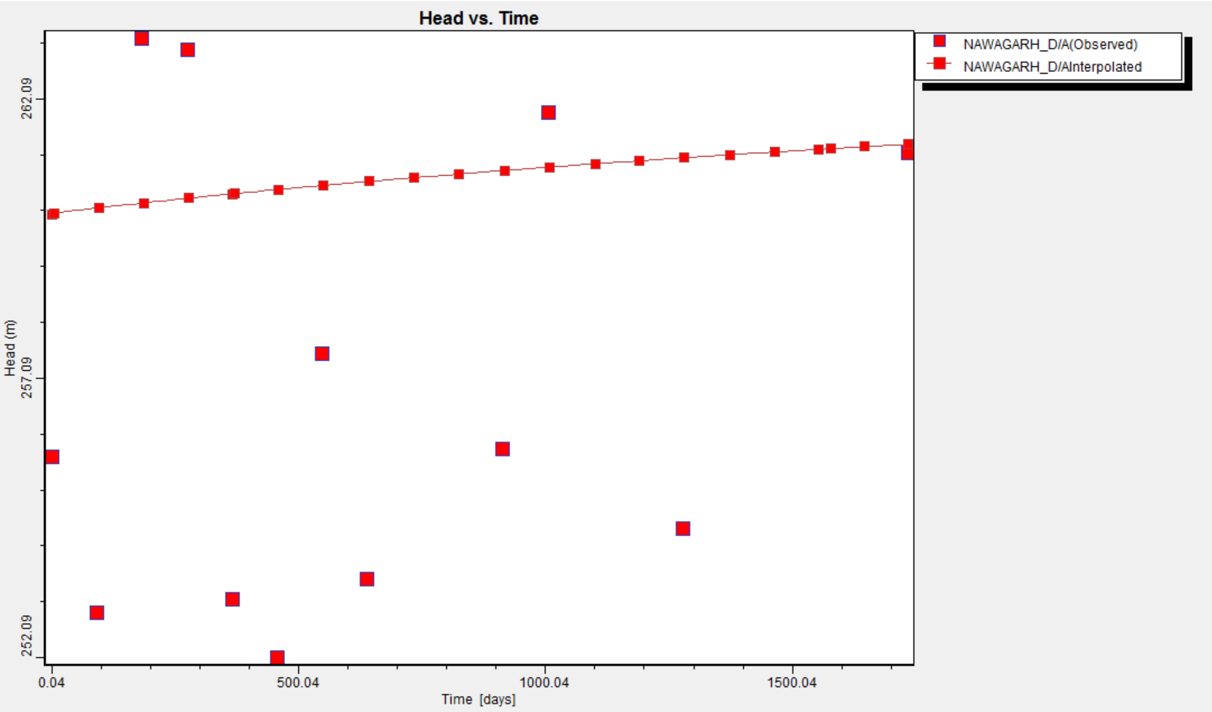


Fig. 52(e). Variation of groundwater table for the piezometer well located at Nawagarh

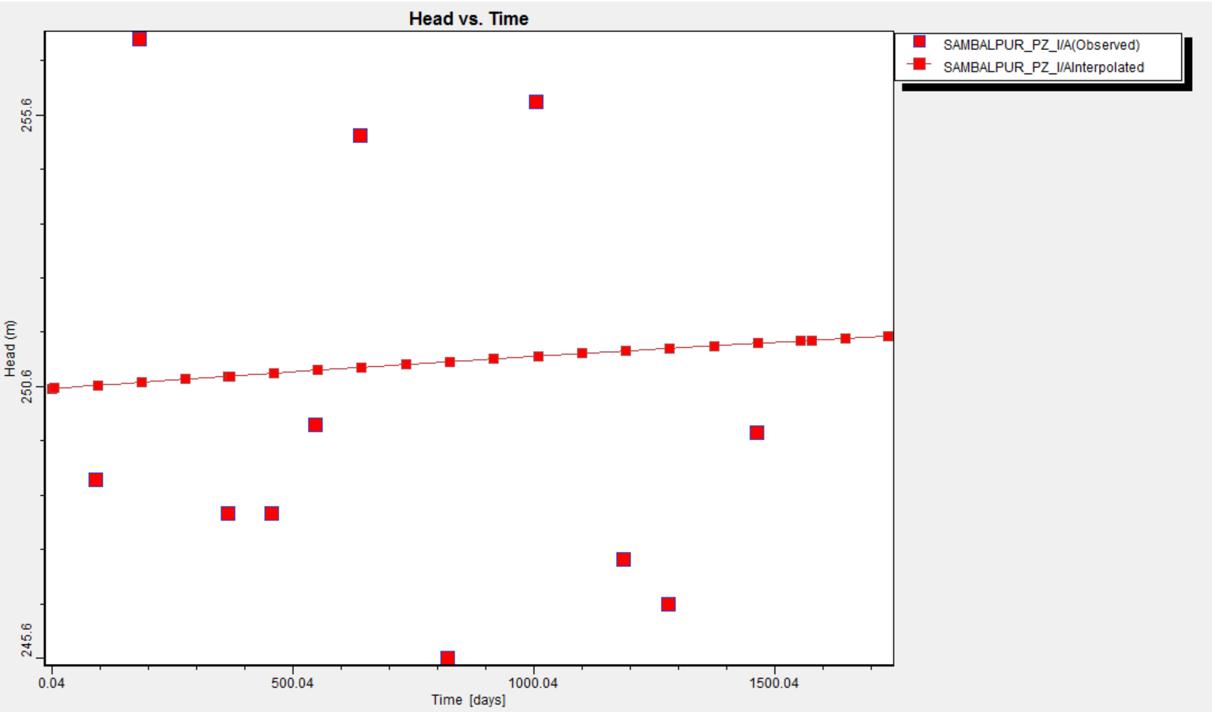


Fig. 52(f). Variation of groundwater table for the piezometer well located at Sambalpur

5.7 Contaminant Transport Modelling: Calibration and Validation

Setting of MT3D Model

Fig. 53 depicts the discretized domain map with position of active and inactive cells. The MT3D is setup for the area covering two districts viz. Bemetara and Mungeli with various databases. The total modeling area of these two districts is 5,639.29 km^{2}comprising part of four administrative blocks namely Bemetara, Mungeli, Nawagarh and Patharia. For the contaminant transport modelling, the same MODFLOW model descritization is used as already described in the groundwater flow modelling. All the cells inside the modeling domain are considered active and outside cells were consideredinactive.

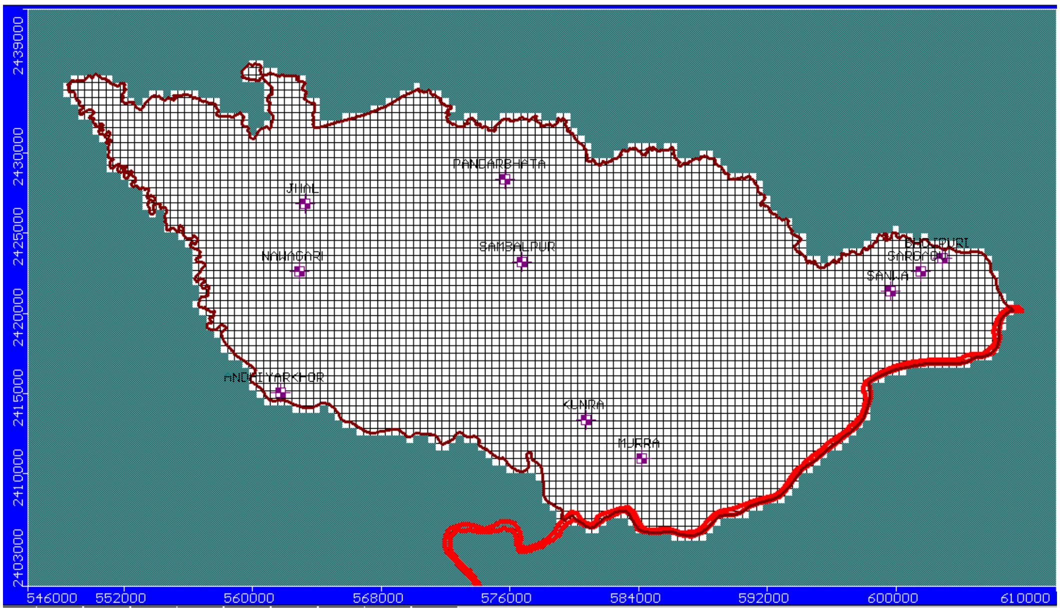
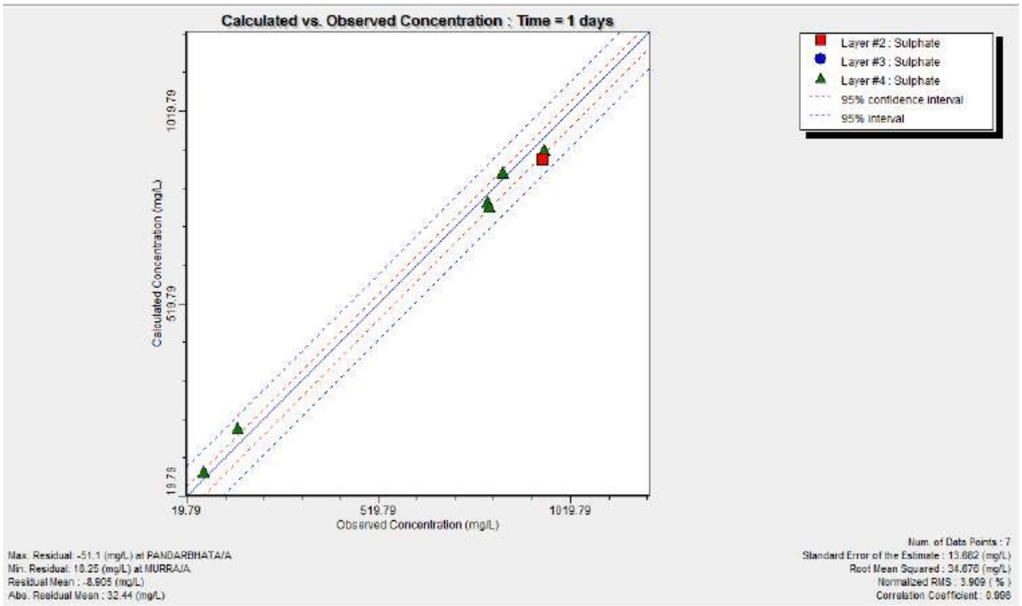


