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

# भोपाल शहरी समूह की राष्ट्रीय जलभृत मानचित्रण और प्रबंधन योजना

# NATIONAL AQUIFER MAPPING AND MANAGEMENT PLAN OF BHOPAL URBAN AGGLOMERATE

**North Central Region**
**Bhopal 2024**

भारत सरकार

Government of India

जल शक्ति मंत्रालय

Ministry of Jal Shakti

जल संसाधन विभाग,नदी विकास और गंगा संरक्षण

Department of Water Resources,
River Development and Ganga Rejuvenation

केंद्रीय भूजल बोर्ड

Central Ground Water Board

# भोपाल शहरी समूह की राष्ट्रीय जलभृत मानचित्रण और प्रबंधन योजना

# NATIONAL AQUIFER MAPPING AND MANAGEMENT PLAN OF BHOPAL URBAN AGGLOMERATE

## North Central Region
## Bhopal 2024

डॉ. सुनील कुमार अम्बष्ट
अध्यक्ष
Dr. Sunil Kumar Ambast
Chairman

सत्यमेव जयते

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन,
नदी विकास और गंगा संरक्षण विभाग
केन्द्रीय भूमि जल बोर्ड
Government of India
Ministry of Jal Shakti
Department of Water Resources,
River Development & Ganga Rejuvention
Central Ground Water Board

**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 $km^2$ 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 agencies.

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**

Bhujal Bhawan, NH-IV, Faridabad-121001 (Haryana) Tel : 0129-2477101, 0129-2477104
E-mail : chmn-cgwb@nic.in | Fax 0129-2477200

ए. के. बिस्वाल
क्षेत्रीय निदेशक
A.K. Biswal
Regional Director

आज़ादी का अमृत महोत्सव
भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास एवं गंगा संरक्षण मंत्रालय
केन्द्रीय भूमिजल बोर्ड, उत्तर मध्य क्षेत्र, भोपाल
Government of India
Ministry of Jal Shakti
Department of Water Resources, R D & G R
Central Ground Water Board, North Central Region, Bhopal

# Foreword

The state of Madhya Pradesh is in the process of an accelerated development in the fields of irrigation and industrial activities and groundwater occupies a key position in the developmental activities of the state. Although, groundwater is a replenishable resource, over extraction of groundwater, recurrent droughts, varied monsoon pattern etc., are leading to situation on which several blocks of the state have been categorized as over exploited to Semi- critical.

National Project on Aquifer Mapping 2.0 (NAQUIM 2.0) aims at identification and understanding area specific groundwater related issues for recommending issue specific recommendations for better management and sustainable development of groundwater. The study involves a scientific process, where in a combination of geological, geophysical, hydrological and chemical analyses are applied to characterize the quantity, quality and sustainability of groundwater in aquifers.

Under the National Project on Aquifer Mapping 2.0 (NAQUIM 2.0), Central Groundwater Board (CGWB), North Central Region, Bhopal has taken up Urban Agglomerates in Bhopal district to prepare the aquifer maps in 1:10000 scale and formulate the focused interventions for aquifer management. Urban areas face a range of complex issues related to pollution and overexploitation of water resources due to dense populations. These challenges include industrial emissions, pollutants from transportation, inadequate waste and sewage management, and unplanned construction disrupting natural drainage systems. Encroachment on open lands and water catchment areas, coupled with increased concretization, contributes to surface and groundwater pollution, fluctuating groundwater levels, waterlogging, and ecosystem degradation. Contaminated groundwater threatens drinking water quality, aquatic ecosystems, and long-term water resource management. This study includes the demarcation of aquifers in both horizontal and vertical extents, assessment of their suitability for drinking water supply, analysis of changes in groundwater levels over past decades, demarcation of recharge zones and assessment of groundwater quality and accordingly Proper Management Plan for sustainability of groundwater resources.

Geographical area of Bhopal Urban Agglomerate is 416 km$^2$ in part of Phanda Block of Bhopal District. The area is mainly occupied by Deccan Trap Basalt and rocks of Vindhyan Supergroup. As per the Dynamic Groundwater Resources Assessment Report (2023), study area falls under Semi-Critical category.

I would like to place on record, my appreciation of the efforts of Mrs. Paisnee Patel, Scientist-C, Sh. Kamlesh Ojha, Scientist-C, Ms. Saumya Chaudhary, Scientist-B, Sh. Tej Singh, Assistant Chemist and Ms. Saumya Siddartha, Assistant Geophysicist for carrying out the study in Bhopal Urban Agglomerate. Mrs. Paisnee Patel, Scientist-C deserves immeasurable debt for commendation for carrying extensive exercises and converging into report.

I sincerely hope that this report will serve as a valuable guide for sustainable development of groundwater in Bhopal Urban Agglomerate, Madhya Pradesh.

Water is elixir of life

**(Ashok Kumar Biswal)**
**Regional Director**

पर्यावास भवन, ब्लाक–1, चौथा तल, अरेरा हिल्स, जेल रोड, भोपाल–462011,
फोन : 0755–2557639, 2525201, 2760090, ई–मेल : rdncr-cgwb@nic.in, वेब साइट : www.cgwb.gov.in
Paryavas Bhawan, Block 1, 4th Floor, Arera Hills, Jail Road, Bhopal-462 011
Ph.:0755-2525201, 2557639, 2760090, E-mail : rdncr-cgwb@nic.in, Websites : www.cgwb.gov.in

# Acknowledgements

Firstly, the authors would like to extend their sincere gratitude to **Dr. Sunil Kumar Ambast**, **Chairman** of Central Ground Water Board, for providing the invaluable opportunity and necessary facilities to carry out the NAQUIM 2.0 study in Bhopal Urban Agglomerate.

The authors would also like to take this opportunity to extend sincere thanks to **Sh. Anurag Khanna**, **Member (North & West)** CGWB, for providing the essential opportunity and facilities needed to conduct the NAQUIM 2.0 study.

The authors are deeply grateful to **Sh. Ashok Kumar Biswal, Regional Director**, CGWB, NCR, Bhopal, for his invaluable support and guidance throughout the study. His leadership and encouragement were crucial to the successful completion of this report.

The authors also wish to extend their gratitude to the Executive Engineers of all zones of the Bhopal Municipal Corporation and their staff for their support and assistance regarding site selection for drilling of PZ/EW and establishing key wells.

The authors would like to take this opportunity to thank Dr. Krishna Kumar Dhote, Professor in the Department of Architecture & Planning at MANIT, Bhopal, as well as all the teaching and non-teaching staff of Maulana Azad National Institute of Technology, Bhopal, for providing the essential information needed to prepare the Artificial Recharge plan for MANIT.

The authors would like to extend thanks to officers of the Environmental Planning and Coordination Organization (EPCO) for providing valuable information regarding the water bodies of Bhopal.

The authors extend special thanks to Sh. Chittaranjan Biswal, Sc-C and Sh. Pradip Roy, Sc - B for their crucial assistance in the preparation of the Artificial Recharge Plan of Bhopal Urban Agglomerate.

The authors extend their heartfelt appreciation to all the officers of CGWB, NCR, Bhopal, including Dr. Rakesh Singh, Sc-D, Ms. Lata Udsaiya, Sc-C, Mrs. Anakha Ajai, Sc-C, Sh. Sumanta Kumar Mohanta, Sc-C, Ms. Vaishnavi Parihar, Sc-B, Sh. Kodali Lakshmana Pradeep, AHG and Sh. J. Sreemannarayan, STA. Their insightful feedback and constructive suggestions have significantly enhanced the quality of this study.

The authors would like to take an opportunity to thank all officers from CGWB, Division XII, Bhopal and officials deployed at drilling unit DTH/REL-06/113 for timely completion of drilling operations during the study.

The authors wish to express their gratitude to the officials of CGWB, NCR, Bhopal for help and cooperation in completing the study.

At last the authors wish to express their heartfelt gratitude to the Almighty and extend their sincere thanks to all those who have contributed to and supported in the completion of the NAQUIM 2.0 study report on the Bhopal Urban Agglomerate.

# Executive Summary

Over the past decade, India has witnessed a remarkable transformation in its urban landscape, characterized by rapid urbanization and unprecedented growth in urban population. There is a direct correlation between population growth, urbanization, and water resources. Rapid urbanization has resulted in the overexploitation of groundwater resources and posing a threat to groundwater quality due to various anthropogenic activities. To address these challenges, the Central Groundwater Board, North Central Region, Bhopal, initiated a study in the Bhopal Urban Agglomerate under NAQUIM 2.0 as part of the AAP 2023-24, covering an area of 416 $Km^2$. The primary objectives of the study were to delineate the horizontal and vertical distribution of aquifers, assess their sustainability for drinking water supply, monitor temporal changes in water levels, and evaluate groundwater quality within the study area including Union Carbide India Limited (known for the worst industrial disaster) and Bhanpur Khanti (The largest landfill site). Additionally, the study aimed to develop an issue-based, implementable management plan.

The study utilized data from 34 exploratory wells and 69 Vertical Electrical Soundings (VES), revealing that the major aquifers in the study area are formed by vesicular/fractured basalt and fractured Vindhyan sandstone. Exploration results indicated a limited thickness of deeper aquifers within the area. Depth to water level data of 87 observation wells were utilized to assess groundwater behaviour within the shallow aquifers, showing an average water level ranging between 5-10 mbgl. A ten-year trend analysis (2013-2023) indicated a declining water level trend in some wells, at a rate of 0-0.15 m/year, largely due to increased groundwater demand driven by population growth. A direct correlation between the depth to water level in the shallow aquifer and rainfall was established by interpreting rainfall and water level data for the year 2023. Waterlogging conditions was observed near waterbodies attributed to siltation in waterbodies and encroachment around them. Groundwater quality analysis from 83 monitoring stations identified nitrate and heavy metal (Fe and Mn) contamination in the study area. Nitrate pollution is linked to domestic effluent and sewage as evidenced by bivariate plot of $NO_3^-/Cl^-$ vs. Cl, while heavy metal contamination was found to be geogenic. The water quality index indicated that, except for areas impacted by wastewater from automobile cleaning, the shallow aquifers are generally suitable for drinking purposes. Rock-water interaction is the primary factor influencing groundwater quality in and around UCIL as suggested by Gibb's Diagram, with no significant contamination related to the UCIL gas tragedy. Additionally, only Mn contamination was found at the Bhanpur Khanti landfill site which is geogenic in nature. Paired t-test analysis proved that groundwater quality of shallow aquifer is affected by monsoon. However, surface water quality is deteriorating due to the mixing of untreated sewage and wastewater.

To address the identified issues, the study proposed an issue-based management plan, including the delineation of recharge-worthy areas and proposed artificial recharge structures. The recharge-worthy areas, located outside the urban boundary, were recommended for the construction of 94 check dams, 110 gully plugs, and 7 percolation tanks, with a cumulative recharge capacity of 338 Ham. Additionally, rooftop rainwater harvesting in urban areas was suggested, contributing to a recharge potential of 179.57 Ham. The plan also recommended

utilization of existing unused dug wells as recharge wells and installation of storage tanks for rainwater collection in non-recharge-worthy areas. For catering the groundwater demand, Groundwater potential zones have been demarcated based from geophysical data. These zones were identified in the northwestern and northeastern portions of the study area, with a suggested borewell depth of up to 80 mbgl. Hydrofracturing was recommended as a viable option for areas with limited deeper aquifer thickness. To mitigate nitrate contamination, utilization of existing STPs at its full capacity and lining of unlined canal were recommended. Additionally, desilting of water bodies was recommended to mitigate waterlogging issues, along with prohibiting the direct disposal of sewage and wastewater into surface water bodies to prevent deterioration of surface water quality. Finally, the study called for district administration to take necessary action against illegal groundwater extraction to ensure the sustainable management of this vital resource.

# कार्यकारी सारांश

पिछले दशक में, भारत के शहरी परिदृश्य में एक महत्वपूर्ण परिवर्तन देखा गया है, जिसमें तीव्र शहरीकरण और शहरी जनसंख्या में अभूतपूर्व वृद्धि हुई है। जनसंख्या वृद्धि, शहरीकरण और जल संसाधनों के बीच सीधा संबंध है, तीव्र शहरीकरण ने भूजल संसाधनों के अत्यधिक दोहन का कारण बना दिया है और विभिन्न मानवजनित गतिविधियों के कारण भूजल की गुणवत्ता के लिए खतरा उत्पन्न हो रहा है। इन चुनौतियों का समाधान करने के लिए, केंद्रीय भूजल बोर्ड, उत्तर मध्य क्षेत्र, भोपाल ने NAQUIM 2.0 के तहत भोपाल शहरी समूह में 416 वर्ग किमी के क्षेत्र को कवर करते हुए एक अध्ययन शुरू किया। इस अध्ययन का मुख्य उद्देश्य जलभृतों के क्षैतिज और ऊर्ध्वाधर वितरण को स्पष्ट करना, पीने के पानी की आपूर्ति के लिए उनकी स्थिरता का आकलन करना, जल स्तर में समय के साथ होने वाले परिवर्तनों की निगरानी करना और अध्ययन क्षेत्र के भीतर भूजल गुणवत्ता का मूल्यांकन करना जिसमें यूनियन कार्बाइड इंडिया लिमिटेड (जो सबसे खराब औद्योगिक आपदा के लिए जाना जाता है) और भानपुर खंती (सबसे बड़ा लैंडफिल साइट) भी शामिल रहे।इसके अलावा, इस अध्ययन का उद्देश्य एक मुद्दा-आधारित, क्रियान्वित करने योग्य प्रबंधन योजना विकसित करना था।

अध्ययन ने 34 खोजी कुओं और 69 वर्टिकल इलेक्ट्रिकल साउंडिंग्स (VES) से प्राप्त आंकड़ों का उपयोग किया, जिससे पता चला कि अध्ययन क्षेत्र में प्रमुख जलभृत वेसिक्युलर/दरारयुक्त बेसाल्ट और दरारयुक्त विंध्यन बलुआ पत्थर द्वारा बने हैं। अन्वेषण परिणामों ने क्षेत्र में गहरे जलभृतों की सीमित मोटाई को इंगित किया। उथले जलभृतों के भीतर भूजल व्यवहार का आकलन करने के लिए 87 अवलोकन कुओं के जल स्तर आंकड़ों का उपयोग किया, जिसमें औसत जल स्तर 5-10 मीटर नीचे भूमि स्तर के बीच पाया गया। दस साल के रुझान विश्लेषण (2013-2023) में कुछ कुओं में जल स्तर के घटने की प्रवृत्ति पाई गई, जो मुख्यतः जनसंख्या वृद्धि से प्रेरित भूजल मांग में वृद्धि के कारण रही। 2023 के वर्षा और जल स्तर आंकड़ों की व्याख्या से उथले जलभृतों में जल स्तर की गहराई और वर्षा के बीच सीधा संबंध स्थापित हुआ। जल निकायों के पास जलभराव की स्थिति पाई गई, जो जल निकायों में गाद जमने और उनके आसपास अतिक्रमण के कारण हुई। 83 निगरानी स्टेशनों से भूजल गुणवत्ता विश्लेषण में अध्ययन क्षेत्र में नाइट्रेट और भारी धातु (Fe और Mn) संदूषण की पहचान हुई। नाइट्रेट प्रदूषण घरेलू अपशिष्ट और सीवेज से संबंधित रहा, जैसा कि $NO_3^-/Cl^-$ बनाम Cl के द्विआधारी ग्राफ से प्रमाणित हुआ, जबकि भारी धातु संदूषण भूगर्भिक पाया गया। जल गुणवत्ता सूचकांक ने संकेत दिया कि, ऑटोमोबाइल की सफाई से प्रभावित क्षेत्रों को छोड़कर, उथले जलभृत पीने के लिए आमतौर पर उपयुक्त पाए गए। रॉक-वॉटर इंटरैक्शन यूसीआईएल के आसपास भूजल की गुणवत्ता को प्रभावित करने वाला प्रमुख कारक रहा, और यूसीआईएल गैस त्रासदी से संबंधित कोई महत्वपूर्ण संदूषण नहीं देखा गया। इसके अलावा, भानपुर खंती लैंडफिल साइट पर केवल Mn संदूषण पाया गया जो भूगर्भिक रूप से उत्पन्न हुआ। युग्मित टी-टेस्ट विश्लेषण ने साबित किया कि उथले जलभृत का भूजल गुणवत्ता मानसून से प्रभावित हुआ। हालाँकि, सतही जल गुणवत्ता बिना उपचार के सीवेज और अपशिष्ट जल के मिश्रण के कारण बिगड़ रही है।

पहचान की गई समस्याओं को हल करने के लिए, अध्ययन ने एक मुद्दा-आधारित प्रबंधन योजना प्रस्तुत की, जिसमें पुनर्भरण-योग्य क्षेत्रों का निर्धारण और कृत्रिम पुनर्भरण संरचनाओं का प्रस्ताव किया गया। शहरी सीमा के बाहर स्थित पुनर्भरण-योग्य क्षेत्रों में 94 चेक डैम, 110 गली प्लग और 7 पर्कोलेशन टैंकों के निर्माण का सुझाव दिया गया, जिनकी संयुक्त पुनर्भरण क्षमता 338 Ham है। इसके अलावा, शहरी क्षेत्रों

