भारत सरकार
Government of India
जल शक्ति मंत्रालय,
Ministry of Jal Shakti,
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग,
Department of Water Resources,
River Development and
Ganga Rejuvenation

केंद्रीय भूमि जल बोर्ड
Central Ground Water Board

NAQUIM 2.0

जलभृत प्रबंधन योजना
Aquifer Management Plan
गुरूग्राम औद्योगिक क्लस्टर, गुरूग्राम जिला, हरियाणा
Gurugram Industrial Cluster, Gurugram District, Haryana

North Western Region (NWR)
Chandigarh
2024

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Gurugram Industrial Cluster, Gurugram District, Haryana

प्राथमिकता प्रकार: औद्योगिक क्लस्टर

Priority Type: Industrial Cluster

North Western Region (NWR)

Chandigarh

2024

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Message

National Aquifer Mapping and Management Programme (NAQUIM) was initiated by Central Ground Water Board (CGWB) in 2012 with the goal of mapping and managing aquifers across India to promote sustainable groundwater use. So far the entire mappable area of 25 lakh km2 has been covered under the NAQUIM programme. While these initial efforts have been highly impactful, they faced certain limitations especially in terms of spatial resolution.

Taking it forward, CGWB has now initiated NAQUIM 2.0, the next phase of aquifer mapping designed to provide a deeper, more detailed understanding of India's groundwater systems. During 2023-24, CGWB had completed NAQUIM 2.0 studies in 68 study areas. The study areas were selected in consultation with the State/UT government agendes.

I am confident that this report of NAQUIM 2.0 study will serve as a critical resource for government agencies, research institutions, NGOs, and the general public. By fostering a collaborative approach to groundwater management, this report will play a key role in safeguarding and sustaining India's precious ground water resources.

(Dr. Sunil Kumar Ambast)
Chairman, CGWB

Sh Anurag Khanna
Member (North & West)

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Message

I am glad to present the report on National Aquifer Mapping and Ground Water Management Plan for Industrial clusters in Gurugram, Haryana.

This report suggests a ground level, implementable management plan that addresses groundwater issues of Gurugram city. The plan incorporates a multidisciplinary approach, including geological, geophysical, hydrogeological, hydrological, and water quality analyses, leveraging issue-based high-density dynamic data.

I am hopeful that management plan suggested in this report will help in proper management of ground water resources in the targeted area.

I would like to appreciate the work done by the team of NAQUIM 2.0, Central Ground Water Board, North Western Region, Chandigarh.

(Sh Anurag Khanna)
Member (North & West)

FOREWORD

Keeping in mind the success & shortcomings of previous NAQUIM studies, NAQUIM 2.0 was launched in 2023. It aims to provide information in higher granularity with a focus on increasing the density of dynamic data like groundwater level, groundwater quality, etc. providing issue-based scientific inputs for groundwater management up to the Panchayat level and to ensure the implementation of the recommended strategies.

Gurugram, a rapidly urbanizing city in the National Capital Region (NCR) of India, has undergone significant transformation over the past two decades. The city's rapid expansion, marked by the proliferation of residential, commercial, and industrial developments, has put considerable pressure on its groundwater resource. Groundwater has traditionally been a critical source of water for Gurugram's population; however, the intensified urbanization has raised concerns regarding the quality and sustainability of this vital resource. The main objective of the present study is to analyze the current status of groundwater quality in the study area, examining the impact of urbanization on potability of groundwater and thereafter provide the practically implementable aquifer management plan for the better sustainability of the groundwater systems. Keeping in view all these parameters in Gurugram urban area related to Groundwater depletion & quality deterioration and considering the future requirements, the area has been taken up for NAQUIM 2.0 studies.

I hope this report will set an example in areas of the country that have similar interests. I feel heartened to record my deep appreciation of the untiring efforts made by the NAQUIM 2.0 team for this study to bring out this report in the shortest possible time.

ANURAG KHANNA

(REGIONAL DIRECTOR)

CGWB, NWR

CHANDIGARH

ACKNOWLEDGMENTS

The completion of the NAQUIM 2.0 Report for Gurugram urban area was made possible through the collective efforts and guidance of ***Shri Anurag Khanna****, Member (North & West), and Regional Director of the Central Ground Water Board (CGWB), Northwestern Region, Chandigarh.*

We are deeply grateful to ***Dr. Sunil Kumar Ambast****,* ***Chairman*** *of the* ***Central Ground Water Board (CGWB)****, for his visionary leadership and unwavering support in implementing the National Aquifer Mapping and Management (NAQUIM 2.0) program. His dedication to sustainable groundwater management has been a cornerstone of this project.*

We also appreciate the contributions of the ***Haryana Irrigation Department*** *for their collaboration and assistance in data collection. Their local knowledge and logistical support were crucial for the smooth execution of this project.*

Our heartfelt thanks go to the various stakeholders, including local communities, and NGOs, for their active participation and valuable input during consultations and field surveys. Their involvement has provided practical insights and enriched the study with on-ground realities.

Special recognition is given to ***Shri Vidya Nand Negi****, Scientist D (Hg),* ***Sh Sunil Kumar****, STA (GP), and* ***Shri Kiran Lale****, STA (Chemical) for their dedication, hard work, and professionalism, which have been the backbone of this report. I thank* ***K. G. Bhartariya****, Scientist-C (Chemical) and* ***Sh Ayush Kesharwani,*** *Scientist B for all possible help and technical guidance to complete the preparation of this report.*

Finally, we express our gratitude to everyone who, directly or indirectly, contributed to the completion of the NAQUIM 2.0 Report for Gurugram urban area. Your support and collaboration have been vital in advancing our understanding of groundwater resources and promoting sustainable management practices.

Thank you all for your invaluable contributions.

EXECUTIVE SUMMARY

Gurugram, once dominated by agricultural land, has undergone rapid urbanization, becoming an industrial hub. This transformation has led to the conversion of vast agricultural areas into built-up spaces, severely impacting natural groundwater recharge processes. Additionally, the rise of industries has elevated groundwater quality issues. The Najafgarh drain, flowing through the northwest part of the region, primarily consists of wastewater from the Badshahpur drain and rainwater during the monsoon season. It collects sewage from the surrounding urban sprawl, contributing to the contamination of groundwater. Major industries, including textiles, paper mills, pharmaceuticals, soaps and detergents, and engineering and metal industries, are particularly prone to groundwater contamination in the area.

Groundwater levels in Gurugram vary significantly across the region. During the pre-monsoon season of 2023, the depth to the water level ranged from 1.16 meters below ground level (bgl) to 74.10 meters (bgl). In the post-monsoon season, the levels varied from 2.05 meters (bgl) to 74.20 meters (bgl). The presence of the Sahibi River in the northwest provides a potential recharge source for groundwater, contributing to the shallow water levels in that area. However, the central part of the city, particularly along the Delhi-Jaipur highway, experiences the deepest water levels due to high demand for industrial and domestic consumption and reduced recharge rates caused by urbanization.

The groundwater situation in Gurugram is critical, with the Net Annual Groundwater Availability as of March 2023 calculated at 5538.43 Ham (55.38 mcm), while total extraction for all uses stands at 18077.73 Ham (180.77 mcm). This results in a groundwater extraction stage of 326.415, placing the Gurugram urban area in the over-exploited category. Water quality analysis during the post-monsoon season revealed varying pH levels, with electrical conductivity ranging from 220 to 5612 µS/cm at 25°C. The fluoride concentration in groundwater samples varied between 0.05 to 2.52 mg/l, while nitrate levels ranged from 5.8 to 120 mg/l, with some areas exceeding safe nitrate concentrations. The Total Hardness in groundwater samples varied significantly, indicating a range of water quality from good to saline.

Geophysical studies of the area show a diverse range of groundwater qualities, including fresh, marginally saline, and saline groundwater. Saline groundwater is particularly prevalent in the northwestern part of the study area, extending throughout the depth of investigation. The central and northeastern regions display marginally saline groundwater, with fresh groundwater pockets being localized and discontinuous. This variation in groundwater quality is attributed to geological controls on groundwater movement and localized recharge zones.

The management plan for Gurugram's groundwater resources includes controlled abstraction of saline water for industrial use, the adoption of water conservation structures for drinking water needs, and the installation of recharge shafts in areas with deep water levels. It also emphasizes the need for proper wastewater treatment before discharge, the collection of treated municipal wastewater in urban tanks for non-drinking purposes, and the construction of stormwater drains and perforated tiles to manage flooding and enhance groundwater recharge. Additionally, making Rainwater Harvesting structures mandatory in all buildings is recommended to promote effective groundwater management, combining regulatory oversight, pollution prevention, monitoring, enforcement, and community engagement.

कार्यकारी सारांश

कभी मुख्यतः कृषि भूमि और ग्रामीण क्षेत्र वाले गुरुग्राम में तेजी से शहरीकरण हुआ है और यह शहर एक औद्योगिक केंद्र बन कर उभरा है।इस परिवर्तन ने विशाल कृषि क्षेत्रों को निर्मित स्थानों में परिवर्तित कर दिया है, जिससे प्राकृतिक भूजल पुनर्भरण प्रक्रियाएँ गंभीर रूप से प्रभावित हुई हैं।इसके अतिरिक्त, उद्योगों के बढ़ने से भूजल गुणवत्ता संबंधी समस्याएं बढ़ी हैं।क्षेत्र के उत्तर-पश्चिमी हिस्से से बहने वाले नजफ़गढ़ नाले में मुख्य रूप से बादशाहपुर नाले का अपशिष्ट जल और मानसून के मौसम के दौरान बारिश का पानी शामिल होता है।यह आसपास के शहरी क्षेत्र से सीवेज एकत्र करता है, जो भूजल के प्रदूषण में योगदान देता है।कपड़ा, पेपर मिल, फार्मास्यूटिकल्स, साबुन और डिटर्जेंट, और इंजीनियरिंग और धातु उद्योग सहित प्रमुख उद्योग, विशेष रूप से क्षेत्र में भूजल प्रदूषण में योगदान कर सकते हैं।

गुरुग्राम में भूजल स्तर पूरे क्षेत्र में काफी भिन्न-भिन्न है।2023 के प्री-मानसून सीज़न के दौरान, जल स्तर की गहराई जमीनी स्तर से 1.16 मीटर नीचे (बीजीएल) से 74.10 मीटर (बीजीएल) तक थी।पोस्ट-मॉनसून के दौरान भूजल स्तर 2.05 मीटर (बीजीएल) से 74.20 मीटर (बीजीएल) के बीच था।उत्तर पश्चिम में साहिबी नदी की उपस्थिति भूजल के लिए एक संभावित पुनर्भरण स्रोत प्रदान करती है, जो उस क्षेत्र में उथले जल स्तर में योगदान करती है।हालाँकि, शहर का मध्य भाग, विशेष रूप से दिल्ली-जयपुर राजमार्ग के साथ, औद्योगिक और घरेलू खपत की उच्च मांग और शहरीकरण के कारण कम रिचार्ज दरों के कारण सबसे गहरे जल स्तर का अनुभव करता है।

गुरुग्राम में भूजल की स्थिति गंभीर है, मार्च 2023 तक शुद्ध वार्षिक भूजल उपलब्धता 5538.43 हैम (55.38 एमसीएम) आंकी गई है, जबकि सभी उपयोगों के लिए कुल निकासी 18077.73 हैम (180.77 एमसीएम) है। इसके परिणामस्वरूप स्टेज ऑफ़ ग्राउंडवाटर एक्सट्रैक्शन 326.415% आंकी जाती है, जिससे गुरुग्राम शहरी क्षेत्र अत्यधिक दोहित क्षेत्र की श्रेणी में आता है।पोस्ट-मॉनसून के दौरान पानी की गुणवत्ता के विश्लेषण से पीएच स्तर की varying range का पता चला, व 220 से 5612 μS/cm at 25°C तक विद्युत चालकता मिली।भूजल के नमूनों में फ्लोराइड की सांद्रता 0.05 से 2.52 मिलीग्राम/लीटर के बीच थी, जबकि नाइट्रेट का स्तर 5.8 से 120 मिलीग्राम/लीटर के बीच था, कुछ क्षेत्रों में नाइट्रेट सांद्रता सुरक्षित सीमा से अधिक थी।भूजल के नमूनों में कुल कठोरता काफी अलग-अलग थी, जो अच्छे से लेकर खारे पानी तक की गुणवत्ता का संकेत देती है।

क्षेत्र में भूभौतिकीय अध्ययन भूजल गुणों की विविध श्रेणियाँ दिखाते हैं, जिनमें ताजा, मामूली खारा और खारा भूजल शामिल है।खारा भूजल विशेष रूप से अध्ययन क्षेत्र के उत्तर-पश्चिमी भाग में मिलता है, जो सर्वे की गहराई तक मिला है।मध्य और उत्तरपूर्वी क्षेत्रों में भूजल थोड़ा खारा है, ताजा भूजल क्षेत्र स्थानीयकृत और असंतत हैं।भूजल गुणवत्ता में इस भिन्नता का श्रेय भूजल संचालन और स्थानीयकृत पुनर्भरण को दिया जाता है।

गुरुग्राम के भूजल संसाधनों की प्रबंधन योजना में औद्योगिक उपयोग के लिए खारे पानी की नियंत्रित निकासी, पीने के पानी की जरूरतों के लिए जल संरक्षण संरचनाओं को अपनाना और गहरे जल स्तर वाले क्षेत्रों में रिचार्ज शाफ्ट की स्थापना शामिल है।साथ ही साथ उचित अपशिष्ट जल उपचार, गैर-पीने के उद्देश्यों के लिए शहरी टैंकों में उपचारित नगरपालिका अपशिष्ट जल का संग्रह, और बाढ़ का प्रबंधन करने और भूजल पुनर्भरण को बढ़ाने के लिए storm water drains और छिद्रित टाइलों के उपयोग पर भी जोर देता है।इसके अतिरिक्त सभी इमारतों में वर्षा जल संचयन संरचनाओं को अनिवार्य बनाने के साथ नियामक निरीक्षण, प्रदूषण की रोकथाम, निगरानी, प्रवर्तन और सामुदायिक भागीदारी के संयोजन के साथ प्रभावी भूजल प्रबंधन को बढ़ावा देने के लिए कहा गया है।

CONTENTS

List of figures

List of Tables

Annexures

Chapter 1- Introduction

1.1 Background of Aquifer Mapping

The Aquifer Mapping and Management programme (NAQUIM) was launched by CGWB in the year 2012 as per the recommendations of the Report of the Steering Committee on Water Resources and Sanitation for Twelfth Five Year Plan (2012-2017), Planning Commission. NAQUIM was taken up with the objectives of delineating aquifers, characterizing aquifers and preparing aquifer management plans. National level mapping of Aquifers on 1:50,000 scale was considered sufficient for planning requirements up to block level. Some of the important uses of Aquifer mapping at 1:50,000 scale include identification of suitable areas for ground water based supply to large urban agglomerations, determine sustainability of groundwater development, identification of aquifers capable of providing water supply during protracted drought periods, prioritization of aquifers for managed aquifer recharge, identification of aquifers and determination of their suitability for various purposes in regions where new urban centres or industrial hubs are likely to come up in future, planning of integrated ground water recharge schemes, issuing advisories to the state agencies on repercussions of continued development of groundwater in select areas, recommendations to state agencies in respect of areas that have prospects for ground water development etc. Many states/UTs are using the information for planning management interventions at the block level. The entire targeted area has been covered by 2022-23. The findings of NAQUIM studies are being utilized by many agencies, especially the State government agencies involved in ground water management and water supply.

NAQUIM 2.0

Though the NAQUIM outputs have been useful for sustainable ground water management in numerous ways, large scale implementation of its recommendations at ground level by the user agencies has been lacking. As per the feedback received from the agencies using the NAQUIM outputs, major limitations of the ongoing studies include i) non availability of printed maps at usable scales and ii) lack of site specific recommendations for implementation at Panchayat or village level.

Keeping the above limitations in mind and considering the future requirements, broad objectives of NAQUIM 2.0 studies are i) providing information in higher granularity with a focus on increasing density of dynamic data like ground water level, ground water quality etc. ii) providing issue based scientific inputs for ground water management upto Panchayat level, iii) providing printed maps to the users and iv) putting in place a strategy to ensure implementation of the recommended strategies. Involving state agencies in the studies for a sense of ownership.

1.2 Study area

Gurugram district is located in Haryana state having latitude and longitude coordinates as 28.3606° N and 76.8721° E, respectively. It is located 30 km south of New Delhi, the National Capital of India. The district is one of Delhi's major satellite cities and is part of the National Capital Region. Gurugram is the industrial and financial centre of Haryana. The district is located in the south-eastern bulge of the State and shares a common border with Delhi in the north. Jhajjar district lies in its north-west direction, Rewari district in its south west, Mewat district in its south, Palwal district in its south east, and Faridabad district shares its eastern boundary. Gurugram contains many small hill ranges which are part of the Aravali and Mangar Bani ranges. Gurugram district is one of the 22 districts located in Haryana, which covers an area of 1257 km^2 including 976 km^2 of rural area and 281 km^2 of urban area. The district is divided into five revenue tehsils, namely Gurugram, Sohna, Pataudi, Farrukh Nagar, and Manesar and four sub-tehsils, namely Wazirabad, Badshahpur, Kadipur, and Harsaru. It also comprises four rural development blocks – Gurugram, Sohna, Farrukhnagar, and Pataudi. For the purpose of this study, Gurugram city (municipal area) of Gurugram tehsil in Gurugram district, having an area of 321 sq km is considered. The Gurugram urban area is confined within North Latitudes 28° 19' 51.6" and 28° 32' 31.2" and East Longitudes 76° 10' 33.6" and 76° 55' 40.8" The area is falling mainly and partly in Survey of India Toposheets nos. 53I/3, 53I/2, 53D/14 and 53D/15.

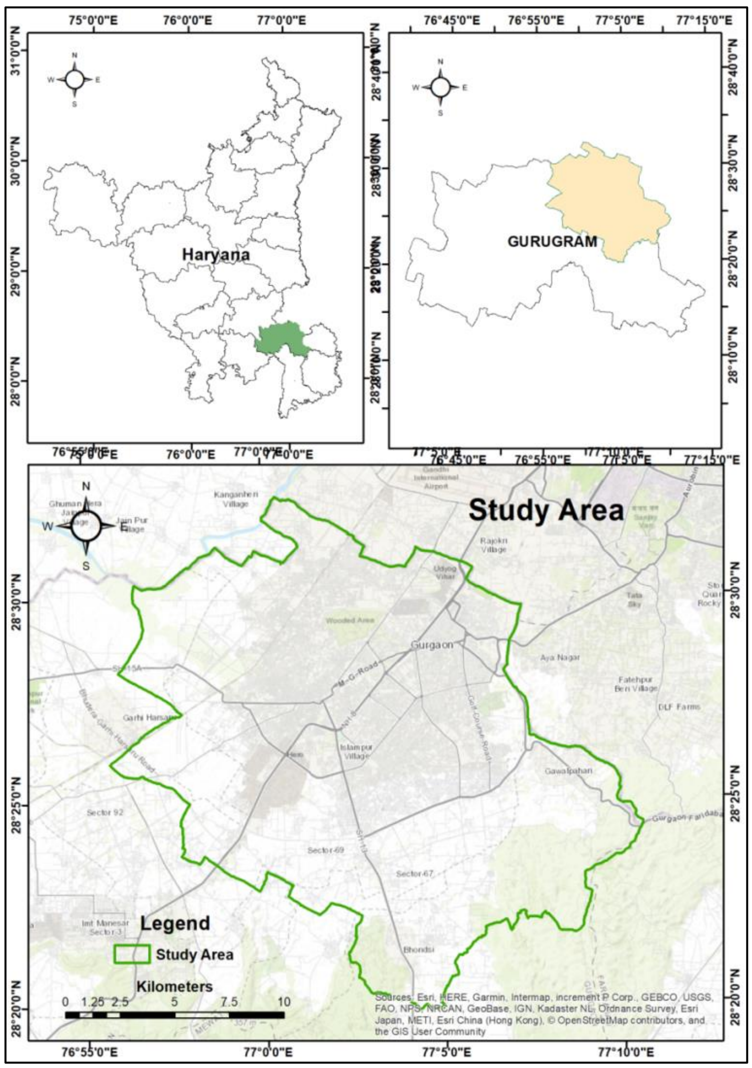


Figure 1 Location of study area

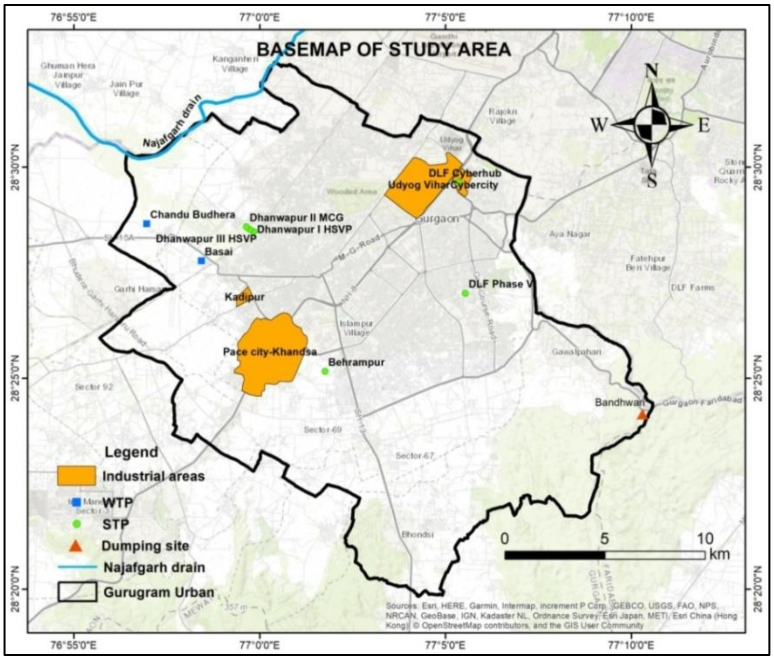


Figure 2 Location of study area

1.3 Physiography Gurugram district comprises hills on the one hand and depressions on the other, forming irregular and diverse nature of topography. Two ridges: Delhi ridge and Firozpur Jhirka–Delhi ridge form the eastern and the western boundaries, respectively, of the district. These hills are northern extension of the Aravalli hills. The hillocks are dissected by rainfed torrents.

The study area can be divided into two sub-parts – a major alluvial plain in the north and an undulating plain with Aravalli offshoots on the eastern & southern sides. The undulating plain is covered with rocky surfaces of Aravalli offshoots. Only some patches of the land are under cultivation owing to rocky areas, poor soil cover, and roughness of surface. Elevation ranges from 173 to 263 meter above mean sea level.

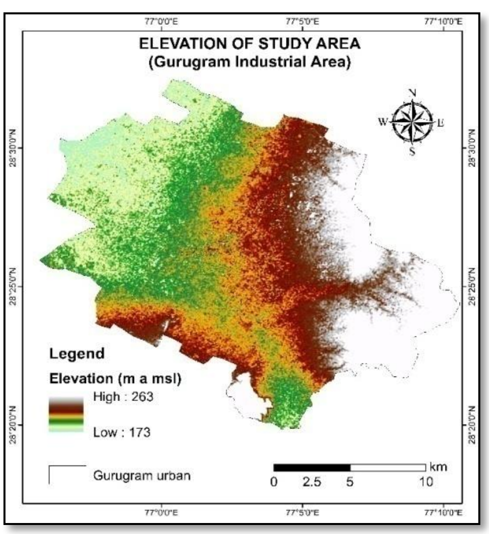


Figure 3 Elevation of study area

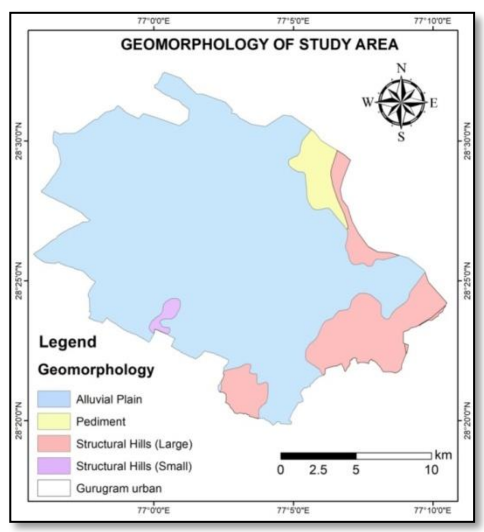


Figure 4 Geomorphology of study area

1.4 Drainage

Although Gurugram itself is not situated on a major river, it is located in close proximity to the Yamuna river, one of the largest rivers in northern India, flowing to the east of Gurugram and has played a crucial role in shaping the landscape through erosion and sedimentation. Sahibi and Indori are two important seasonal streams of the district. The Sahibi river, a tributary of the Yamuna, originates in the Sewar hills of Jaipur, makes its presence in Gurugram tehsil after flowing in northern direction through Rajasthan and Rewari district and before losing itself in the topographic depression of Jhajjar district. The Indori Nadi, a rain-fed river originates from Aravalli hills in Rajasthan in Sikar district, flows through Alwar district, Rewari district and joins Sahibi Nadi near Pataudi.Apart from the aforementioned streams, Badshahpur, Mehndwari, Kasan, Manesar and Landoha nallahs play havoc during heavy rains. Seasonal streams are only a few, smaller in size, and are inland. The drainage of the study area is typical of the arid and semi-arid areas. Important depressions of the district are Khalilpur Lake, Chandani Lake, Sangel – Ujhina Lake, Kotla Dhar Lake, and Najafgarh Lake.