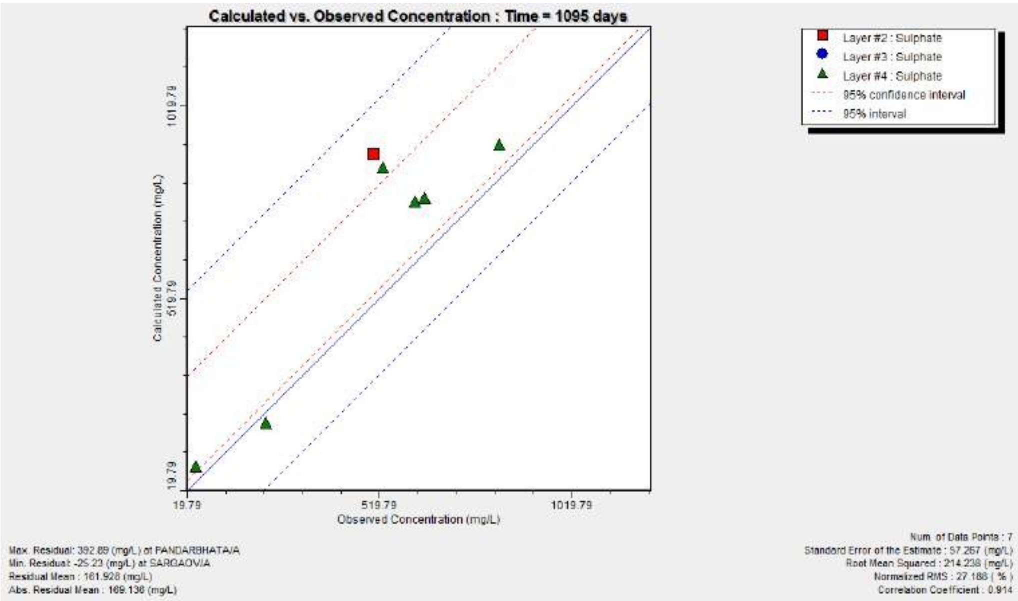
Fig. 53. Map showing various locations of sulphate monitoring

Model Calibration

The observed sulphate concentration was available for the period May, 2018 to December, 2019. The validated flow model was then used to simulate for contaminant transport for the period 2017 to 2019. Making use of the data monitored, the MT3D model was calibrated to the extent possible by adjusting the diffusivity parameter, as the data for the common period of flow modelling and contaminant transport modelling period was not available. The 1:1 plot of calibrated results is shown in Fig. 54 (a)&(b) for 1st day and 1095thday, respectively. It is seen that the values fall within the 95% confidence interval, as shown in Fig.54.



(a)



(b)

Fig. 54. 1:1 plot of computed and observed sulphate concentration

The transient variation of observed and calculated concentration is shown in Fig. 55. Fig. 56 shows the spatial variation of sulphate concentration calculated in the whole study area at t=1095 days. It is seen that in the north-western part and eastern portion, sulphate concentration is low and within permissible limits. Concentration increases on moving away from south to north side. South central portion has the highest sulphate concentration up to 1900mg/L.

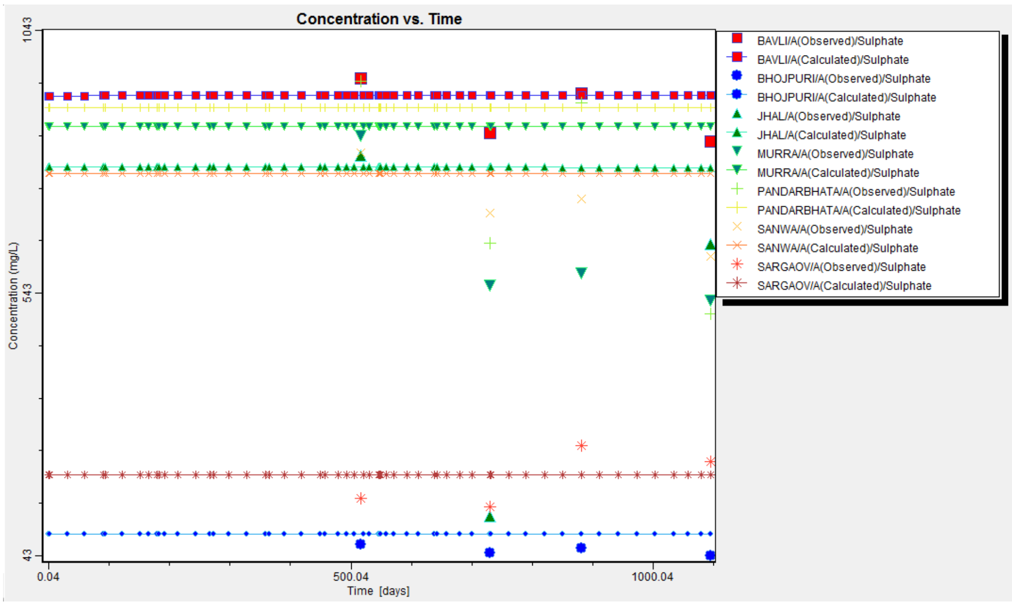


Fig. 55. Comparison of temporal variation of computed and observed sulphate concentration in groundwater of various wells