में छत के वर्षा जल संचयन को प्रोत्साहित किया गया, जिससे 179.57 Ham की पुनर्भरण क्षमता में वृद्धि हो सके। गैर-पुनर्भरण योग्य क्षेत्रों में वर्षा जल संग्रहण के लिए मौजूदा अप्रयुक्त कुओं को पुनर्भरण कुओं के रूप में उपयोग करने और जल संग्रहण टैंकों की स्थापना की बात की गई। भूजल की मांग को पूरा करने के लिए भूभौतिकीय आंकड़ों के आधार पर भूजल क्षमता क्षेत्रों का निर्धारण किया गया। ये क्षेत्र अध्ययन क्षेत्र के उत्तर-पश्चिमी और उत्तर-पूर्वी भागों में पहचाने गए, और बोरवेल की गहराई 80 मीटर तक रखने की सलाह दी गई। सीमित गहरे जलभृत मोटाई वाले क्षेत्रों के लिए हाइड्रोफ्रैक्चरिंग को एक व्यवहार्य विकल्प के रूप में अपनाने की बात कही गई। नाइट्रेट संदूषण को कम करने के लिए, मौजूदा एसटीपी का पूरी क्षमता से उपयोग करने और बिना लाइन वाले नहर की लाइनिंग करने की आवश्यकता बताई गई। इसके अलावा, जलभराव की समस्याओं को कम करने के लिए जल निकायों की सफाई का महत्व बताया गया, साथ ही सतही जल निकायों में सीवेज और अपशिष्ट जल के सीधे निपटान पर रोक लगाने की सलाह दी गई, ताकि सतही जल की गुणवत्ता में गिरावट न हो। अंत में, अध्ययन ने जिला प्रशासन से अवैध भूजल निकासी के खिलाफ आवश्यक कार्रवाई करने का आग्रह किया, ताकि इस महत्वपूर्ण संसाधन का स्थायी प्रबंधन सुनिश्चित हो सके।

# At a Glance

| S. No | Item Description | Results/Remarks |
|---|---|---|
| 1 | Area Covered | 416 $Km^2$ |
| 2 | Priority Type | Urban Agglomerate |
| 3 | Study Area | Bhopal Urban Agglomerate |
| 4 | Latitude | 23º04' and 23º24' N |
| 5 | Longitude | 77º10' and 77º40'E |
| 6 | Number of Zone/Ward | 21/85 |
| 7 | Block | Phanda |
| 8 | District | Bhopal |
| 9 | Categorization as per GWRA 2023 | Semi-Critical |
| 10 | Principle Aquifer | Deccan Trap Basalt and Sandstone of Vindhyan Super group of rocks |
| 11 | Major Aquifer | Weathered/Vesicular/Fractured Basalt and Weathered/Fractured/ Sandstone |
| 12 | Yield of Aquifer | Deccan Trap basalt-0.1-4.75 lps<br>Vindhyan Sandstone-0.1-10.43 lps |
| 13 | Average Water Level (mbgl) | 5-10 |
| 14 | Projected Population (Urban) | 23,50,582 (Year 2023) |
| 15 | Issues Identified | ▪ Declining Groundwater level of shallow aquifer<br>▪ Water logging condition and rising groundwater level<br>▪ Water quality issues (Nitrate/ Heavy Metal/Total Hardness)<br>▪ Degradation of water bodies<br>▪ Limited thickness of deeper Aquifer<br>▪ Improper Well Design<br>▪ Illegal Groundwater Extraction |
| 16 | Management strategies | • Delineation of Recharge worthy area and Artificial recharge plan<br>• Recommendation for mitigation of Waterlogging<br>• Water quality management interventions including demarcation of safer aquifer<br>• Recommendation for Protection of waterbodies and their catchment area<br>• Hydro fracturing to enhance the yield of wells and demarcation of Groundwater potential zones<br>• Recommendation for drinking water source sustainability<br>• Regulation of Groundwater extraction |

# Table of Contents


| DESCRIPTION | | Page No. |
|---|---|---|
| **1. INTRODUCTION** | | 1 |
| 1.1 | Background of the Study | 1 |
| 1.2 | Priority type | 3 |
| 1.3 | Objectives | 3 |
| 1.4 | Previous Studies | 3 |
| **2. ABOUT THE STUDY AREA** | | 5 |
| 2.1 | Location | 5 |
| 2.2 | Population and Land use and Land cover Pattern | 5 |
| 2.3 | Cropping Pattern | 9 |
| 2.4 | Irrigation | 9 |
| 2.5 | Urban Area/Industrial Area | 9 |
| 2.6 | Climate and Rainfall | 10 |
| 2.7 | Geomorphology | 10 |
| 2.8 | Physiography | 10 |
| 2.9 | Soil | 14 |
| 2.10 | Geology | 14 |
| 2.11 | Prevailing Water Conservation Structures | 14 |
| **3. AQUIFER DISPOSITION** | | 17 |
| 3.1 | Objective | 17 |
| 3.2 | Methodology | 17 |
| 3.3 | Result and Discussion | 19 |
| | 3.3.1 Details of Exploration in and around the study area | 19 |
| | 3.3.2 Hydrogeology of the Study Area | 21 |
| | 3.3.3 Principal and Major Aquifer | 23 |
| | 3.3.4 Aquifer Characteristics | 23 |
| | 3.3.5 2-Dimensional Cross Section | 26 |
| | 3.3.6 3-D Model of Aquifer Disposition within Study Area | 28 |
| **4. GROUND WATER REGIME** | | 33 |
| 4.1 | Objective | 33 |
| 4.2 | Methodology | 33 |
| 4.3 | Result and Discussion | 35 |
| | 4.3.1 Pre-Monsoon Depth to Water Level of Shallow Aquifer | 35 |
| | 4.3.2 Post-Monsoon Depth to Water Level of Shallow Aquifer | 35 |
| | 4.3.3 Seasonal Water level fluctuation of shallow Aquifer | 35 |
| | 4.3.4 Ground water Flow Direction | 35 |
| | 4.3.5 Water Level Trend of Shallow Aquifer | 39 |
| | 4.3.6 Effect of Urbanization on Depth to Water Level of Shallow Aquifer | 39 |
| | 4.3.7 Rainfall and Depth to water level of shallow aquifer (2023) | 42 |
| **5. ASSESSMENT OF DYNAMIC GROUND WATER RESOURCES** | | 44 |
| 5.1 | Objective | 44 |
| 5.2 | Methodology | 44 |
| | 5.2.1 Categorization of Assessment Unit | 44 |

5.3 Result and Discussion 45
5.3.1 Comparison of Dynamic Ground Water Resources of year 2020, 2022 and 2023 46
**6. WATER QUALITY OF BHOPAL URBAN AGGLOMERATE** 48
6.1 Objective 48
6.2 Methodology 48
6.3 Result and Discussion 50
6.3.1 Ground Water Quality 50
6.3.2 Surface Water Quality 64
6.3.3 Water Quality of Rain Water 65
6.4 Ground Water Quality in and around Bhanpur Khanti (dumping site) and Union Carbide India Limited (UCIL) 67
6.4.1 Bhanpur Khanti 67
6.4.2 Union Carbide India Limited (UCIL) 69
**7. GROUNDWATER RELATED ISSUES** 72
**8. GROUND WATER MANAGEMENT PLAN** 75
**8.1 Delineation of Recharge worthy Area and Proposed Artificial Recharge Plan** 76
8.1.1 Objective 76
8.1.2 Methodology 76
8.1.3 Result and Discussion 78
8.1.3.1 Urban Watershed 80
8.1.3.2 Kolans Watershed 82
8.1.3.3 Kerwa Watershed 84
**8.2 Ground Water Quality Management Interventions** 87
8.2.1 Objective 87
8.2.2 Methodology 87
8.2.3 Result and Discussion 87
8.2.3.1 Issue: Nitrate Contamination in Shallow Aquifer 87
8.2.3.1 Management: Proper Sewerage disposal to mitigate nitrate contamination and reuse of recycled water 88
8.2.3.2 Issue: High Value of Total Hardness and Heavy metal Contamination (Fe, Mn) in shallow Aquifer 89
8.2.3.2 Management: Recommendation for high value of total hardness and Heavy metal contamination in shallow Aquifer 90
**8.3 Demarcation of Aquifers Suitable for Drinking Water Supply** 92
8.3.1 Objective 92
8.3.2 Materials and methods 92
8.3.3 Results and Discussion 92
**8.4 Identification of Ground Water Potential Aquifer for Drinking Water Supply** 96
8.4.1 Objective 96
8.4.2 Methodology 96
8.4.3 Result and Discussion 96

**8.5 A Plan for Drinking Water Source Sustainability** 99
8.5.1 Objective 99
8.5.2 Methodology 99
8.5.3 Result and Discussion 99
**8.6 Identification of Waterlogged Condition and Its Remediation** 106
8.6.1 Objective 106
8.6.2 Methodology 106
8.6.3 Results and discussion 106
**8.7 Management Plan for Ensuring Long Term Sustainability of Bore Wells** 109
8.7.1 Objective 109
8.7.2 Methodology 109
8.7.3 Result and Discussion 109
**8.8 Management Plan for Area Having Limited Deeper Aquifer Thickness** 111
8.8.1 Objective 111
8.8.2 Methodology 111
8.8.3 Result and Discussion 111
**8.9 Management Plan for Ensuring Protection of Water bodies from Pollution** 112
8.9.1 Objective 112
8.9.2 Methodology 112
8.9.3 Result and Discussion 112
**8.10 Recommendations of Regulation of Ground Water Extraction** 114
**9. CONCLUSIONS AND RECOMMENDATIONS** 117
**10. REFERENCES** 120
**ANNEXURES** 124

## List of Annexures

| Annexure | Description | Page No. |
|---|---|---|
| Annexure-I | Litholog of Exploratory wells | 124 |
| Annexure-II | Vertical Electrical Sounding data in and around study area | 131 |
| Annexure-III | Pre- and Post-Monsoon Ground water Level and Fluctuation for year 2023 of Bhopal Urban | 135 |
| Annexure-IV | Ground Water Samples collected from key wells stations during pre-monsoon and post-monsoon season under NAQUIM 2.0 (2023-24) | 137 |
| Annexure -V | Water Samples collected from Surface water bodies, Rain Water and Exploratory wells stations under NAQUIM 2.0 (2023-24) | 139 |
| Annexure-VI | Statistical outline of the measured water quality parameters of pre- and post-monsoon in shallow aquifer with comparison to Indian Standards for drinking water | 140 |
| Annexure-VII | Statistical outline of the measured water quality parameters in deeper aquifer with comparison to Indian Standards for drinking water | 141 |

| | | |
|---|---|---|
| Annexure-VIII | The maximum concentration of nitrate (mg/l) in shallow aquifer of Bhopal urban agglomerate during pre-monsoon and post-monsoon | 142 |
| Annexure-IX | The maximum concentration of total hardness (mg/l) in shallow aquifer of Bhopal urban agglomerate during pre-monsoon and post-monsoon | 143 |
| Annexure-X | Type of groundwater of shallow aquifer on the basis of Piper Trilinear Diagram in pre-monsoon and post-monsoon of Bhopal urban agglomerate under NAQUIM 2.0 | 143 |
| Annexure-XI | Type of groundwater of deeper aquifer on the basis of Piper Trilinear Diagram of Bhopal urban agglomerate under NAQUIM 2.0 | 145 |
| Annexure-XII | Irrigation Class in Shallow Aquifer in pre-monsoon and post-monsoon of Bhopal urban agglomerate under NAQUIM 2.0 | 146 |
| Annexure-XIII | Irrigation Class in Deeper Aquifer of Bhopal urban agglomerate under NAQUIM 2.0 | 148 |
| Annexure-XIV | Sample calculation of WQI for Ground Water of HP 34 represented shallow aquifer during post-monsoon | 148 |
| Annexure-XV | WQI Values for Shallow Aquifer ground water in pre-monsoon and post-monsoon sources of Study Area | 149 |
| Annexure-XVI | WQI Values for Deeper Aquifer ground water sources of Study Area | 151 |
| Annexure-XVII | Paired Sample t-test for significance of concentration difference in pre-monsoon and post-monsoon samples, Sample Size (N) = 51, Degree of Freedom = 50, and confidence level 95. | 152 |
| Annexure-XVIII | Ground water quality data of Bhopal urban agglomerate of shallow aquifer under NAQUIM 2.0 | 153 |
| Annexure-XIX | Ground water quality data of Bhopal urban agglomerate of Surface water, Rain water and Exploratory Wells under NAQUIM 2.0 | 162 |
| Annexure-XX | Chemical analysis results showing major ions concentrations in and around Bhanpur Khanti study area of Bhopal in Decmber-2014 | 163 |
| Annexure- XXI | Chemical analysis results showing major ions concentrations in and around Union Carbide India Limited (UCIL), Bhopal 2011 | 164 |
| Annexure XXII | Showing Groundwater Quality Results for basic parameters of areas surrounding Union Carbide India limited, Bhopal, 2023 | 165 |
| Annexure-XXIII | Showing Groundwater Quality Results for heavy metals of areas surrounding Union Carbide India limited, Bhopal, 2023 | 167 |
| Annexure-XXIV | Correlation matrix of pre-monsoon water samples of Shallow aquifer | 169 |
| Annexure-XXV | Co-relation matrix of post-monsoon water samples of Shallow aquifer | 170 |
| Annexure- XXVI | Strange Table to determine surface runoff coefficient | 171 |
| Annexure-XXVII | Norms Recommended for specific yield (Source: GEC-2015) | 172 |
| Annexure-XXVIII | Proposed Artificial Recharge structures of Kolans Watershed | 177 |
| Annexure-XXIX | Proposed Artificial Recharge structures of Kerwa watershed | 180 |
| Annexure-XXX | Categories Exempted from seeking No Objection Certificate for Ground Water extraction | 182 |
| Annexure- XXXI | Farmers Feedback Proforma | 183 |

| | | |
|---|---|---|
| Annexure-XXXII | Field Photographs | 187 |


## List of figures


| **Figure No.** | **Description** | **Page No.** |
|---|---|---|
| Fig. 1.1 | Picture showing the instruction letter of District Collector, Bhopal regarding declining water level and Photographs of Union Carbide India Limited and Bhanpur Khanti Landfill Site | 2 |
| Fig. 2.1 | Change in Population over period of time | 5 |
| Fig. 2.2 | Administrative map of the Study area | 7 |
| Fig. 2.3 | Land use/Land Cover pattern of year 2017 and 2022 | 8 |
| Fig. 2.4 | Geomorphological map | 11 |
| Fig. 2.5 | Physiography Map | 12 |
| Fig. 2.6 | Drainage Map | 13 |
| Fig. 2.7 | Change in Area of waterbodies in and around the study area | 16 |
| Fig. 3.1 | Location map of Geophysical surveys and Exploratory wells | 18 |
| Fig. 3.2 | Hydrogeological Map of the study area | 22 |
| Fig.3.3 | A map depicting thickness of shallow aquifer in and around study area | 24 |
| Fig. 3.4 | A map depicting transmissivity of deeper aquifer | 25 |
| Fig. 3.5 | A map showing directions of cross sections for deciphering aquifer disposition | 26 |
| Fig. 3.6 | Aquifer disposition along A-A’ | 29 |
| Fig. 3.7 | Aquifer disposition along B-B’ | 30 |
| Fig. 3.8 | Aquifer disposition along C-C’ | 31 |
| Fig. 3.9 | 3-D Model of Aquifer Disposition within the Study Area | 32 |
| Fig. 4.1 | Location Map of keywells | 34 |
| Fig. 4.2 | Pre-monsoon Depth to water level of shallow Aquifer (2023) | 36 |
| Fig. 4.3 | Post-monsoon Depth to water level of shallow Aquifer (2023) | 36 |
| Fig. 4.4 | Seasonal ground water level fluctuation map of shallow aquifer (2023) | 37 |
| Fig. 4.5 | Water table Contour Map of Phreatic Aquifer with flow direction of Ground Water | 38 |
| Fig. 4.6 | Pre-Monsoon groundwater level trend map of shallow aquifer | 40 |
| Fig. 4.7 | Post-Monsoon groundwater level trend map of shallow aquifer | 40 |
| Fig. 4.8 | Comparison between Pre-Monsoon Depth to water level map of shallow aquifer for year 2002, 2013 and 2022 | 41 |