1.5 Geology

The study area is situated in the transitional zone ofGanga plain in the north and Aravalli Hills in the south and comprises of Indo Gangetic alluvial plain and Aravali Hills. In the eastern and southern parts of the city, aravalli hills are exposed which are composed of Aravalli basement rocks overlain by Ajabgarh group of Delhi Supergroup, consisting mainly of quartzite and phyllite.The Yamuna river and its tributaries have contributed to the accumulation of extensive alluvial deposits in the region consisting of micaceous sand, silt and clay with kankar.

1.6 Climate

The climate is characterized by dry and extreme temperature and scanty rainfall. The district has a sub-tropical continental monsoon climate where seasonal rhythm, hot summer, cool winter, unreliable rainfall, and great variation in temperature are found. Four seasons are observed in a year in this region, which are as follows: (i) Summer – from mid-March to end of June, (ii) followed by a rainy season from July to mid-September, (iii) after which a transition period of two months follows, and (iv) then the cold season starts from mid-November to mid-March. January is the coldest month when mean daily maximum temperature is about 21.4°C and mean daily minimum temperature remains at 5.4°C. On the other hand, May and June are the hottest months. The mean daily maximum temperature in May is around 40.2°C. Occasionally, the day temperature may exceed to 45°C. The highest maximum temperature recorded at Gurugram was 49°C on May 10, 1966 and the lowest minimum temperature was 0.4° C on December 5, 1966.

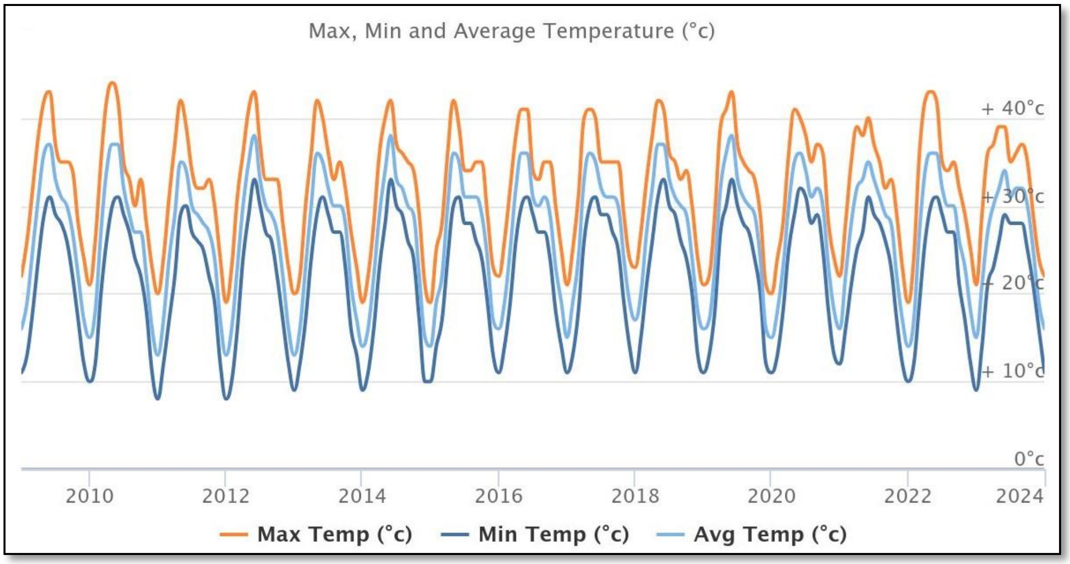


Figure 5 Maximum, Minimum and Average temperature

1.7 Rainfall

The district receives 62% of the normal annual rainfall during June–September, wherein July and September are the rainiest months. The normal annual rainfall in the Gurugram urban area is 773.87 mm. The actual annual rainfall data is shown below.

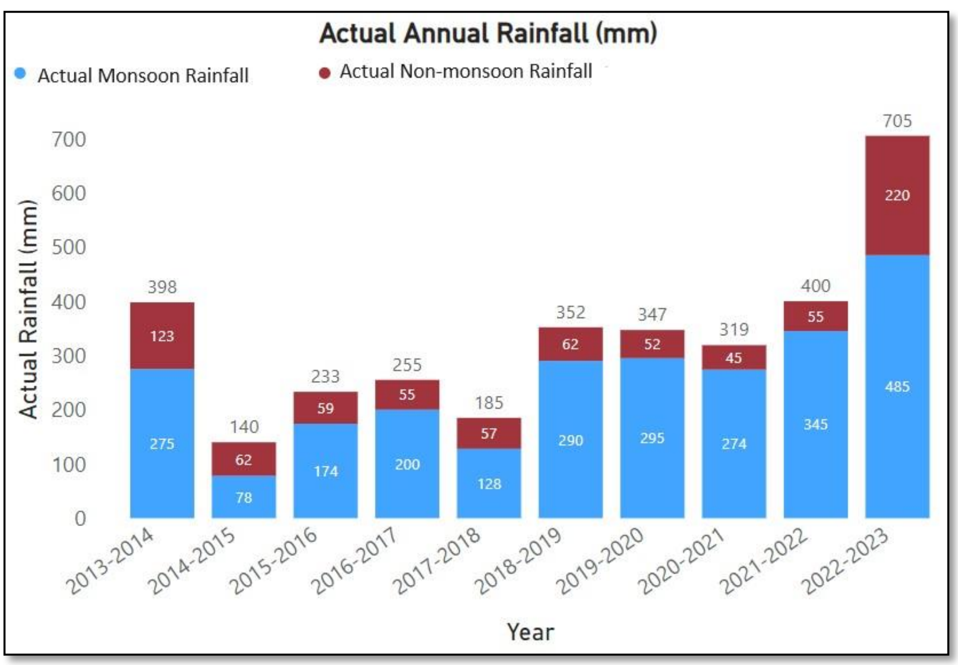


Figure 6 Actual Annual Rainfall

1.8 Land use

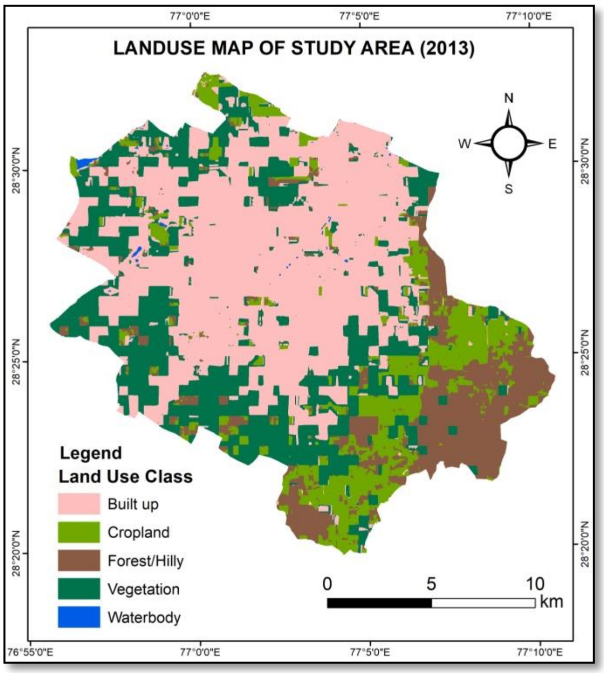


Figure 7 Landuse map of study area 2013

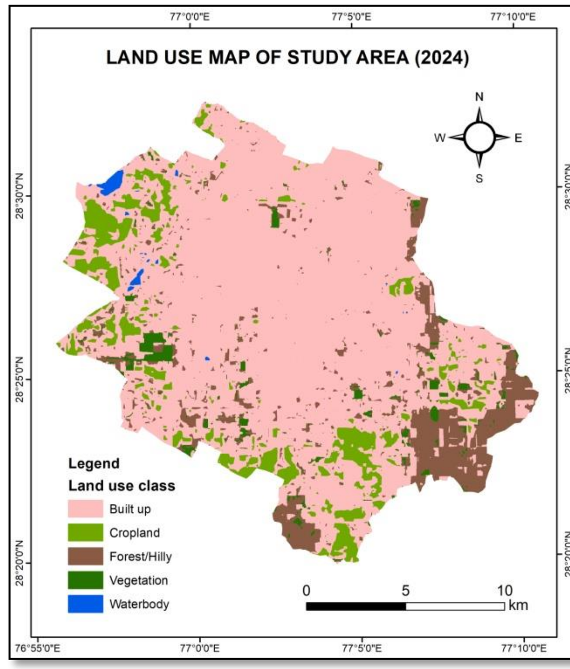


Figure 8 Landuse map of study area 2024

1.9 Industrial Clusters

Overview of Industrial Zones in Gurugram Urban Area – The major industrial zones within the Gurugram city are Udyog Vihar , Sector 34 industrial area, DLF Cybercity and Pace city industrial areas.

Udyog Vihar is one of the largest and most well-known industrial zones in Gurugram & hosts a wide range of manufacturing, IT services, automobile, electronics, and pharmaceuticals industries. Sector 34 Industrial area comprises a mix of small and medium-sized industrial units engaged in manufacturing, production, and processing activities.DLF Cybercity is primarily known as a prominent IT and commercial hub, it also accommodates several industrial units and corporate offices of multinational companies operating in various sectors.Pace City is an industrial area situated in Sector 37 of Gurugram and is home to numerous manufacturing, warehousing, and logistics companies.

Types of Industries

A brief overview of industries in Gurugram district is given below:

Table 1 Industries in Gurugram district

S NO.	TYPE OF INDUSTRY (MSME)	NO. OF UNITS
1	Agro based	66
2	Soda water	--
3	Cotton textile	10
4.	Woolen, silk & artificial Thread based clothes.	5
5.	Jute & jute based	--
6.	Ready-made garments& embroidery	1255
7.	Wood/wooden based furniture	15
8.	Paper & Paper products	36
9.	Leather based	145
10.	Chemical/Chemical based	616
11.	Rubber, Plastic & petro based	90
12.	Mineral based	85
13.	Metal based (Steel Fab.)	1035
14.	Engineering units	2000
15.	Electrical machinery and transport equipment	28
16.	Repairing & servicing	760
17.	Others	8104
	TOTAL	**14250**
S NO.	**TYPE OF INDUSTRY (LARGE SCALE)**	**NO. OF UNITS**
1	Auto parts	8
2	Cotton textile	2
3	Steel pipe	2
4	Stone cutting tools	1
5	Ready-made garments	6
6	Stationary	1
7	Medical items	1
8	Tea processing	1
9	Information technolgy	2
10	Passenger cars	1
11	Sports goods	1
12	Diesel engine	1
	TOTAL	27

(MSME Development Institute, Karnal, Ministry of MSME)

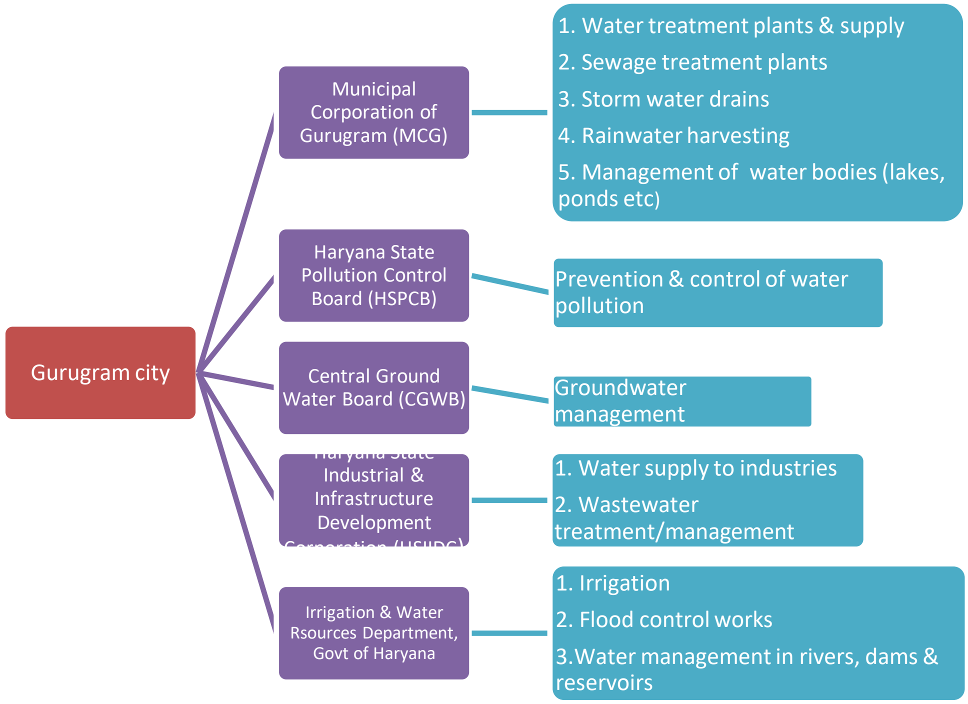
Impact of Industrial Activities on Groundwater Quality

The primary industry sectors prone to contaminate groundwater are textile industry, paper mill industry, chemical based pharmaceutical industry, soaps and detergent industry, engineering & metal industries in the study area. The major industrial effluents which affect the groundwater quality are heavy metals, synthetic dyes, PPCPs, POPs etc.

Heavy metals, known for their non-biodegradable and bioaccumulative properties, increasingly contaminate groundwater, posing severe health risks. Synthetic dyes, pivotal in industries like textiles, pose grave threats to groundwater. Azo dyes are linked to cancer. Dermatologists highlight skin irritations, rhinitis, dermatitis, and asthma as common ailments from dye exposure. Pharmaceuticals and Personal Care Products (PPCPs) significantly impact groundwater quality, originating from both consumer and industrial sources such as pharmaceutical, cosmetic, and fragrance industries. These compounds infiltrate groundwater through various pathways like manufacturing residues, sewage discharge, and unused medication disposal. PPCPs can lead to neurotoxicity, genotoxicity, hormonal imbalances, and antibiotic resistance, affecting not only humans but also aquatic life. For instance, diclofenac has caused a decline in vulture populations. PPCPs bioaccumulate along food chains, escalating risks to ecosystems. Persistent Organic Pollutants (POPs), derived from biphenyl and pesticides, pose significant threats to groundwater quality and public health. These chemicals, prevalent in transformer oils and agrichemical products, accumulate in the environment, bioaccumulate in organisms, and can travel vast distances via groundwater pathways, causing hepatotoxicity and homeostatic disruption upon consumption.

Regulatory Framework for Industrial Water Usage and Pollution Control

The administrative set up in the water sector of Gurugram City and their functions are as follows:



Industries are required to obtain consent to establish and operate permits from the Haryana State Pollution Control Board (HSPCB) before initiating any industrial activities. Industries must adhere to effluent standards set by the HSPCB and CPCB for the discharge of wastewater into water bodies.The Haryana State Pollution Control Board (HSPCB) also implements waste management rules to regulate the handling, treatment, and disposal of hazardous and non-hazardous industrial waste.

Chapter 2- Data Collection & Generation

2.1 Data availability & generation

Two monitoring stations (NHS) are located in the Meoka village and Wazirpur sector 95A area. It was proposed to establish 5 nos. of monitoring wells including all industrial areas. 17 nos. of exploratory wells/ piezometers are present in the study area. It is proposed to establish 1 EW and 1 OW for new data generation, out of which the EW has been constructed.

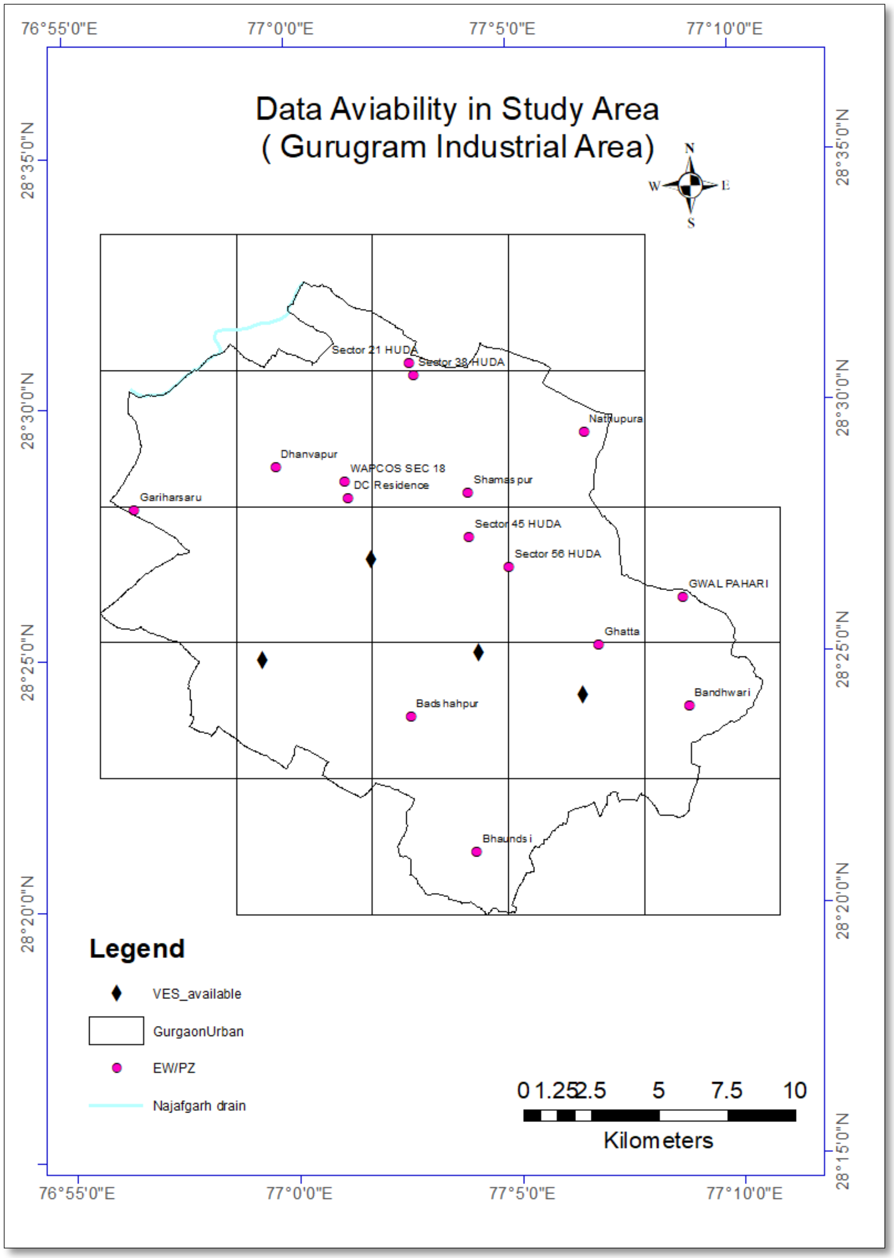
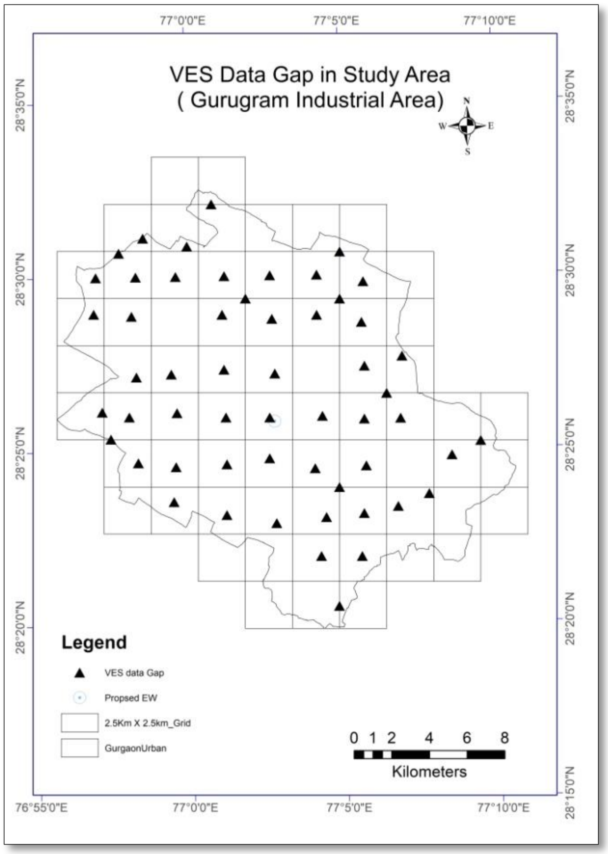


Figure 9 Data availability in study area



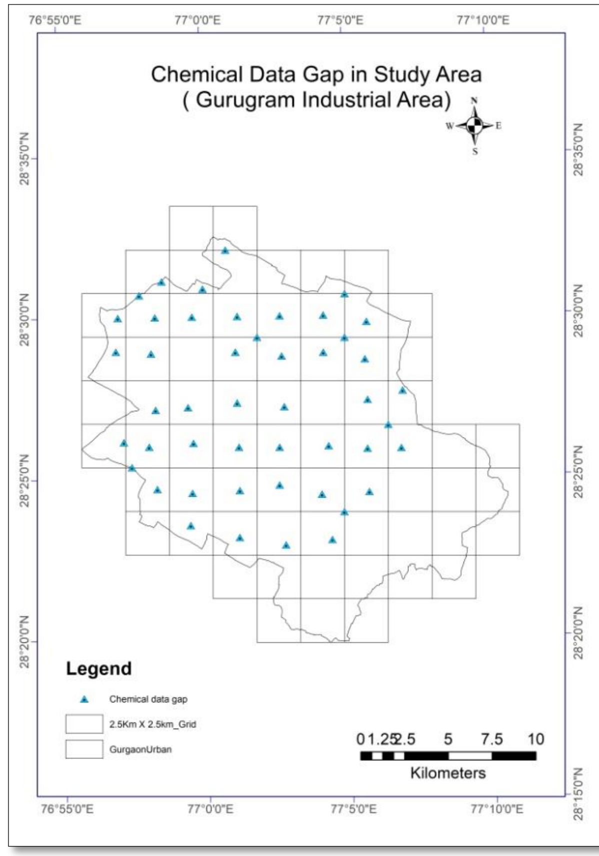


Figure 10a VES data gap in study area

Figure 10b Chemical data gap in study area

2.2 Hydrogeology

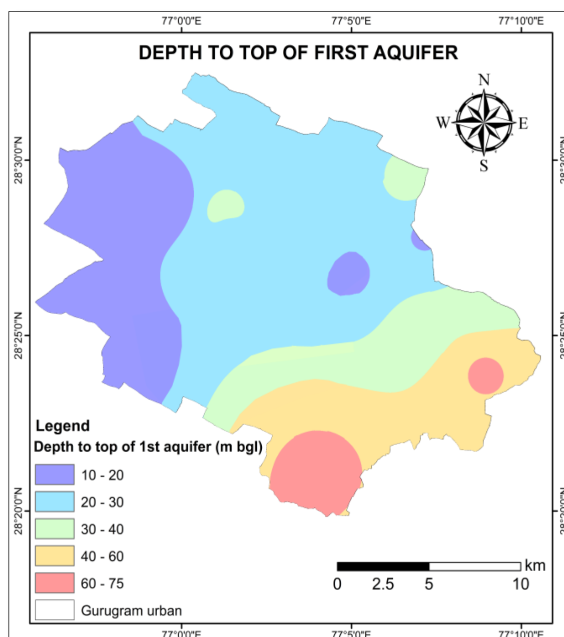


Figure 11 Depth to top of first aquifer

The major part of Gurgaon district is underlain by Quaternary alluvium consisting of sand, clay and silt. The quartzite ridge trending NNE-SSW is located about 7 Km east of town in which ground water occurs in fractures, joints and crevices. Sandy layers at various depths form major water bearing horizons above the crystalline basement. Ground water occurs in unconfined and semi-confined condition. The upper zone of saturation consists of fine sand with silt varying from place to place. In Udyog Vihar and city area the depth of first aquifer varies from 34 to 43m below ground level. However in industrial area of Manesar, top most aquifer can be encountered upto 20 m. The thickness of sandy layer is very limited. The drawdown is generally high indicating absence of highly potential ground water bearing aquifers. Tube wells in the depth range of 45 to 90 m below ground level have been installed by different agencies. The yield of these tube-wells varies in different areas ranging within 129 to 606 lpm. Geothermal springs exist in and around Sohna. The alluvium sediments consist of fine to medium sand, clay and kankar. The clay and sand belts are mostly mixed up with kankar. These sediments rest upon the basement of the block of Delhi system. Cross section A-A’ shows the sub-surface lithology in N-S direction, where sand layers are intercalated between widespread clay, sand increase on going south but on far south, quartzite is observed in the borewell, where the groundwater potential is low.