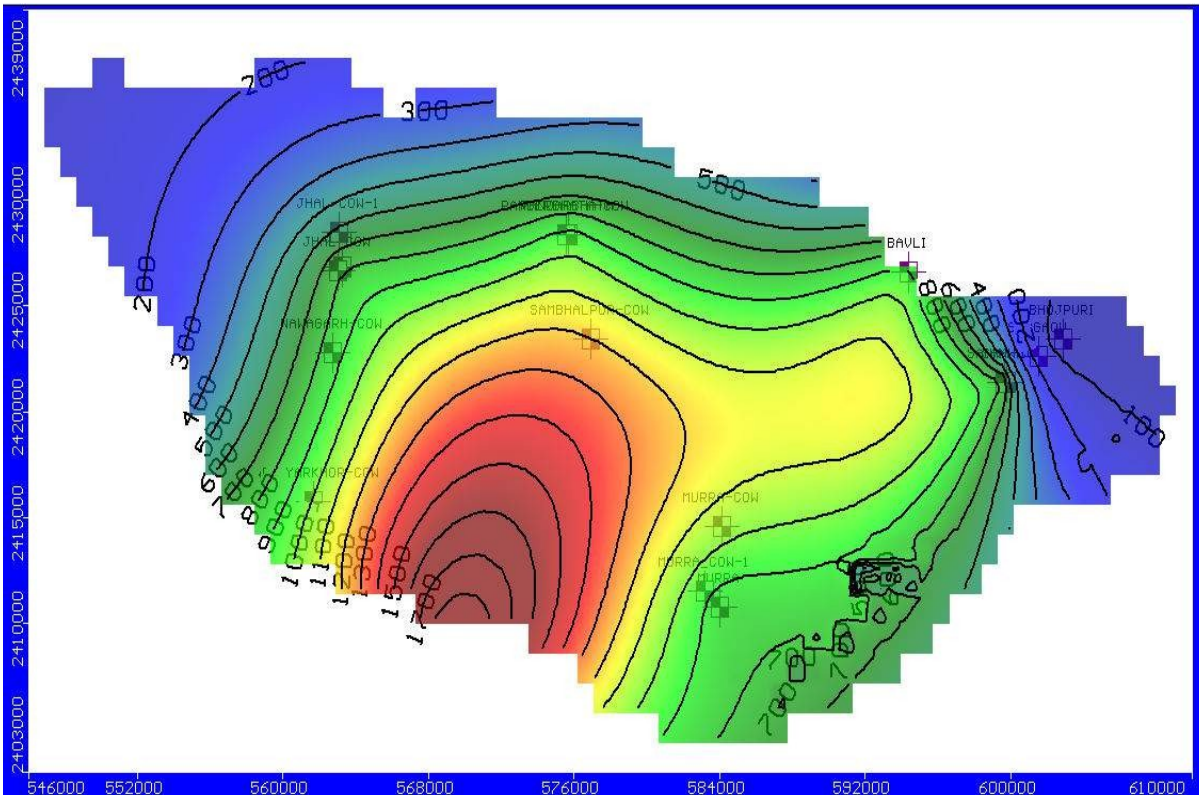


Fig. 56. Calculated sulphate concentration at 1095 days

5.8 Scenarios on Artificial Recharge of Groundwater on Sulphate Contamination

Pre- and post-monsoon data of physico-chemical parameters of different locations in Maniyari Shell Formation Region may be used to identify the probable locations for artificial recharge to improve the quality of the degraded zones. Locations of TDS natural dilution and sulphate natural dilution having more than 60% dilution have been considered as artificial recharge locations in Maniyari Region [Fig. 57(a)&(b) and 58(a)&(b)].

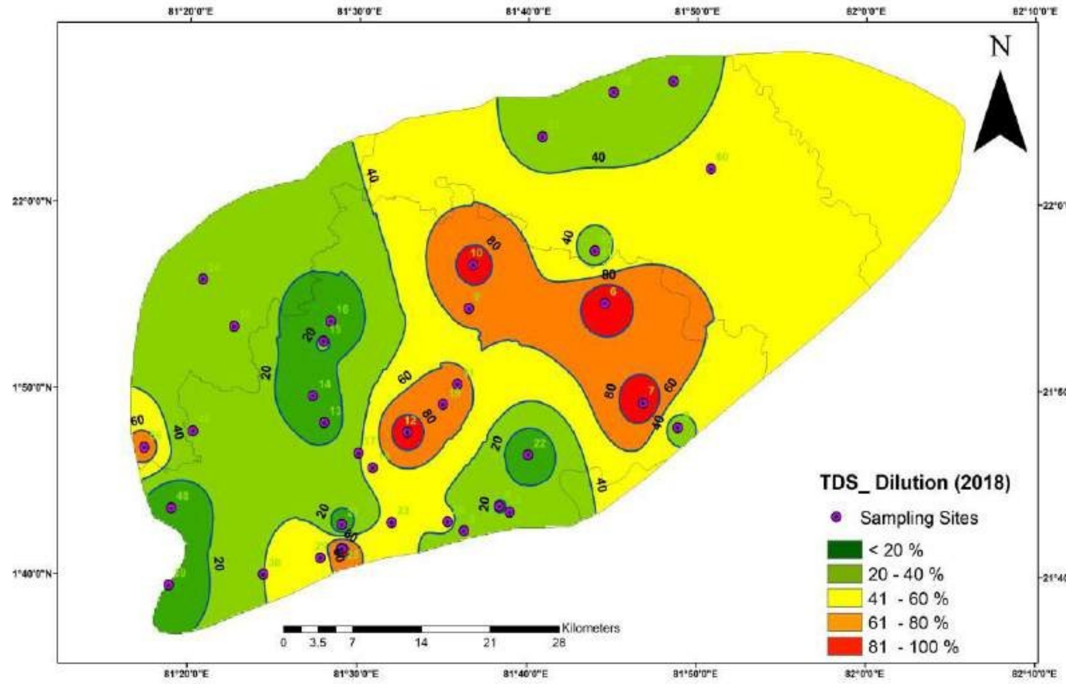


Fig. 57(a). Location of TDS natural dilution in Maniyari Region(2018-19)

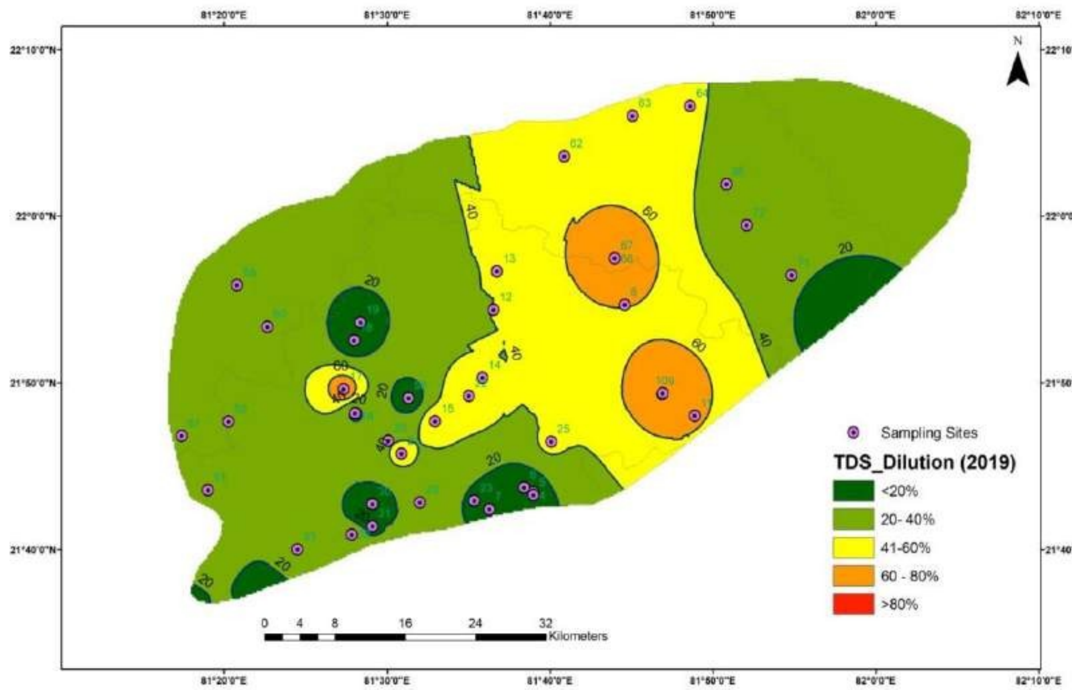


Fig. 57(b). Location of TDS natural dilution in Maniyari Region (2019-20)

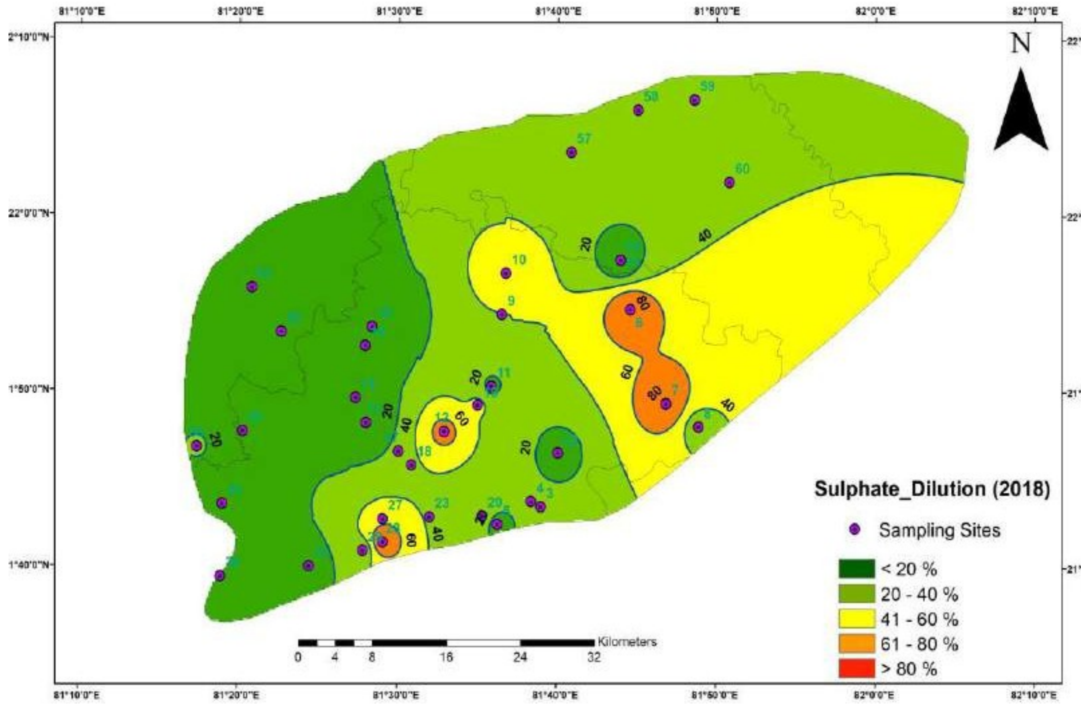


Fig. 58(a). Location of Sulphate natural dilution in Maniyari Region (2018-19)