| | | |
|---|---|---|
| Fig. 4.9 | Graph showing correlation between Rainfall and Depth to water level for the year 2023 | 43 |
| Fig. 5.1 | Dynamic Ground water Resource Estimation (2023) | 46 |
| Fig. 5.2 | Comparison between Dynamic Ground water Resources of Year 2020, 2022 and 2023 | 47 |
| Fig. 6.1 | Water Sampling Location Map | 49 |
| Fig. 6.2 | Spatial distribution of electrical conductivity of shallow aquifer (Pre-Monsoon, 2023) | 51 |
| Fig. 6.3 | Spatial distribution of electrical conductivity of shallow aquifer Monsoon, 2023) | 51 |
| Fig. 6.4 | Fluoride concentration map of shallow aquifer (Pre-Monsoon, 2023) | 53 |
| Fig. 6.5 | Fig. 6.5 Fluoride concentration map of shallow aquifer (Post-Monsoon, 2023) | 53 |
| Fig. 6.6 | Nitrate Contamination map of shallow aquifer (Pre-Monsoon, 2023) | 57 |
| Fig. 6.7 | Nitrate Contamination map of shallow aquifer (Post-Monsoon, 2023) | 57 |
| Fig. 6.8 | Total Hardness map of shallow aquifer (Pre-Monsoon, 2023) | 58 |
| Fig. 6.9 | Total Hardness map of shallow aquifer (Post-Monsoon, 2023) | 58 |
| Fig. 6.10 | Heavy Metal (Fe and Mn) contamination map of shallow aquifer (Pre-Monsoon, 2023) | 59 |
| Fig. 6.11 | Heavy Metal (Fe and Mn) contamination map of shallow aquifer (Post-Monsoon, 2023) | 59 |
| Fig. 6.12 | Piper linear diagram for shallow and deep aquifer | 60 |
| Fig. 6.13 | Gibb's Diagram for shallow Aquifer | 61 |
| Fig. 6.14 | USSL classification for shallow and deeper aquifer | 64 |
| Fig. 6.15 | Groundwater sampling locations in and around Bhanpur Khanti Landfill Site during 2014 and 2023 | 68 |
| Fig. 6.16 | Gibb's Diagram illustrating ground water chemistry in and around UCIL | 70 |
| Fig. 6.17 | Ground water sampling locations in and around UCIL during 2011 and 2023 | 71 |
| Fig. 7.1 | showing map of groundwater related issues within the study area | 74 |
| Fig. 8.1.1 | Different Layers used to demarcate the recharge worthy zone in and around the study area | 79 |
| Fig. 8.1.2 | Schematics of Filtration Tank | 81 |
| Fig. 8.1.3 | depicting Roof top rainwater harvesting with recharge of aquifer system | 82 |
| Fig. 8.1.4 | Proposed Watershed-wise Artificial Recharge Structures | 86 |
| Fig. 8.2.1 | Bivariate plot of $NO_3^-/Cl^-$ vs. $Cl^-$ | 87 |
| Fig. 8.2.1 | Pictures showing some unlined sewerage of Bhopal Urban Agglomerate | 89 |
| Fig. 8.2.2 | Wastewater disposal from automobile servicing and cleaning centre at Transport Nagar | 90 |
| Fig. 8.3.1 | Water Quality Index Map of Shallow aquifer for pre-monsoon (2023) | 95 |
| Fig. 8.3.2 | Water Quality Index Map of Shallow aquifer for post-monsoon (2023) | 95 |

| | | |
|---|---|---|
| Fig. 8.4.1 | Map of Transverse Resistance | 97 |
| Fig. 8.4.2 | Map of Longitudinal Conductance | 97 |
| Fig. 8.4.3 | Ground water Potential zone map | 98 |
| Fig. 8.5.1 | Layout of Maulana Azad National Institute of Technology with demarcation of Building No. 40 | 104 |
| Fig. 8.5.2 | Schematics of Dug cum Recharge well | 105 |
| Fig. 8.6.1 | Change in area of water bodies due to siltation and encroachment | 107 |
| Fig. 8.6.2 | Hydrographs of wells located in waterlogged areas | 107 |
| Fig. 8.6.3 | Map illustrate both the waterlogged areas and areas prone to waterlogging conditions | 108 |
| Fig. 8.7.1 | Recommended Well Design in areas having collapsible formation | 110 |
| Fig. 8.9.1 | Graph showing increasing Nitrate concentration and fecal coliform in Upper Lake | 113 |


## List of Tables

| Table No. | Description | Page No. |
|---|---|---|
| Table 2.1 | Change in Population in 9 decades | 6 |
| Table 2.2 | Comparison of LULC for Year 2017 and 2022 | 9 |
| Table 2.3 | Geology of the Study Area | 14 |
| Table 2.4 | Change in area of Water bodies | 16 |
| Table 3.1 | Details of Exploratory wells in and around the Study area | 19 |
| Table 4.1 | Trend of Depth to Water level within shallow aquifer during pre- and post-monsoon | 39 |
| Table 5.1 | Categorization of Assessment Unit | 44 |
| Table 5.2 | Area Details of Bhopal Urban | 45 |
| Table 5.3 | Ground Water Recharge Scenario of Bhopal Urban | 45 |
| Table 5.4 | Recharge from Other Sources in Bhopal Urban | 45 |
| Table 5.5 | Ground Water Extraction Scenario Bhopal Urban | 46 |
| Table 5.6 | Comparison between Dynamic Ground water Resources of Year 2020, 2022 and 2023 | 47 |
| Table 6.1 | Frequency distribution (in %) of electrical conductivity (µS/cm at 25°C) | 50 |
| Table 6.2 | Frequency distribution (in %) of chloride concentration (mg/l) | 52 |
| Table 6.3 | Frequency distribution (in %) of fluoride concentration (mg/l) | 52 |
| Table 6.4 | Frequency distribution (in %) of total hardness (mg/l) | 54 |
| Table 6.5 | Categorization of Total Hardness | 55 |
| Table 6.6 | Frequency distribution of Iron concentration | 55 |
| Table 6.7 | Frequency distribution of Manganese concentration | 56 |

| | | |
|---|---|---|
| Table 6.8 | Frequency distribution of RSC Values | 63 |
| Table 6.9 | Frequency distribution of USSL classification of the study area | 64 |
| Table 8.1.1 | Proposed Artificial Recharge Structures within Kolans Watershed | 83 |
| Table 8.1.2 | Proposed Artificial Recharge Structures within Kerwa Watershed. | 85 |
| Table 8.2.1 | Details of operational STP of Bhopal Urban Agglomerate | 88 |
| Table 8.2.2 | List of Wells with High Total Hardness (Recommendation: Use water for drinking purpose only After Boiling) | 90 |
| Table 8.2.3 | List of wells contaminated by Iron (Recommendation: To use only for domestic purpose) | 91 |
| Table 8.2.4 | List of wells contaminated by Manganese (Recommendation: To use only for domestic purpose) | 91 |
| Table 8.3.1 | The Minimum, Maximum and Mean value of WQI in Shallow and Deeper Aquifer | 93 |
| Table 8.3.2 | Percent Distribution of water samples in shallow and deeper aquifer based on Yenugu et al. WQI classification. | 93 |
| Table 8.5.1 | Existing STP location along with quantity of reuse of treated water | 100 |
| Table 8.5.2 | Calculation for deciding storage tank capacity | 101 |
| Table 8.5.3 | Month-wise generated runoff for building no. 40. | 101 |
| Table 8.5.4 | Month-wise Available Runoff for Recharge after Storage | 102 |
| Table 8.10.1 | List of firms which didn’t apply for NOC for ground water withdrawal | 114 |


## Abbreviations

IMD- India Meteorological Department
CGWB -Central Ground Water Board
NAQUIM -National Aquifer Mapping and Management programme
UCIL- Union Carbide India Limited
lps – litres per second
mbgl – meter below ground level
Km - kilometers
ICP-MS - Inductively Coupled Plasma Mass Spectrometer
BMC -Bhopal Municipal Corporation
WQI -Water Quality Index
DW -Dug well
HP -Hand pump
BDL – below detection limit
TDS – total dissolved solids
mamsl- metre above mean sea level
MPIDC- Madhya Pradesh Industrial Development Corporation

# 1. INTRODUCTION

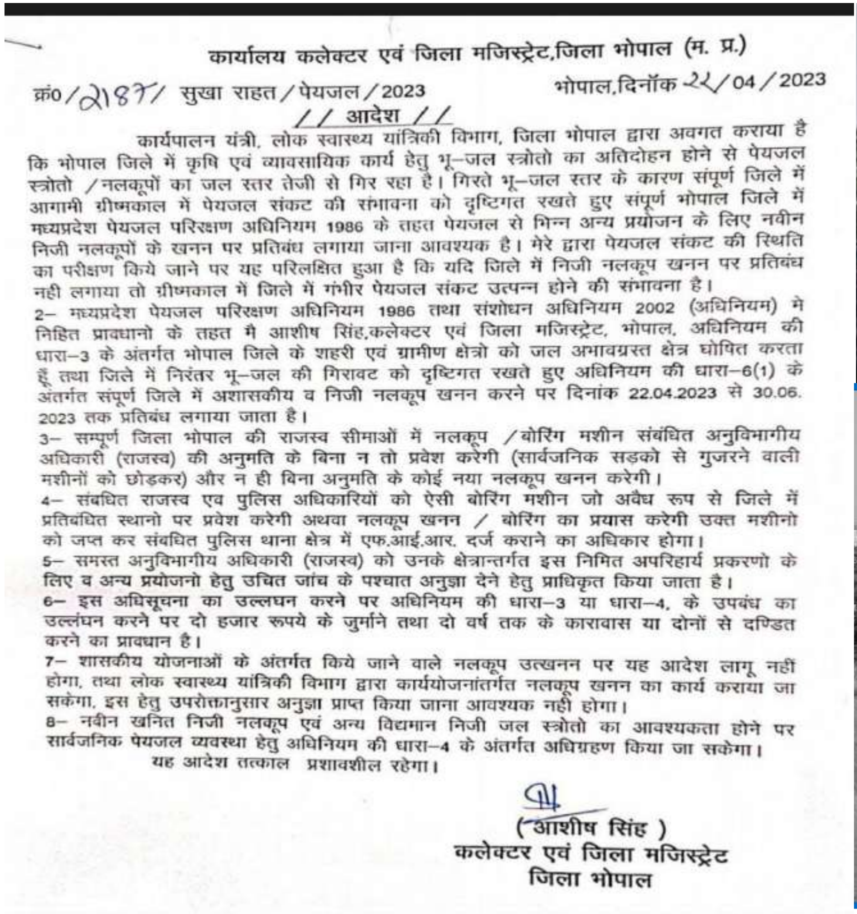
## 1.1 Background of the Study

The National Aquifer Mapping and Management (NAQUIM) program, initiated by the Central Groundwater Board (CGWB) in 2012, has played a crucial role in mapping and characterizing aquifers throughout India. In 2015-16, the Central Groundwater Board, North Central Region, Bhopal, conducted NAQUIM studies at the block level in Bhopal District. This effort aimed to develop detailed aquifer management plans on a 1:50,000 scale, offering valuable insights for sustainable groundwater management.

The study revealed significant groundwater related issues in Phanda block of Bhopal District including Bhopal Urban area such as declining water level and limited aquifer yield potential. Additionally, according to the Dynamic Groundwater Resource Estimation-2022, Bhopal Urban is categorized as a Semi-Critical category. Groundwater contamination investigations by the CGWB in 2011 near the Union Carbide India Limited (UCIL) site, which suffered a gas leak in 1984, and in 2014 around the largest landfill site, Bhanpur Khanti, highlighted groundwater quality issues in these areas. Population growth further exacerbates the challenges affecting groundwater quality and availability. **Fig.1.1** showing the instruction letter from District Collector, Bhopal concerning decline in water level and photographs of Union Carbide India Limited and Bhanpur Khanti Landfill Site.

Despite the utilization of NAQUIM study findings by various state government bodies for groundwater management and water supply, practical implementation at the local level has been inadequate. To address these shortcomings and meet future demands, NAQUIM 2.0 has been introduced by Central Groundwater Board. NAQUIM 2.0 focuses on detailed aquifer mapping at a 1:10,000 scale, aims to deliver high-resolution data, with a focus on enhancing the density of dynamic parameters such as groundwater levels and quality. It seeks to provide issue-specific scientific recommendations for groundwater management at the Panchayat level. Furthermore, a comprehensive strategy will be formulated to ensure the effective implementation of the proposed management solutions.

After the launch of NAQUIM 2.0, critical groundwater issues in Bhopal Urban were highlighted during the State Groundwater Coordination Committee meeting on April 19, 2023, chaired by the Additional Chief Secretary of the Water Resources Department, Government of Madhya Pradesh. In response, the Central Groundwater Board, North Central Region, Bhopal has taken up “Bhopal Urban Agglomerate” as a study area for effective monitoring of the impacts of urbanization on groundwater resources and the implementation of appropriate management practices. This study aims both horizontal and vertical delineation of aquifers, evaluating their suitability for drinking water supply, analysing historical changes in groundwater levels, assessing dynamic groundwater resources, and developing sustainable management strategies.



कार्यालय कलेक्टर एवं जिला मजिस्ट्रेट,जिला भोपाल (म. प्र.)

क्रं0/21871/ सुखा राहत/पेयजल/2023 भोपाल,दिनॉक 22/04/2023

// आदेश //

कार्यपालन यंत्री, लोक स्वास्थ्य यांत्रिकी विभाग, जिला भोपाल द्वारा अवगत कराया है कि भोपाल जिले में कृषि एवं व्यावसायिक कार्य हेतु भू-जल स्त्रोतो का अतिदोहन होने से पेयजल स्त्रोतो /नलकूपों का जल स्तर तेजी से गिर रहा है। गिरते भू-जल स्तर के कारण संपूर्ण जिले में आगामी ग्रीष्मकाल में पेयजल संकट की संभावना को दृष्टिगत रखते हुए संपूर्ण भोपाल जिले में मध्यप्रदेश पेयजल परिरक्षण अधिनियम 1986 के तहत पेयजल से भिन्न अन्य प्रयोजन के लिए नवीन निजी नलकूपों के खनन पर प्रतिबंध लगाया जाना आवश्यक है। मेरे द्वारा पेयजल संकट की स्थिति का परीक्षण किये जाने पर यह परिलक्षित हुआ है कि यदि जिले में निजी नलकूप खनन पर प्रतिबंध नही लगाया तो ग्रीष्मकाल में जिले में गंभीर पेयजल संकट उत्पन्न होने की संभावना है।

2- मध्यप्रदेश पेयजल परिरक्षण अधिनियम 1986 तथा संशोधन अधिनियम 2002 (अधिनियम) मे निहित प्रावधानो के तहत मै आशीष सिंह,कलेक्टर एवं जिला मजिस्ट्रेट, भोपाल, अधिनियम की धारा-3 के अंतर्गत भोपाल जिले के शहरी एवं ग्रामीण क्षेत्रो को जल अभावग्रस्त क्षेत्र घोषित करता हूँ तथा जिले में निरंतर भू-जल की गिरावट को दृष्टिगत रखते हुए अधिनियम की धारा-6(1) के अंतर्गत संपूर्ण जिले में अशासकीय व निजी नलकूप खनन करने पर दिनांक 22.04.2023 से 30.06.2023 तक प्रतिबंध लगाया जाता है।

3- सम्पूर्ण जिला भोपाल की राजस्व सीमाओं में नलकूप /बोरिंग मशीन संबंधित अनुविभागीय अधिकारी (राजस्व) की अनुमति के बिना न तो प्रवेश करेगी (सार्वजनिक सड़को से गुजरने वाली मशीनों को छोड़कर) और न ही बिना अनुमति के कोई नया नलकूप खनन करेगी।

4- संबधित राजस्व एव पुलिस अधिकारियों को ऐसी बोरिंग मशीन जो अवैध रूप से जिले में प्रतिबंधित स्थानो पर प्रवेश करेगी अथवा नलकूप खनन / बोरिंग का प्रयास करेगी उक्त मशीनो को जप्त कर संबधित पुलिस थाना क्षेत्र में एफ.आई.आर. दर्ज कराने का अधिकार होगा।

5- समस्त अनुविभागीय अधिकारी (राजस्व) को उनके क्षेत्रान्तर्गत इस निमित अपरिहार्य प्रकरणो के लिए व अन्य प्रयोजनो हेतु उचित जांच के पश्चात अनुज्ञा देने हेतु प्राधिकृत किया जाता है।

6- इस अधिसूचना का उल्लघन करने पर अधिनियम की धारा-3 या धारा-4, के उपबंध का उल्लंघन करने पर दो हजार रूपये के जुर्माने तथा दो वर्ष तक के कारावास या दोनों से दण्डित करने का प्रावधान है।

7- शासकीय योजनाओं के अंतर्गत किये जाने वाले नलकूप उत्खनन पर यह आदेश लागू नहीं होगा, तथा लोक स्वास्थ्य यांत्रिकी विभाग द्वारा कार्ययोजनांतर्गत नलकूप खनन का कार्य कराया जा सकेगा, इस हेतु उपरोक्तानुसार अनुज्ञा प्राप्त किया जाना आवश्यक नही होगा।

8- नवीन खनित निजी नलकूप एवं अन्य विद्यमान निजी जल स्त्रोतो का आवश्यकता होने पर सार्वजनिक पेयजल व्यवस्था हेतु अधिनियम की धारा-4 के अंतर्गत अधिग्रहण किया जा सकेगा।

यह आदेश तत्काल प्रशावशील रहेगा।

(आशीष सिंह )
कलेक्टर एवं जिला मजिस्ट्रेट
जिला भोपाल

**Instructions from District Collector, Bhopal regarding declining water level**


**Union Carbide India Limited**


**Bhanpur Khanti Landfill site**

**Fig. 1.1 showing the instruction letter of District Collector, Bhopal regarding declining water level and Photographs of Union Carbide India Limited and Bhanpur Khanti Landfill Site**

### 1.2 Priority type

An urban agglomerate refers to a densely populated area encompassing a central city along with its adjacent suburban and peri-urban regions, characterized by economic integration and functional interdependence.

Bhopal, the capital city of Madhya Pradesh, has undergone significant urbanization marked by population growth, industrialization, and infrastructural expansion. While urbanization has fostered economic development by attracting investments and generating employment opportunities, it has also led to negative consequences such as urban sprawl and unplanned development. These factors contribute to congestion, pollution, and strain on natural resources, particularly groundwater and surface water. The present study focuses on the Bhopal urban agglomerate, aiming to investigate groundwater-related issues arising from population growth and to devise strategies for their sustainable management.