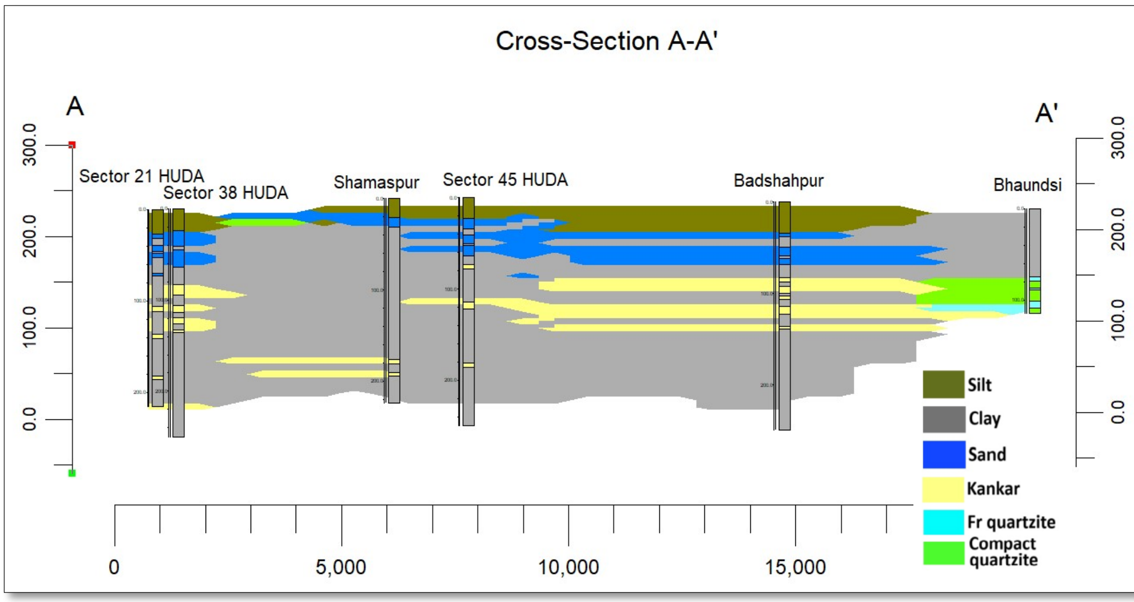


Figure 12 Cross section A-A'

2.3 Groundwater level scenario

During pre monoon, water level data from 38 nos. of wells of state department, Atal Bhujal Yojana & keywells was analysed. During post monsoon, water level data from 20 nos. of wells of state department, Atal Bhujal Yojana & keywells was analysed. Location of monitoring stations is shown in map below.

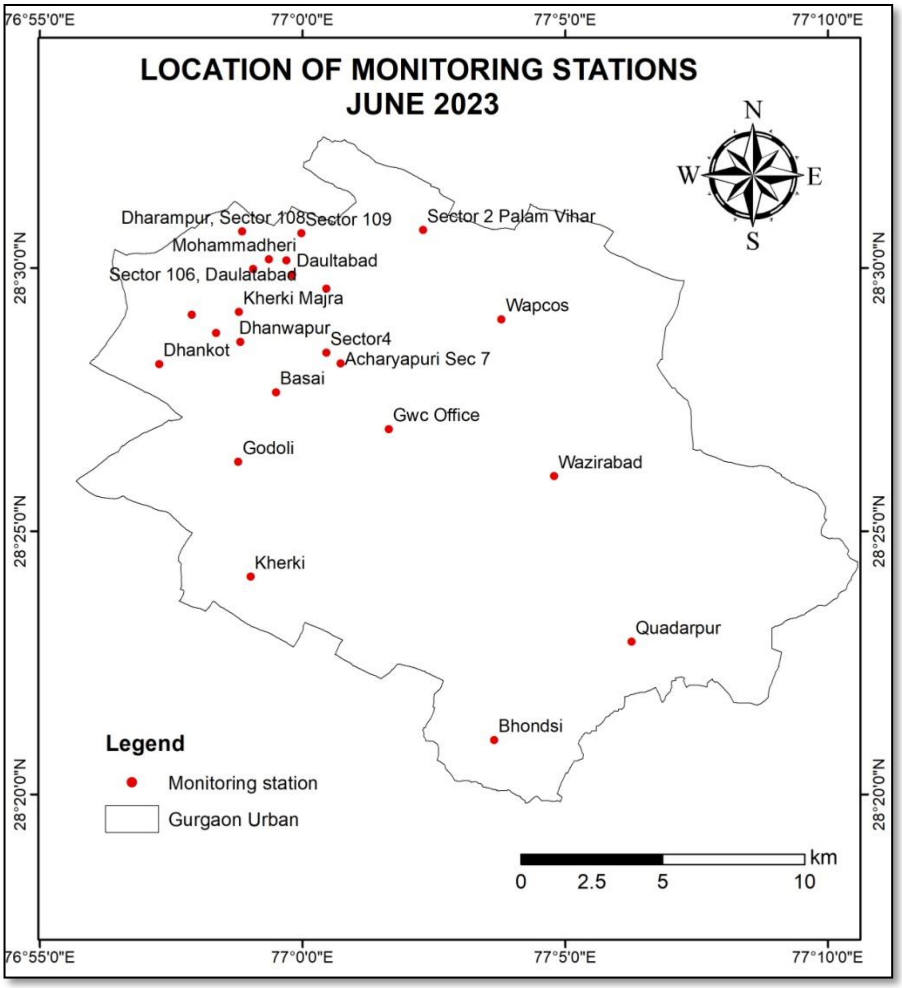


Figure 13 Location of monitoring stations

Pre-monsoon 2023

Water level data from 38 nos. of wells of state department, Atal Bhujal Yojana &keywells established under NAQUIM 2.0 was analysed. The depth to water level during pre-monsoon 2023 varies from 1.16 m bgl at Basai to 74.10 m bgl at Chakarpur. Very shallow water level (0-2m) is observed in 5% wells. Shallow & moderate water levels (2-10m) observed in 42% wells in the northwestern parts. Moderately deep water levels (10-20m) are observed in the eastern side in 5% wells. Deep water levels of 20-40m are observed in nearly 24% wells falling along the periphery of most urbanized areas. Very Deep water levels (>40m) occur in 24% of the wells along the most urbanized Delhi-Jaipur highway& on the eastern side.

Post-monsoon 2023

Water level data from 20 nos. of wells of state department, Atal Bhujal Yojana &keywells established under NAQUIM 2.0 was analysed. The depth to water level during post-monsoon 2023 varies from 2.05 m bgl at Dharampur to 74.20 m bgl at Chakarpur. Shallow & moderate water levels (2-10m) are observed in 25% wells ina small patch in the northwest. Deep water levels of 20-40m are observed in nearly 35% wells falling along the periphery of most urbanized areas& on the eastern side. Very Deep water levels (>40m) occur in 40% of the wells along the most urbanized Delhi-Jaipur highway.

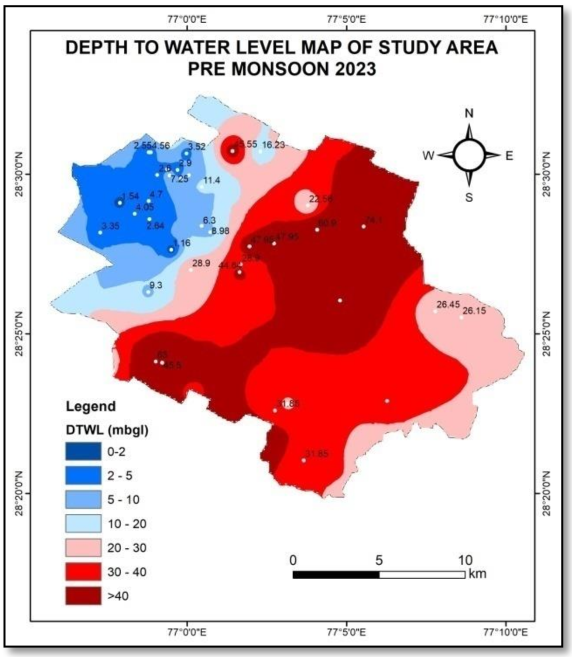


Figure 14 Depth to water level map Pre monsoon

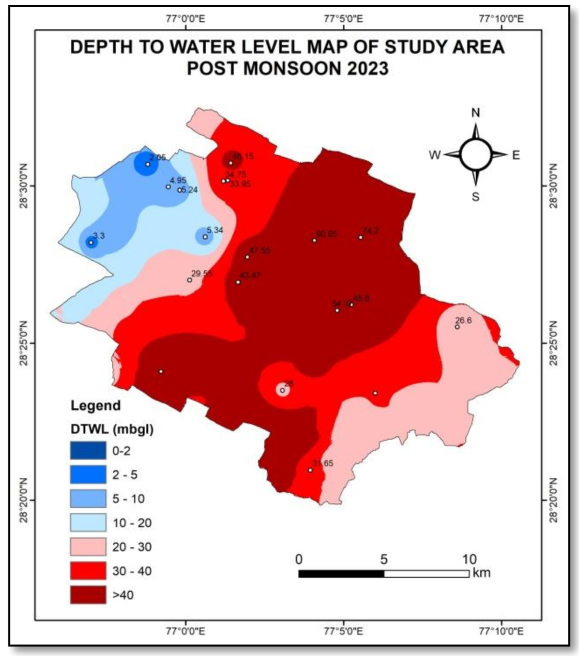


Figure 15 Depth to water level map Post monsoon

The presence of Sahibi river in the northwest side provides a potential recharge source for groundwater through infiltration from the river, hence the shallow water level in the northwest. The central part of the city along the Delhi-Jaipur highway shows deepest water levels owing to high demand for industrial and domestic consumption and reduced recharge rates due to urbanization. The groundwater flow direction is from northwest to southeast.

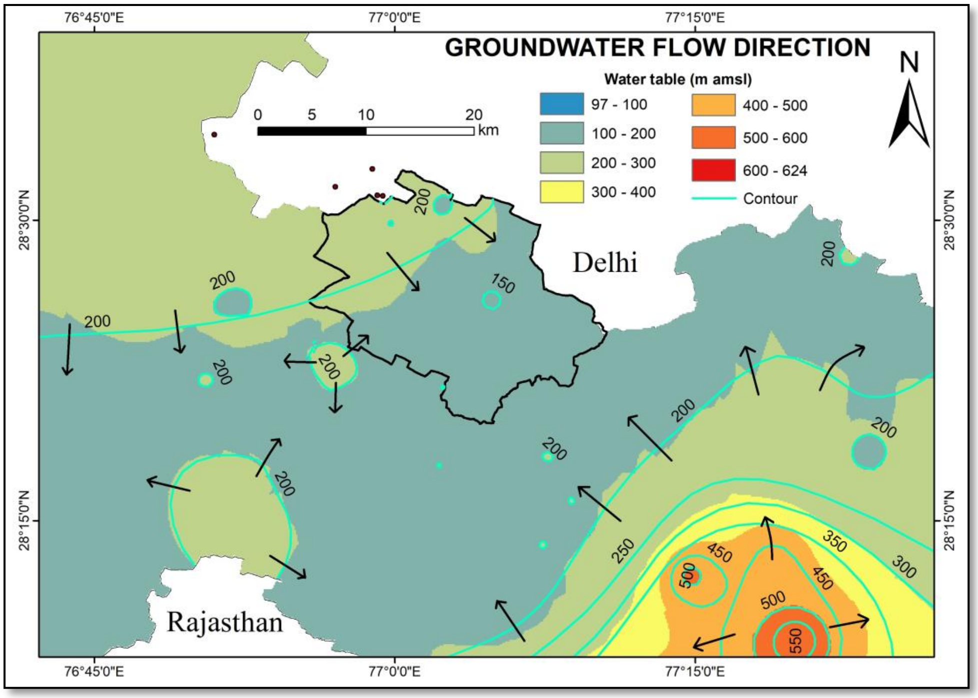


Figure 16 Groundwater flow direction

Hydrographs of some wells are given below. Hydrograph of Daulatbad pz shows rise in water level owing to its location near the Sahibi river. Hydrographs of Gurgaon pz, Kadipur, Wazirpurpz &Manesar pz show decline in water levels over time.

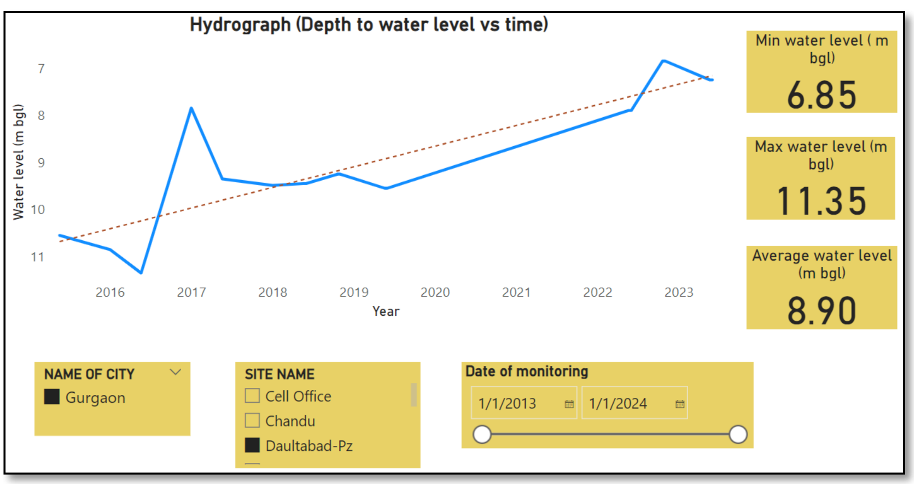


Figure 17 Hydrograph- Daulatabad pz

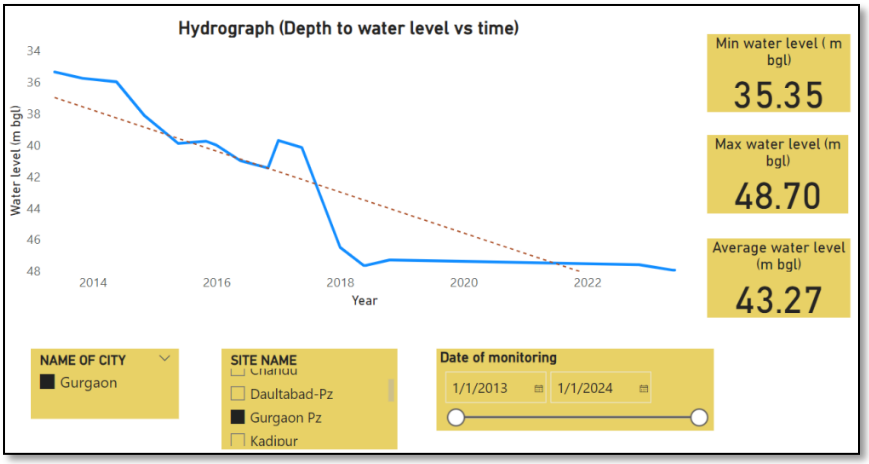


Figure 18 Hydrograph- Gurgaon pz

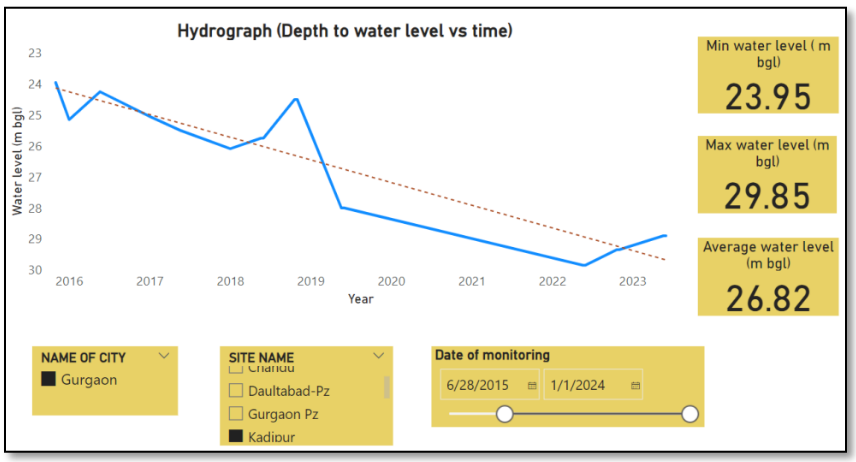


Figure 19 Hydrograph- Kadipur

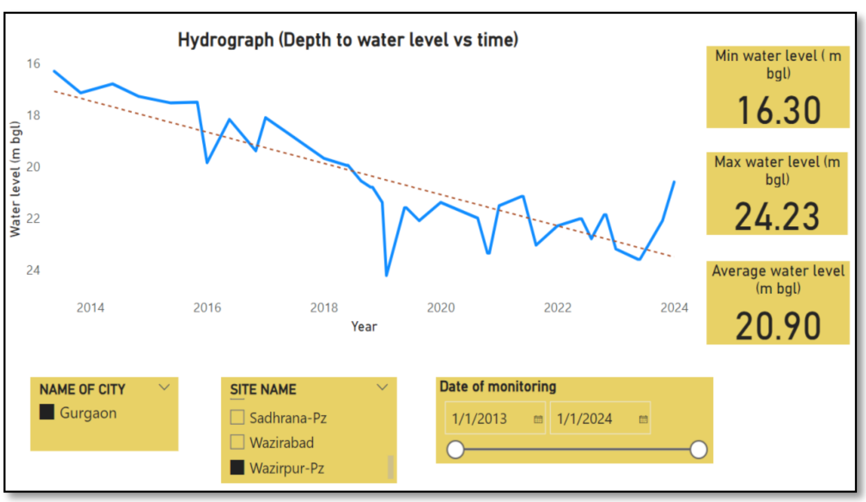


Figure 20 Hydrograph- Wazirpur pz

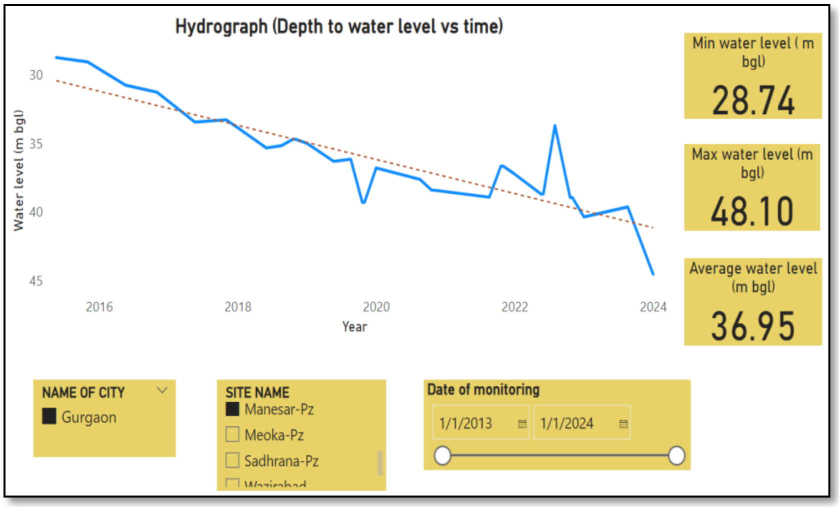


Figure 21 Hydrohgraph- Manesar pz

2.4 Groundwater exploration

18 nos of exploratory wells have been drilled by Central Ground Water Board in the Gurugram urban area. On the basis of samples collected during drilling, lithologs have been prepared. The aquifer parameters are calculated on the basis of pumping tests. 1 EW & OW are constructed in Kadipur under NAQUIM 2.0. In the newly constructed EW, the unconfined aquifer exists upto the depth of 98 mbgl, from 99 to 126 mbgl is the confining layer of clay, second aquifer starts from 127 mbgl. Litholog is given in annexure III. The salient details of the drilled exploratory wells is given in Table. Locations of exploratory wells is shown in figure below.