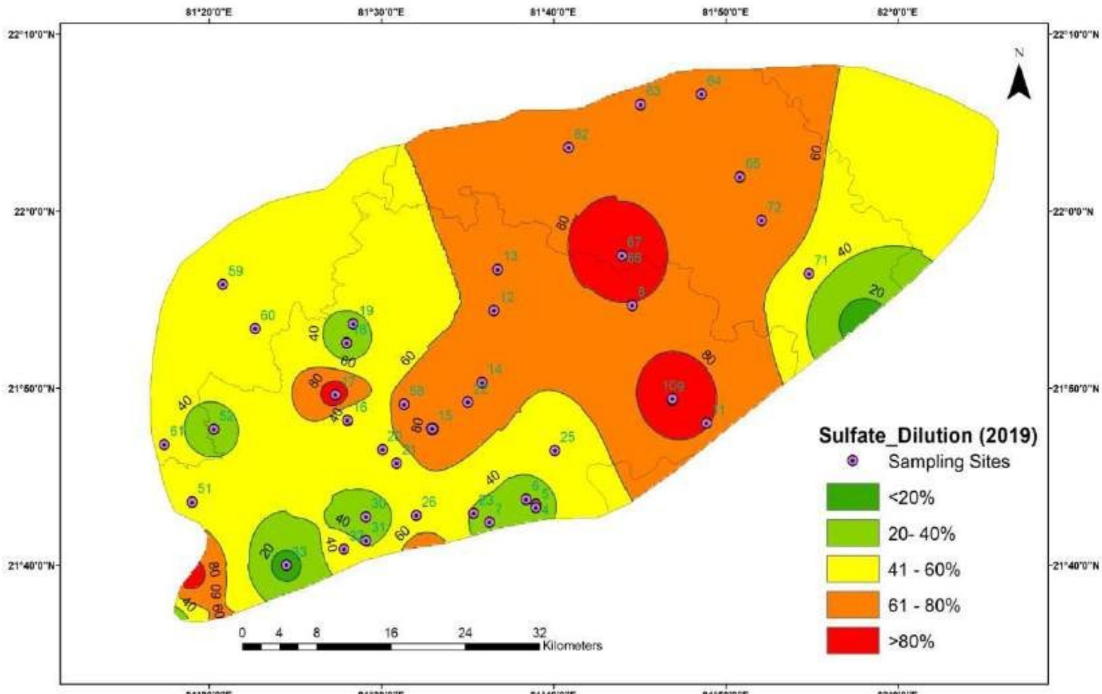


Fig. 58(b). Location of Sulphate natural dilution in Maniyari Region (2019-20)

In the study area, sulphate concentration varies up to around 2000 mg/l. This creates problems in supplying safe water for the drinking water supplies at many places particularly in rural areas as the groundwater sulphate concentration exceeds 400 mg/L [maximum permissible limit as per BIS (2012)]. Therefore, to restore the sulphate concentration in groundwater around 400 mg/L to make it potable, some scenarios have been investigated at three different locations by diluting groundwater quality through artificial groundwater recharge measures. Out of these three sites, one site is located near Sanwa, and two sites are located near Murra, as shown below in Fig.59.

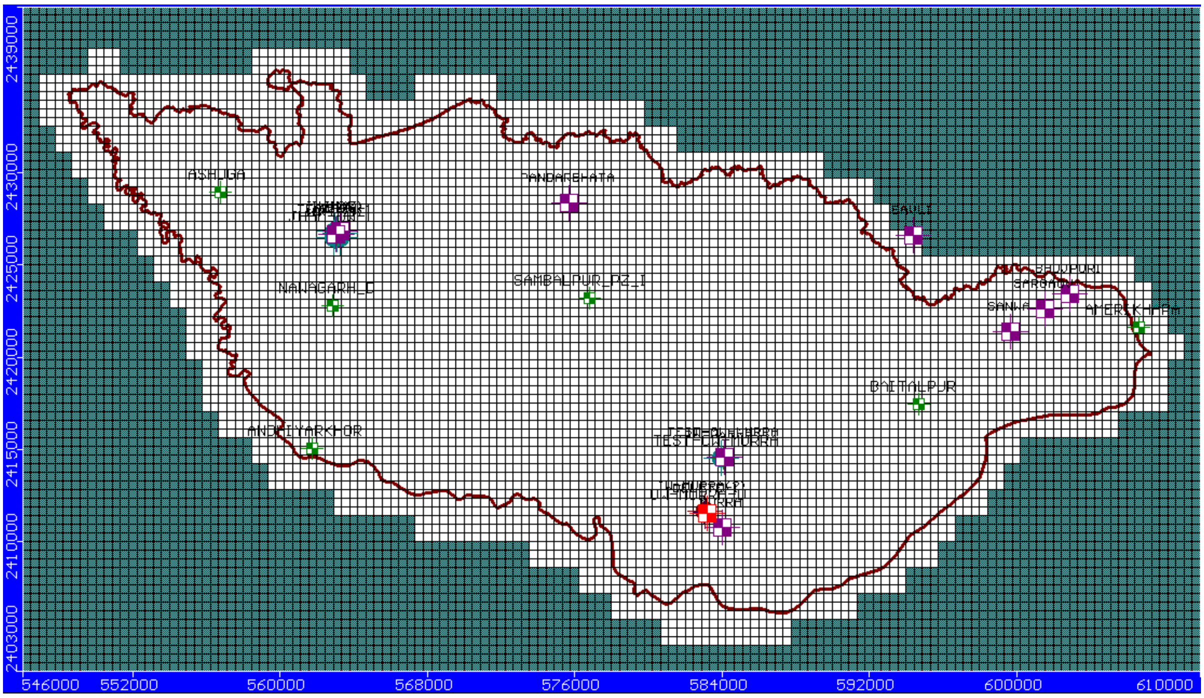


Fig. 59. Map showing locations of artificial recharge locations in the study area

1st Site - Sanwa

The first scenario is developed at the Sanwa location (Fig. 60). The general sulphate concentration in Sanwa is around 590 mg/L and the ground water table is around 247 m above mean sea level. A scenario is considered by application of one injection well with recharge rate at 50 m^3/d. The results of model run indicates that the sulphate concentration in groundwater continuously reduces from 590 mg/L to 395 mg/L (close to 400 mg/L) by running the model for a period of 1.5 year, as shown in Fig. 61. The variation of groundwater table at the same location is also presented in Fig. 62, which indicates that the groundwater table rises up to 255 m above mean sea level. Further it is also mentioned that the concentration decreases with increase in the rate of ground water recharge through injection well. If the rate of recharge is low, then it will take more time to decrease the sulphate concentration to bring within the permissible limit. The groundwater recharging may also be practiced by a single well or multiple wells depending on the local site conditions and availability of source water for recharging to groundwater. The standard design of the injection well may be followed as per CGWBguidelines.