### 1.3 Objectives

The report focuses on following key points:

- To decipher aquifer disposition in both horizontally and vertically and to assess the aquifer properties.
- Observation of aquifer wise depth to water level and detection of change in water level over a period of time.
- To assess the impact of urbanization on depth to water level of shallow aquifer.
- To observe the effect of rainfall on depth to water level of shallow aquifer.
- Assessment of Dynamic Groundwater Resources.
- To determine the effects of urbanization on groundwater quality and surface water quality.
- To assess the groundwater quality in and around large dumping site and Union Indian Carbide Limited (UCIL), known for gas tragedy.
- Identification and demarcation of safer aquifers for drinking water supply.
- A plan for drinking water source sustainability.
- Identification of water logging areas and possible management strategy.
- To identify the recharge worthy zone and prepare the artificial recharge plan.

### 1.4 Previous Studies

Previous studies, reports and publications of the study area are mentioned below;

**By Central Groundwater Board, North Central Region, Bhopal**

- Report on comprehensive hydrogeological surveys in Bhopal District under Indo-British Betwa groundwater project,1975-1980.
- Report on systematic hydrogeological surveys in Bhopal district,1990.

- Report on hydrogeological framework for urban development of Bhopal city, 1999.
- Report on detailed reappraisal hydrogeological surveys in Bhopal District 2003-04.
- Report on information of waterbodies of Bhopal City, 2009.
- Collaborative Hydrogeological studies in Central Institute of Agriculture Engineering (CIAE) Research Farm area, Nabibagh, Berasia road, Bhopal, 2010.
- Report on hydrogeological scenario of Bhopal city, 2011.
- District Brochure of Bhopal district, 2013.
- The Aquifer Mapping and Management Plan conducted at Phanda Block in Bhopal District, Madhya Pradesh during 2015-2016, at a scale of 1:50,000, revealed that the Vindhyan Sandstone and Deccan Trap basalt constitute the principal aquifers in the region. However, these aquifers were found to have limited yield potential due to their restricted porosity and the presence of limited fractures/joints. Additionally, a significant issue identified was the declining water levels observed in the Phanda Block.
- Groundwater Resource Assessment of Bhopal Urban using GEC-2015 methodology for the year of 2020 and 2022. The data indicates that stage of groundwater extraction was 79.46% in 2020 and decreased slightly to 71.13% by 2022. Despite this decrease, the area remained under the Semi-critical category for both years.
- Groundwater Quality Assessment in and around Bhanpur Khanti (dumping site) was carried out by CGWB in year 2014. It was the largest dumping site in the study area used by Bhopal Municipal Corporation for dumping of Municipal Solid Waste. The study identified that nitrate concentration and electrical conductivity exceeded the permissible limits set by the Bureau of Indian Standards for drinking water in certain locations surrounding the landfill site.
- The Groundwater Quality Assessment conducted in and around Union Indian Carbide Limited (UCIL) by CGWB in 2011found heavy metal contamination surrounding the area.

**Research Papers;**

- Sen et al; 2022, highlighted the issue of pollution in waterbodies through mixing of sewage.
- Wadwekar M and Pandey R, 2021; concluded the importance of rainwater harvesting to mitigate the water scarcity.
- Ghosh S and Salla S, 2014; highlighted that surface water quality of lower lake is in alarming stage.
- Kamat R; 2019 assessed the urban flood vulnerability of Bhopal due to increasing urbanization and haphazard construction.
- Tiwari, A., & Mishra, P. K. (2019) highlighted the change in urban landscape of Bhopal city with time.

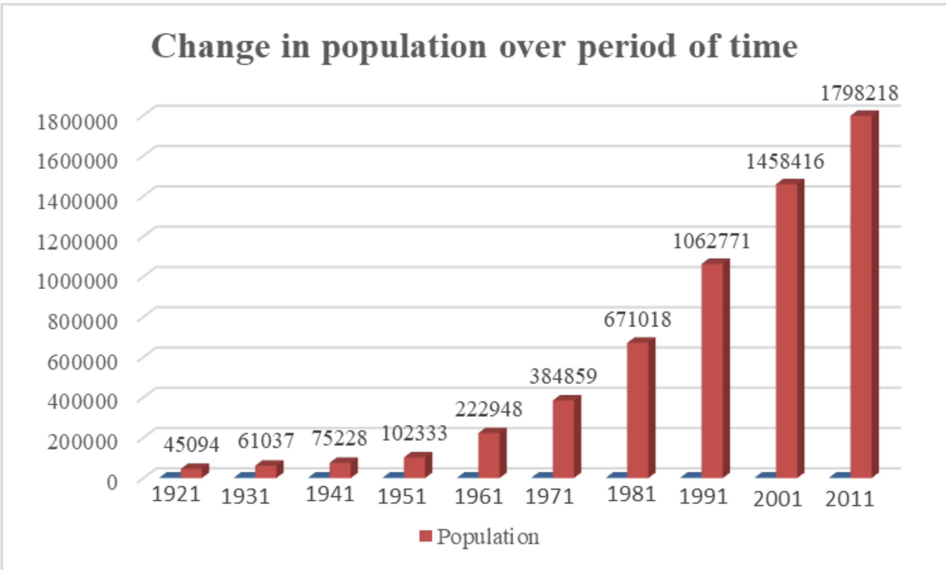
# 2. ABOUT THE STUDY AREA

## 2.1 Location

Bhopal urban, spanning over an area of about **416 Sq km**, lies in the southern part of the Bhopal district. It comes under administrative boundary of Phanda block and lies between North latitude **23$^{0}$04'** and **23$^{0}$24'** and East longitude **77$^{0}$10'** and **77$^{0}$40'**, falling in Survey of India Topo sheet No. **55E/7,55E/8,55E/11** & **55E/12**. Bhopal Urban area is divided into 21 zones and 85 wards. The Bhopal city is bounded by Berasia block on the north, Raisen district on the east and Sehore and Rajgarh district on the southwest and west respectively. Administrative map of the study area is given in **Fig.2.2**.

## 2.2 Population and Land use and Land cover Pattern

The 2011 census data reveals a substantial urban population surge over a span of 90 years, with an exponential increase observed from 45,094 individuals in 1921 to nearly 1.8 million by 2011 **(Fig.2.1 and Table:2.1).** This growth pattern, highlights a pronounced demographic transition. Calculating a consistent annual growth rate of 2.3%, from Census data of 2001 and 2011, projected population of city is approximately 2.4 million by 2023, reflecting a notable 31% escalation within a mere 12-year period.




(Source; Census report 2011)

**Fig. 2.1 Change in Population over period of time**

**Table 2.1 Change in Population in 9 decades**

| Year | Population | Change in population | Percentage growth |
|---|---|---|---|
| 1921 | 45094 | - | - |
| 1931 | 61037 | +15943 | 35.4 |
| 1941 | 75228 | +14191 | 23.2 |
| 1951 | 102333 | +27105 | 36.0 |
| 1961 | 222948 | +120615 | 117.9 |
| 1971 | 384859 | +161911 | 72.6 |
| 1981 | 671018 | +286159 | 74.4 |
| 1991 | 1062771 | +391753 | 58.4 |
| 2001 | 1458416 | +395645 | 37.2 |
| 2011 | 1798218 | +339802 | 23.3 |

The increasing population exerts heightened pressure on natural resources, driven by escalating demands for sustenance and livelihood. An attempt is made to compare changes in land use/land cover patterns between 2017 and 2022 in response to population growth. The population increased from 2060757 in 2017 to 2308912 in 2022, representing a 12% rise over five years. This demographic change corresponded with a **5.4%** expansion in built-up areas. Detailed alterations in various land cover types are documented in **Table 2.2**, while visual representations of these transformations are depicted in **Fig.2.3**.

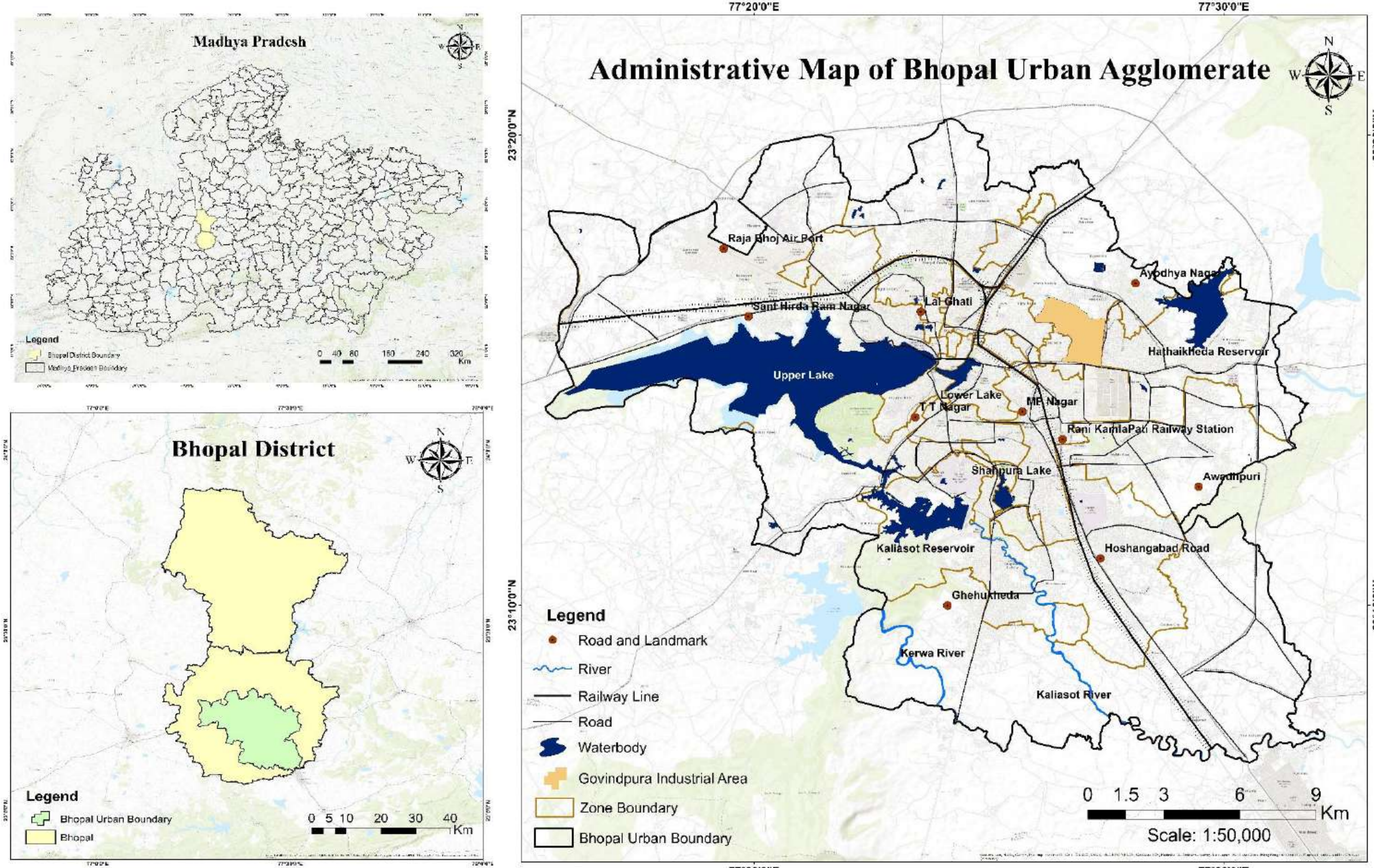
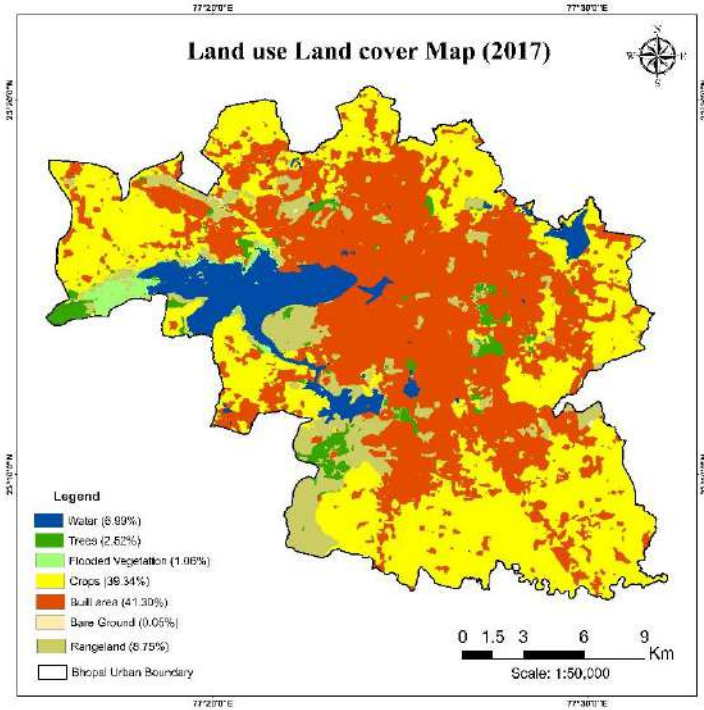
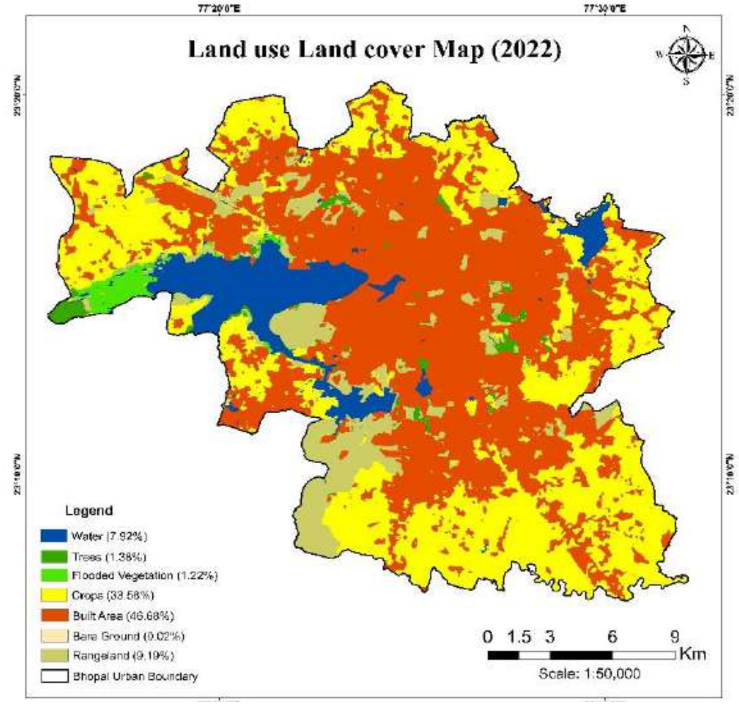
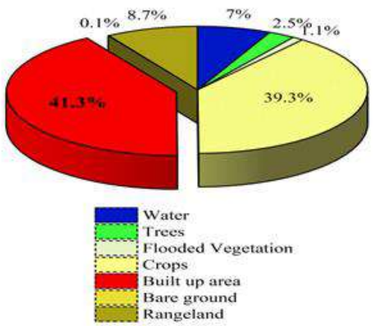



**Fig.2.2 Administrative map of the Study area**




(Source: ESRI Sentinel-2 Land Cover Explorer)



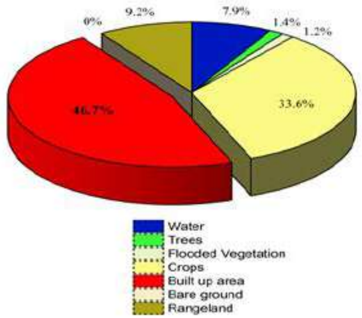




**Fig.2.3 Land use/Land Cover pattern of year 2017 and 2022**

**Table 2.2: Comparison of LULC for Year 2017 and 2022**

| Year | 2017 | 2022 | Change in Area % |
|---|---|---|---|
| **Type of Area** | **Area (Sq Km)** | **Area (Sq Km)** | |
| Water | 29.1 | 32.9 | 0.9 (Increase) |
| Trees | 10.5 | 5.8 | 1.1 (Decrease) |
| Flooded Vegetation | 4.4 | 5.1 | 0.2 (Increase) |
| Crops | 163.6 | 139.7 | 5.8 (Decrease) |
| **Built up area** | **171.8** | **194.1** | **5.4 (Increase)** |
| Bare ground | 0.2 | 0.1 | 0.0 |
| Rangeland | 36.4 | 38.2 | 0.4 (Increase) |

## 2.3 Cropping Pattern

Study area has a diverse cropping pattern influenced by its climate, soil, and water availability. Here's an overview of the common cropping patterns in and around Bhopal based on farmers feedback collected during the study:

- During the Rabi season (winter) from November to April major crops grown are wheat and pulses like gram, peas, lentils and pigeon peas.
- During the Kharif season (monsoon) from June to October significant crops grown are soyabean, paddy, urad, moong, corn etc. The availability of water from monsoon rains is crucial for rice cultivation. Soybean is a major oilseed crop in the region.
- Horticultural crops like fruits and vegetables are also grown in the area including Tomatoes, onions, and potatoes in various seasons depending on water availability and market demand. Mangoes, guavas, and pomegranates are common fruit crops.

## 2.4 Irrigation

About 140 $Km^2$ area of Bhopal Urban Agglomerate is covered by agricultural land. Irrigation primarily relies on surface water supplies. During fieldwork and while gathering feedback from farmers, it was noted that surface water supply remains accessible for agriculture throughout both the kharif and rabi seasons. In instances when surface water is not readily available, farmers rely on bore wells, which they operate for approximately 2 to 4 hours daily.