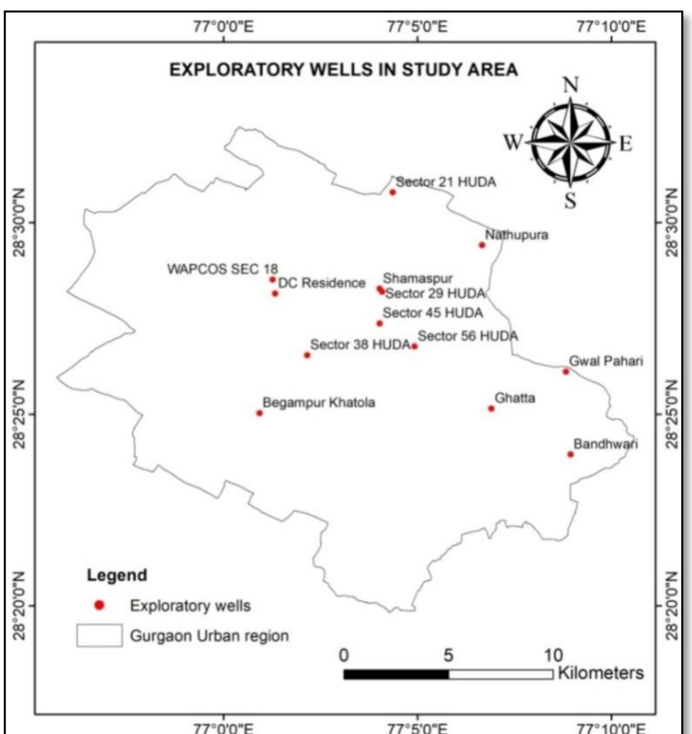


Figure 22 Exploratory wells in study area

Table 2 Details of exploratory wells in Gurugram urban area

S no	Location	Latitude	Longitude	Depth drilled (m bgl)	Major Lithology Encountered	Zone Encountered / Desifered (m bgl)						Zones Tapped	Static Water level (m bmp)	Discharge (lpm)	Drawdown (m)	Specific Capacity (lpm/m)of dd	T (m2/day)	Storativity
						0-50	50-100	100-150	150-200	200-250	250-300							
1	Bandhwari	28.3990	77.1490	137	Weathered/fractured Quartzite	--	65-68 50-71	105-107, 120-122, 128-131	--	--	--	66-72, 96-108, 120-132	12.82	48	22.4	2	--	--
2	Chandu	28.4712	76.9173	209	Sand, Clay and Kankar	16-20, 27-38, 42-47, 48-60	88-92, 102-107, 110-115, 126-133, 144-148	181-183, 189-193	--	--	--	--	6.33			--	--	--
3	DC Residence	28.4690	77.0220	218	Sand, Clay and Kankar	25-35, 37-42, 44-54	58-68, 77-85	102-107, 114-120, 133-141, 148-156	180-187, 193-198	202-209	--	--	38.1	270	7.8	35	100	2.4x10-4
4	Ghatta	28.4190	77.1150	125	Weathered/fractured Quartzite	33.40-34.40 36.20-37.40 39-43.80 45.40-49.80	51-54, 55-57, 58-59, 60-61, 62-63, 65-69, 71-72, 73-75, 77-79, 81-83, 84-86, 88-90, 96-104	107.80-108.80 109.20-110.60	--	--	--	32-44 69-90 96-111	16.6	409	5.6	73	--	--
5	Gwal Pahari	28.4350	77.1470	51	Alluvium/Delhi Qtzite	30-38, 40-43, 45-57	--	--	--	--	--	30-38, 40-43, 45-47, 49-50	13.62		--	--		--
6	Begampur Khatola	28.4170	77.0153	212	sand, Clay and Kankar	16-19, 28-32	54-55, 78-84, 89-91	--	--	--	--	77-86	13.41	--	--	--	--	--
7	Nathupura	28.4900	77.1110	78	Weathered/fractured Quartzite	28-32, 34-37, 40-42	68-72	--	--	--	--	--	23	--	--	--	--	--
8	Nawada Fatehpur	28.3930	76.9460	222	Kankar mix with Clay, Sand	23-29, 35-39, 40-43	54-61, 64-70, 75-79	112-120, 125-130, 181-190	--	--	--	--	16	--	--	--	--	--
9	Sector 21 HUDA	28.5129	77.0726	216	Sand, Clay and Kankar	27-32, 39-46, 48-53	70-73	106-112, 137-141, 148-186	--	--	--	40-52 70-73	34.94	270	6.02	45	--	--
10	Sector 29 HUDA	28.4698	77.0680	230	Sand, Clay and Kankar	18-25, 31-34, 42-50	52-59, 73-78, 80-85, 95-98	103-106, 109-114, 131-135, 142-151	168-171, 192-195	--	--	43-52, 57-60, 74-80, 101-107, 121-127, 147-153	--	--	--	--	--	--
11	Sector 38 HUDA	28.4422	77.0358	250	Sand, Clay and Kankar	24-41, 45-64	83-95	106-114, 119-126, 133-136	--	--	--	36-42, 48-60	22.73	503	7.8	64	462	--
12	Sector 45 HUDA	28.4560	77.0670	250	Sand, Clay and Kankar	23-34, 41-50	52-64, 73-78	114-122	181-186	--	--	29-34, 41-50,	20.71	480	8.62	56	230	--

												52-56, 59-64						
13	Sector 56 HUDA	28.4460	77.0820	236	Sand, Clay and Kankar	16-22, 31-39, 48-54	61-66, 79-90	108-113, 102-124, 131-137	--	--	--	29-39, 48-54, 79-83, 85-90, 108-113, 120-124	17.78	480	5.95	81	183	7.3x10-4
14	Meoka	28.4050	76.9250	250	Sand, Clay and Kankar	19-33, 40-46	60-66, 82-86	103-110, 125-130, 140-146	177-180, 182-186, 196-200	228-232	--	140-146	14.14	--	--	--	--	--
15	Shamaspur	28.4710	77.0670	224	Kankar mix with Clay, Sand	21-31	--	--	176-181, 190-194	--	--	--	--	--	--	--	--	--
16	Shikohpur	28.3690	76.9860	63	Weathered/fractured Quartzite	28-31, 36-38, 44-48	--	--	--	--	--	28-38,44-48	19.18	--	--	--	--	--
17	WAPCOS SEC 18	28.4750	77.0210	154	Sand, Clay and Kankar	38-47	53-56, 59-63, 86-91, 97-100	112-116	--	--	--	45-48, 53-56, 59-63, 89-92, 98-101, 113-116	37.5	--	--	--	--	--
18	Kadipur	28.4507	77.0056	193	Sand, Clay and Kankar	32-36, 42-44.50, 47-51	60-67, 92-95, 97-99	-	-	-	-	64-67,92-95						

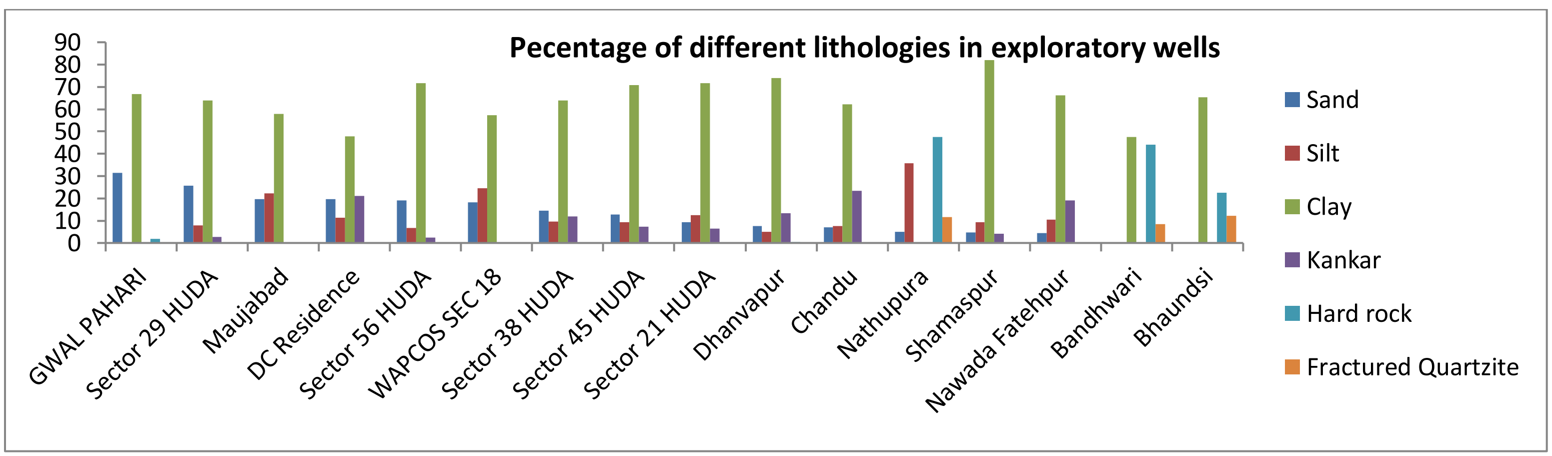


Figure 23 Lithology in different wells

Table 3 Percentage of different lithologies in exploratory wells

Well name	Sand	Silt	Clay	Kankar	Hard rock	Fractured Quartzite
GWAL PAHARI	31	0	67	0	2	0
Sector 29 HUDA	26	8	64	3	0	0
Maujabad	20	22	58	0	0	0
DC Residence	20	11	48	21	0	0
Sector 56 HUDA	19	7	72	3	0	0
WAPCOS SEC 18	18	25	57	0	0	0
Sector 38 HUDA	14	10	64	12	0	0
Sector 45 HUDA	13	9	71	7	0	0
Sector 21 HUDA	9	13	72	6	0	0
Dhanvapur	7	5	74	13	0	0
Chandu	7	8	62	23	0	0
Nathupura	5	36	0	0	48	12
Shamaspur	5	9	82	4	0	0
Nawada Fatehpur	4	10	66	19	0	0
Bandhwari	0	0	48	0	44	8
Bhaundsi	0	0	65	0	23	12
Ghatta	0	0	27	0	23	50

2.5 Groundwater Resource Estimation

The Net Annual Ground Water Availability as on March 2023 works out to be 5538.43 Ham (55.38 mcm). Total extraction for all uses is 18077.73 Ham (180.77 mcm). The stage of groundwater extraction is 326.415 and the Gurugram urban area falls in over-exploited category.

Table 4 Groundwater Resource Estimation

Year	Annual Extractable GW Resource (Ham)	GW Extraction for Irrigation Use (Ham)	GW Extraction for Industrial Use (Ham)	GW Extraction for Domestic Use (Ham)	Total Extraction (Ham)	Stage of GW Extraction (%)	Category
2023	5538.43	45.14	17115.36	917.23	18077.73	326.41	Over exploited
2022	5538.93	47.38	17115.36	909.32	18072.06	326.27	Over exploited

Chapter 3- Hydrochemical scenario

3.1 Pre & post monsoon groundwater quality analysis

35 nos. of groundwater samples were collected during pre & post monsoon season each from borewells in clean double stopper HDPE poly ethylene bottles of capacity 1L & 60 ml for carrying out analysis of basic parameters & heavy/trace metals respectively. The sampling locations are shown in the map below.

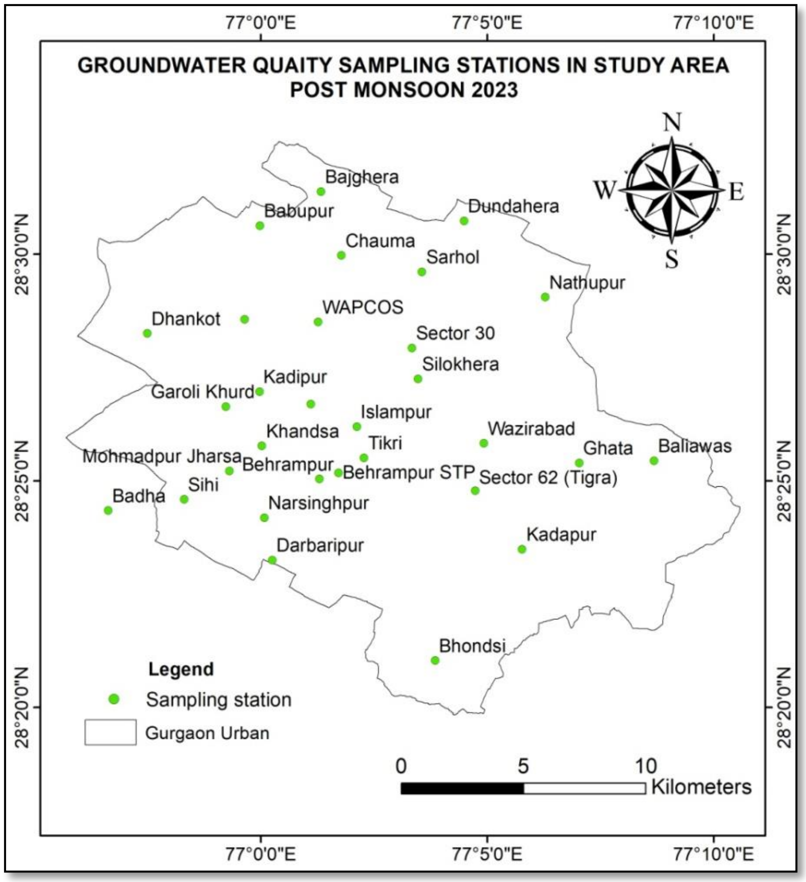


Figure 24 Location of Groundwater quality sampling stations

Pre monsoon

The ground water samples have varied range of pH from 7.06 to 8.07. As per BIS (IS 10500 : 2012) recommendation, all the water samples have pH recorded within the permissible limits of 6.5 to 8.5, the maximum pH recorded in the water sample of Sihi (8.07). The ground water of the study area can be assessed as slightly alkaline in nature. The electrical conductivity of ground water samples varies from 298 to 6750 µS/cm at 25°C. In 9 nos. of ground water samples recorded electrical conductivity less than 1000 µS/cm; 21 nos. of water samples recorded electrical conductivity in between 1000 to 3000 µS/cm at 25°C, 4 no. of water sample recorded electrical conductivity in between 3000 to 5000 µS/cm at 25°C whereas 1 no. of water sample recorded electrical conductivity more than 5000 µS/cm at 25°C namely Begumpur khatola (6750 µS/cm at 25°C). So, overall ground water quality in is good to saline in nature. The fluoride concentration in study area lies in between 0.2 to 2.81 mg/l, 94.2% of the samples are within the permissible limit i.e. 1.5 mg/l as per BIS (IS 10500 : 2012). The maximum fluoride concentration has been observed in the water sample of Garoli khurd i.e. 2.81 mg/l. Nitrate concentration in ground water samples within the 0.3 to 380 mg/l. It is observed that 51.4% samples have nitrate concentration more than the permissible limit i.e. 45 mg/l. Highest concentration of nitrate is reported in the water samples of Shikohpur (380 mg/l). The range of Total Hardness (as CaCO3) in ground water samples of study area is 100 to 1721 mg/l. In 85.7% of the locations, total hardness concentrations are within the permissible limit of 600 mg/l.

Table 5 Range of chemical constituents in Pre-monsoon 2023

	pH	EC	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	TH
Min	7.06	298	0	144	28	0	0.3	0.2	0	12	10	9.2	0.8	14	100
Max	8.07	6750	0	976	1727	714	380	2.81	24.5	297	250	870	20	29	1721

Post monsoon

The ground water samples have varied range of pH from 7.31 to 8.81. As per BIS(IS 10500 : 2012) recommendation, 82% of water samples have pH recorded within the permissible limits of 6.5 to 8.5, the maximum pH recorded in the water sample of Sihi & Chauma(8.81). The ground water of the study area can be assessed as slightly alkaline in nature. The electrical conductivity of ground water samples varies from 220 to 5612 µS/cm at 25°C. In 12 nos. of ground water samples recorded electrical conductivity less than 1000µS/cm; 20 nos. of water samples recorded electrical conductivity in between 1000 to 3000 µS/cm at 25°C, 1 no. of water sample recorded electrical conductivity in between 3000 to 5000 µS/cm at 25°C whereas 1 no. of water sample recorded electrical conductivity more than 5000 µS/cm at 25°C namely Behrampur (5612 µS/cm at 25°C). So, overall ground water quality in is good to saline in nature. The fluoride concentration in study area lies in between 0.05 to 2.52 mg/l, 94% of the samples are within the permissible limit i.e. 1.5 mg/l as per BIS (IS 10500 : 2012). The maximum fluoride concentration has been observed in the water sample of Garoli khurd i.e. 2.52 mg/l. Nitrate concentration in ground water samples within the 5.8 to 120 mg/l. It is observed that 8.8% samples have nitrate concentration more than the permissible limit i.e. 45 mg/l. High concentration (more than 45 mg/L) of nitrate is reported in the water samples of Kadipur (55 mg/l), Dhanwapur (64 mg/l) & Bajghera (120 mg/l). The range of Total Hardness (as CaCO3) in ground water samples of study area is 56 to 1357 mg/l. In 91% of the locations, total hardness concentrations are within the permissible limit of 600 mg/l.

Table 6 Range of chemical constituents in Post-monsoon 2023

	pH	EC	CO_3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	TH
Min	7.31	220	0	35	14	0	0	0.05	0	7	9	19	0.5	15	56
Max	8.81	5612	104	926	1459	442	120	2.52	24.5	247	912	843	31	41	1357

The groundwater quality maps of some parameters are shown below.

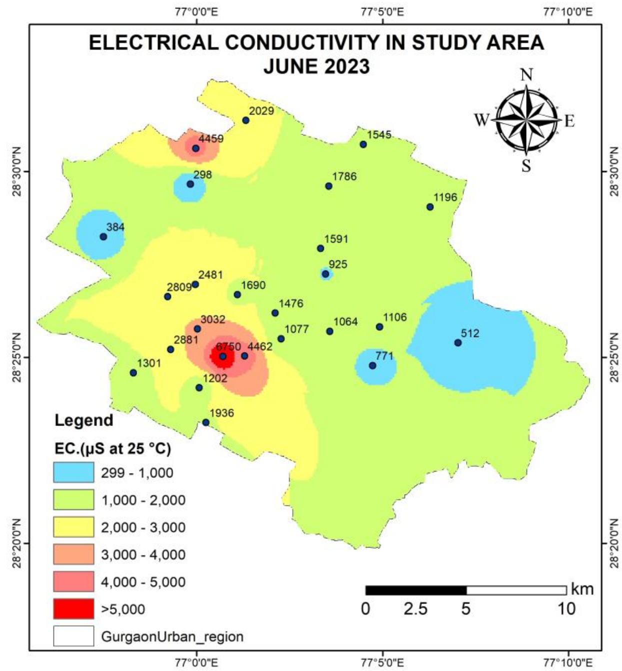


Figure 25 EC in study area Pre-monsoon

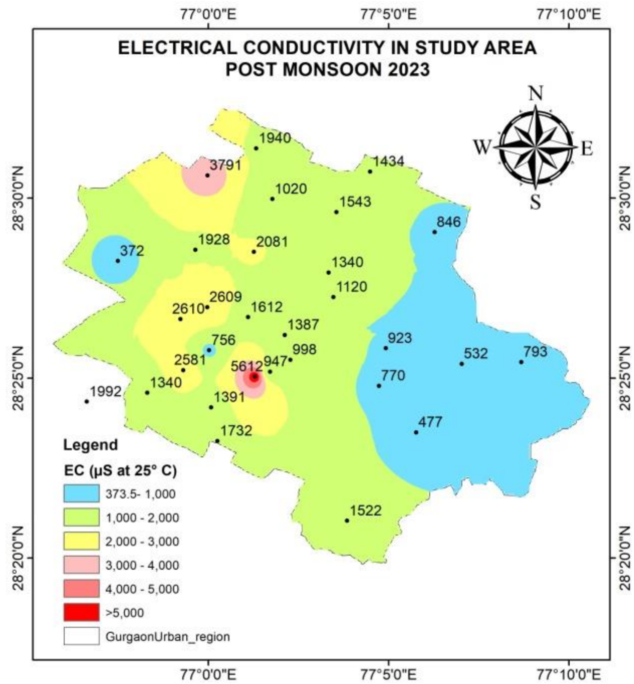


Figure 26 EC in study area Post-monsoon

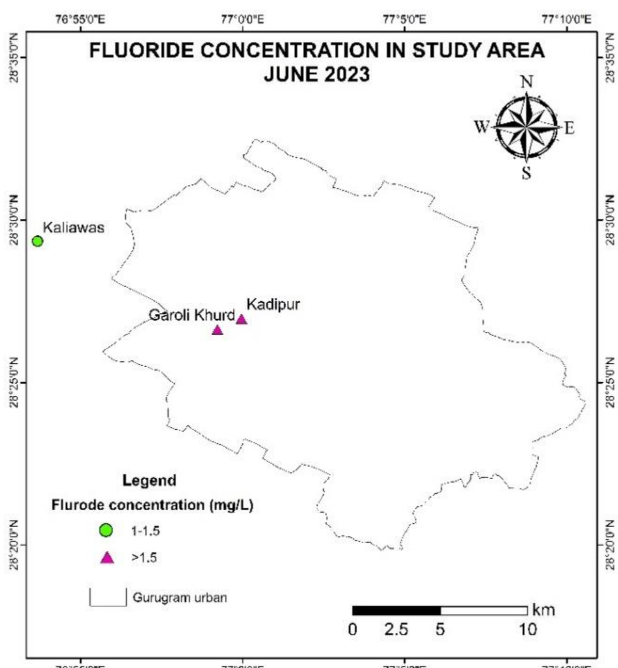


Figure 27 Fluoride in study area Pre-monsoon

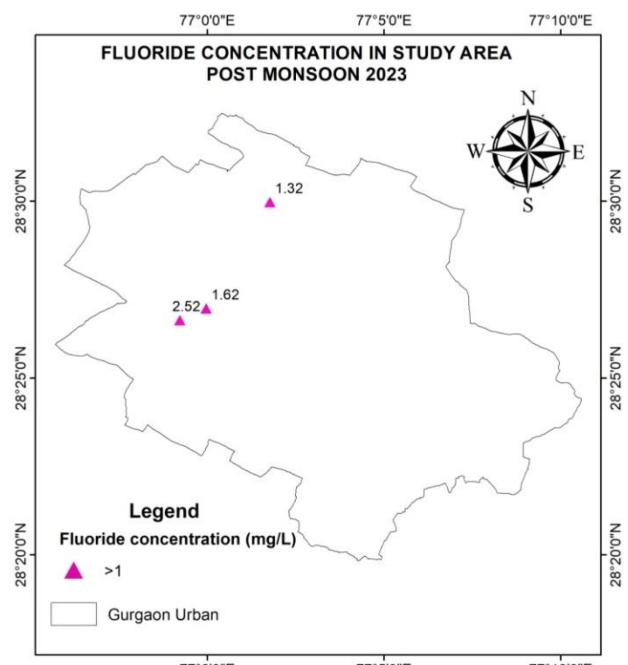


Figure 28 Fluoride in study area Post-monsoon

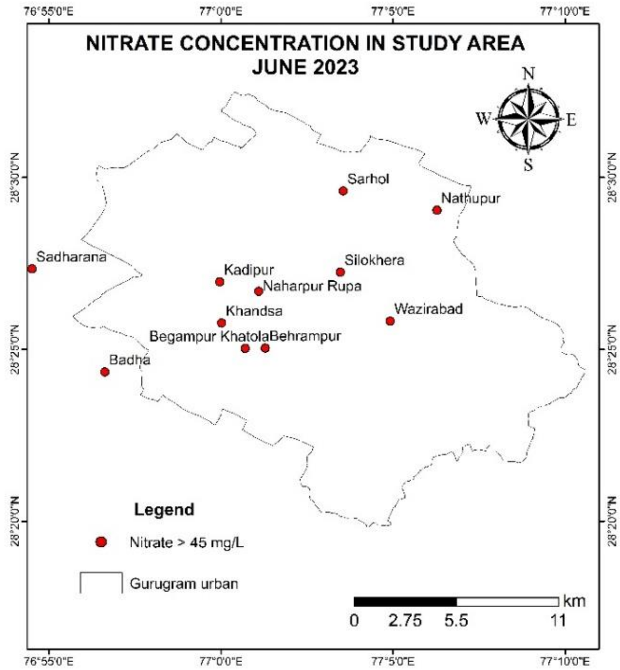


Figure 29 Nitrate in study area, Pre-monsoon

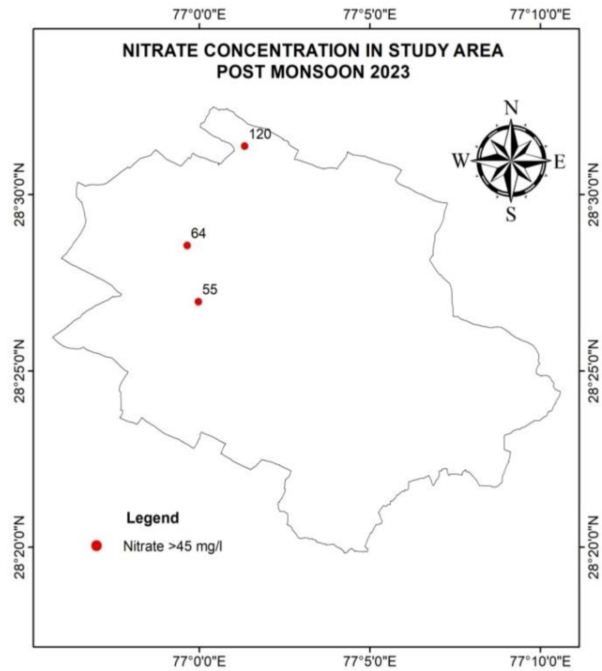


Figure 30 Nitrate in study area, Pre-monsoon

Comparison of Piper diagram during pre monsoon & post monsoon season

Pre-monsoon:

Types of ground water in the study area (Decreasing order): Calcium magnesium bicarbonate, Sodium Bicarbonate type, Sodium Chloride type

Dominant anion: Bicarbonate, Dominant cation: Sodium

The dominance of sodium as the primary cation suggests that ion exchange processes are likely occurring within the aquifer system. This could involve the exchange of calcium and magnesium ions with sodium ions, potentially due to the presence of sodium-rich clay minerals. The high sodium concentration may also indicate the influence of industrial effluents or wastewater in the area. The predominance of bicarbonate ions suggests a relatively recent recharge of groundwater, where CO_2 from the atmosphere or soil has dissolved in water, forming carbonic acid, which then reacts with the minerals to release bicarbonate ions. Groundwater samples falling within the calcium-magnesium bicarbonate and sodium bicarbonate fields indicate that the water is typically fresh with a tendency toward alkalinity. This type of water is generally considered suitable for most domestic and agricultural uses.

Post-monsoon:

Types of ground water in the study area (Decreasing order): Mixed type, Calcium magnesium sulphate type, Calcium magnesium bicarbonate type.