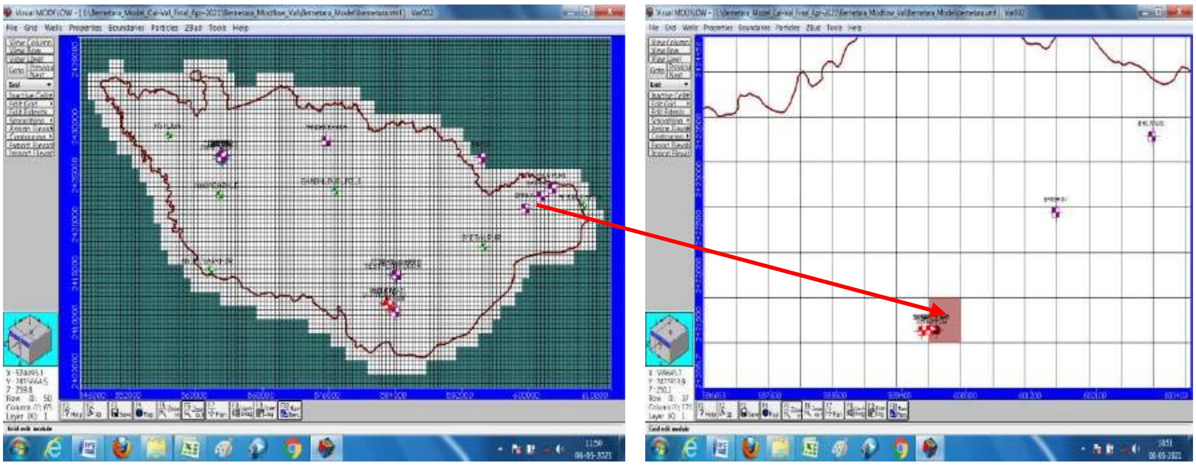


Fig. 60. Map showing Sanwa location

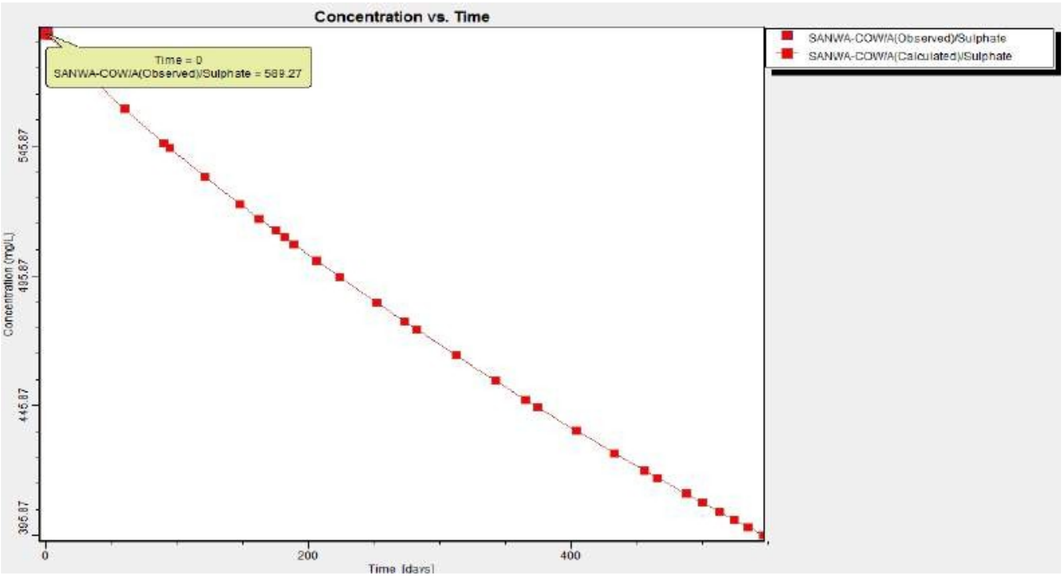


Fig. 61. Decline in sulphate concentration due to artificial recharge to groundwater at Sanwa location

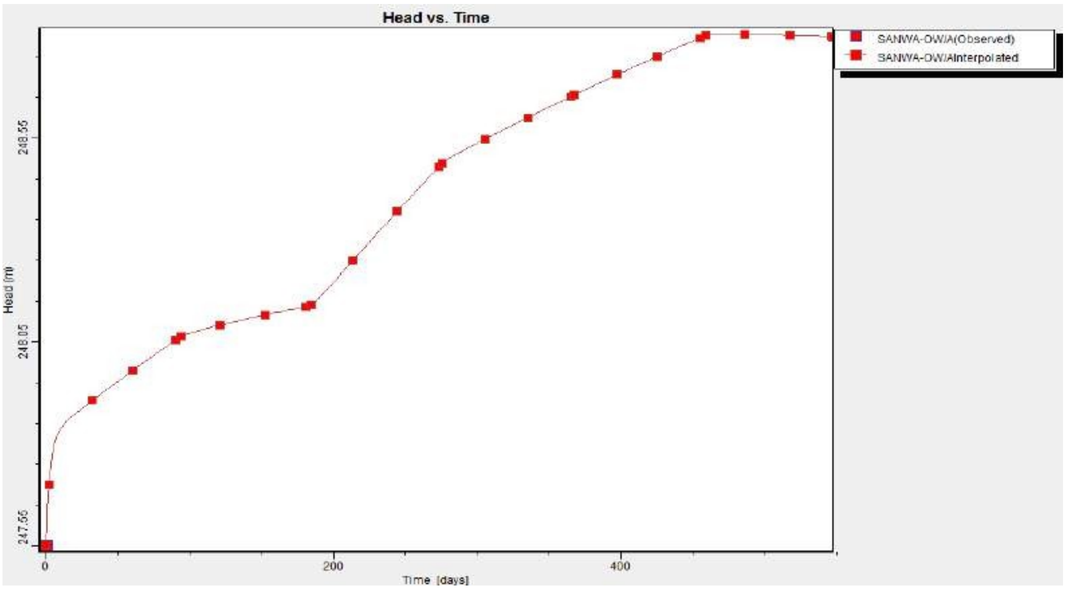


Fig. 62. Rise in groundwater table due to artificial recharge at Sanwa location

2nd Site - Murra location 1

The second scenario is developed at the Murra location (Fig. 63). The general sulphate concentration at this location in Murra is around 940 mg/L and the ground water table is around 250 m above mean sea level. A scenario is considered by application of one injection well with variable recharge rate varied from 65 m^3/d to 55 m^3/d. The results of model run indicates that the sulphate concentration in groundwater declined from 940 mg/L to 400 mg/L. The sulphate concentration in groundwater is obtained close to 400 mg/L by running the model for a period of 2.5 years, as shown in Fig. 64. The variation of groundwater table at the same location is presented in Fig. 65, which indicates that the groundwater table rises up to 255 m above mean sea level. Further it is also mentioned that the concentration decreases with increase in the rate of ground water recharge through injection well. If the rate of recharge is low, then it will take more time to decrease the sulphate concentration to bring within the permissible limit. The groundwater recharging may also be practiced by a single well or multiple wells depending on the local site conditions and availability of source water for recharging togroundwater.