## 2.5 Urban Area/Industrial Area

Urban areas in Bhopal are characterized by their dense development and diverse land uses. They include Residential Zones, Commercial Zones, Transportation Infrastructure, Recreational and Cultural Spaces. The total build-up area of Bhopal Urban Agglomerate is depicted in **Fig. 2.3**.

The Govindpura Industrial Cluster in Bhopal **(Fig.2.2)** is a notable industrial area that plays a significant role in the region's economic development. The Industrial Park spans over an area of **728.99 Ha** and is dedicated to Micro, Small, and Medium Enterprises (MSMEs), positioned approximately **23 Km** from the Mandideep Industrial Area (MPIDC).

**2.6 Climate and Rainfall**

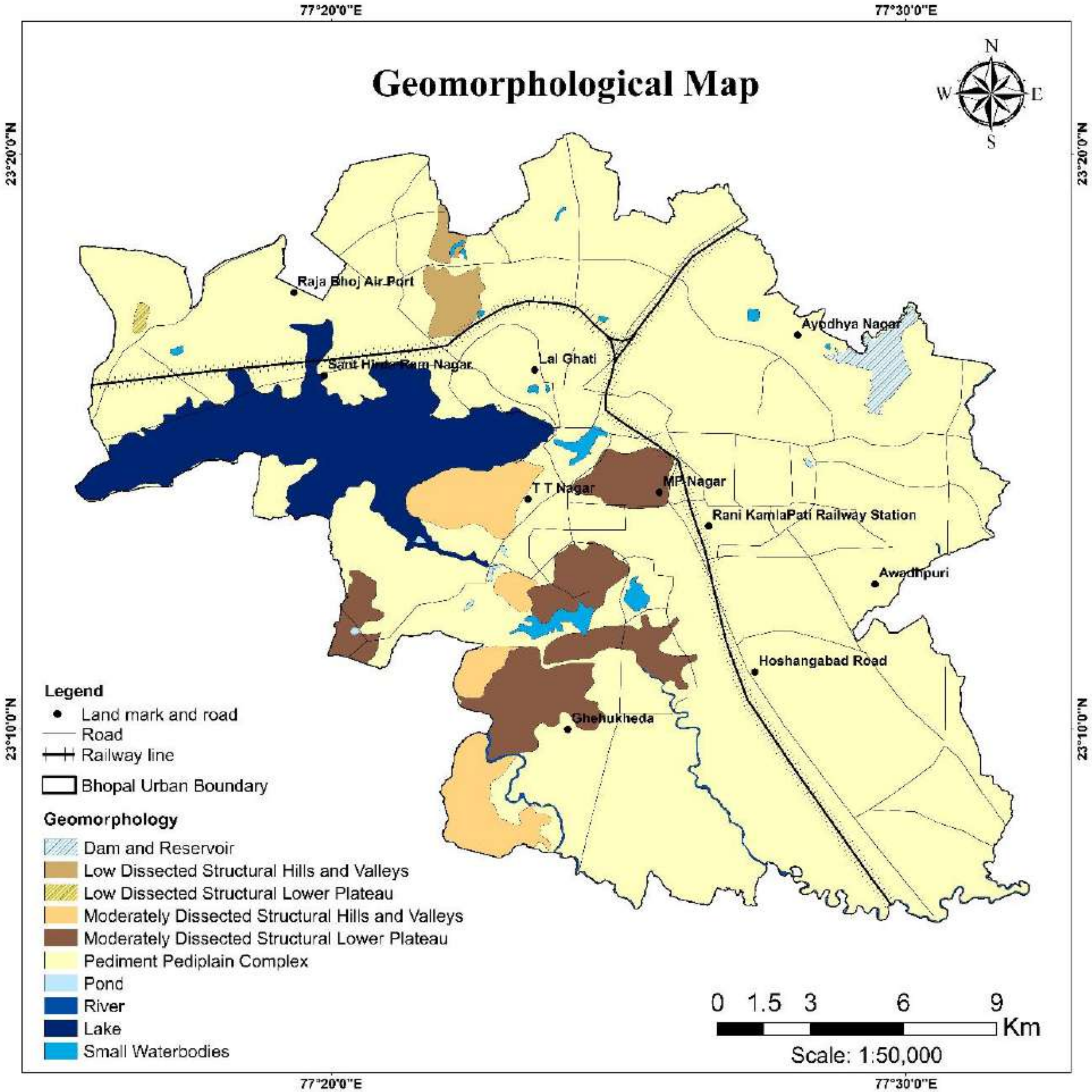
Bhopal experiences a humid subtropical climate characterized by gentle, arid winters, sweltering summers and a humid monsoon season. Summer typically begins in late March and lasts until mid-June, marked by an average temperature of around 30°C. May sees the peak of summer, with temperatures often surpassing 40°C (104°F), (A. Tiwari and P. K. Mishra, 2019). The average normal rainfall of the study area received from South-west monsoon during the month of June to September is recorded around 1008 mm (IMD).

**2.7 Geomorphology**

The geomorphological features of the area are primarily characterized by low to moderately dissected structurally hills and valleys, with a predominant coverage of a pediment-pediplain complex **(Fig.2.4).** This landscape is further accentuated by the presence of numerous lakes and water bodies, a defining characteristic of Bhopal, due to which Bhopal is known as the "city of lakes." These geomorphological characteristics can be attributed to the underlying lithology, which comprises a combination of basaltic and sandstone formations. Basaltic formations typically contribute to relatively flat surfaces, while the presence of sandstone formations may lead to the development of hills and valleys through erosional processes.

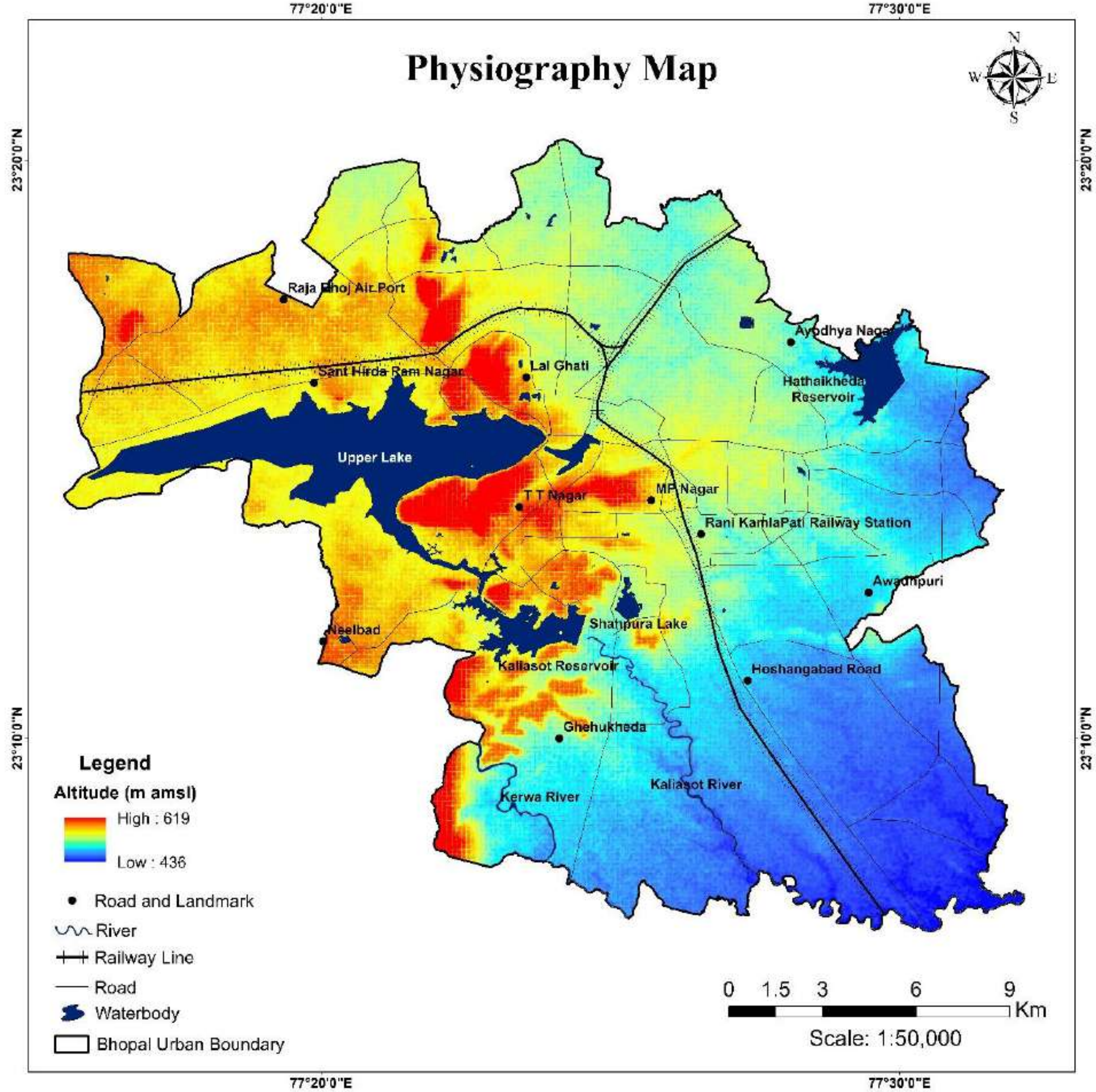
**2.8 Physiography**

The region exhibits undulating topography, with elevations ranging from 436 to 619 (mamsl). Study area lie in the part of Betwa sub-basin of Yamuna River Basin (NAQUIM report of Phanda block). Drainage within the study area is primarily facilitated by the Kaliasot River, a tributary of the Betwa River, and the Kerwa River, which serves as a sub-tributary to the Betwa River **(Fig.2.5).** The Upper Lake stands out as one of the prominent lakes within the study area, attracting attention due to its notable features. Moreover, the region encompasses several reservoirs, including the Kaliasot and the Hathaikheda Reservoir, contributing to the water resources. According to Gupta et al. (2021), the drainage pattern observed in the area is predominantly dendritic to sub-dendritic, occasionally exhibiting parallel features in certain areas. This drainage pattern is depicted in **Fig. 2.6.**



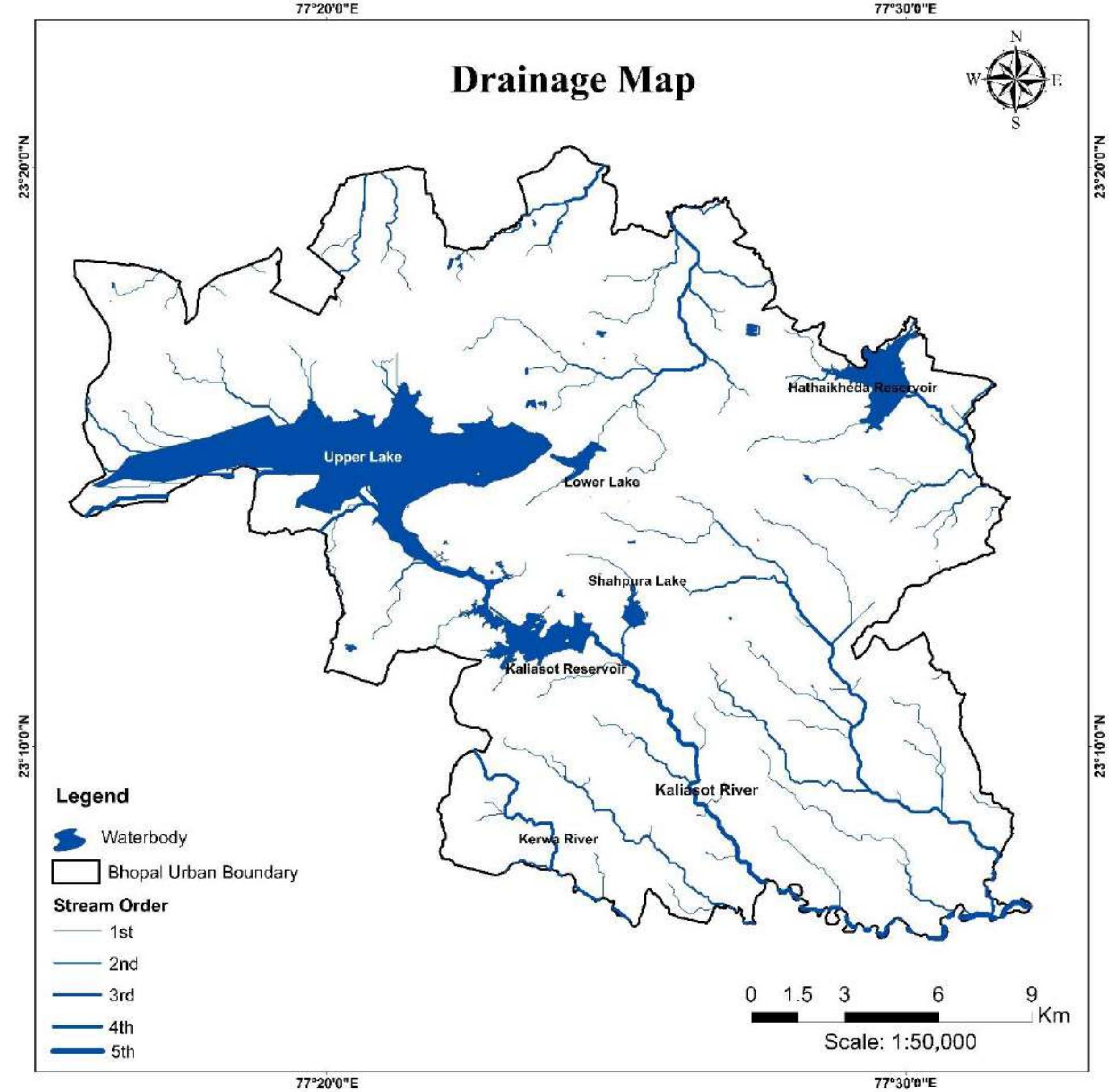

(Source: Geological Survey of India)

**Fig. 2.4 Geomorphological map**




(Source: USGS)

**Fig.2.5 Physiography Map**




(Source: USGS)

**Fig.2.6 Drainage Map**

## 2.9 Soil

The predominant soil type covering a significant portion of the study area is black cotton soil, resulting from the weathering process of the Deccan trap formation. Additionally, in certain areas, yellowish-red and mixed soils are observed, which are outcomes of sandstone weathering processes.

## 2.10 Geology

The geological composition of the study area consists of the Upper Proterozoic-aged Vindhyan Supergroup, specifically the Bhander Group, and the Upper Cretaceous-Lower Eocene aged Deccan trap basalt **(Table:2.3).** The Vindhyan Supergroup is predominantly found in the southern, southeastern, and eastern regions, while the Deccan trap basalts are exposed in the western and northern areas, filling the valleys of the pre-existing Vindhyan topography as lava flows. According to the Geological Survey of India, localized patches of alluvium are present in the southeastern part of the area; however, various geophysical surveys and explorations have not identified alluvium within the study area.

**Table:2.3 Geology of the Study Area**

| **Age** | **Group** | **Formation** |
|---|---|---|
| Upper Cretaceous to Lower Eocene | Deccan Trap (Malwa Group) | Deccan Trap Basalt |
| ----------------------------------------(Unconformity) ----------------------------------------------- | | |
| Upper Proterozoic | Vindhyan Supergroup | Upper Bhander Sandstone and Sirbu Shale |

(Source: Geological Survey of India)

## 2.11 Prevailing Water Conservation Structures

Bhopal, often referred to as the "City of Lakes," is renowned for its numerous lakes that add to its scenic beauty and play a crucial role in the city's ecology and water management. There are about 18 water bodies of varying sizes within and around its vicinity. Detailed information about the main water bodies is described below:

- **Upper Lake**

The Upper Lake, a prominent feature of Bhopal city, having a surface area of 31 km² and a catchment area of 361 km². It is located at the western edge of the study area and serves as a major source of surface water supply. However, the inflow of untreated sewage and domestic waste has led to the deterioration of the lake's water quality.

- **Lower Lake**

The Lower Lake is located at the eastern end of the Upper Lake and is almost entirely surrounded by urban development. It has a catchment area of 9.6 km² and a water spread area of 1.29 km². Unlike the Upper Lake, the Lower Lake is not utilized for water supply and suffers from pollution due to the inflow of untreated sewage.

- **Shahpura Lake**

Shahpura Lake has a catchment area of 8.29 $km^2$ and a water spread area of 0.96 $km^2$. It is surrounded by human settlements and is affected by the inflow of untreated wastewater.

- **Kaliasot Reservoir**

The Kaliasot Reservoir was constructed for storage purposes to conserve the excess water discharged from the Upper Lake through the Bhadbhada spill gate. It is located near the WALMI Institute, the reservoir has a catchment area of 381.38 $km^2$ and a gross storage capacity of 38.387 MCM.

- **Motia Tank**

Motia Tank is a small water body with a water spread area of 0.0189 $km^2$. It was primarily constructed for washing purposes and Nistar activities.

- **Siddiqui Hussain and Munsi Hussain Tank**

These small waterbodies located near Motia Tank currently receive only wastewater. Siddiqui Hussain Tank, in particular, is completely overgrown with vegetation and has transformed into swampy land.