Dominant anion: Chloride, Dominant cation: Magnesium

The presence of magnesium as the dominant cation suggests that the groundwater may be influenced by the dissolution of magnesium-bearing minerals. The dominance of chloride as the primary anion indicates that the groundwater is affected by salinity. This could result from factors such as the inland salinity or contamination from industrial effluents and domestic sewage. Chloride is often associated with human activities, which could be a sign of urban impact on groundwater quality. The mixed-type classification, along with the calcium-magnesium-sulfate composition, suggests that the groundwater is undergoing mixing between different water sources. The mixed water type may also result from the blending of fresh and saline waters or from the interaction between surface water and groundwater.

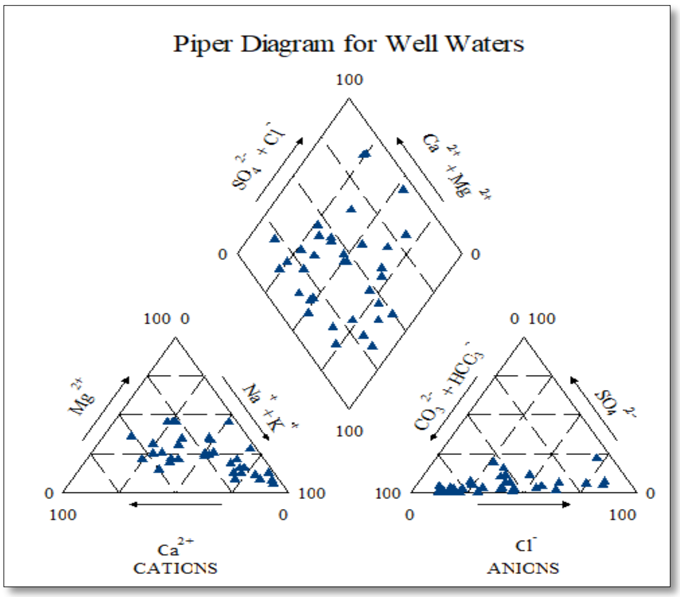


Figure 31 Piper diagram, Pre-monsoon 2023

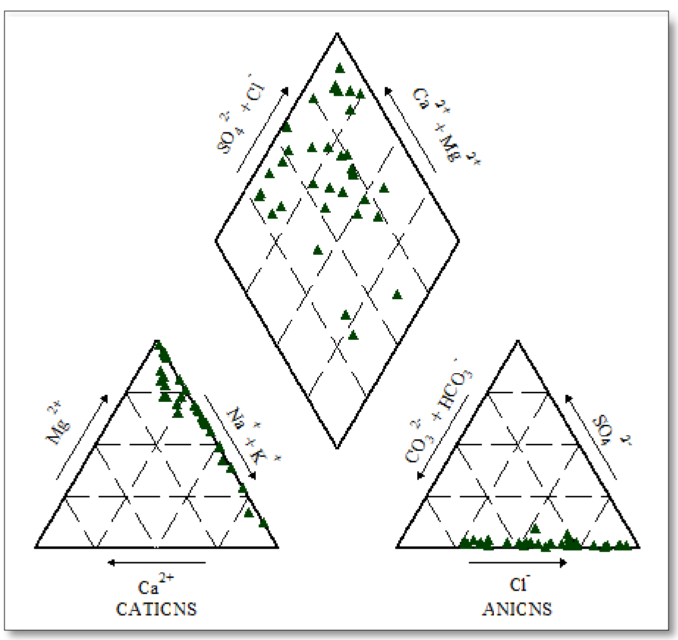


Figure 32 Piper diagram, Post-monsoon 2023

Table 7 Detailed statistical summary of parameters

	N	Minimum	Maximum	Mean	Std. Deviation
pH	52	7.1	8.8	7.9	0.4
EC in µS/cm at 250 C	52	220.0	6750.0	1869.2	1308.9
CO3	35	0.0	104.0	11.9	23.9
HCO3	52	35.2	976.0	418.1	204.4
Cl	52	28.0	1727.0	333.8	394.3
SO4	44	0.0	714.0	103.0	139.7
NO3	51	0.3	206.0	49.1	40.1
F	52	0.1	2.8	0.6	0.5
PO4	0				
Ca	52	7.0	297.0	73.6	65.0
Mg	52	9.0	250.0	55.7	57.5
Na	52	9.2	870.0	252.1	204.0
K	52	0.5	27.0	5.1	5.6
SiO2	51	15.0	29.0	21.7	2.9
TH as CaCO3	52	56.0	1721.0	413.0	379.6
As	52	0.0	6.6	1.7	1.9
Cd	52	0.0	0.7	0.1	0.1
Pb	52	0.0	3.1	0.4	0.6
U	52	0.0	33.5	8.6	7.4
Cr	31	0.0	0.0	0.0	0.0
Mn	47	0.0	0.6	0.0	0.1
Fe	51	0.0	2.3	0.4	0.5
Ni	28	0.0	0.0	0.0	0.0
Cu	46	0.0	0.2	0.0	0.0
Zn	52	0.0	1.6	0.1	0.2

Table 8 Correlation among various groundwater parameters

	pH	EC in µS/cm at 250 C	CO3	HCO3	Cl	SO4	NO3	F	Ca	Mg	Na	K	SiO2	TH as CaCO3	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	U
pH																								
EC in µS/cm at 250 C	-0.266																							
CO3	.805**	-0.082																						
HCO3	-0.170	0.231	-0.097																					
Cl	-.300*	.941**	-0.143	-0.052																				
SO4	0.102	.702**	0.173	0.036	.563**																			
NO3	-.392**	.278*	-0.259	0.209	0.186	0.007																		
F	0.155	0.055	0.115	.609**	-0.161	0.119	-0.061																	
Ca	-.378**	.669**	-0.246	-.275*	.782**	.407**	0.179	-.298*																
Mg	-.332*	.812**	-0.196	-0.126	.910**	.402**	0.169	-0.176	.804**															
Na	-0.074	.824**	0.102	.533**	.634**	.713**	0.234	.291*	0.186	.374**														
K	0.016	.393**	0.017	-.299*	.484**	0.278	0.000	-0.108	.565**	.575**	0.040													
SiO2	-0.130	.434**	-0.130	.325*	.333*	.343*	0.156	.447**	0.094	0.260	.478**	0.137												
TH as CaCO3	-.369**	.792**	-0.227	-0.196	.902**	.425**	0.183	-0.237	.929**	.967**	.312*	.601**	0.201											
Cr	-.379*	0.106	-.487**	.649**	-0.074	-0.080	0.203	0.250	-0.234	-0.160	0.340	-0.302	0.162	-0.199										
Mn	-0.201	.309*	-0.106	-0.070	.380**	0.118	-0.105	-0.033	.495**	.485**	-0.002	.451**	0.078	.515**	-0.055									
Fe	-.603**	.536**	-.404*	0.010	.573**	0.240	.388**	-0.192	.577**	.672**	0.237	0.215	0.061	.667**	0.097	.494**								
Ni	-0.184	.397*	-0.225	-0.310	.452*	.518**	-0.105	-.389*	.513**	.479**	0.158	.698**	0.066	.523**	-0.038	.612**	.571**							
Cu	-0.065	-0.152	-.504**	-0.250	-0.066	0.205	.390**	-0.154	-0.138	-0.093	-0.123	-0.131	0.081	-0.116	0.339	0.048	-0.078	0.138						
Zn	0.048	0.011	-0.128	0.018	-0.050	0.293	-0.087	-0.011	-0.007	-0.033	0.051	.489**	-0.066	-0.023	0.312	0.269	0.021	.533**	-0.080					
As	-.399**	0.065	-.495**	.374**	-0.036	-0.112	.288*	0.215	-0.072	-0.042	0.154	-0.224	0.064	-0.057	.490**	-0.070	.373**	-0.213	-0.111	-0.060				
Cd	.315*	-0.185	.378*	-.320*	-0.135	0.071	-0.185	-0.171	0.003	-0.165	-0.197	0.125	-0.130	-0.102	-0.169	-0.093	-.311*	0.184	0.127	0.071	-.423**			
Pb	-0.130	-0.045	-0.155	0.106	-0.061	-0.196	0.146	-0.041	-0.179	0.024	-0.017	-0.093	0.104	-0.062	0.300	-0.096	0.120	-0.038	-0.015	0.093	.330*	-0.212		
U	-0.241	.281*	-0.139	.669**	0.103	0.017	0.150	.476**	-0.081	0.088	.396**	-0.120	.288*	0.020	.611**	0.110	0.135	-0.068	-0.146	-0.073	.343*	-.377**	0.210	

- **pH & Fe (-0.603):** A moderate negative correlation suggests that lower pH levels are associated with higher concentrations of iron. As pH decreases (becomes more acidic), the concentration of dissolved iron tends to increase. Under acidic conditions (low pH), iron is more soluble. Iron in groundwater is often present as ferrous iron (Fe^{2+}) which remains dissolved in water at lower pH levels. At higher pH levels (neutral to basic conditions), iron tends to precipitate out of solution as ferric hydroxide [$Fe(OH)_3$] or other insoluble iron oxides. This is because the solubility of ferric iron (Fe^{3+}) compounds decreases as pH increases, causing them to form solid precipitates.

- **HCO3 & F (0.609):** A moderate positive correlation suggests that higher bicarbonate levels are associated with higher fluoride concentrations. Groundwater with higher bicarbonate content typically has a higher pH (more alkaline), which can enhance the dissolution of fluoride-bearing minerals. Alkaline conditions can increase the solubility of fluoride, leading to higher concentrations in the water.

- **Fe & TH as CaCO3 (0.667):** The value of r=0.667indicates a moderate to strong positive correlation between iron and total hardness as CaCO3 in groundwater. This means that as the total hardness of the water increases, the concentration of iron tends to increase as well, and vice versa. Processes such as ion exchange, dissolution, and precipitation can simultaneously affect both iron and hardness. For instance, acidic conditions can enhance the dissolution of iron from minerals while also affecting carbonate solubility

- **HCO3 & U (0.669):** The value of r=0.669 indicates a moderate to strong positive correlation between bicarbonate and uranium in groundwater. This means that as the concentration of bicarbonate increases, the concentration of uranium also tends to increase, and vice versa. Uranium is more soluble under oxidizing conditions, where it exists as U(VI), typically as uranyl ion (UO2^2+). Bicarbonate, under such conditions, can stabilize uranium in the aqueous phase by forming soluble complexes such as uranyl carbonate complexes (e.g., UO2(CO3)3^4-). These complexes are more soluble in water, which can increase the mobility and concentration of uranium in groundwater.
- **Ca & Cl (0.782):** The strong positive correlation indicates similar geochemical processes influencing both ions, in this case, maybe inland salinity.

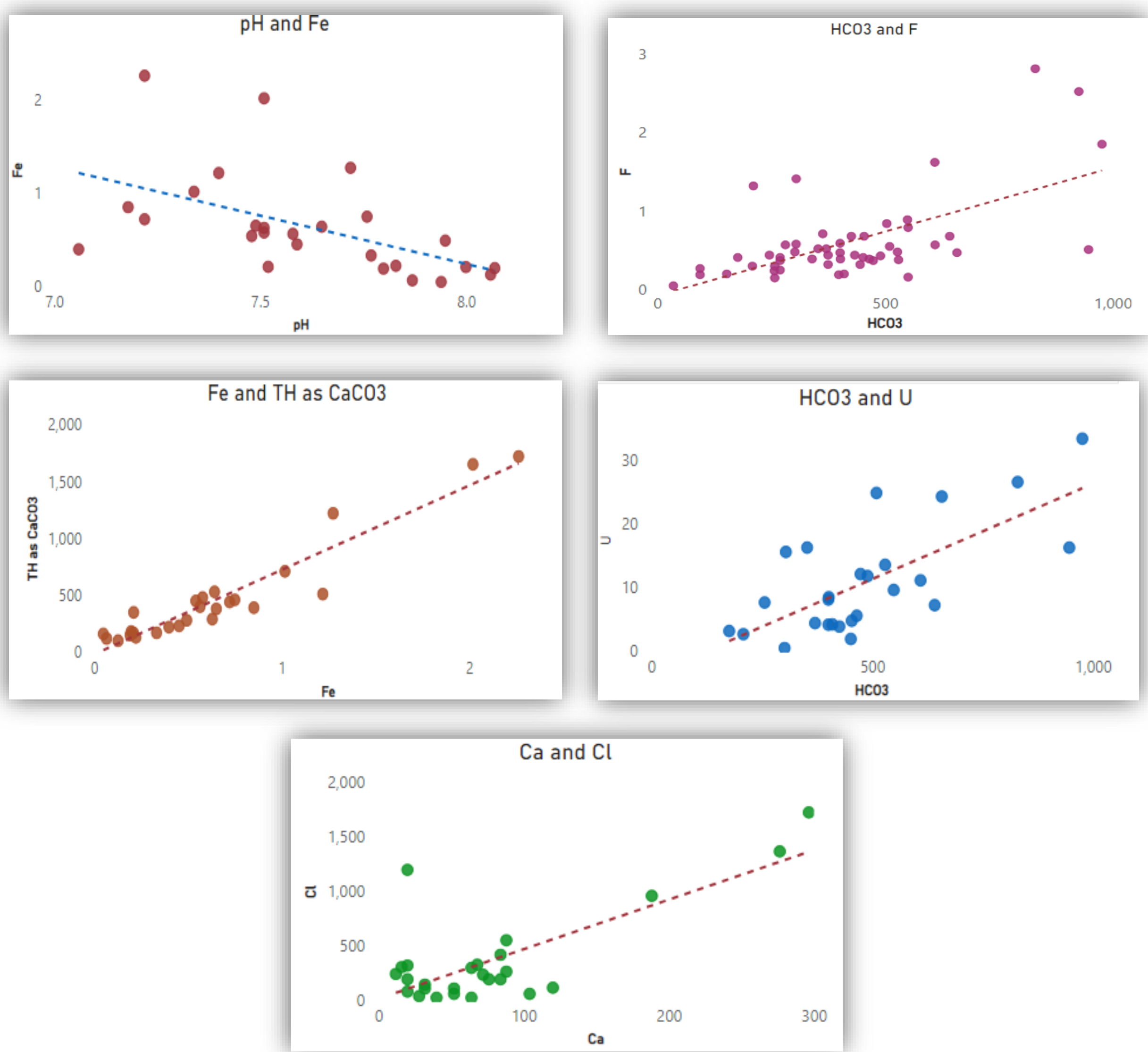


Figure 33 Bivariate plots of different parameters

3.2 Nemerow's Pollution Index

$$NPI = C_n/S_n$$

where C_n = Concentration of the nth parameter

S_n= Prescribed standard limit of the nth parameter

If the parameter's NPI value>1, it indicates its presence in surplus amount & the particular parameter has the potential to contribute to pollution of the water body. NPI values of pre & post monsoon groundwater samples is shown in the tables below & NPI values>1 are highlighted red.

Table 9 NPI values of Pre monsoon groundwater samples

S no	Parameters	pH	EC in µS/cm at 250 C	Cl	SO4	NO3	F	Ca	Mg	TH as CaCO3	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	U
	BIS standards	**8.5**	**3000**	**1000**	**400**	**45**	**1.5**	**200**	**100**	**600**	**0.05**	**0.3**	**0.3**	**0.02**	**1.5**	**15**	**0.05**	**0.003**	**0.01**	**0.03**
1	Kaliawas	0.88	0.29	0.11	0.12	0.49	0.94	0.26	0.54	0.58	0.14	0.00	0.71	0.06	0.00	0.00	0.03	0.00	0.02	0.52
2	Sadharana	0.91	1.11	0.96	0.27	1.93	0.20	0.94	1.82	2.03	0.16	0.01	4.25	0.14	0.00	0.00	0.01	0.00	0.01	0.09
3	Dhankot	0.94	0.13	0.03	0.00	0.01	0.27	0.20	0.17	0.28	0.07	0.02	0.70	0.13	0.00	0.00	0.02	0.00	0.00	0.11
4	Babupur	0.85	1.49	1.37	0.27	0.80	0.35	1.38	2.50	2.87	0.16	2.13	7.55	0.24	0.00	0.00	0.04	0.00	0.02	0.54
5	Bajghera	0.87	0.68	0.31	0.03	2.44	0.31	0.08	1.14	0.85	0.24	0.04	4.07	0.17	0.00	0.00	0.09	0.00	0.17	0.81
6	Kadipur	0.93	0.83	0.20	0.14	1.60	1.23	0.10	0.17	0.20	0.43	0.02	0.22	0.05	0.00	0.01	0.08	0.00	0.07	1.12
7	Garoli Khurd	0.93	0.94	0.32	0.50	0.84	1.87	0.10	0.27	0.27	0.29	0.05	0.17	0.04	0.00	0.00	0.11	0.00	0.01	0.89
8	Naharpur Rupa	0.92	0.56	0.25	0.05	1.36	0.45	0.06	0.29	0.25	0.24	0.01	0.64	0.10	0.00	0.01	0.09	0.00	0.10	0.24
9	Behrampur	0.86	1.49	1.20	0.32	1.16	0.25	0.10	1.61	1.18	0.29	0.03	3.39	0.14	0.00	0.01	0.02	0.00	0.12	0.45
10	BegampurKhatola	0.88	2.25	1.73	1.79	2.09	0.16	1.48	2.21	2.75	0.16	0.02	6.74	0.20	0.00	0.00	0.07	0.00	0.00	0.26
11	Khandsa	0.88	1.01	0.42	0.22	1.67	0.34	0.42	0.58	0.75	0.37	0.24	1.81	0.16	0.00	0.00	0.02	0.00	0.00	0.54
12	MohmadpurJharsa	0.88	0.96	0.55	0.20	4.58	0.26	0.44	0.63	0.80	0.18	0.07	1.93	0.06	0.00	0.00	0.01	0.00	0.00	0.19
13	Sihi	0.95	0.43	0.11	0.07	0.69	0.59	0.16	0.24	0.30	0.32	0.00	0.66	0.03	0.00	0.01	0.07	0.00	0.06	0.32
14	Badha	0.90	0.67	0.24	0.24	1.18	0.38	0.36	0.85	0.88	0.29	0.00	2.14	0.07	0.00	0.00	0.09	0.00	0.01	0.37
15	Darbaripur	0.91	0.65	0.27	0.21	4.09	0.39	0.44	0.58	0.77	0.31	0.00	2.50	0.09	0.00	0.00	0.11	0.00	0.14	0.14
16	Narsinghpur	0.89	0.40	0.20	0.03	0.87	0.31	0.42	0.46	0.67	0.13	0.02	1.89	0.10	0.00	0.00	0.09	0.02	0.03	0.27
17	Ghata	0.83	0.17	0.03	0.00	0.27	0.32	0.32	0.15	0.37	0.18	0.14	1.33	0.08	0.00	0.00	0.02	0.00	0.00	0.02
18	Wazirabad	0.85	0.37	0.06	0.03	1.78	0.29	0.52	0.44	0.73	0.30	0.04	2.41	0.09	0.00	0.00	0.03	0.00	0.01	0.39
19	Nathupur	0.84	0.40	0.12	0.05	1.84	0.27	0.60	0.22	0.65	0.28	0.01	2.84	0.13	0.00	0.01	0.06	0.24	0.01	0.06
20	Dundahera	0.89	0.52	0.30	0.06	0.56	0.13	0.32	0.17	0.38	0.21	0.01	1.51	0.12	0.00	0.00	0.13	0.00	0.01	0.14
21	Sarhol	0.88	0.60	0.33	0.08	2.16	0.26	0.34	0.29	0.48	0.21	0.03	2.10	0.14	0.00	0.01	0.13	0.00	0.00	0.28
22	Sector 30	0.91	0.53	0.15	0.37	0.27	0.37	0.16	0.22	0.28	0.40	0.23	1.11	0.22	0.00	0.01	0.07	0.00	0.13	0.83
23	Silokhera	0.92	0.31	0.04	0.00	1.64	0.45	0.14	0.15	0.22	0.17	0.03	0.75	0.09	0.00	0.00	0.04	0.00	0.21	0.13
24	Islampur	0.88	0.49	0.20	0.10	0.87	0.25	0.38	0.46	0.63	0.29	0.02	2.17	0.10	0.00	0.03	0.09	0.02	0.31	0.40
25	Tikri	0.95	0.36	0.08	0.09	0.87	0.45	0.10	0.12	0.17	0.23	0.01	0.43	0.05	0.01	0.00	0.06	0.00	0.05	0.16
26	Sector 62 (Tigra)	0.94	0.26	0.06	0.03	0.78	0.35	0.26	0.36	0.47	0.26	0.01	1.65	0.09	0.00	0.00	0.04	0.00	0.02	0.15

Table 10 NPI values of Post monsoon groundwater samples

S no	Parameters	pH	EC in µS/cm at 250 C	Cl	SO4	NO3	F	Ca	Mg	TH as CaCO3	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	U
	BIS standards	**8.5**	**3000**	**1000**	**400**	**45**	**1.5**	**200**	**100**	**600**	**0.05**	**0.3**	**0.3**	**0.02**	**1.5**	**15**	**0.05**	**0.003**	**0.01**	**0.03**
1	Kaliawas	0.96	0.45	0.28	0.15	0.49	0.88	0.39	0.73	0.83	Nil	0.00	0.08	Nil	0.00	0.00	0.01	0.07	0.06	0.25
2	Sadharana	0.99	0.94	0.79	0.23	0.84	0.13	0.79	1.66	1.79	0.07	0.00	0.19	Nil	0.00	0.00	0.00	0.08	0.09	0.06
3	Dhankot	0.99	0.12	0.04	Nil	0.13	0.18	0.19	0.11	0.23	Nil	Nil	0.07	Nil	0.00	0.00	0.01	0.07	0.02	0.08
4	Babupur	0.92	1.26	1.15	0.10	0.62	0.29	1.24	1.80	2.26	Nil	0.60	0.18	Nil	Nil	0.00	0.00	0.05	0.00	0.19
5	Bajghera	0.90	0.65	0.35	0.09	2.67	0.21	0.64	0.30	0.73	Nil	0.00	0.19	Nil	Nil	0.00	0.00	0.04	0.03	0.80
6	Kadipur	1.04	0.87	0.24	0.72	1.22	1.08	0.07	0.23	0.22	Nil	0.01	0.22	Nil	0.00	0.01	0.01	0.07	0.03	0.38
7	Garoli Khurd	0.96	0.87	0.27	0.64	0.71	1.68	0.11	0.43	0.39	Nil	0.02	0.01	Nil	0.00	0.00	0.02	0.05	0.00	0.37
8	Naharpur Rupa	1.00	0.54	0.23	0.20	0.78	0.29	0.17	0.18	0.27	Nil	0.00	0.05	Nil	0.00	0.00	0.01	0.05	0.01	0.15
9	Behrampur	0.89	1.87	1.46	0.94	0.51	0.11	0.97	1.48	1.82	Nil	0.01	0.16	Nil	Nil	0.01	0.00	0.03	0.02	0.35
10	Begampur Khatola	0.92	0.07	0.07	Nil	Nil	0.03	0.04	0.09	0.09	Nil	Nil	0.03	Nil	0.11	0.00	0.00	0.08	0.03	0.00
11	Khandsa	1.02	0.25	0.08	0.16	0.20	0.13	0.24	0.20	0.34	Nil	0.01	0.09	Nil	0.00	0.00	0.02	0.08	0.11	0.09
12	Mohmadpur Jharsa	0.99	0.86	0.51	0.74	0.82	0.17	0.28	0.59	0.64	Nil	0.01	0.06	Nil	Nil	0.00	0.00	0.16	0.00	0.11
13	Sihi	1.04	0.45	0.12	0.09	0.69	0.56	0.13	0.27	0.30	0.07	0.00	0.07	0.03	0.00	0.01	0.01	0.04	0.02	0.20
14	Badha	0.97	0.66	0.20	1.11	0.60	0.47	0.41	0.45	0.66	Nil	0.81	1.28	0.32	Nil	0.11	0.00	0.06	0.01	0.10
15	Darbaripur	0.96	0.58	0.24	0.54	0.82	0.38	0.41	0.43	0.64	0.11	Nil	0.07	Nil	0.00	0.00	0.00	0.06	0.01	0.07
16	Narsinghpur	0.96	0.46	0.25	0.22	0.82	0.25	0.36	0.61	0.72	Nil	0.01	0.04	Nil	0.00	0.00	0.00	0.07	0.01	0.25
17	Ghata	0.97	0.18	0.04	Nil	0.33	0.27	0.32	0.16	0.37	Nil	0.08	0.03	Nil	0.00	0.00	0.01	0.08	0.02	0.03
18	Wazirabad	0.89	0.31	0.06	Nil	0.91	0.21	0.43	0.30	0.56	Nil	0.02	0.07	Nil	0.00	0.00	0.00	0.05	0.02	0.31
19	Nathupur	0.94	0.28	0.11	0.03	0.80	0.20	0.37	0.27	0.50	Nil	0.03	0.63	Nil	0.00	0.02	0.00	0.07	0.01	0.04
20	Dundahera	0.95	0.48	0.33	Nil	0.78	0.10	0.28	0.27	0.42	Nil	0.01	0.55	Nil	0.00	0.00	0.00	0.05	0.01	0.12
21	Sarhol	0.94	0.51	0.30	0.12	0.89	0.26	0.28	0.27	0.42	Nil	0.01	0.14	Nil	0.00	0.01	0.00	0.11	0.02	0.17
22	Sector 30	1.02	0.45	0.11	Nil	0.22	0.32	0.07	0.11	0.14	Nil	0.05	0.07	Nil	Nil	0.00	0.01	0.05	0.00	0.55
23	Silokhera	0.93	0.37	0.07	Nil	0.87	0.53	0.22	0.20	0.33	0.02	0.00	0.06	Nil	0.00	0.01	0.01	0.04	0.03	0.22
24	Islampur	0.96	0.46	0.24	0.02	0.89	0.13	0.19	0.61	0.58	Nil	0.00	0.03	Nil	0.00	0.02	0.00	0.06	0.04	0.36
25	Tikri	1.02	0.33	0.10	0.02	0.60	0.39	0.09	0.11	0.16	Nil	Nil	Nil	Nil	0.00	0.00	0.02	0.05	0.01	0.10
26	Sector 62 (Tigra)	0.97	0.26	0.06	Nil	0.67	0.29	0.34	0.41	0.56	0.06	Nil	0.03	Nil	0.00	0.00	0.01	0.06	0.01	0.11

3.3 Weighted Arithmetic Water Quality Index

The WAWQI method was used in this study, consisting of 4 steps, which are as follows:

1. Select parameters to measure the quality of the groundwater;
2. Quality ratings are scaled for each parameter;
3. The unit weight (Wi) is calculated, and Wi is inversely dependent upon the standard value (Si) of the parameters recommended;
4. Calculating the overall WQI by summing the sub-index value.