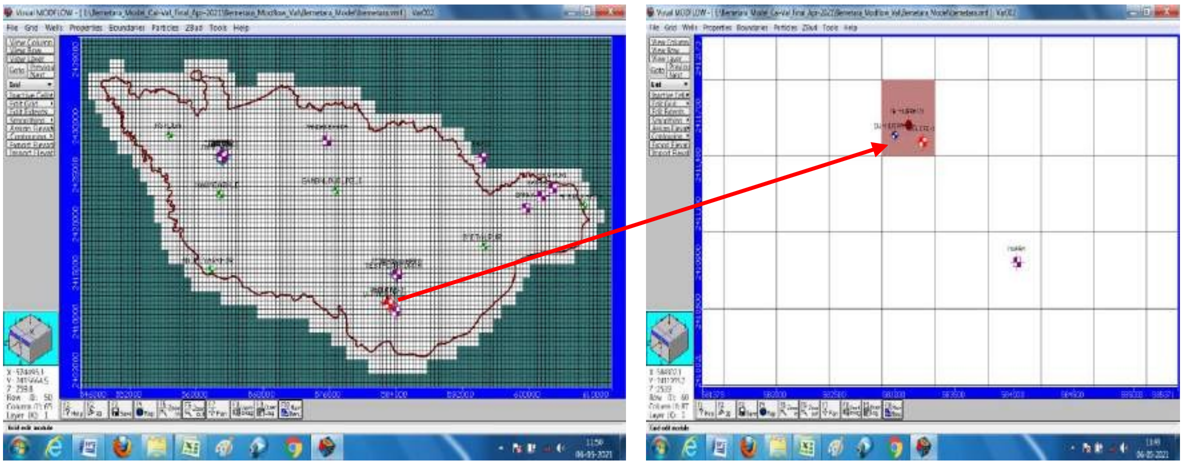


Fig. 63. Map showing Murra location 1

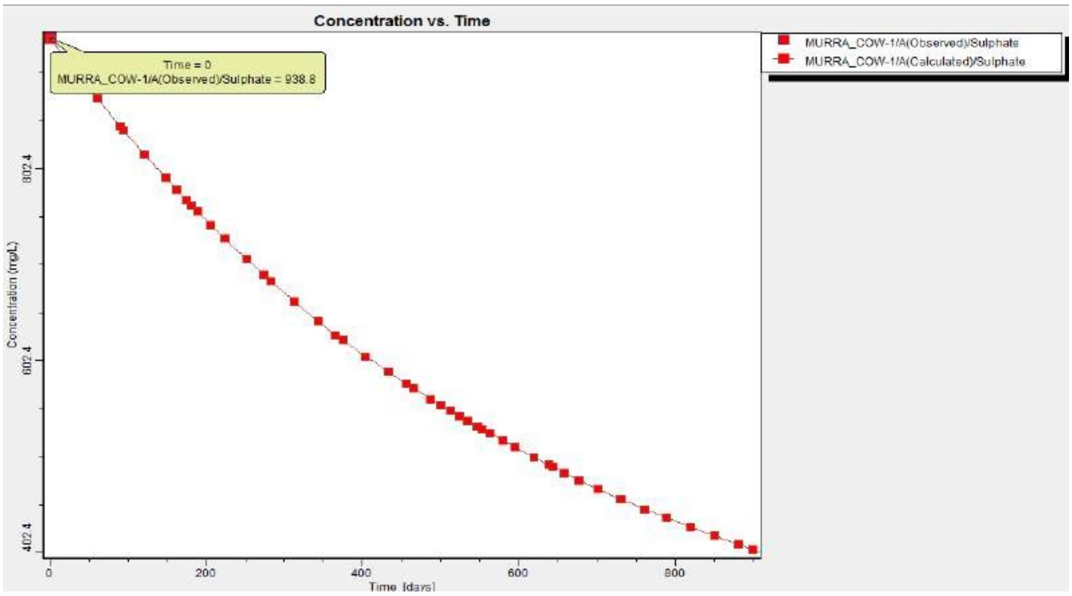


Fig. 64. Decline in sulphate concentration due to artificial recharge to groundwater at Murra location 1

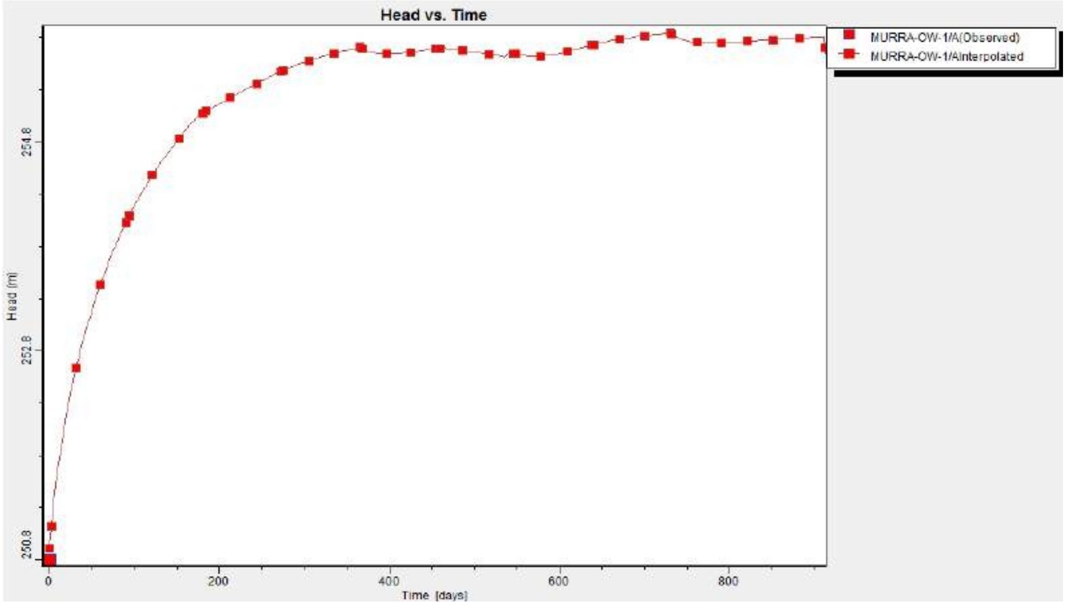


Fig. 65. Rise in groundwater table due to artificial recharge at the Murra location 1

3rd Site - Murra location 2

The third scenario is developed at the location near Murra (Fig. 66). The general sulphate concentration at this location in Murra is around 1042 mg/L and the ground water table is around 252 m above mean sea level. A scenario is considered by application of one injection well with constant recharge rate of 100 m^3/d. The results of model run indicates that the sulphate concentration in groundwater declined from 1042 mg/L to 414 mg/L. The sulphate concentration in groundwater is obtained close to 400 mg/L by running the model for a period of 2 years, as shown in Fig. 67. The variation of groundwater table at the same location is presented in Fig. 68, which indicates that the groundwater table rises up to 258.6 m above mean sea level. Further it is also mentioned that the concentration decreases with increase in the rate of ground water recharge through injection well. If the rate of recharge is low, then it will take more time to decrease the sulphate concentration to bring within the permissible limit. The groundwater recharging may also be practiced by a single well or multiple wells depending on the local site conditions and availability of source water for recharging togroundwater.

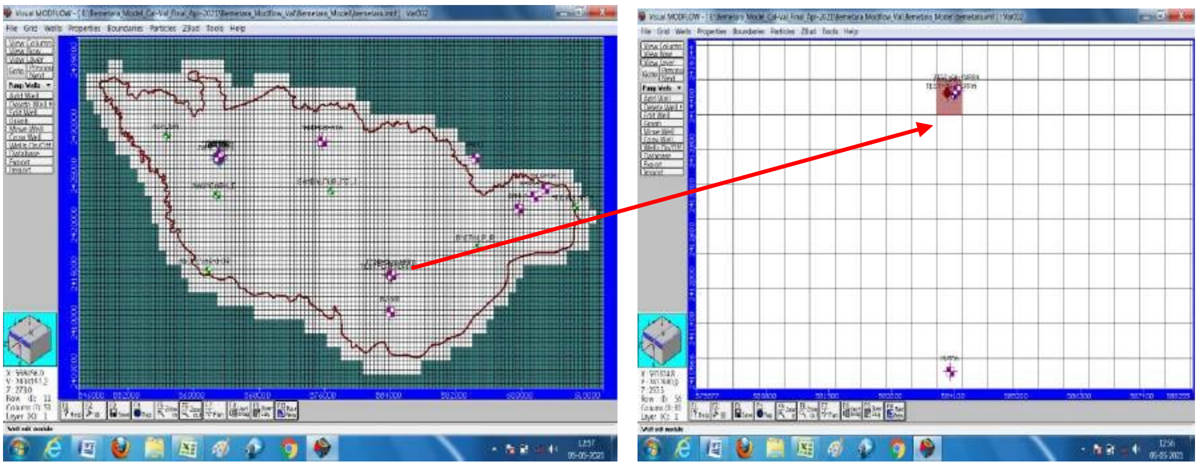


Fig. 66. Map showing location near Murra location 2

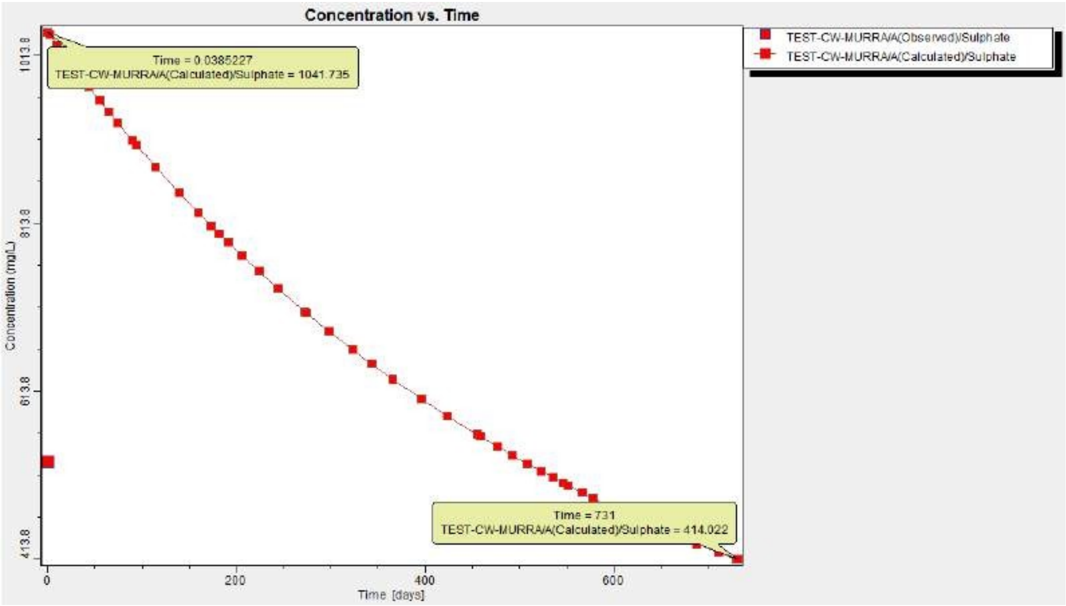


Fig. 67. Decline in sulphate concentration due to artificial recharge to groundwater at the location near Murra location 2