- **Lendiya Talab**

It is located near Shahjahanabad, and having a water spread area of less than 1 $km^2$. It was historically used for horticulture but now primarily receives sewage from nearby settlements.

- **Sarangpani Lake**

Sarangpani Lake was originally utilized for horticultural activities before the establishment of BHEL. After the development of BHEL, the lake was converted into a settling tank for sewage from nearby settlements.

- **Char Imli Pond**

This small waterbody, originally used for horticulture, has experienced pollution in recent years due to the development of slums in the upstream direction, which has led to the discharge of sewage into the waterbody.

- **Laharpur Reservoir**

Laharpur Reservoir, located in the southwest corner of the city, was built to store rainwater for irrigation purposes. It has a water spread area of 3.5 $Km^2$ and a storage capacity of 6.13 million cubic meters (MCM). However, due to rapid urbanization, the reservoir now receives untreated sewage from the surrounding areas.

- **Hathaikheda Reservoir**

Located about 5 km northeast of BHEL Township, this reservoir was constructed for irrigation purposes. It has a water spread area of 1.13 $Km^2$. The inflow of untreated sewage from the nearby BHEL Township is a primary factor contributing to the deterioration of its water quality.

- **Kerwa Reservoir**

Kerwa Reservoir, situated outside the study area, is a crucial source of surface water supply for the city. It has a catchment area of 5.24 $Km^2$ and a gross capacity of 25 MCM.

Change in area of waterbodies are tabulated in **table: 2.4** and illustrating in **Fig. 2.7.**

**Table: 2.4 Change in area of Waterbodies**

| S. No | Waterbody | Latitude | Longitude | Area (Sq-Km) before 2010 | Area (Sq-km) 2019 |
|---|---|---|---|---|---|
| 1 | Upper Lake | 23.249722 | 77.339722 | 31 | 36.817 |
| 2 | Lower Lake | 23.247778 | 77.406944 | 1.29 | 0.714 |
| 3 | Shahpura Lake | 23.203889 | 77.421667 | 0.96 | 0.553 |
| 4 | Motia Tank | 23.265556 | 77.392500 | 0.0189 | 0.062 |
| 5 | Siddiqui Hussain | 23.265556 | 77.395000 | 0.01 | 0.081 |
| 6 | Munsi Hussain Tank | 23.265556 | 77.395000 | 0.012 | 0.021 |
| 7 | Lendiya Talab | 23.275000 | 77.391389 | 0.015 | 0.022 |
| 8 | Sarang pani Lake | 23.243611 | 77.472222 | 0.042 | 0.038 |
| 9 | Char Imli Pond | 23.225278 | 77.421389 | 0.012 | 0.03 |
| 10 | Laharpur Reservoir | 23.196200 | 77.479100 | 3.5 | 0.071 |
| 11 | Hathaikheda Reservoir | 23.270556 | 77.495000 | 1.13 | 3.9 |
| 12 | Kerwa Reservoir | 23.165278 | 77.361111 | 5.24 | 4.041 |
| 13 | Kaliasot Reservoir | 23.197500 | 77.399722 | 1.2 | 4.509 |

(Source: CGWB and https://vedas.sac.gov.in)

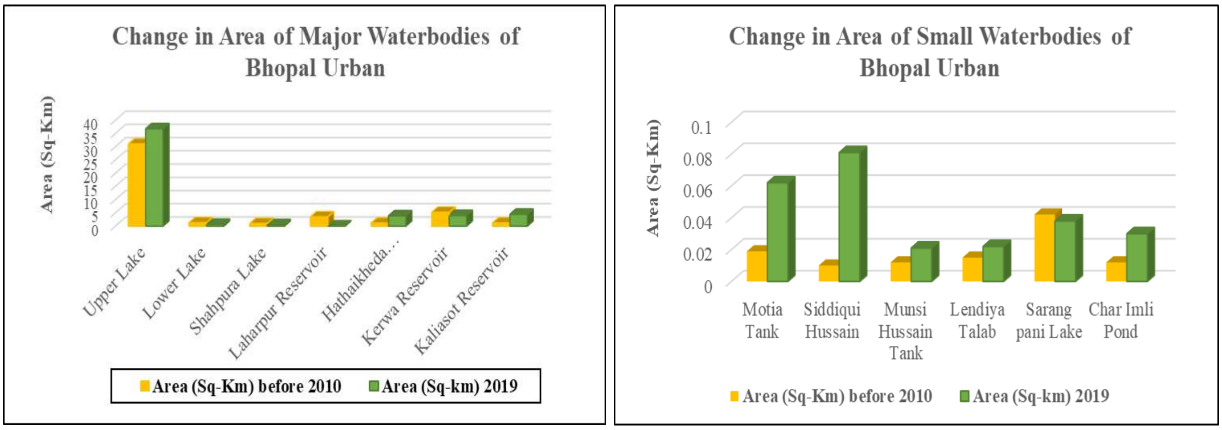



**Fig. 2.7 Change in Area of waterbodies in and around the study area**

# 3. AQUIFER DISPOSITION

## 3.1 Objective

This chapter aims to elucidate the vertical and lateral disposition of aquifers within the study area with delineation of their inherent properties.

## 3.2 Methodology

The present study utilized data derived from the exploratory boreholes drilled by the Central Groundwater Board (CGWB), along with information gathered from extensive geophysical surveys exclusively Vertical Electrical Sounding (VES). VES were conducted in and around the study area due to open space constraints in urban area. A total 34 lithologs (25 existing and 9 new) acquired from exploration data and 69 (39 existing and 30 new), VES data **(Fig. 3.1)** were utilized to construct two-dimensional geological cross-sections using Rockworks 17 software. The 2-D and 3-D diagrams aiding in defining the aquifer geometry. Pumping test data (Preliminary Yield Test and Slug Test) were employed to analyse aquifer properties, while in areas lacking boreholes, transverse resistance was used to calculate transmissivity (Sattar et al., 2014). Transmissivity value was derived from existing data of Slug Test/PYT conducted in the study area. VES locations close to the EW/PZ sites were initially selected to calculate transverse resistance. Transmissivity values from the Slug Test/PYT were then plotted against transverse resistance. A relationship between transmissivity and transverse resistance was established from the best fit line. This relationship was subsequently used to determine the transmissivity of the aquifer at all VES locations. Relationship between transmissivity and transverse resistance was found as;

Transmissivity= 0.011* (transverse resistance)-1.919

Transmissivity in $m^2$/day and transverse resistance in ohm-$m^2$.

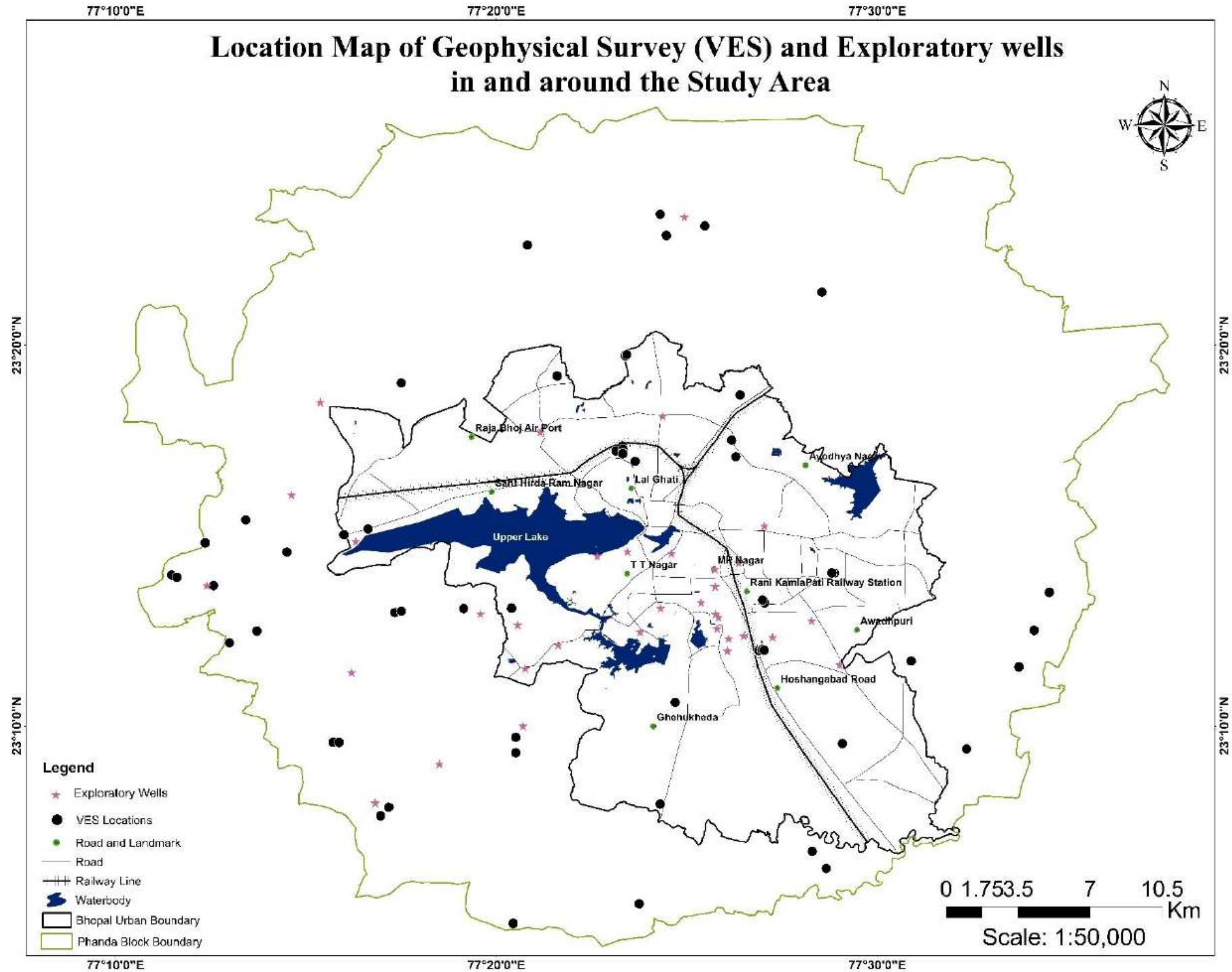



**Fig.3.1 Location map of Geophysical surveys and Exploratory wells**

## 3.3 Result and Discussion

### 3.3.1 Details of Exploration in and around the study area

Details of existing and new exploratory wells in and around the study area are tabulated in **Table 3.1.**

**Table 3.1: Details of Exploratory wells in and around the Study area**

| S. No. | District | Block | Site | Total Depth (mbgl) | Discharge (lps) | Water bearing zones (mbgl) | Principal Aquifer | Major Aquifer |
|---|---|---|---|---|---|---|---|---|
| **Exploratory wells Constructed under NAQUIM 2.0 lie within the study area** | | | | | | | | |
| 1 | Bhopal | Phanda | 1100 quarters | 105 | Negligible | 5.00-6.00 | Deccan trap Basalt | Weathered Basalt |
| 2 | Bhopal | Phanda | Arvind Vihar | 200 | 0.8 | 23.3-26.4 and 78.22-84.30 | Vindhyan sandstone/Shale | Fractured Vindhyan sandstone |
| 3 | Bhopal | Phanda | Basantkunj | 99.8 | 0.7 | 8.30-11.30 and 35.7-38.8 | Deccan trap Basalt | Weathered and fractured basalt |
| 4 | Bhopal | Phanda | MP Nagar Police Station | 148.4 | Negligible | 18-20 | Vindhyan sandstone | - |
| 5 | Bhopal | Phanda | Neelbad EW | 200 | 0.5 | 47-50 | Deccan trap Basalt | Fractured basalt |
| 6 | Bhopal | Phanda | Nehru Nagar Park | 105 | 0.6 | 35.5-38.6 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 7 | Bhopal | Phanda | Yatayat park | 101 | 1.5 | 71-75 and 87-90 | Vindhyan sandstone | Fractured basalt |
| 8 | Bhopal | Phanda | Water Purification plant BMC | 105.7 | Dry | NA | Vindhyan sandstone | NA |
| **Exploratory wells Constructed under NAQUIM 2.0 lie outside the study area** | | | | | | | | |
| 9 | Bhopal | Phanda | Phanda kalan | 75.2 | 3.2 | 14.2-17.5 and 44.70-47 | Deccan trap Basalt | Weathered/ Fractured basalt |
| **Existing Exploratory wells lie within the study area** | | | | | | | | |
| 10 | Bhopal | Phanda | Gandhi Nagar | 91.17 | 0.75 | 0-8.8 | Deccan trap Basalt | Weathered and vesicular basalt |
| 11 | Bhopal | Phanda | Barkatullah Universitty | 182.89 | 0.8 | 31.9-35 | Deccan trap Basalt | Vesicular/fractured basalt |
| 12 | Bhopal | Phanda | GSI | 98 | 10.43 | 61.35 - 72.55 | Vindhyan sandstone | Fractured vindhyan sandstone |
| 13 | Bhopal | Phanda | Gautam Nagar | 61 | 8.8 | 15-23, 25-28, 33-45 | Vindhyan sandstone | Fractured Vindhyan sandstone |

| S. No. | District | Block | Site | Total Depth (mbgl) | Discharge (lps) | Water bearing zones (mbgl) | Principal Aquifer | Major Aquifer |
|---|---|---|---|---|---|---|---|---|
| 14 | Bhopal | Phanda | Shivaji Nagar (6 No. Bus stop) | 76.42 | 1.13 | 31-34.4 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 15 | Bhopal | Phanda | Janta Colony | 51.9 | NA | No water bearing zone was encountered | NA | NA |
| 16 | Bhopal | Phanda | Ashoka Society (E-7 Sector) | 76.52 | NA | No water bearing zone was encountered | NA | NA |
| 17 | Bhopal | Phanda | Baghira Apartment (E-5 Sector) | 122.02 | 0.8 | No informarion available | No informarion available | No informario n available |
| 18 | Bhopal | Phanda | Shyam Nagar | 93 | 0.3 | 35-36, 55-57 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 19 | Bhopal | Phanda | Char Imli | 30.57 | 3.4 | 9.8-21.3 | Vindhyan sandstone | Weathered Vindhyan sandstone |
| 20 | Bhopal | Phanda | M.A.C.T | 91.62 | 2.3 | 28-34.5 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 21 | Bhopal | Phanda | Manav Sanghralay a | 458 | 6.3 | below 430 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 22 | Bhopal | Phanda | Barkheda Pathani | 200 | 0.75 | 47-48, 65-66, 198-199 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 23 | Bhopal | Phanda | Kolu Kheri | 142.3 | 4.75 | 69-75 | Deccan trap Basalt | Fractured basalt |
| 24 | Bhopal | Phanda | Nabibagh | 122.41 | 1.83 | 25.8-26.5 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| 25 | Bhopal | Phanda | Neelbad | 200 | 0.75 | 128-129 | Deccan trap Basalt | Vesicular/F ractured basalt |
| 26 | Bhopal | Phanda | Govindpur a | 102 | No informario n available | 87-100 | Vindhyan sandstone | Fractured Vindhyan sandstone |
| **Existing Exploratory wells lie outside the study area** | | | | | | | | |
| 27 | Bhopal | Phanda | Barkheri Kalan | 200 | 2.07 | 99-100 | Deccan trap Basalt | Fractured basalt |
| 28 | Bhopal | Phanda | Khamkhed a | 200 | - | - | - | - |
| 29 | Bhopal | Phanda | Bakaniya | 184.9 | 0.85 | 62.9-70 | Deccan trap Basalt | Fractured basalt |

| S. No. | District | Block | Site | Total Depth (mbgl) | Discharge (lps) | Water bearing zones (mbgl) | Principal Aquifer | Major Aquifer |
|---|---|---|---|---|---|---|---|---|
| 30 | Bhopal | Phanda | Barjhiri | 238.8 | 0.14 | 8-9, 35.4-38.4 | Deccan trap Basalt | Weathered and fractured basalt |
| 31 | Bhopal | Phanda | Barkheda Nathu | 300.7 | 0.62 | 264.1-267.2 | Deccan trap Basalt | Fractured basalt |
| 32 | Bhopal | Phanda | Nandini | 81.2 | 8.24 | 77-80.2 | Deccan trap Basalt | Vesicular basalt |
| 33 | Bhopal | Phanda | Ratibad | 242 | 0.78 | 128.7-129.7, 153-154 | Deccan trap Basalt | Fractured basalt |
| 34 | Bhopal | Phanda | Sarwar | 118.12 | 4 | 15.7-26.9 | Deccan trap Basalt | Vesicular basalt |

### 3.3.2 Hydrogeology of the Study Area

The principal aquifers within the study area comprise the Deccan trap and Vindhyan sandstone formations, where groundwater occurrence and dynamics are predominantly influenced by the presence of joints or fractures. The Deccan trap exhibits a yield range of 0.1 to 4.75 lps, while the Vindhyan sandstone yields between 0.1 to 10.43 lps. Analysis of the groundwater table contour suggests a prevailing movement of groundwater from the northwest to the southeast direction. The Kerwa and Kalisot rivers function as effluent channels within the study area. These findings are graphically represented in **Fig.3.2**, illustrating the hydrogeological characteristics of the region.

### 3.3.3 Principal and Major Aquifer

Based on hydrogeological and geophysical information, it is inferred that Deccan trap basalt and Vindhyan Sandstone act as principal aquifer system of the study area. The area consists of two aquifer system;

Aquifer-I (Phreatic Aquifer): Comprises weathered Deccan Trap Basalt and Vindhyan Sandstone.