The following equations were used to calculate the WQI. Each water quality parameter's unit weight (Wi) was computed as follows:

$$W_i = \frac{K}{S_i}$$

where Wi stands for the unit weight of ith parameters. K is a proportionality constant. Si is the standard value of each parameter.

$$K = \frac{1}{\Sigma \frac{1}{S_i}}$$

Each parameter'squality rating scale(Qi) was calculated as:

$$Q_i = \left(\frac{V_i - V_0}{S_i - V_0}\right)$$

For the pH,the quality rating scale was determined by:

$$Q_i = \left(\frac{V_i - 7}{S_i - 7}\right)$$

where Vi is the concentration value for the ith analysed parameter and V0 is the ideal value of the parameter. Whereas, except for pH (ideal value 7, all other parameter's ideal value is zero. The final equation can be presented as:

$$SI_i = \frac{\Sigma W_i Q_i}{\Sigma W_i}$$
$$WQI = \sum SI_i$$

SI_is the subindex of the ith parameter and i represents the number of parameters taken into consideration.

WAWQI	0-25	25-50	51-75	76-100	Above 100
Water quality status	Excellent	Good	Poor	Very poor	Unsuitable for drinking purposes

The ideal values and unit weights for the water quality variables and their standard values are shown in table.

Table 11 WAWQI calculation

S no	Parameter	BIS standard value	1/Sn	Proportionality constant K=1/∑1/Sn	Unit weight W_i=K/Sn
1	pH	8.5	0.117647	0.001770245	0.000208
2	ECin µS/cm at 25^0 C	3000	0.000333	0.001770245	5.9E-07
3	Cl	1000	0.001	0.001770245	1.77E-06
4	SO_4	400	0.0025	0.001770245	4.43E-06
5	NO_3	45	0.022222	0.001770245	3.93E-05
6	F	1.5	0.666667	0.001770245	0.00118
7	Ca	200	0.005	0.001770245	8.85E-06
8	Mg	100	0.01	0.001770245	1.77E-05
9	TH as $CaCO_3$	600	0.001667	0.001770245	2.95E-06
10	Cr	0.05	20	0.001770245	0.035405
11	Mn	0.3	3.333333	0.001770245	0.005901
12	Fe	0.3	3.333333	0.001770245	0.005901
13	Ni	0.02	50	0.001770245	0.088512
14	Cu	1.5	0.666667	0.001770245	0.00118
15	Zn	15	0.066667	0.001770245	0.000118
16	As	0.05	20	0.001770245	0.035405
17	Cd	0.003	333.3333	0.001770245	0.590082
18	Pb	0.01	100	0.001770245	0.177024
19	U	0.03	33.33333	0.001770245	0.059008

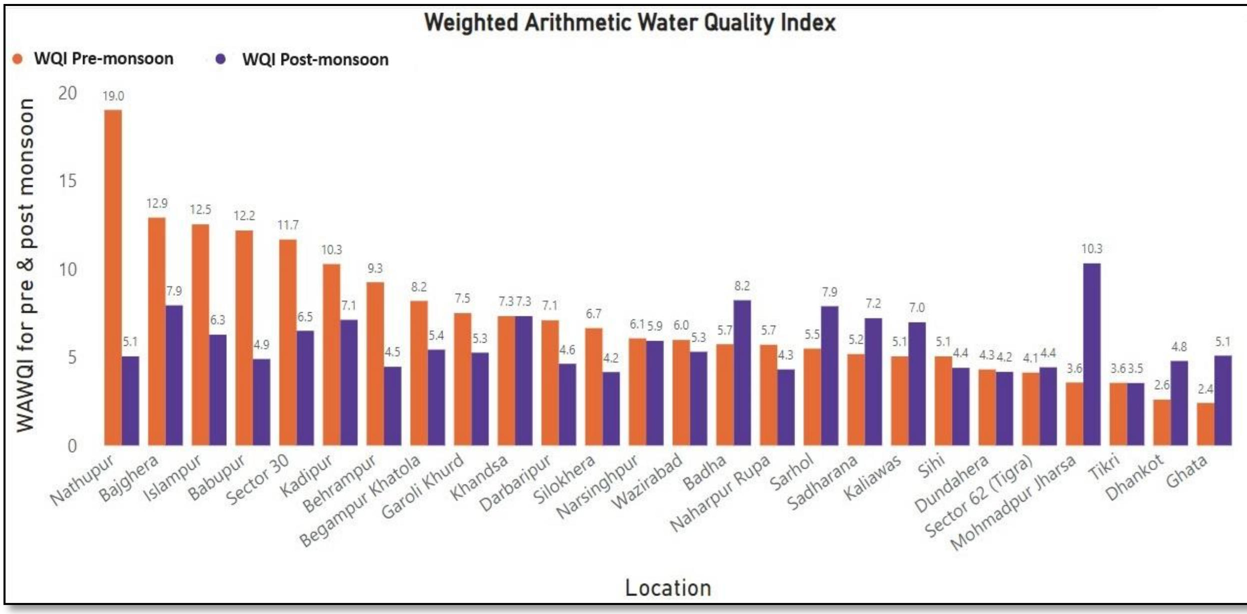


Figure 34 Weighted Arithmentic water quality index of pre & post-monsoon

3.4 CCME Water Quality Index

The CCME WQI skips subindex generation for the variables, establishment of weights, and classical index aggregation. According to the CCME, the CCME WQI uses a target value (objective or guideline) for each parameter that should not be exceeded and quantifies three essential elements (factors) for the calculation of a single unitless number that eventually indicates the overall water quality. The three factors are as follows: (a) scope, which refers to the number of variables of a dataset that were not meeting the objectives of water quality; (b) frequency, which refers to the number of times the objectives are not met; and (c) amplitude, which represents the amount by which the objectives are not met. The index's output ranges from 0, indicating the worst water quality, and 100, indicating the best quality.

The equations of the CCME WQI are as follows. F1 (Scope) represents the percentage of parameters that do not meet their guidelines at least once during the time period under consideration (failed parameters), relative to the total number of parameters measured. The term "guidelines" is equivalent to "objectives" or "target values".

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \qquad (1)$$

F2 (Frequency)represents the percentage of individual tests that do not meet guidelines (failed tests). A test is a single comparison of a parameter's value from a certain sampling campaign with the respective guideline for that parameter.

$$F_2 = \frac{\text{Number of failed test}}{\text{Total number of tests}} \times 100 \qquad (2)$$

F3 (Amplitude) represents the amount by which failed test values do not meet their guidelines and is calculated in three steps.

The number of times an individual concentration is greater than (or less than, when the guideline is a minimum) the guideline is termed an excursion and is expressed as follows: Whenthe ith test value must not exceed the guideline (objective) of the jth parameter:

$$\text{excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_i}\right) - 1$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their guidelines and dividing by the total number of tests (both those meeting guidelines and those not meeting guidelines). This parameter, referred to as the normalized sum of excursions, or nse, is calculated as

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Total number of tests}}$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from guidelines (nse) to yield a range between 0 and 100.

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01}$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as follows:

$$\text{CCME} - \text{WQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the ‘worst’ water quality and 100 represents the ‘best’ water quality.

CCME-WQI	**95–100**	**80–94**	**65–79**	**45–64**	**0–44**
Water quality status	Excellent	Good	Fair	Marginal	Poor

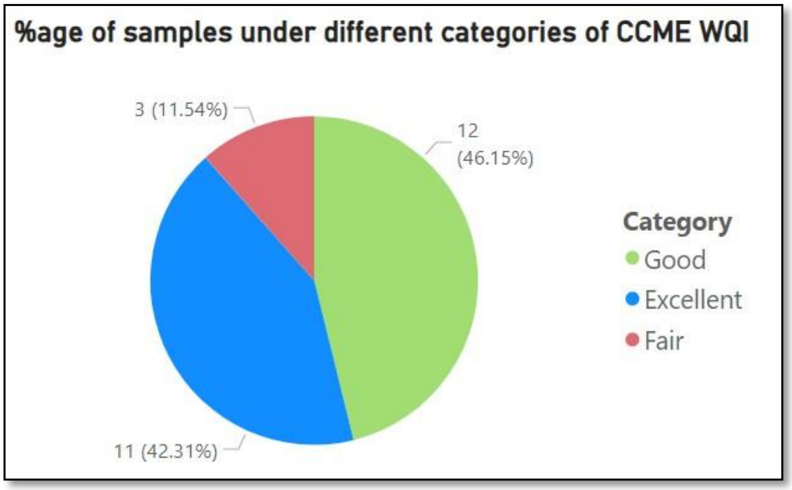


Figure 35 Percentage of samples under different categories of CCMW WQI

Table 12 Values of CCME WQI & WAWQI for groundwater samples

S. No	Location	CCME WQI	WAWQI Pre	WAWQI Post	Change in WAWQI from pre to post monsoon
1	Kaliawas	100	5.05	6.98	Deteriorated
2	Sadharana	83.77	5.18	7.21	Deteriorated
3	Dhankot	100	2.60	4.79	Deteriorated
4	Babupur	67.57	12.18	4.9	Improved
5	Bajghera	86.3	12.91	7.94	Improved
6	Kadipur	84.69	10.28	7.12	Improved
7	Garoli Khurd	95.14	7.50	5.26	Improved
8	Naharpur Rupa	96.56	5.71	4.31	Improved
9	Behrampur	74.75	9.25	4.46	Improved
10	BegampurKhatola	72.5	8.19	5.43	Improved
11	Khandsa	86.23	7.33	7.33	No change
12	MohmadpurJharsa	90.85	3.57	10.32	Deteriorated
13	Sihi	96.6	5.05	4.4	Improved
14	Badha	86.19	5.74	8.23	Deteriorated
15	Darbaripur	90.78	7.09	4.63	Improved
16	Narsinghpur	96.36	6.07	5.93	Improved
17	Ghata	96.57	2.41	5.09	Deteriorated
18	Wazirabad	92.51	5.98	5.31	Improved
19	Nathupur	96.38	19.01	5.05	Improved
20	Dundahera	96.52	4.31	4.17	Improved
21	Sarhol	92.47	5.49	7.89	Deteriorated

22	Sector 30	93.2	11.67	6.5	Improved
23	Silokhera	93.14	6.65	4.16	Improved
24	Islampur	91.79	12.53	6.28	Improved
25	Tikri	96.6	3.55	3.54	Improved
26	Sector 62 (Tigra)	96.47	4.13	4.43	Deteriorated

Chapter 4-Geophysical studies

VES survey

The survey work for conducting Vertical Electrical Soundings (VES) utilized the symmetrical method of Schlumberger to delineate sub-surface lithology. Here's an overview of the interpretation techniques adopted:

1. Curve Matching with Empirical Techniques:

- This technique involves comparing the obtained sounding curves with standard or master curves. By visually matching the shapes of the curves and analyzing their characteristics, approximate interpretations of the subsurface layers can be made.

- Empirical techniques rely on established patterns and relationships between resistivity values and geological formations. They provide a quick initial interpretation of the data.

2. Interactive Computer Modeling using Software (IPi2Win):

- IPi2Win is a software tool used for geophysical data interpretation, specifically for electrical resistivity data. It allows for interactive modeling of subsurface structures based on the input data from the VES.

- With IPi2Win, users can input the measured resistivity data and geological constraints to create 2D or 3D models of the subsurface. These models can be adjusted iteratively to fit the observed data accurately.

3. Automatic Computer Inversion:

- Automatic computer inversion techniques involve computational algorithms that iteratively adjust model parameters to minimize the difference between observed and calculated resistivity values.

- These techniques automate the process of interpreting VES data by systematically optimizing the subsurface model to best fit the measured data.

- While this approach can provide more objective interpretations, it requires careful consideration of inversion parameters and constraints to ensure reliable results.

Overall, these interpretation techniques aim to extract meaningful information about the geological sequence and subsurface lithology from VES data. By integrating field observations, hydrogeological knowledge, and drilling logs with computational methods, a comprehensive understanding of the subsurface structure can be achieved.

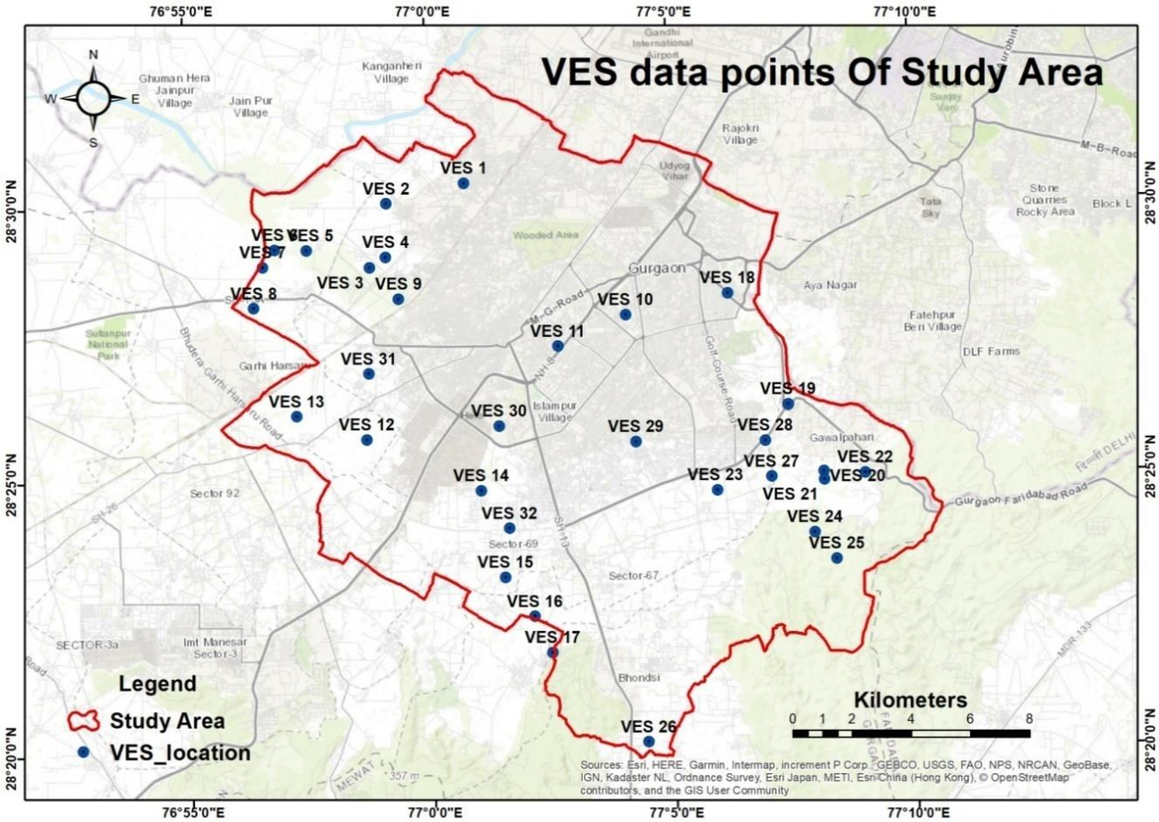


Figure 36 Map showing the location of VES in study area

The below table outlines the relationship between resistivity values and inferred lithology for the study area.

Table 13 Inferred lithology on the basis of resistivity values in the study area

Resistivity Value	Inferred Lithology
<5	Clay with fine sand and highly saline ground water (shown as saline sand)
5-10	Clay with fine sand and saline ground water (shown as saline sand)
10-20	Fine sand with Marginally Saline ground water (shown as Marginally saline sand)
20-30	Medium Sand with Marginally saline water (shown as Marginally saline sand)
30-45	Medium Sand with Fresh Water (shown as Fresh sand)
45-100	Coarse sand with fresh water (shown as Fresh sand)

100-200	Coarse sand with gravel and fresh water
>200	Weathered formation and Massive Formation

Horizontal Apparent Resistivity Maps (HRM):

The process of preparing Horizontal Apparent Resistivity Maps (HRMs) involves adjusting the apparent resistivity data by making a curve shift with the first layer. Here's an overview of the steps involved:

1. Acquisition of Apparent Resistivity Data: The apparent resistivity data is collected through geophysical surveys such as Vertical Electrical Sounding (VES) or Electrical Resistivity Tomography (ERT). These surveys involve measuring the apparent resistivity at multiple points across the study area.

2. Layer Interpretation: The acquired apparent resistivity data is interpreted to delineate the subsurface layers and their corresponding resistivity values. This interpretation is typically based on curve matching techniques or inversion algorithms, as mentioned earlier.

3. Horizontal Apparent Resistivity Maps (HRMs): After interpreting the apparent resistivity data, HRMs are prepared. In this process, the apparent resistivity values are plotted spatially on a map, typically in a grid pattern covering the study area.

4. Curve Shift with the First Layer: To account for the near-surface effects and improve the accuracy of the interpretation, a curve shift is applied with the resistivity values of the first layer. This adjustment helps in correcting for the influence of shallow layers on the apparent resistivity data.

5. Map Generation: Once the curve shift is applied, the HRMs are generated or updated accordingly. These maps provide a visual representation of the spatial distribution of apparent resistivity values across the study area, after accounting for the influence of near-surface layers.

6. Interpretation and Analysis: The HRMs are then interpreted and analyzed to identify subsurface features, geological structures, and potential groundwater resources. Geologists and hydrogeologists use these maps to make informed decisions related to resource exploration, environmental assessment, and engineering projects.

By incorporating the curve shift with the first layer, the HRMs provide a more accurate representation of the subsurface resistivity distribution, enhancing the utility of geophysical data for geological and hydrogeological investigations.

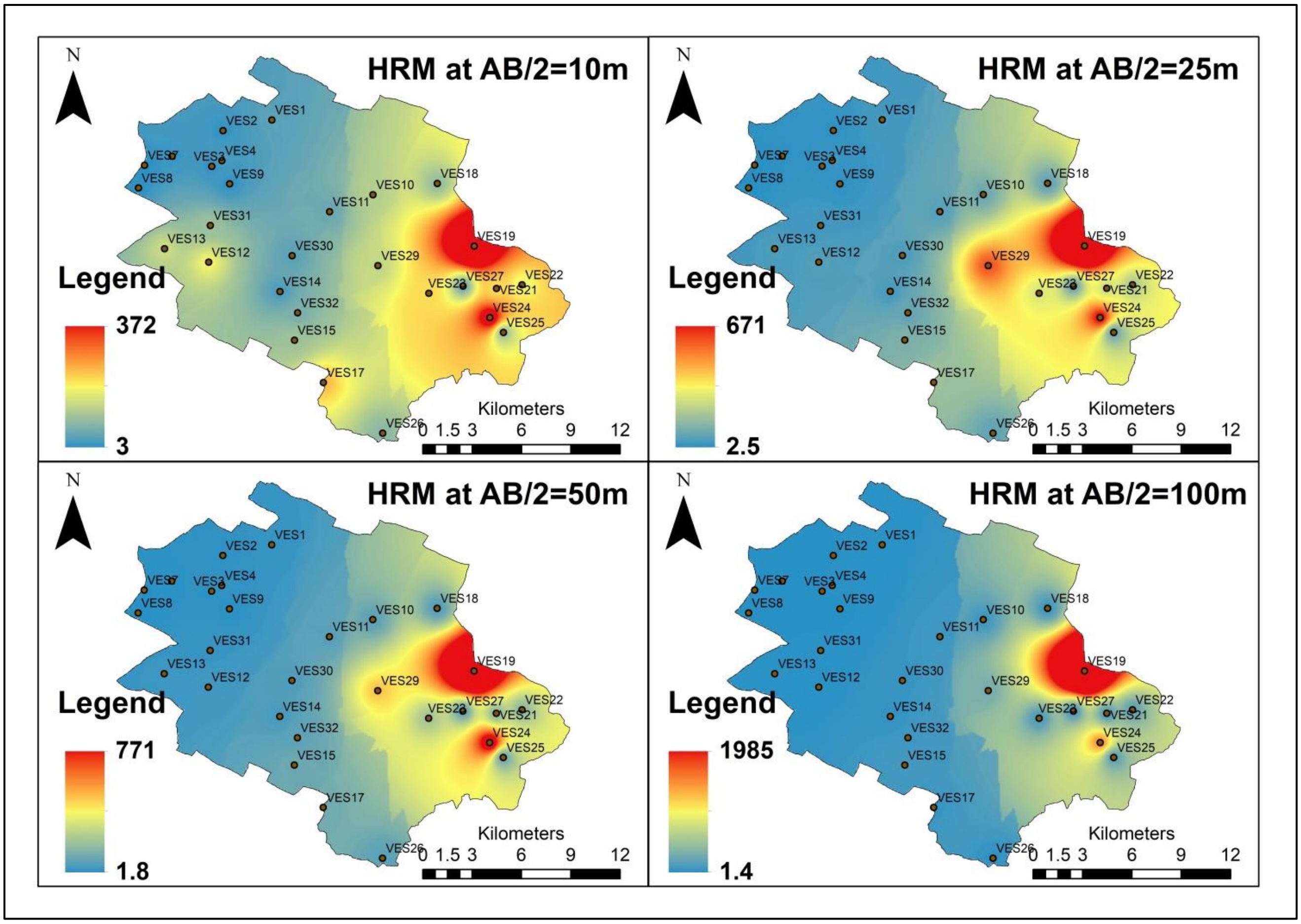


Figure 37 Horizontal Apparent Resistivity Maps(HRM) at different AB/2

The above maps offer a comprehensive view of the Horizontal Apparent Resistivity Maps (HRMs) at different AB/2 spacings (10m, 25m, 50m, and 100m). Let's analyze the patterns observed in these maps:

1. HRM at AB/2 = 10m:

- Resistivity values range from 3 to 372 ohm-m.
- Lowest resistivity observed in the northwestern side.
- Highest resistivity observed in the southeastern side.