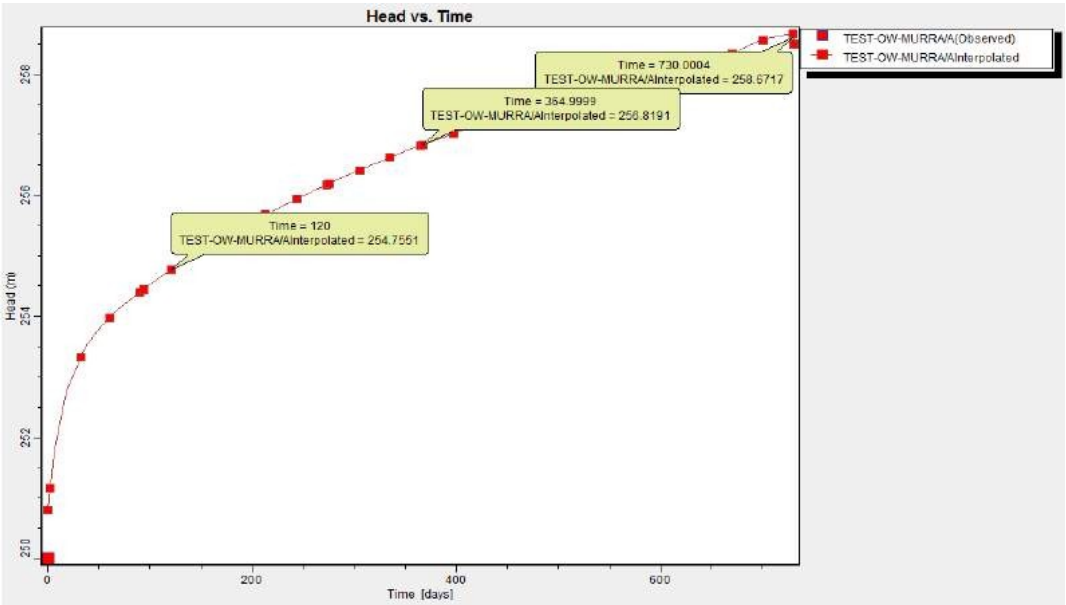


Fig. 68. Rise in groundwater table due to artificial recharge at the location near Murra location 2

6.0 CONCLUSIONS AND SCOPE OF FUTURE WORK

(i) For the study of sulphate contamination in the groundwater of district Bemetara, Chhatttisgarh, the ground water quality of Maniyari Shale Formation Region covering district Bemetara has been assessed to see the suitability of ground water for drinking purpose and irrigationapplications.

(ii) The hydro-chemical data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types`identified. BIS Standards for drinking water have been violated for physico-chemical parameters viz; TDS, Total hardness, Calcium, Magnesium, Sulphate and Nitrate and metal concentrations viz; Fe, Mn, Pb, Cd and As by the groundwater of few locations of the study area. The quality of the ground water varies from place to place with the depth of watertable. Spatial distribution maps were prepared to identify degraded water quality zones, possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water qualitystandards. Most of the ground waters falls between poor to good type as per Water QualityIndex for drinking water purpose.

(iii) The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR) and Residual Sodium Carbonate (RSC) and found to be fit forirrigation.

(iv) An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram, U.S. Salinity Laboratory. Majority of the samples of the study area belong to Ca-Mg-Cl-SO_4 or Ca-Mg-CO_3-HCO_3 hydrochemical facies and fall under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage.

(v) Hydrogeochemical investigations revealed that hydrochemistry of groundwater of the study area is controlled by precipitation induced chemical weathering along with dissolution of rock forming minerals. Carbonate weathering is a major source of dissolved ions in the groundwater of the study area. Reverse ion exchange process controls the chemistry of groundwater of the region, which may be due to the excess of Ca+Mg. The source of sulphate in the groundwater of the study area may be $CaSO_4$i.e. Gypsum as evident from relationship between Ca and SO_4 ($r^2>0.8$).

(vi) Groundwater flow of the study area was simulated using transient flow model MODFLOW. Surface water hydrological features are considered as the boundary.The vertical discretization of 4-layers represents the formations as top layer of variable thickness represent top soil having characteristics of aquitard, followed by an unconfined aquifer of varying thicknesses, then an aquitard of varying thicknesses, and then confined aquifer of variable thickness. The model was calibrated and validated satisfactorily. For contaminant transport modelling, MT3D model was calibrated to the extent possible by adjusting the diffusivity parameter andvalidated.

(vii) Pre- and post-monsoon data of physico-chemical parameters of different locations in Maniyari Shell Formation Region may be used to identify the probable locations for artificial recharge to improve the quality of the degraded zones. Some scenarios have been investigated at three different locations by diluting groundwater quality through artificial groundwater recharge measures. It was observed that the concentration of sulphate decreases with increase in the rate of ground water recharge through injection well. If the rate of recharge is low, then it will take more time to decrease the sulphate concentration to bring within the permissible limit. The groundwater recharging may also be practiced by a single well or multiple wells depending on the local site conditions and availability of source water for recharging to groundwater. This technique may be used to restore the quality and sustainable use of groundwater for drinking purpose in the degraded zones.

Scope of future work

(i) The concept of artificial groundwater recharge can be successfully used to restore the groundwater quality for drinking purpose. For estimating this artificial recharge using MODFLOW and MT3d, the longterm groundwater level observations and groundwater quality monitoring data are required for simulation of groundwater flow and contaminant transport model. There are only few piezometric wells maintained either by State Water Resources Department, Chhattisgarh or NCCR, CGWB, Raipur in the present study area. Therefore there is a need to strengthen the groundwater level observations by installing more piezometric wells and regular groundwater quality monitoring.

(ii) Urbanization, industrialization and changing life style further aggravates the problem of groundwater pollution. Indiscriminate use of fertilizers, pesticides, insecticides in agricultural field also increases groundwater contamination. A number of studies have been attempted on general water quality by different workers but no attempt has been made on emerging contaminants (VOCs and pesticides). Therefore there is a need to study emerging contaminants with their remediation using cost effective, economic viable and environmental friendly measure considering hydrogeology of the area.

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Training Course Organized:

i) 5-Days Training Course on "Ground Water Quality Modelling" during February 12-16, 2018 at NIH,Roorkee

ii) 5-Days Training Course on "Groundwater Quality Monitoring and Assessment" during January 21-25, 2019 at NIH,Roorkee

APPENDIX-A Project summary

TableA.1: Summary

Project objectives		
Objectives as per project document	Revised objective	Reasons for revision
i) Groundwater quality monitoring in pre-monsoon (April-May) and post-monsoon (October-November) season at identifiedlocations. ii) To map degraded ground water quality zones and possible sources of pollution and identify specific parameters not conforming to drinking/ &irrigation water qualitystandards. iii) To investigate the important geochemical processes responsible for the groundwatercontamination. iv) Modelling flow and transport of sulphate contamination using MODFLOW &MT3D. v) To suggest ameliorative measuresto restore the quality and sustainable use of groundwater for drinking/ &irrigation purpose by investigating the hydro-geology of the area. vi) Dissemination of knowledge and findings to field engineers/scientists and common people through preparation of manual, leaflets, booklets and by organizingworkshops/training.	None	NA

***Manpower* deployed (against sanctioned manpower)**			
Sanctioned		Deployed	
Designation	Person months	Designation	Person months
JRF - 1	36	JRF - 1	40

Infrastructure/ equipment		
Planned (as per project proposal)	Developed/ procured	Reasons for deviation
Visual MODFLOW Flex Premium Version	None	Already exist with Co-PI
Field work		
Planned (as per project proposal)	Completed	Reasons for deviation
• Field work for 3years • Chemicals/Standards/Glasswares/Plasticwares for water qualityanalysis	• Yes • Purchased as per requirement	None

Workshop/ Capacity building/ technology transfer		
Planned (as per project proposal)	Organized	Reasons for deviation
Training / Workshop – 2 nos.	Organized 2 Training Course at NIH Roorkee **i)** 5-Days Training Course on “Ground Water Quality Modelling" duringFeb. 12-16, 2018 **ii)** 5-DaysTraining Course on “Groundwater Quality Monitoring and Assessment" during Jun. 03-07, 2019	None

Study area	
Planned	Extended
District Bemetara	Extended to Maniyari Shell Formation Region after discussion with WRD, Raipur