Aquifer-II (Fractured Aquifer): Comprises fractured/Jointed Deccan Trap Basalt and Vindhyan Sandstone.

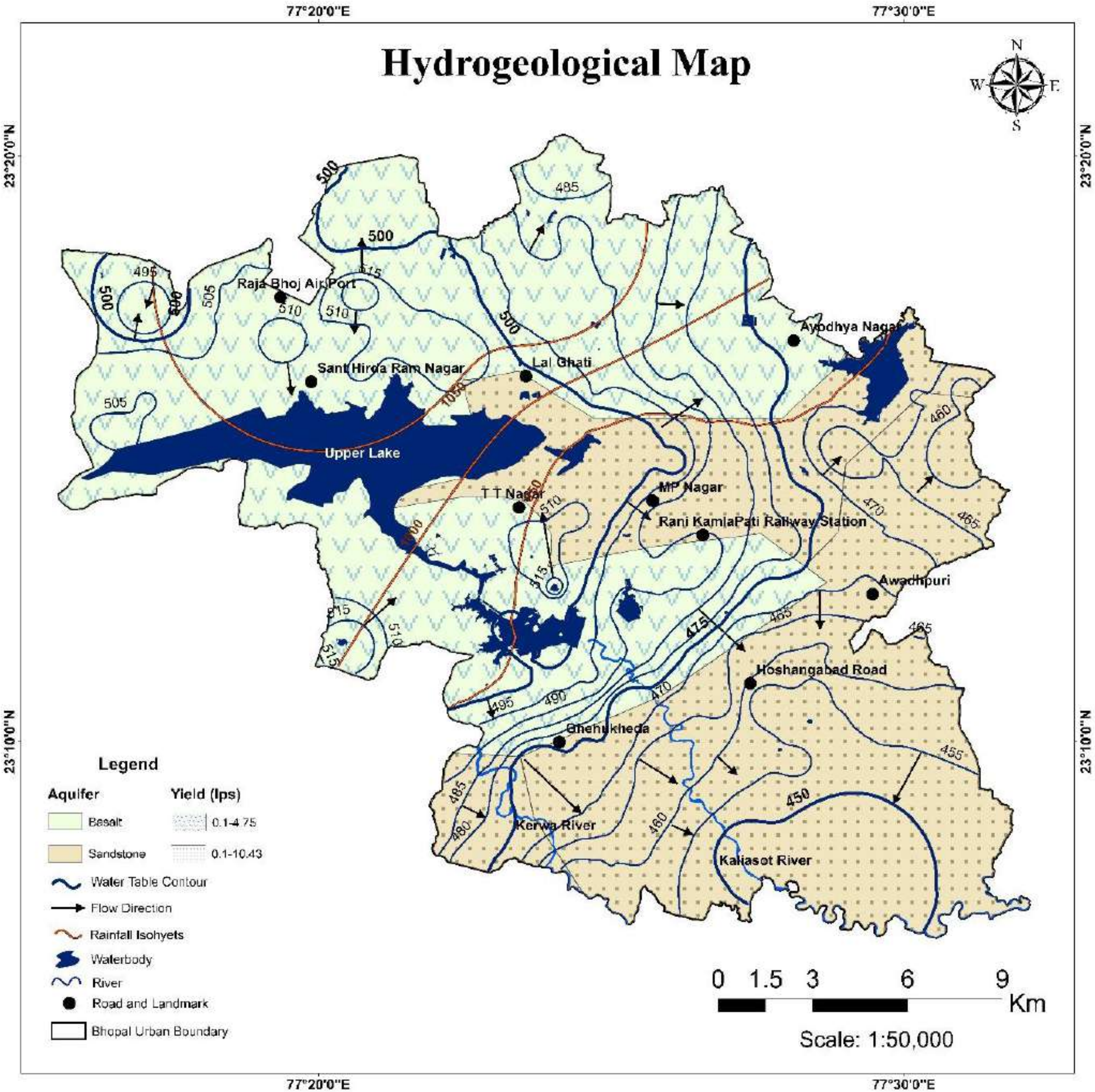



**Fig. 3.2 Hydrogeological Map of the study area**

### 3.3.4 Aquifer Characteristics

#### Aquifer-I (Unconfined/ Phreatic Aquifer)

The Upper Proterozoic-aged weathered Bhander Sandstone, a constituent of the Vindhyan Supergroup, occupies the central, eastern, and southeastern sectors of the study area, functioning as a phreatic aquifer with thickness varying between 3.5 and 40 m. Concurrently, the Upper Cretaceous to Lower Eocene-aged Weathered Deccan Trap Basalt predominates in the northern, western, and northwestern regions, exhibiting thicknesses ranging from 4 to 52 m. These aquifers are unconfined in nature with their maximum thickness observed in the southeastern and northwestern extents of the study area. Thickness exceeding 40 m in the vicinity of Misrod and Kolukhedi. In contrast, the thickness of the shallow aquifer in the central part of the study area ranges from 5 to 10 m, with some locations having a thickness of less than 5 m **(Fig.3.3).** This is particularly evident in areas such as Bittan Market, MP Nagar, Ashoka Society, Janta Colony, Arvind Vihar, Nehru Nagar, Shyam Nagar, Manav Sangrahalaya, Gandhi Nagar, and near Hathaikheda Dam. On average, thickness of the phreatic aquifer within the study area ranges between 10 to 20 m. The yield of unconfined aquifers can vary up to 3.4 lps under favourable conditions.

#### Aquifer-II (Fractured/Semi-confined Aquifer)

Explorations conducted by the CGWB to depths ranging from 60 to 458 mbgl have revealed that the fractured/jointed Vindhyan Sandstone and fractured/vesicular Deccan Trap Basalt serve as semi-confined aquifers within the study area. Depths of the semi-confined aquifer within the Vindhyan Sandstone vary between 25 and 200 mbgl, whereas within the Deccan Trap Basalt, depths range from 30 to 130 mbgl, based on comprehensive exploration data. Notably, zones of contact between the Vindhyan Sandstone and Deccan Trap Basalt are identified as prolific groundwater occurrence zones. Field data indicates discharge rates between 0.1 and 4.75 lps for the Deccan Trap Basalt and predominantly between 0.1 and 10.43 lps for the Vindhyan Sandstone. Transmissivity values for semi-confined aquifer across the study area exhibit variation, ranging from 0.18 to 103 $m^2$/day. Specifically, the northern, northwestern, and northeastern regions demonstrate transmissivity values between 30 and 50 $m^2$/day, while the central portion displays values between 20 and 30 $m^2$/day. In contrast, the southern and southeastern portion exhibit transmissivity values between 10 and 20 $m^2$/day, with localized areas registering values below 10 $m^2$/day **(Fig.3.4).**

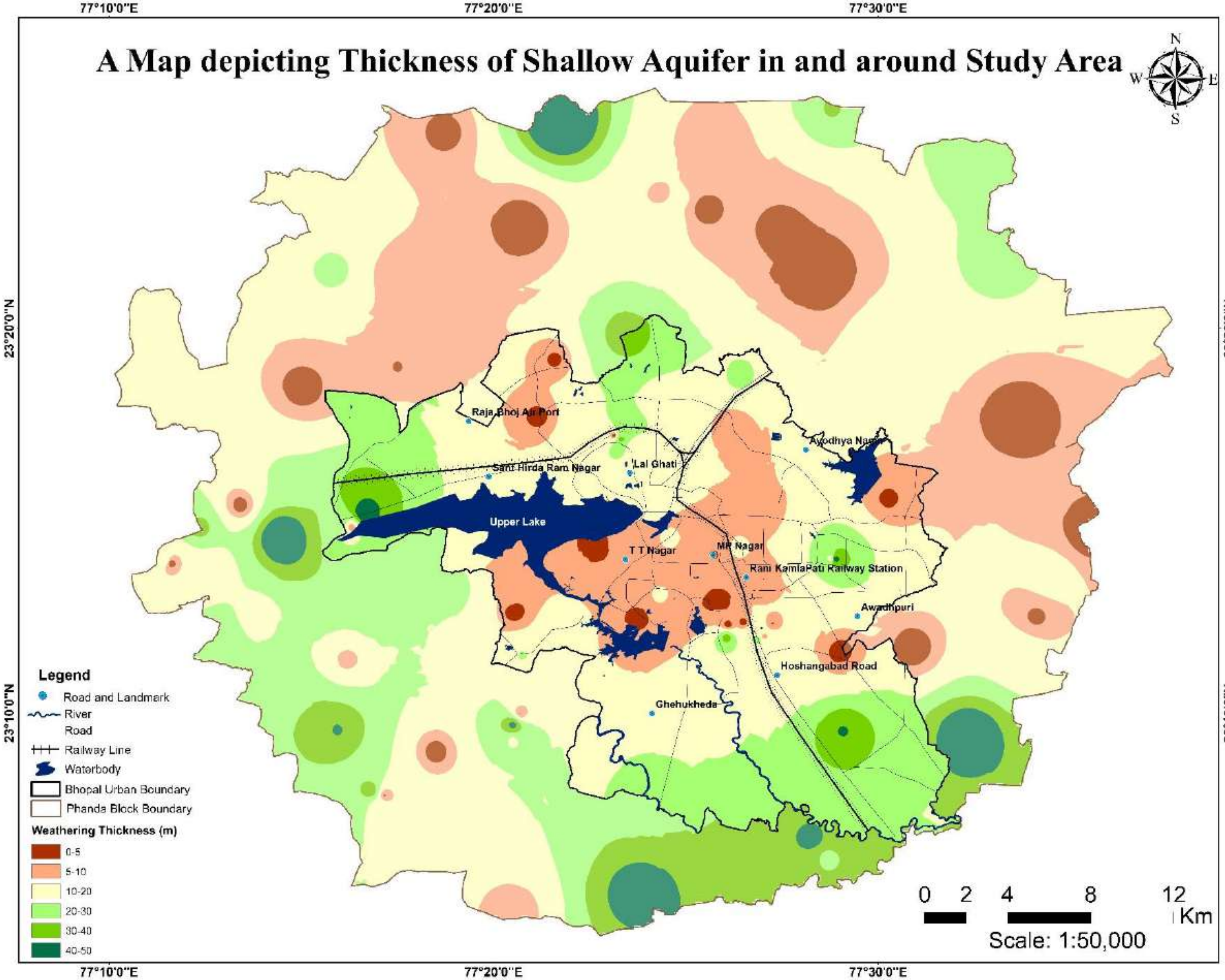



**Fig.3.3 A map depicting thickness of shallow aquifer in and around study area**

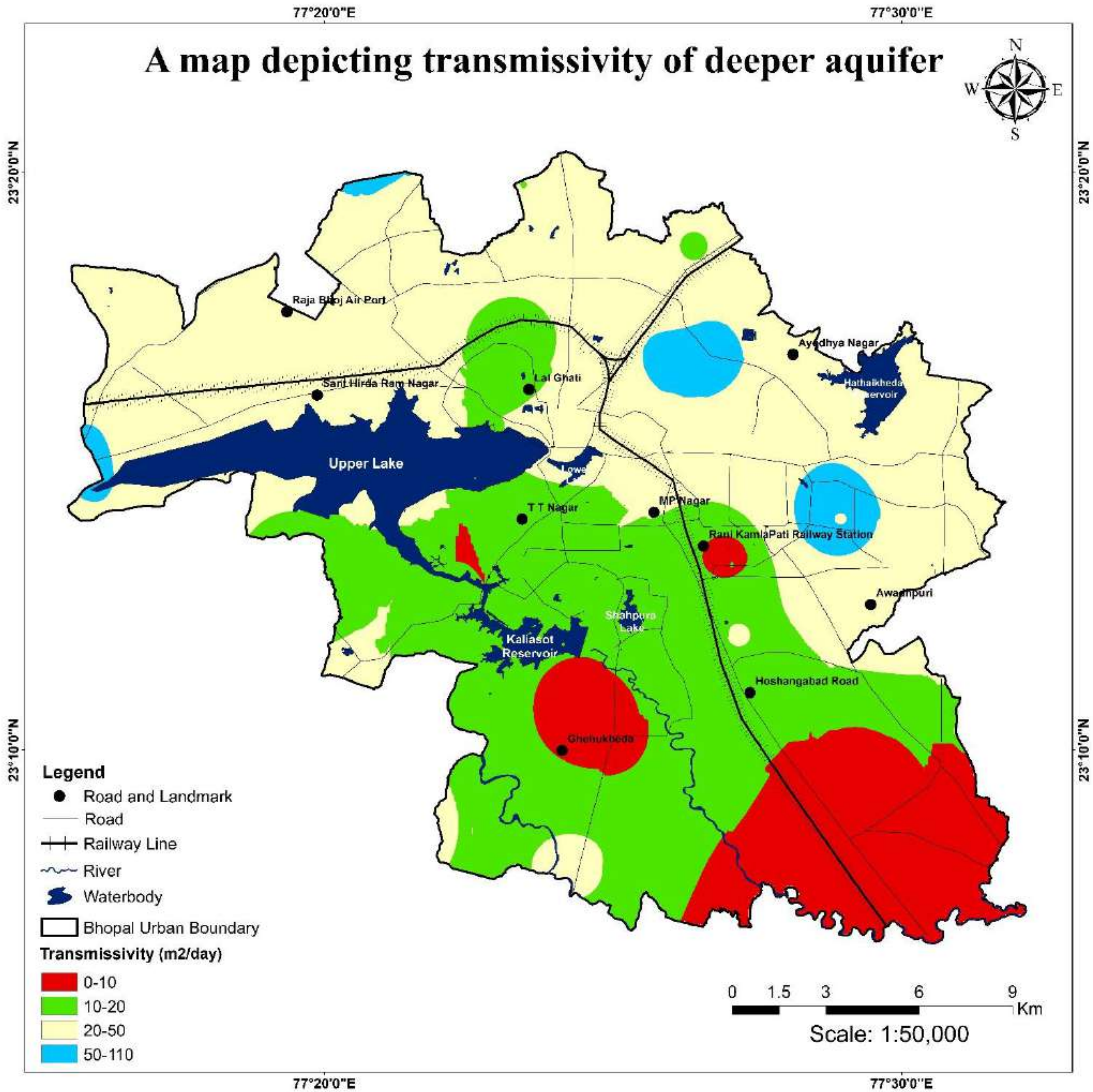



**Fig.3.4 A map depicting transmissivity of deeper aquifer**

### 3.3.5 2-Dimensional Cross Section

The 2-D cross-sectional analysis depicts both the vertical and horizontal disposition of aquifers within the study area. Three cross sections have been delineated along the North-South, East-West, and Northeast-Southwest orientations **(Fig.3.5).** These sections provide detailed insights into the spatial distribution of the aquifer systems.

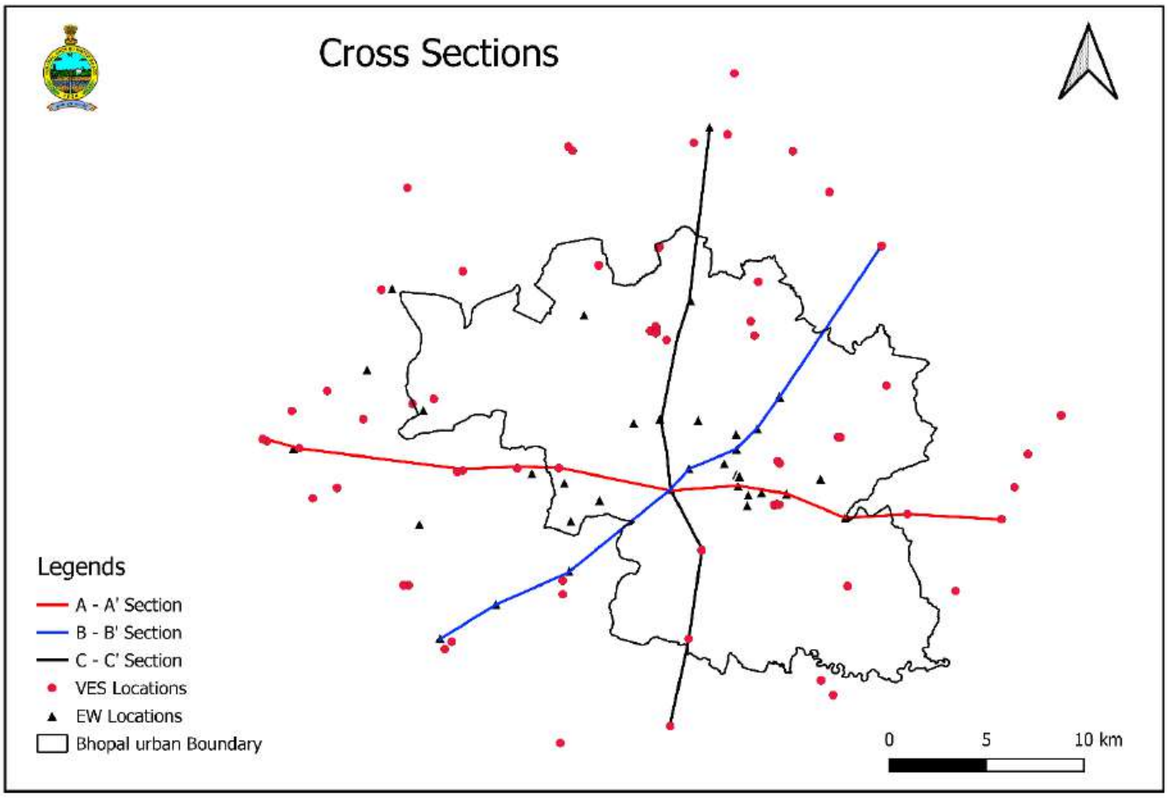



**Fig.3.5 A map showing directions of cross sections for deciphering aquifer disposition**

**i) Aquifer Disposition along A-A' Cross Section**

Section A–A', extending from Phanda Kalan to Padriya Jat in a West-East direction for approximately 41 km, delineates the aquifers encountered along this transect **(Fig. 3.5 and Fig. 3.6).**

In the western portion of the section, the lithological sequence comprises topsoil, weathered basalt, fractured basalt, and massive basalt. The weathering thickness in this part ranges from 14 to 30 m. Groundwater zones at Phanda Kalan are identified at depths of 14.2 to 17.5 mbgl and 44.7 to 47 mbgl.