2. HRM at AB/2 = 25m:

- Resistivity values vary between 2.5 to 671 ohm-m.
- Similar directional pattern as the HRM at 10m AB/2 spacing.
- Lower resistivity values in the northwest, higher resistivity values in the southeast.

3. HRM at AB/2 = 50m:

- Resistivity values range from 1.8 to 771 ohm-m.

- Consistent directional pattern from northwest to southeast.

- Lower resistivity values shifting towards the northwest, higher resistivity values towards the southeast.

4. HRM at AB/2 = 100m:

- Resistivity values vary between 1.4 to 1985 ohm-m.

- Continued directional pattern with lower values in the northwest and higher values in the southeast.

- The widest range of resistivity values among the four maps, indicating deeper variations in subsurface properties.

Overall Preliminary Interpretation based upon HRMs:

- The consistent directional pattern observed across all HRMs suggests a gradual change in subsurface resistivity from northwest to southeast.

- Lower resistivity values in the northwest may indicate the presence of more conductive materials like clay or saline groundwater, while higher resistivity values in the southeast could signify less conductive materials such as sand or gravel or fresher groundwater.

- The increasing range of resistivity values with depth suggests deeper variations in lithology and hydrogeological conditions.

- The observed patterns are valuable for understanding the geological structure and hydrogeological characteristics of the study area at different depths.

2D Sections of Study Area:

Two geo-electrical sections as A-A’ and B-B’ are drawn in order to show the vertical variation of geolectrical properties in the study area

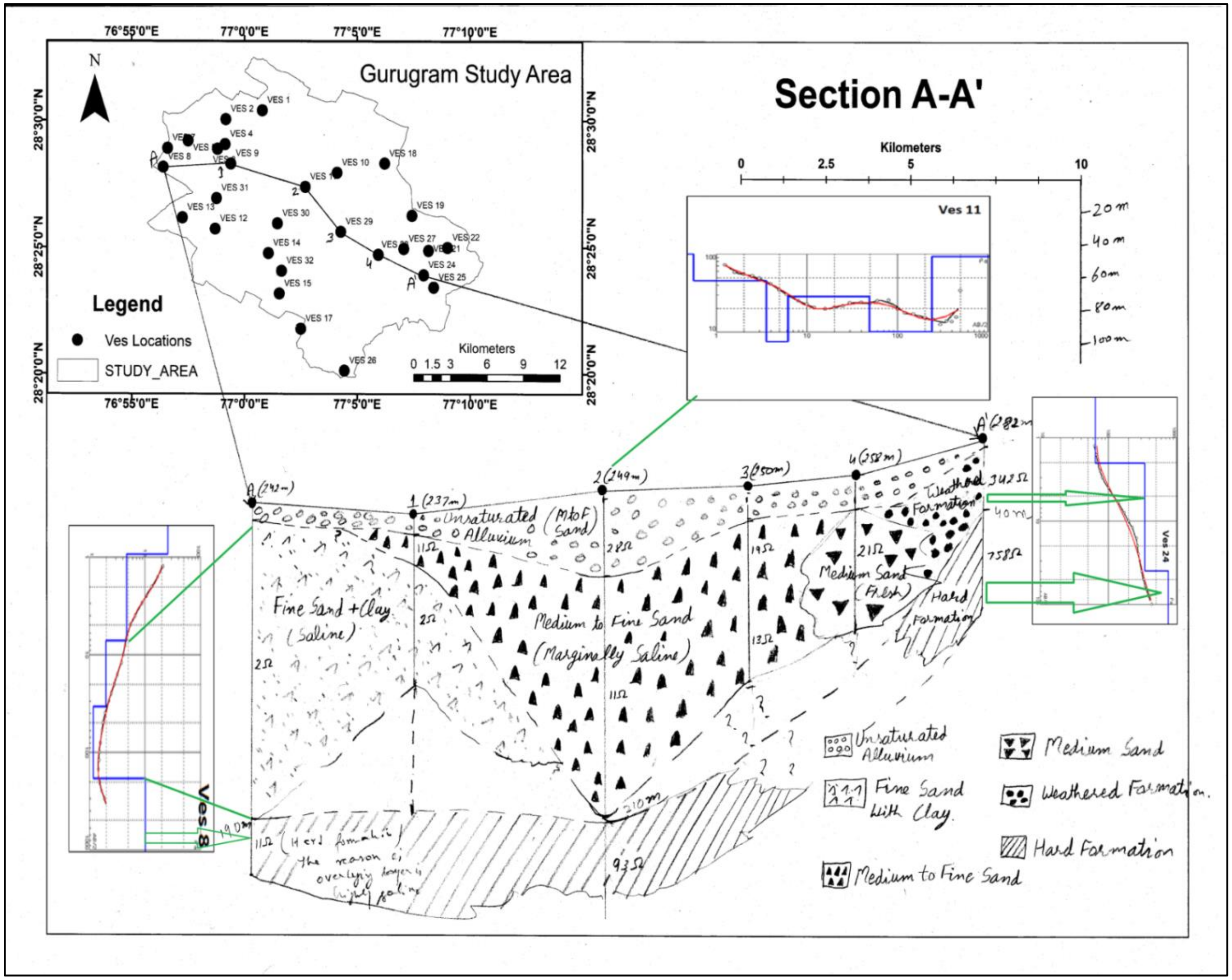


Figure 38 Cross-section A-A'

The Section A-A' provides additional insights into the subsurface characteristics of the study area:

1. **Low Resistivity and Saline Groundwater Quality:** In the northwestern part, resistivity values of Ves8are extremely low (below 5 ohm-m) throughout the depth of investigation. This indicates the presence of saline groundwater and the dominance of clay and very fine sand, which are typical of areas with poor groundwater quality.

2. **Change in Subsurface Characteristics:** Moving towards the southeastern side, there is a gradual increase in resistivity values of the subsurface layers. This indicates a shift in both groundwater quality and the grain size of sediments, suggesting a transition to less saline groundwater and possibly coarser materials.

3. **Presence of Marginal Saline Groundwater Column:** Similarly to the findings in the previous diagram, Ves11 indicates the presence of a column of marginally saline groundwater over a hard formation at depths ranging from 200 to 220 meters bgl. This consistent finding reinforces the hydrological understanding of the area.

4. **Increase in Resistivity and Elevation:** Towards the further eastern side, both resistivity and elevation of the study area increase. This suggests a transition to drier and possibly more elevated terrain.

5. **Identification of Soil Layers:**Ves24, located at an elevation of about 282 meters above mean sea level (amsl), indicates three distinct layers with resistivity values on the higher side (in hundreds of ohm-m). These layers likely represent the topsoil, weathered material, and hard formation, providing a detailed understanding of the subsurface structure.

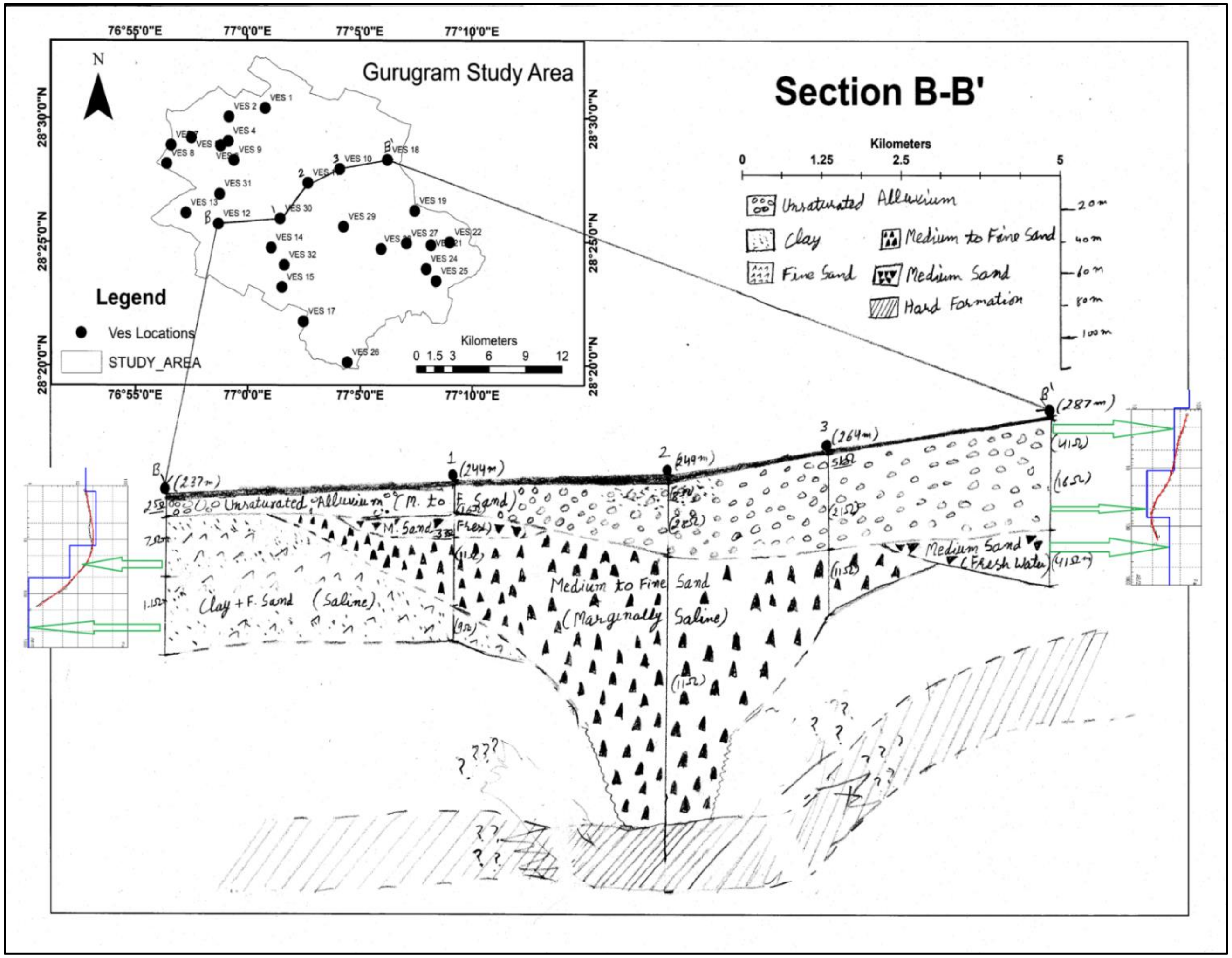


Figure 39 Cross-section B-B'

Section B-B' provides valuable insights into the subsurface characteristics of the study area:

1. Low Resistivity and Poor Groundwater Quality: In the northwestern part, the resistivity values are consistently low (below 10 ohm-m) up to a depth of 100 meters. This suggests the presence of clay and fine sand, which typically indicate poor groundwater quality.

2. Change in Subsurface Characteristics: Moving towards the eastern side, there is a noticeable increase in resistivity values of the subsurface layers. This change indicates a shift in both groundwater quality and the granulometry of the material.

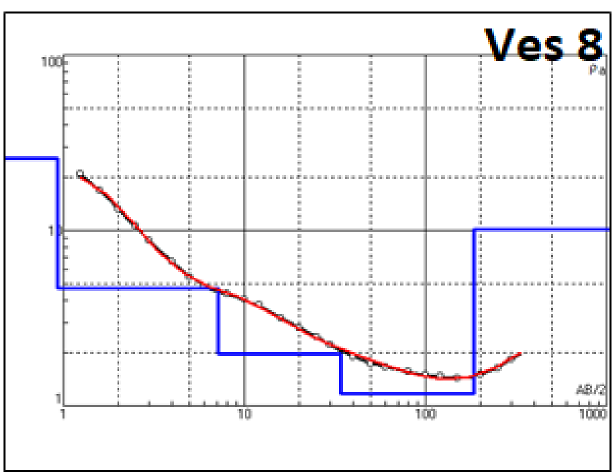
3. Presence of Marginal Saline Groundwater Column: The ves11 indicates the presence of a column of marginally saline groundwater over a hard formation at depths ranging from 200 to 220 meters below ground level (bgl). This suggests the existence of a distinct layer with specific hydrological characteristics.

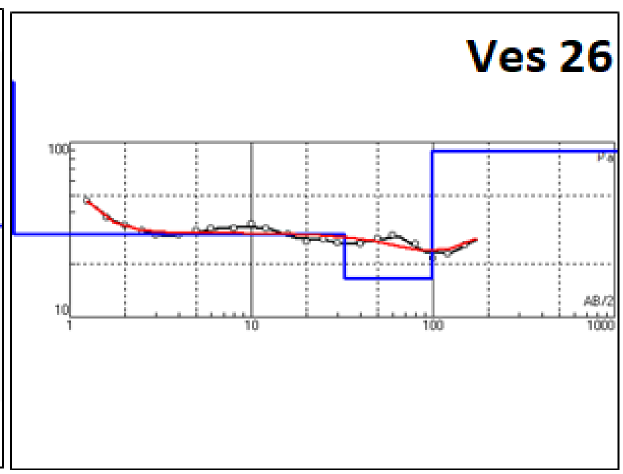
4. Unsaturated Zone Followed by Freshwater: Further towards the eastern side, both resistivity and elevation increase. This indicates an unsaturated zone extending up to depths of 60 to 70 meters below ground level (bgl), followed by a layer containing freshwater. This delineation is crucial for understanding groundwater resources and their potential utilization in the region.

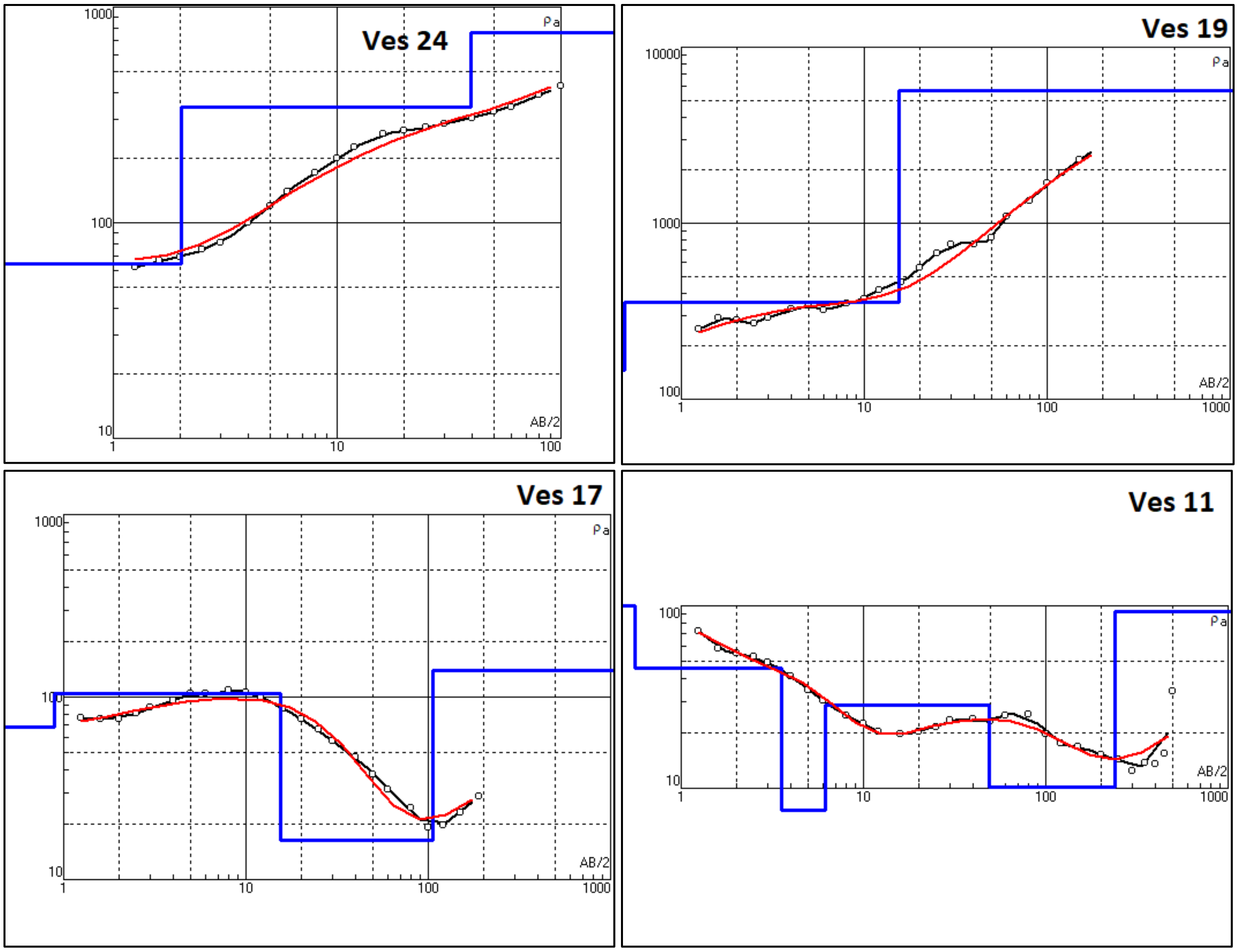
Overall, fence diagram B-B' complements the findings of diagram A-A', providing a comprehensive overview of the subsurface characteristics and groundwater quality variations across the study area from northwestern to southeastern directions.

Indications of presence of Hard Formation:

The presence of hard formations encountered at different depths on some sounding locations, including VES-8, VES-19, VES-11, VES-17, VES-24, and VES-26, underscores the geological complexity of the study area. These hard formations likely represent resistant lithological units characterized by higher compressive strength and lower permeability compared to surrounding materials.







Interestingly, at these locations, it is observed that the resistivity of the last layer is significantly higher than that of the second last layer. This discrepancy in resistivity values between adjacent layers may indicate a lithological boundary or a transition zone between different geological formations. Such variations in resistivity profiles can provide valuable information about subsurface stratigraphy and the distribution of lithological units within the study area.

However, despite the presence of hard formations, the resistivity values for these rock units are observed to be relatively low. This observation is attributed to the predominance of saline to marginally saline groundwater in the study area. The conductive nature of saline groundwater tends to lower the resistivity values measured in hard rock formations, complicating the interpretation of geophysical data.

Overall, the identification of hard formations and the observation of resistivity variations between adjacent layers highlight the heterogeneous nature of the subsurface geology in the study area. These findings contribute to a better understanding of the geological framework and hydrogeological conditions, informing groundwater management strategies, geological modeling efforts, and environmental assessments in the Gurugram district and surrounding regions.

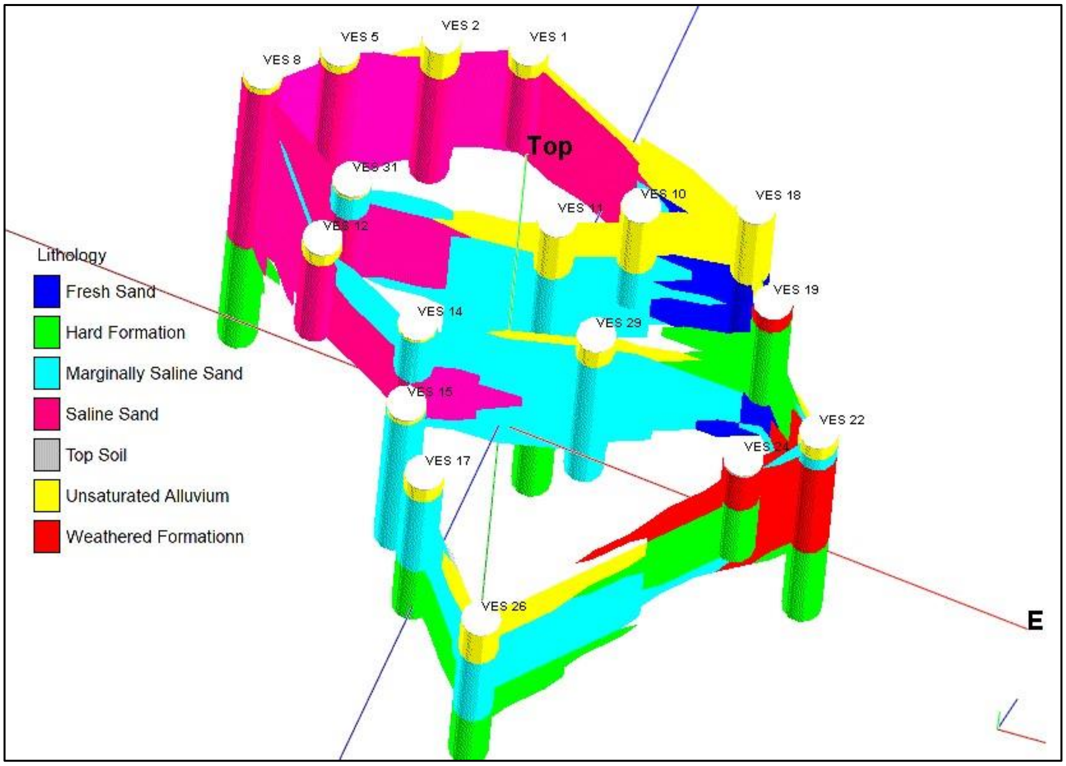


Figure 40 Fence model of Gurugram urban area

A. Conclusion:

Based on the findings of the geophysical survey conducted in the Gurugram study area and the interpretation of the fence diagram, several key observations can be made:

1. Groundwater Quality Variation: The study area exhibits a range of groundwater qualities, including fresh, marginal saline, and saline groundwater. This variation in groundwater quality is spatially distributed across the study area.

2. Formation Identification: In the southeastern part of the study area, weathered formations followed by hard formations are identified. These geological formations contribute to the hydrogeological characteristics of the area.

3. Saline Groundwater Presence: The northwestern part of the study area shows the presence of saline groundwater from shallow depths, which persists throughout the depth of investigation. This indicates a significant saline groundwater zone in this region.

4. Contact with Hard Formation: At specific locations, such as VES-8, the saline groundwater column is observed to rest on hard formation. This geological contact between saline groundwater and hard formation may influence groundwater flow and aquifer properties in the area.

5. Distribution of Marginally Saline Groundwater: The central and northeastern parts of the study area are characterized by marginally saline groundwater. Fresh groundwater pockets are localized in these areas and are not continuous, indicating localized recharge zones or geological controls on groundwater movement.

6. Identification of Hard Formation: Hard formations are identified at various locations within the study area, including VES-8, VES-19, VES-11, VES-17, VES-24, and VES-26, at different depths. The presence of hard formations influences the resistivity values observed in the geophysical survey.

7. Resistivity Values: Due to the predominance of saline to marginally saline groundwater in the study area, the resistivity values for hard rock formations are observed to be on the lower side. This indicates the influence of groundwater salinity on resistivity measurements.

Overall, the geophysical survey findings provide valuable insights into the hydrogeological characteristics, groundwater quality, and geological formations present in the Gurugram study area. These observations are essential for groundwater management, resource planning, and environmental assessment initiatives in the region.

Chapter 5 - Groundwater Management Plan

Rainwater harvesting systems

The promotion of rainwater harvesting systems for water storage and reuse should be a priority. This can be achieved by encouraging the installation of localized rainwater storage systems in new buildings, specifically for domestic purposes. Additionally, localized rainwater collection through the development of artificial water bodies should be implemented. Stormwater, when channeled through drains before merging with the main drain, often evaporates or becomes contaminated. Instead, this rainwater can be effectively utilized by directing it into these artificial water bodies, thereby enhancing groundwater recharge. This approach also reduces groundwater contamination by allowing rainwater to naturally percolate into the ground. Moreover, treated wastewater from sewage treatment plants (STPs) can be discharged into these local water bodies to further boost groundwater levels. A list of villages in dire need of RWHS & artificial recharge is given in table.

Wastewater management

Zero discharge of untreated waste water from the city into the natural drains and lakes should be ensured to protect them from polluting and to maintain their good quality. Complete waste water should be treated in STPs, ensuring there is no direct untreated waste water discharge into the water bodies. To ensure that 100% no direct untreated waste water discharge gets into the water bodies, the capacities or number of STPs should be increased.

Accounting natural topography in city planning

Proposed and upcoming development plans, housing schemes, and similar projects must take into account the city's natural drainage profile. Any project that obstructs the natural drainage should only be approved if an alternative drainage plan is provided.