New data generated in the project		
Planned (as per project proposal)	Achievement	Reasons for deviation
Groundwater Quality Data	Generated	None
Envisaged contribution of the project		
Planned (as per project proposal)	Contribution made	Reasons for deviation
Very little work has been attempted on groundwater quality assessment and hydrogeochemical study in Chhattisgarh region. The findings of present PDS will be helpful policy makers in water sector about sustainable groundwater supply for drinking purpose in the district.	Groundwater quality & hydrogeochemical assessment in study area and recharging zones have been identified and estimated the recharge to restore the quality and sustainable use of groundwater for drinkingpurpose.	None
How research outcome benefited the end user department and society		
Planned (as per project proposal)	Benefit derived	Reasons for deviation
For any scheme of water supply in an area,	• Degraded ground	None

<table>
<tr><td>it is mandatory to have the status of water quality of the water resources being used for supply. An extensive survey of groundwater quality monitoring of district Bemetara will provide the knowledge about degraded ground water quality zones and possible sources of pollution and specific parameters not conforming to drinking/ & irrigation water quality standards, which will help the policy makers and society. Further, present PDS will suggest ameliorative measures to restore the quality and sustainable use of groundwater for drinking and irrigation purpose by investigating the hydro-geology of thearea.</td><td colspan="2">water quality zones and possible sources of pollution and specific parameters not conforming to drinking/irrigation water quality standards have been identified.
• Artificial recharge to restore the quality and sustainable use of groundwater for drinking purpose have been estimated at few locations.</td><td colspan="2"></td></tr>
<tr><td colspan="5">End-of-project deliverables</td></tr>
<tr><td>Planned (as per project proposal)</td><td colspan="2">Achieved</td><td colspan="2">Reasons for deviation</td></tr>
<tr><td>The study will identified degraded groundwater quality zones, possible sources of pollution, understanding geochemical processes controlling the aquifer chemistry and will suggest the measures for sustainable groundwater supply for drinking purpose in the district, therefore enable better planning and management of groundwater resources. Findings of the proposed PDS will be published in the form of leaflets/research papers.</td><td colspan="2">• Degraded ground water quality zones and possible sources of pollution and specific parameters not conforming to drinking/irrigation water quality standards have been identified.
• Artificial recharge to restore the quality and sustainable use of groundwater for drinking purpose have been estimated at few locations.</td><td colspan="2">None</td></tr>
<tr><td colspan="5">Outsourcing (>1 lakh)/ consultancy(All): Not Applicable</td></tr>
<tr><td>Consultant (name and qualifications), organization/ outsource agency</td><td colspan="2">Work assigned</td><td>Estimated cost</td><td>Actual cost Rs</td></tr>
</table>

		Rs	

Financial achievement					
S No	Head	Approved budget	Approved revised budget	Final expenditure	Reasons for deviation
1	Remuneration/Emoluments for Manpower etc.	10.30	12.71	11.75	-
2	Travelling Expenditure	2.60	2.60	2.69	-
3	Infrastructure/Equipment	4.00	4.00	0	Not purchased
4	Experimental Charges/Field work/Consumables	3.00	3.00	2.35	-
5	Capacity building/Technology transfer	4.00	4.40	2.90	Could not organize Workshop due toCorona
6	Contingency	1.50	1.50	0.14	-
7	Outsourcing/ consultancy	-	-	-	-
	Total	25.40	28.21	19.83	

TableA.2: Quantitativeoutcome

i. Research papers published/ submitted		
S No	Research paper (National/ International Journal/ conferences/ symposium/ workshop/seminar)	Impact factor for Journal
1.	**International Journal** **i)** Sharma M. K., Kumar, Mohit, Malik, D. S., Singh, Surjeet, Patre, A. K., Prasad, Beena, Sharma, Babita, Saini, Shekhar, Shukla, A. K. and Das, P. C. (2022) Assessment of groundwater quality and its controlling processes in Bemetara District of Chhattisgarh State, India, Applied Water Sciences, 12:102, 1-20, https://doi.org 10.1007/s13201-022-01608-4 **ii)** Sharma, M. K. and Kumar, Mohit (2020) "Sulphate contamination in groundwater and its remediation:An overview, Environ. Monit. Assess., 192: 74, 1-10.	**IF=5.411** **IF=1.959**
2.	**National Journal** Sharma, M. K., Singh, Surjeet, Kumar, Pradeep, Patre, A. K., Kumar, Mohit, Prasad, Beena, Shukla, A. K. and Das, P. C. (2020) Hydrogeochemical Evaluation of Groundwater of Bemetara District, Chhattisgarh, e-Journal ofGeohydrology, International Association of Hydrogeologists Indian National Chapter, Vol. 1, Issue 2, 82-92.	
3.	**International Conference** Sharma, M. K., Kumar, Pradeep, Singh, Surjeet, Kumar, Mohit and Shukla, A. K. (2019) Source Identificationof Sulphate Contamination using Hydrogeochemical Investigation: A Case Study of District Bemetara, Chhattisgarh, India, 8th Int. Nat. Groundwater Conf. (IGWC-2019) on Sustainable Management of Soil-Water Resources, organized by DOH, IIT, Roorkee during Oct.21-	

4.	24, 2019, Abstract Volume pp. 72. **National Conference** मुकेश कुमार शर्मा, प्रदीप कुमार, राकेश गोयल एवं मोहित कुमार (2019) बेमेतरा जिले, छत्तीसगढ़ में भूजल गुणवत्ता का मूल्यांकन, राष्ट्रीय जल संगोष्ठी -२०१९, प्रपत्र 8.6.	

Reports/Monographs/Internal publications brought out: None

S. No.	Reports/Monographs/Internal publications

ii. New techniques/models/ software/ knowledge developed, if any

- Degraded water quality zones have beenidentified.
- Estimated artificial recharge for high sulphate zone to restore the groundwaterquality for sustainable use by various users investigating site-specific measures considering contaminant transportmodeling.

iii. Web site/ application developed: None

Name	Web address	Server location	Launch date	Details of information available

iv. Patents filed/awarded, if any: None

Workshop/ conferences/ seminars/capacity building programmes organised

S. No.	Topic	Dates, duration, No. of participants	Report published (Y/N)
1.	Training Course on "Ground Water Quality Modelling"	Five Days during Feb. 12-16, 2018, 26participants	Submitted
2.	Training Course on "Groundwater Quality Monitoring and Assessment"	Five Days during Jun. 03-07, 2019, 21participants	Submitted

v. Stake holders feedback and action taken on constructive feed back: None

S No.	Feedback received	Action taken
Stake holder meet (Topic and date)		

vi. Field observations obtained, thematic maps generated (water quality and salinity, isotope, soil moisture, stage and discharge, sediment, water level, river cross sections, geophysical/ resistivity survey, hydrogeological investigations etc.)

S No	Parameter, frequency, period, groundwater/ river/ tank/ hand pump/ spring/ sea-water	Number (planned)	Numbers (measured)
1.	Hydro-chemical parameters, metal concentrations in groundwaters of study area, groundwater level, spatial distribution maps for hydro-chemical parameters.	Pre- and post-monsoon sampling (Two years)	Pre- and post-monsoon sampling (Two years)

vii. Field installations (piezometers, river stage/ discharge, soil moisture etc.) NA

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown

viii. Equipment/ software purchased: Not Applicable

a. Equipment purchased: None

S. No	Name, make/ model	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown

b. Software purchased: None

S. No	Name, version, license	Unit price, total price, quantity	Date of installation	% utilization	Remarks regarding maintenance/ breakdown

ix. Plans for utilizing the equipment facilities in future: None

S.No.	Installation/ equipment	Planned future use

x. Data dissemination policy for data generated in the project: Implementing Agency will be trained for using the outcomes of the study in the field by organizing a Workshop.

xi. Number of post-graduate/doctoral candidates completed their courses(Please give a list of such candidates):One

Ms. Vismaya K.P., M. Sc. (Earth Science), School of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies, Kochi on the topic "Evaluation of groundwater quality of Bemetara district, Chhattisgarh using Water Quality Index" May 2020.

xii. Foreign deputation/visit of PI/Co-PIs/students, if any: None

A.3 Activity chart

Include activity chart/ modified activity chart, reasons for modification of activity chart.

Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
1st Year	Literature Survey	Field visit & Sampling, Data Collection	Sample Analysis, Field visit & Sampling, Data Collection	Sample Analysis and processing of the data , Interim Report
2nd Year	Field visit	Sample Analysis	Field visit,	Analysis and

	& Sampling, Data Collection and processing of the data	and processing of the data	Sampling, Data Collection & Analysis and processing of the data	processing of the data, Interim Report
3rd Year	Analysis & Processing of the data	Modellingflow and transportof sulphate using MODFLOW & MT3D	Writing of the Report	Writing of the Report

Appendix B Supplementary results

Provide supplementary results here, if any