Increasing pervious area

The city has become heavily concretized, covered in impervious materials. In urban areas, the common response to most challenges is to increase construction, relying on materials like bitumen, steel, and cement. Water accumulates on these impermeable surfaces, and with encroached and blocked drains, it remains stagnant for hours or even days. To address the issue of waterlogging, the city must incorporate more permeable spaces, which can be achieved through turfing or the use of interlocking tiles.

Table 14 List of villages for installing recharge shaft & RTRWHS

	List of villages for installing recharge shaft & RTRWHS		
S no	Village	S no	Village
1	Adampur	33	Kadipur
2	Aklimpur	34	Kanahi
3	Alla Wardi	35	Khandsa
4	Badshahpur	36	Kharki Dola

5	Balola	37	Mahendwara
6	Bandhwari	38	Mangar
7	Begampur Khatola	39	Medawas
8	Behlpa	40	Mohammadpur Jharsa
9	Behrampur	41	Molahera
10	Bhondsi	42	Naharpur Rupa
11	Bhrempur	43	Nangli Umarpur
12	Bindapur	44	Narsinghpur
13	Chakarpur	45	Nathupur
14	Darbaripur	46	Nurpur Jharsa
15	Dharampur	47	Palra
16	Dhumaspur	48	Rethoj
17	Dundahera	49	Rojka Gujar
18	Fatehpur	50	Sahjawas
19	Fazilpur Jharsa	51	Sarhol
20	Ghamroj	52	Shahpur
21	Ghasula	53	Shamshpur
22	Ghata	54	Shikohpur
23	Gual Pahari	55	Sihi
24	Gurgaon	56	Sikanderpur Badha
25	Haiderpur	57	Sikanderpur Ghosi
26	Harsaru	58	Silokhra
27	Hassanpur	59	Sukhrali
28	Hayatpur	60	Tigra
29	Inayatpur	61	Tikri
30	Islampur	62	Ulhawas
31	Jharsa	63	Wazirabad
32	Kadarpur	64	Wazirpur

CHAPTER 6- CONCLUSION

Due to the rise of Gurugram as an industrial hub & urban centre, vast expanses of agricultural land has been converted to built up area, hindering the natural groundwater recharge processes & elevating the groundwater quality issues. Najafgarh drain flowing through northwest is primarily fed by waste water from the Badshahpur drain and rainwater in monsoons. It comprises largely sewage from the drains of surrounding urban sprawl. The primary industry sectors prone to contaminate groundwater are textile industry, paper mill industry, chemical based pharmaceutical industry, soaps and detergent industry, engineering & metal industries in the study area.

The depth to water level during pre-monsoon 2023 varies from 1.16 m bgl at Basai to 74.10 m bgl at Chakarpur. The depth to water level during post-monsoon 2023 varies from 2.05 m bgl at Dharampur to 74.20 m bgl at Chakarpur. The presence of Sahibi river in the northwest side provides a potential recharge source for groundwater through infiltration from the river, hence the shallow water level in the northwest. The central part of the city along the Delhi-Jaipur highway shows deepest water levels owing to high demand for industrial and domestic consumption and reduced recharge rates due to urbanization. Hydrograph of Daulatbad pz shows rise in water level owing to its location near the Sahibi river. Hydrographs of Gurgaon pz, Kadipur, Wazirpur pz & Manesar pz show decline in water levels over time.

The Net Annual Ground Water Availability as on March 2023 works out to be 5538.43 Ham (55.38 mcm). Total extraction for all uses is 18077.73 Ham (180.77 mcm). The stage of groundwater extraction is 326.415 and the Gurugram urban area falls in over-exploited category.

During post-monsoon, the ground water samples have varied range of pH from 7.31 to 8.81. The electrical conductivity of ground water samples varies from 220 to 5612 µS/cm at 25°C. The overall ground water quality is good to saline in nature. The fluoride concentration in study area lies in between 0.05 to 2.52 mg/l. Nitrate concentration in ground water samples is within the 5.8 to 120 mg/l. High concentration (more than 45 mg/L) of nitrate is reported in the water samples of Kadipur (55 mg/l), Dhanwapur (64 mg/l) & Bajghera (120 mg/l). The range of Total Hardness (as $CaCO_3$) in ground water samples of study area is 56 to 1357 mg/l. The Weighted Arithmetic Water Quality Index of all the samples falls in excellent category. WAWQI of 8 nos. of groundwater samples deteriorated, 17 nos. samples improved and 1 no. showed no change from pre monsoon to post monsoon season. The CCME Water Quality Index of 42.31% of samples falls in excellent category, 46.15% of samples falls in good category and 11.54% samples falls in fair category.

As per the geophysical studies, the study area exhibits a range of groundwater qualities, including fresh, marginal saline, and saline groundwater. This variation in groundwater quality is spatially distributed across the study area. In the southeastern part of the study area, weathered formations followed by hard formations are identified. The northwestern part of the study area shows the presence of saline groundwater from shallow depths, which persists throughout the depth of investigation. This indicates a significant saline groundwater zone in this region. The central and northeastern parts of the study area are characterized by marginally saline groundwater. Fresh groundwater pockets are localized in these areas and are not continuous, indicating localized recharge zones or geological controls on groundwater movement. Due to the predominance of saline to marginally saline groundwater in the study area, the resistivity values for hard rock formations are observed to be on the lower side. This indicates the influence of groundwater salinity on resistivity measurements.

The management plan for the study area includes the controlled abstraction of saline water present at shallow depths in the northwest part for industrial use, adoption of water conservation structures for drinking water needs, recharge shafts in the central part where water level is deep and unsaturated aquifer is present, proper wastewater treatment before releasing in drains, collection of municipal wastewater after proper treatment in 'urban tanks' for non-drinking needs and aquifer replenishment, storm water drains to convey runoff from various catchments (eg. buildings, parks etc). and perforated tiles in all open built up area to manage flooding & induce recharge. RTRWH structures should be mandatory in all the buildings. Effective groundwater management requires a combination of regulatory oversight, pollution prevention, monitoring, enforcement, and community engagement.

Recommendations

- In northwest part, where water level is as shallow as 1.16 mbgl & saline groundwater is present at shallow depth, controlled abstraction of saline water may be allowed for industrial use.
- Emphasis on rainwater conservation structures for drinking water needs instead of groundwater abstraction structures.
- Recharge shafts may be installed where water level is deep and unsaturated aquifer is present.
- Proper wastewater treatment before releasing in drains to avoid contamination.
- Collection of municipal wastewater after proper treatment in 'urban tanks' for non-drinking needs and aquifer replenishment.
- Storm water drains to convey runoff from various catchments (eg. buildings, parks etc). and perforated tiles in all open built up area to manage flooding & induce recharge.
- RTRWH structures should be mandatory in all the buildings.
- Awareness drives for industrial community for pollution prevention, handling wastewater etc. Encourage community participation in groundwater monitoring and protection initiatives.
- Develop integrated water management policies that consider both surface water and groundwater resources.
- Foster partnerships between government agencies, private companies, and non-governmental organizations to implement groundwater conservation and management projects effectively.

References

1. BIS, 2012. Indian standard specification for drinking water (second revision) IS 10500:2012, Bureau of Indian Standards, New Delhi.
2. Brief Industrial Profile of District Gurugram, Micro, Small & Medium Enterprise Development Institute, Govt of India, Ministry of Ministry of MSME.
3. CCME WATER QUALITY INDEX 1.0 User's Manual, CCME Water Quality Guidelines Task Group

Annexure I

Pre-monsoon water level data

S_no	Site name	Well type	Latitude	Longitude	RL (mamsl)	Water level (mbgl)	Source
1	Acharyapuri Sec 7	Tube Well	28.46972	77.01214	222	8.98	Industry
2	Badsahapur	Tube Well	28.38000	77.05233	229	28.85	
3	BALIAWAS	Tube Well	28.42844	77.12973	252	26.45	State dept
4	BANDHWARI	Tube Well	28.42519	77.14333	246	26.15	State dept
5	Basai	Tube Well	28.46055	76.99169	221	1.16	Industry
6	Bhondsi Ew	Tube Well	28.37667	77.04594	227	31.85	CGWB
7	Bhondsi	Tube Well	28.35052	77.06090	229	31.85	State dept
8	CHAKARPUR	Tube Well	28.47266	77.09226	247	74.10	State dept
9	CHOMACATTERPUR	Tube Well	28.51218	77.02372	215	45.55	State dept
10	Daultabad	Tube Well	28.49780	76.99680	215	4.83	State dept
11	Daultabad-Pz	Tube Well	28.49944	77.00097	219	7.25	CGWB
12	DAULTABAD	Tube Well	28.49941	76.99073	217	7.25	State dept
13	Dhankot	Tube Well	28.46950	76.95460	221	3.35	State dept
14	Dhanwapur	Tube Well	28.47652	76.98029	212	2.64	Industry
15	DHARAMPUR	Tube Well	28.51147	76.97993	216	2.55	State dept
16	Dharampur, Sector 108	Tube Well	28.51144	76.98092	211	4.56	Industry
17	Godoli	Tube Well	28.43852	76.97965	218	9.30	Industry
18	Gurgaon Pz	Tube Well	28.46389	77.04541	229	47.95	CGWB
19	GURGAON	Tube Well	28.46226	77.03254	227	47.95	State dept
20	Gwc Office	Tube Well	28.44890	77.02740	227	44.64	State dept
21	Joyville Shapoorji Housing Pvt Ltd	Tube Well	28.47929	76.97261	215	4.05	Industry
22	Kadipur	Tube Well	28.45278	77.02790	226	28.90	State dept
23	KADIPUR	Tube Well	28.45000	77.00200	222	28.90	State dept
24	Kherki	Tube Well	28.40219	76.98363	230	63.00	Atal_Jal/State
25	Kherki Majra	Tube Well	28.48599	76.97989	215	4.70	Industry
26	KHERKIDAULA	Tube Well	28.40152	76.98689	235	45.50	State dept
27	Mohammadheri	Tube Well	28.50267	76.98944	215	4.05	Industry
28	P.S.SEC. 29	Tube Well	28.47102	77.06791	247	60.90	State dept
29	Quadarpur	Tube Well	28.38160	77.10444	248	33.45	State dept
30	Rajendra Park Sec 105	Tube Well	28.49339	77.00759	217	11.40	Industry
31	Sector 103, Daulatabad	Tube Well	28.49956	76.98439	217	2.60	Industry
32	Sector 106, Daulatabad	Tube Well	28.50233	76.99497	214	2.90	Industry
33	Sector 109	Tube Well	28.51089	76.99967	213	3.52	Industry
34	Sector 2 Palam Vihar	Tube Well	28.51192	77.03831	218	16.23	Industry
35	Sector4	Tube Well	28.47307	77.00757	222	6.30	CGWB
36	Shiv Jyoyi Colony, Kherki	Tube Well	28.48505	76.96493	213	1.54	Industry

	Majra						
37	Wapcos	Tube Well	28.48368	77.06307	231	22.56	CGWB
38	Wazirabad	Tube Well	28.43400	77.07990	239	54.50	State dept

Post-monsoon water level data

S no	Site name	Well type	Latitude	Longitude	RL (mamsl)	Water level (mbgl)	Source
1	ALAWARDISARAI	Tube Well	28.50247139	77.01976620	220.1	34.75	State dept
2	BADSAHPUR	Tube Well	28.39162424	77.05104550	233	28.00	State dept
3	BANDHWARI	Tube Well	28.42518615	77.14332812	245.6	26.60	State dept
4	BHONDSI	Tube Well	28.34933176	77.06570990	225.5	31.65	State dept
5	Cell office	Tube Well	28.44899500	77.02747500	227.5	43.47	CGWB
6	CHAKARPUR	Tube Well	28.47266035	77.09225790	246.8	74.20	State dept
7	CHOMACATTERPUR	Tube Well	28.51218036	77.02372245	215.4	45.15	State dept
8	Daulatabad DW	Dug Well	28.49780000	76.99680000	214.9	5.24	CGWB
9	DAULTABAD	Tube Well	28.49941092	76.99073029	217	4.95	State dept
10	Dhankot	Tube Well	28.47000000	76.95000000	213	3.30	CGWB
11	DHARAMPUR	Tube Well	28.51147197	76.97993131	215.6	2.05	State dept
12	GURGAON	Tube Well	28.46226015	77.03253607	227.1	47.55	State dept
13	KADIPUR	Tube Well	28.45000000	77.00200000	222	29.55	State dept
14	KHERKIDAULA	Tube Well	28.40152414	76.98689183	234.6	46.05	State dept
15	P.S.SEC. 29	Tube Well	28.47102405	77.06790459	246.6	60.65	State dept
16	QUADARPUR	Tube Well	28.39000000	77.10000000	249	31.00	State dept
17	Sarai	Tube Well	28.50283200	77.02219300	219.3	33.95	CGWB
18	Sec 4	Tube Well	28.47298400	77.01018400	221.8	5.34	CGWB
19	WAZIRABAD	Tube Well	28.43689857	77.08737979	246.8	45.60	State dept
20	Wazirabad	Tube Well	28.43400000	77.07990000	239	54.37	CGWB

Annexure II

Groundater Quality Analysis data- Pre & Post-monsoon

S. No	Location	Season	pH	EC	Cl	SO_4	NO_3	F	Ca	Mg	TH as $CaCO_3$	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	U
				µS/cm at 250 C	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Kaliawas	Pre	7.52	856	112	46	22	1.41	52	54	350	0.007	0.001	0.212	0.001	0.003	0.035	0.001505	0	0.000159	0.015618
		Post	8.20	1353	284.88	61	22	1.32	78.7	72.8	496	bdl	0.001	0.023	bdl	0.002	0.038	0.000352	0.000214	0.000628	0.007367
2	Sadharana	Pre	7.72	3321	962	108	87	0.3	188	182	1221	0.008	0.002	1.275	0.003	0.004	0.055	0.000725	0	0.000144	0.002692
		Post	8.38	2821	792.09	91	38	0.19	157.4	166.0	1076	0.003	0.001	0.056	bdl	0.002	0.049	0.000135	0.00025	0.000881	0.001658
3	Dhankot	Pre	8.00	384	28	0	0.3	0.41	40	17	170	0.004	0.005	0.210	0.003	0.002	0.026	0.000919	0	0	0.003169
		Post	8.45	372	41.69	nd	5.8	0.27	37.5	11.4	140	bdl	bdl	0.021	bdl	0.001	0.044	0.000403	0.000199	0.000161	0.002493
4	Babupur	Pre	7.22	4459	1369	108	36	0.52	277	250	1721	0.008	0.639	2.264	0.005	0.003	0.056	0.001902	0	0.000228	0.016325
		Post	7.84	3791	1153.40	41	28	0.44	247	180	1357	bdl	0.180	0.055	bdl	bdl	0.054	8.45E-05	0.000161	3.84E-05	0.005806
5	Bajghera	Pre	7.40	2029	309	10	110	0.47	16	114	510	0.012	0.011	1.220	0.003	0.005	0.058	0.004569	0	0.0017	0.024355
		Post	7.66	1940	354.36	34	120	0.32	127	30	440	bdl	0.001	0.056	bdl	bdl	0.020	0.000122	0.000129	0.000272	0.02415
6	Kadipur	Pre	7.87	2481	197	57	72	1.85	20	17	120	0.022	0.007	0.067	0.001	0.003	0.110	0.004071	0	0.000653	0.033452
		Post	8.80	2609	243.19	286	55	1.62	15.0	22.7	131	bdl	0.003	0.067	bdl	0.001	0.091	0.000689	0.000202	0.000304	0.011528
7	Garoli Khurd	Pre	7.94	2809	323	198	38	2.81	20	27	160	0.014	0.016	0.050	0.001	0.004	0.035	0.005306	0	8.25E-05	0.026633
		Post	8.18	2610	270.98	254	32	2.52	22.5	43.2	234	bdl	0.006	0.004	bdl	0.001	0.034	0.001037	0.000138	2.67E-05	0.011062
8	Naharpur Rupa	Pre	7.80	1690	246	21	61	0.68	12	29	150	0.012	0.003	0.193	0.002	0.007	0.172	0.004317	0	0.001024	0.007261
		Post	8.50	1612	229.29	81	35	0.44	33.7	18.2	159	bdl	0.001	0.016	bdl	0.001	0.043	0.000348	0.000162	8.37E-05	0.004372
9	Behrampur	Pre	7.34	4462	1200	127	52	0.38	20	161	711	0.015	0.008	1.018	0.003	0.004	0.161	0.000825	0	0.001214	0.013601
		Post	7.56	5612	1459.12	374	23	0.16	195	148	1095	bdl	0.004	0.048	bdl	bdl	0.121	8.15E-05	9.53E-05	0.000206	0.010544
10	Begampur Khatola	Pre	7.51	6750	1727	714	94	0.24	297	221	1651	0.008	0.006	2.021	0.004	0.007	0.036	0.003501	0	3.06E-05	0.00768
		Post	7.80	220	69.48	nd	nd	0.05	7	9	56	bdl	bdl	0.008	bdl	0.161	0.030	6.55E-06	0.000248	0.000275	3.84E-05
11	Khandsa	Pre	7.48	3032	421	87	75	0.51	84	58	450	0.018	0.071	0.543	0.003	0.006	0.068	0.000793	0	2.75E-05	0.016304
		Post	8.68	756	83.38	62	8.9	0.20	48.7	20.5	206	bdl	0.002	0.026	bdl	0.001	0.033	0.000751	0.000239	0.001099	0.002765
12	Mohmadpur Jharsa	Pre	7.51	2881	555	79	206	0.39	88	63	480	0.009	0.020	0.579	0.001	0.004	0.029	0.000436	0	0	0.005593
		Post	8.38	2581	507.22	297	37	0.25	56.2	59.1	384	bdl	0.004	0.019	bdl	bdl	0.016	0.000198	0.000484	3.28E-05	0.003202

13	Sihi	Pre	8.07	1301	112	27	31	0.89	32	24	180	0.016	0.001	0.198	0.001	0.002	0.148	0.003704	0	0.00058	0.00963
		Post	8.81	1340	118.12	36	31	0.84	26.2	27.3	178	0.003	0.001	0.020	0.001	0.001	0.080	0.000449	0.000114	0.00018	0.005975
14	Badha	Pre	7.65	1996	239	97	53	0.57	72	85	530	0.014	0.001	0.643	0.001	0.003	0.031	0.004381	0	0.00014	0.011145
		Post	8.26	1992	201.50	442	27	0.71	82	45	393	bdl	0.244	0.383	0.006	bdl	1.619	4.73E-05	0.000172	6.04E-05	0.003127
15	Darbaripur	Pre	7.76	1936	267	84	184	0.59	88	58	460	0.015	0.001	0.751	0.002	0.003	0.043	0.005565	0	0.001375	0.004177
		Post	8.12	1732	243.19	217	37	0.57	82.4	43.2	384	0.005	bdl	0.021	bdl	0.001	0.021	0.000199	0.000177	0.000115	0.00224
16	Narsinghpur	Pre	7.58	1202	197	12	39	0.47	84	46	400	0.007	0.007	0.566	0.002	0.003	0.034	0.004442	5.88E-05	0.000263	0.00814
		Post	8.14	1391	250.14	89	37	0.37	71.2	61.4	430	bdl	0.002	0.013	bdl	0.001	0.025	0.000207	0.000218	5.05E-05	0.007367
17	Ghata	Pre	7.06	512	28	0	12	0.48	64	15	220	0.009	0.042	0.400	0.002	0.001	0.032	0.001224	0	0	0.0005
		Post	8.28	532	41.69	nd	15	0.41	63.7	15.9	225	bdl	0.023	0.009	bdl	0.002	0.023	0.000326	0.000227	0.000183	0.000834
18	Wazirabad	Pre	7.22	1106	63	10	80	0.43	104	44	440	0.015	0.012	0.724	0.002	0.003	0.042	0.00153	0	0.00011	0.011841
		Post	7.55	923	55.59	nd	41	0.32	86.2	29.6	337	bdl	0.006	0.021	bdl	0.001	0.046	6.81E-05	0.000158	0.000153	0.009217
19	Nathupur	Pre	7.18	1196	119	18	83	0.41	120	22	390	0.014	0.004	0.853	0.003	0.003	0.161	0.002904	0.000731	7.02E-05	0.001923
		Post	7.95	846	111.17	10	36	0.3	74.9	27.3	299	bdl	0.008	0.188	bdl	0.001	0.362	0.000131	0.000212	9.72E-05	0.00135
20	Dundahera	Pre	7.59	1545	302	22	25	0.2	64	17	230	0.010	0.004	0.454	0.002	0.003	0.071	0.006422	9.92E-06	7.44E-05	0.004224
		Post	8.10	1434	333.51	nd	35	0.15	56.2	27.3	253	bdl	0.002	0.166	bdl	0.001	0.043	0.000245	0.000147	0.000108	0.0036
21	Sarhol	Pre	7.51	1786	330	30	97	0.39	68	29	290	0.011	0.010	0.631	0.003	0.002	0.105	0.006604	0	0	0.0085
		Post	7.96	1543	298.77	49	40	0.39	56.2	27.3	253	bdl	0.002	0.041	bdl	0.001	0.079	0.000201	0.000325	0.00019	0.00515
22	Sector 30	Pre	7.77	1591	148	148	12	0.55	32	22	170	0.020	0.069	0.334	0.004	0.004	0.078	0.003539	0	0.00131	0.024922
		Post	8.67	1340	111.17	nd	10	0.48	15.0	11.4	84	bdl	0.016	0.020	bdl	bdl	0.042	0.000357	0.000156	3.51E-05	0.01636
23	Silokhera	Pre	7.83	925	42	0	74	0.68	28	15	130	0.009	0.008	0.224	0.002	0.006	0.048	0.001876	0	0.002148	0.003885
		Post	7.94	1120	69.48	nd	39	0.79	45.0	20.5	197	0.001	0.001	0.019	bdl	0.001	0.113	0.000258	0.00011	0.000282	0.006519
24	Islampur	Pre	7.49	1476	197	41	39	0.37	76	46	380	0.015	0.006	0.652	0.002	0.003	0.451	0.004315	5.22E-05	0.003117	0.012147
		Post	8.12	1387	236.24	9	40	0.19	37.5	61.4	346	bdl	0.001	0.010	bdl	0.003	0.305	0.000111	0.000171	0.000403	0.010817
25	Tikri	Pre	8.06	1077	84	36	39	0.68	20	12	100	0.011	0.003	0.129	0.001	0.008	0.073	0.002866	0	0.000486	0.004795
		Post	8.71	998	104.22	9	27	0.58	18.7	11.4	94	bdl	bdl	bdl	bdl	0.001	0.013	0.000762	0.000136	7.22E-05	0.003146
26	Sector 62 (Tigra)	Pre	7.95	771	63	10	35	0.52	52	36	280	0.013	0.004	0.494	0.002	0.002	0.032	0.001887	0	0.0002	0.004424
		Post	8.26	770	55.59	nd	30	0.44	67.5	40.9	337	0.003	bdl	0.010	bdl	0.001	0.027	0.000403	0.000169	7.08E-05	0.003367

Annexure III

Litholog of Exploratory well at Kadipur drilled under NAQUIM 2.0

S no	Depth from	Depth to	Lithology
1	0	5	Brownish color clayey silt
2	5	14.2	Brownish color silt
3	14.2	23.4	Brownish color coarse grained sand
4	23.4	29.6	Brownish color fine silt
5	29.6	42	Brownish color medium grained sand
6	42	82.4	Brownish color Fine to Medium grained sand, 5% clay
9	82.4	88.6	Brownish color Fine to Medium grained sand, 10-20% clay
10	88.6	91.6	Brownish color Fine to Medium grained sand, 30-40% clay
11	91.6	97.8	Brownish color Medium to coarse grained sand, 5-10% clay
12	97.8	125.6	Brownish color Sticky clay, with 10-20% sand
14	125.6	128.6	Brown color Fine to medium grained sand
15	128.6	137.8	Brown color Medium grained sand, 10-20% clay
16	137.8	144	Brown color sandy clay
17	144	153.4	Brown color Medium to coarse grained sand, 10% clay
19	153.4	156.4	Brown color sandy clay
20	156.4	165.8	Brown color Fine to medium grained clayey sand
21	165.8	172	Brown color sandy clay
22	172	193	Brown color Sticky clay