The contact zone between the Deccan Trap basalt and Vindhyan sandstone is observed about at 16 km eastward which is characterized by a succession that includes topsoil, weathered basalt, fractured basalt, massive basalt, and compact sandstone. In the exploratory well at Nehru Nagar, the lithology transitions completely to Vindhyan sandstone, with a water-bearing zone detected between 35 and 38 mbgl.

Progressing eastward about 3.5 km at 1100 Quarters, no fracture zones are observed up to a depth of 105.6 mbgl. Further east at Barkatullah University, the sequence comprises Deccan Trap basalt underlain by Vindhyan sandstone, with the contact zone between these lithologies identified at 49.5 mbgl. The water-bearing zone in this area is found within weathered basalt, between 9 and 16.3 mbgl.

Continuing eastward to Arvind Vihar, the area is predominantly underlain by Vindhyan sandstone, with a water-bearing zone in fractured sandstone identified between 78.2 and 84.3 mbgl. Vindhyan sandstone persists eastward up to Padriya Jat, and weathering thickness in eastern portion ranging from 2 to 15 m.

**ii) Aquifer Disposition along B-B' Cross Section**

The cross section between points B-B', extending about 31 km from Barjhiri to Kalyanpur **(Fig.3.7)** and oriented southwest to northeast direction **(Fig.3.5).** In the southwest portion, Deccan Trap Basalt is exposed, while Vindhyan Sandstone dominates in the northeast section.

The Southwestern segment exhibits a vertical succession comprising topsoil, weathered basalt, fractured basalt, and massive basalt, continues approximately up to 13 km northeastward. Weathering thickness in this part ranging from 2.3 to 4.5 m only. Water-bearing zones in Barjhiri are identified at 8-9 mbgl in the weathered basalt and at 35.4-38.4 mbgl in the vesicular basalt. In Ratibad, aquifers in vesicular/jointed basalt occur at depths of 128.7-129.7 mbgl and 153.6-154.5 mbgl.

Transitioning northeastward, a sequence of Vindhyan Sandstone is observed at Nehru Nagar, with water-bearing zones at 35-38 mbgl in fractured sandstone. At MACT, Deccan Trap Basalt overlies Vindhyan Sandstone, with the contact zone at 28 mbgl and aquifers between 28-34.4 mbgl in the weathered Vindhyan Sandstone. Further northeast at the 6 Number Bus Stop and Gautam Nagar, the contact zones occur at 8 and 12.5 mbgl respectively, with aquifers in weathered sandstone at 31-34.4 mbgl (6 No. bus stop) and at 15-23 mbgl, 25-28 mbgl, 33-45 mbgl (Gautam Nagar).

Further within 2 km span, at Govindpura, the complete Vindhyan Sandstone sequence is present, featuring water-bearing zones in fractured/jointed sandstone at 87-100 mbgl.

Moving ahead about 10 km , at Kalyanpur, Deccan Trap Basalt re-emerges, indicating a return to similar hydrogeological conditions as those observed in the southwestern segment and weathering thickness in Northeasten portion is ranging between 5 to 18 mbgl.

**iii) Aquifer Disposition along C-C' Cross Section**

Section C–C', oriented north-south **(Fig. 3.5)** and spanning 35 km **(Fig.3.8)**, delineates the contact zone between Deccan Trap Basalt and Vindhyan Sandstone in the northern segment, transitioning to predominantly Vindhyan Sandstone in the southern segment.

In the northern portion, weathering thickness varies between 8 to 14 mbgl. At Khamkheda, the contact zone between these two lithologies is found at 26 mbgl, but no aquifer is present at this location. Moving approximately 10 km southward, at Nabibagh, contact zone is identified at 23.73 mbgl, with a water-bearing zone detected between 25.8 and 26.5 mbgl.

Further south, around 7 km in the vicinity of the Water Purification Plant at Shyamala Hills, the area is fully occupied by Vindhyan Sandstone, and again, no aquifer is found. Continuing about 8 km further to Gehunkheda, weathered basalt is found underlain by Vindhyan Sandstone.

Progressing towards Kolar and Kalapani, a sequence of Vindhyan Sandstone is observed. In the southern part of this section, the weathering thickness ranges significantly from 3 to 48 mbgl.

This cross-section thus highlights the transition from basalt-dominated geology in the north to sandstone in the south, providing critical hydrogeological insights for groundwater exploration and management in the region.

### 3.3.6 3-D Model of Aquifer Disposition within Study Area

The 3-D model of aquifer disposition within the study area, shown in **Fig. 3.9**, indicates that weathered and fractured/vesicular Deccan Trap basalt, serves as Aquifer-I and Aquifer-II respectively in the western, northern, and northwestern regions. The contact zone between the Deccan Trap basalt and the Vindhyan Sandstone is present in the central and southern parts of the area which act as a prolific aquifer which is dependent on the thickness of the aquifer. In southeastern region, Vindhyan group of rocks (Vindhyan Sandstone and Shale) are predominant and fractured/jointed Vindhyan Sandstone act a Major aquifer.

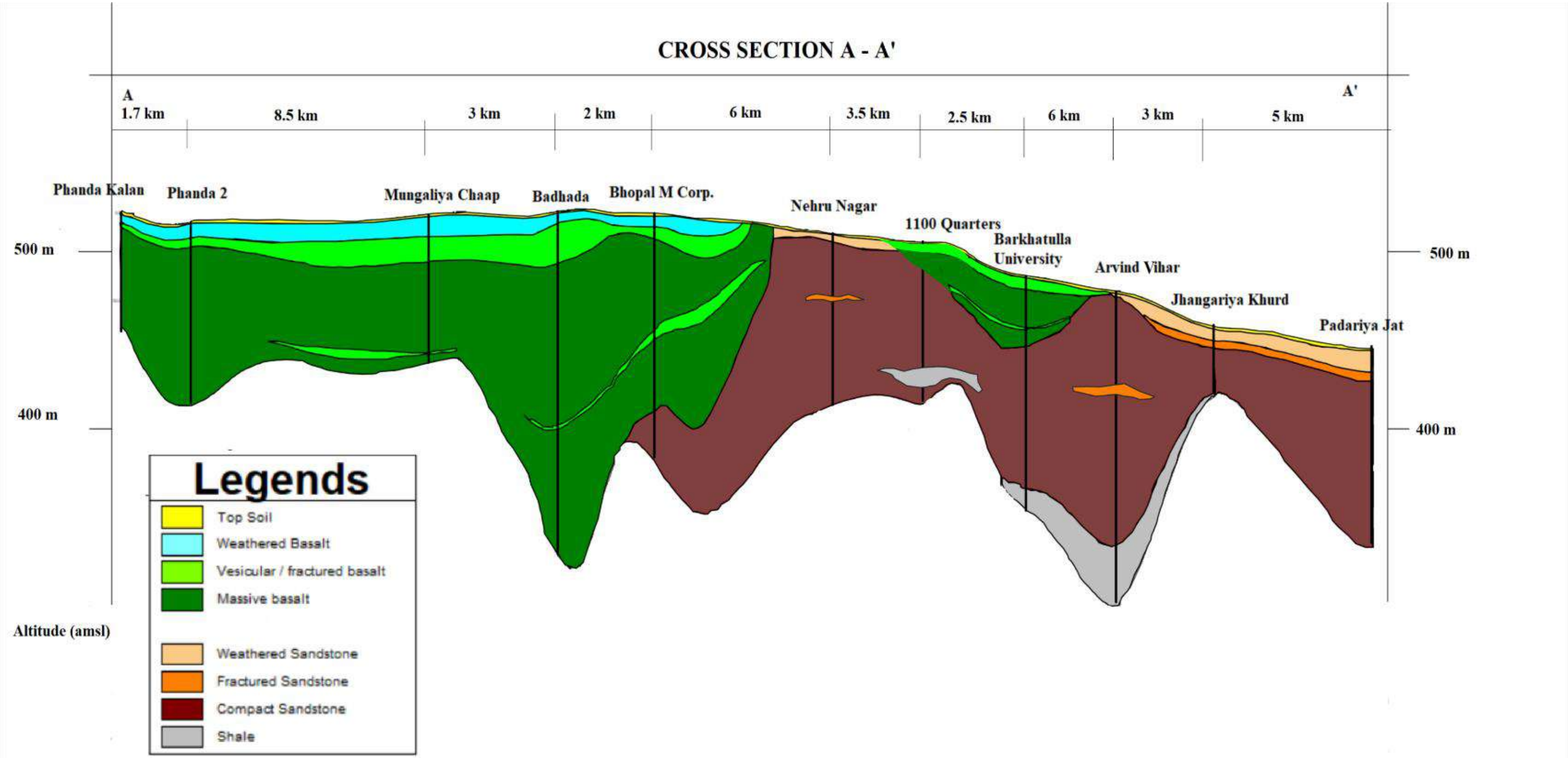



**Fig.3.6 Aquifer disposition along A-A’**

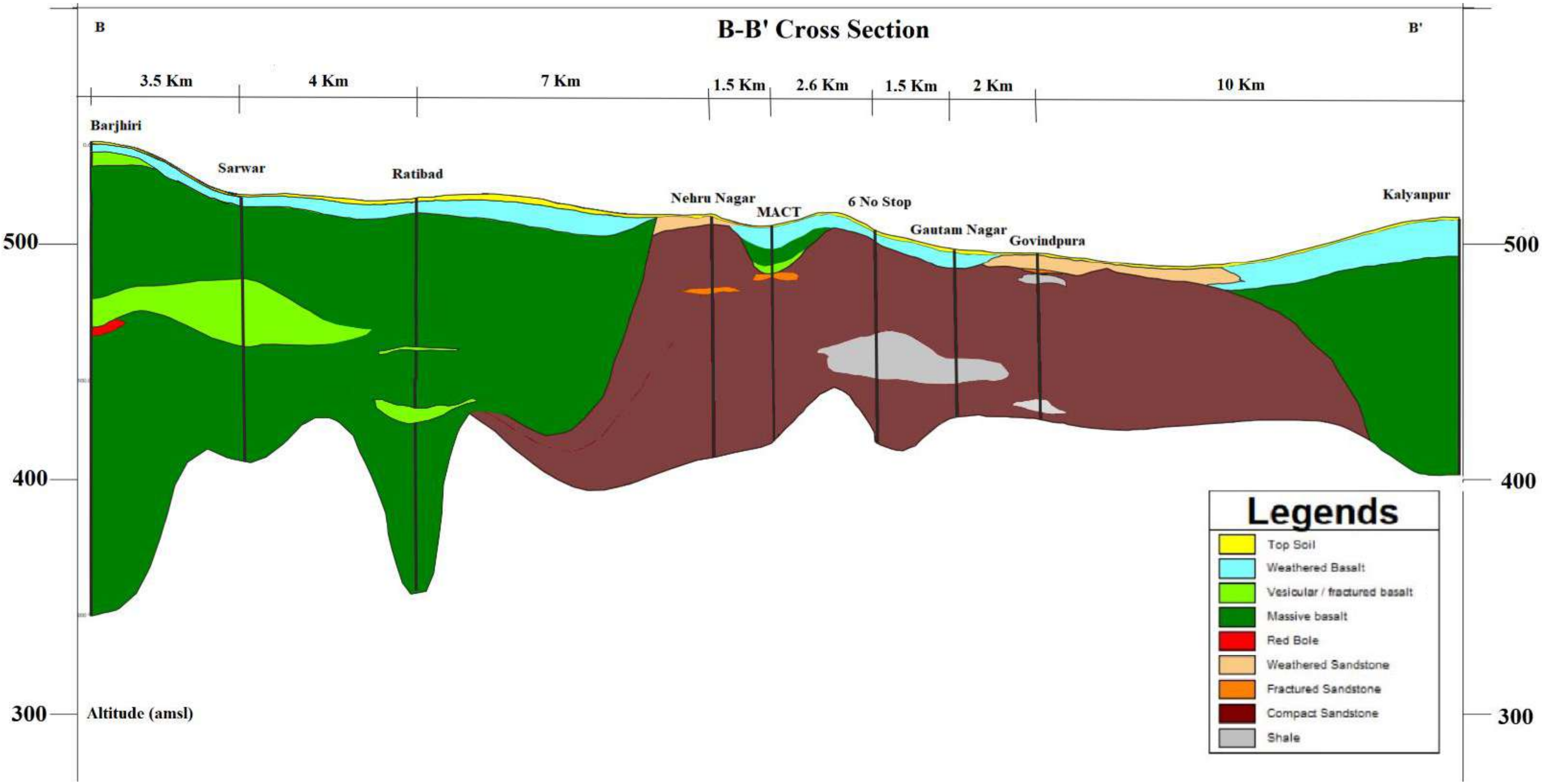



**Fig.3.7 Aquifer disposition along B-B'**

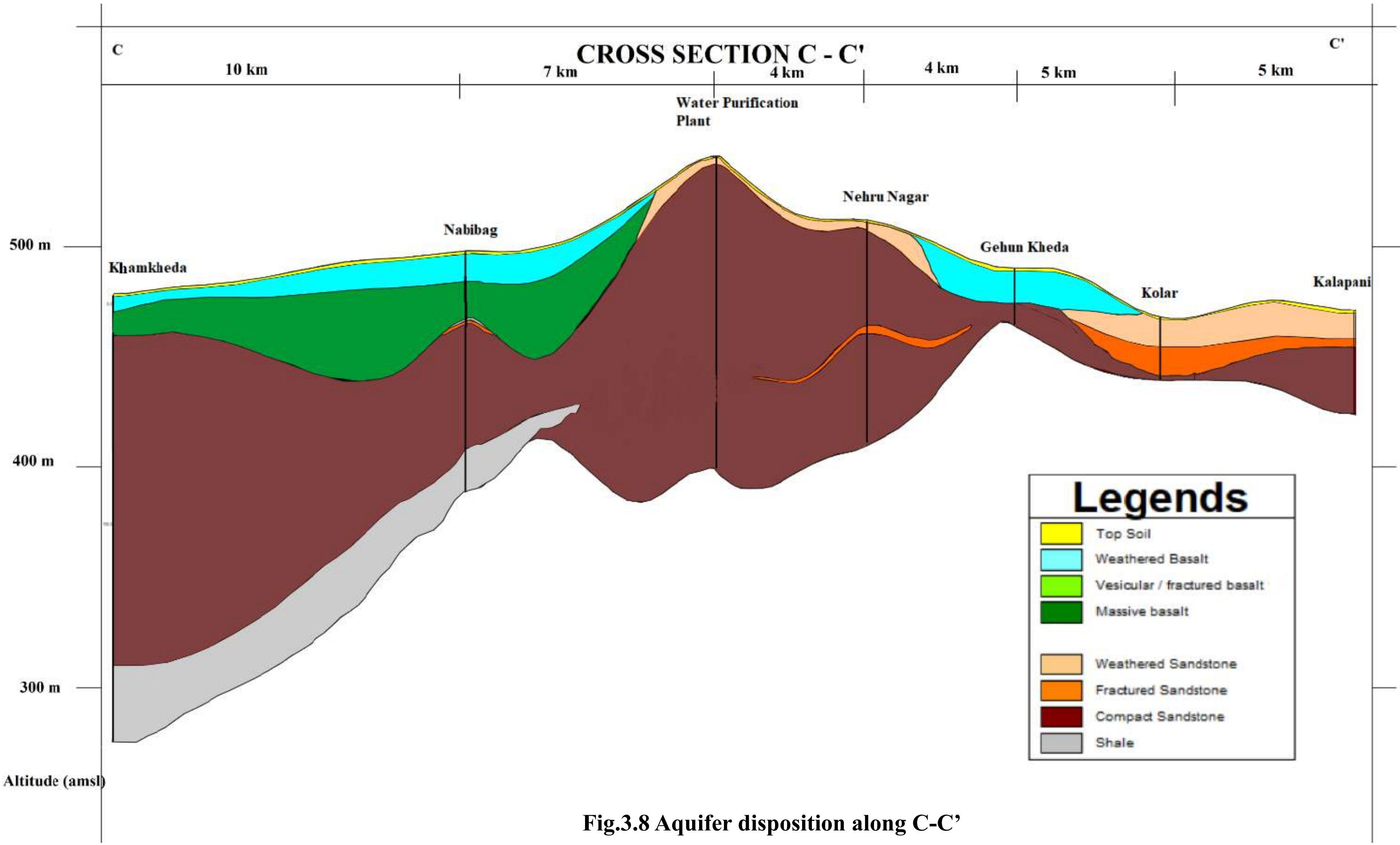



**Fig.3.8 Aquifer disposition along C-C’**

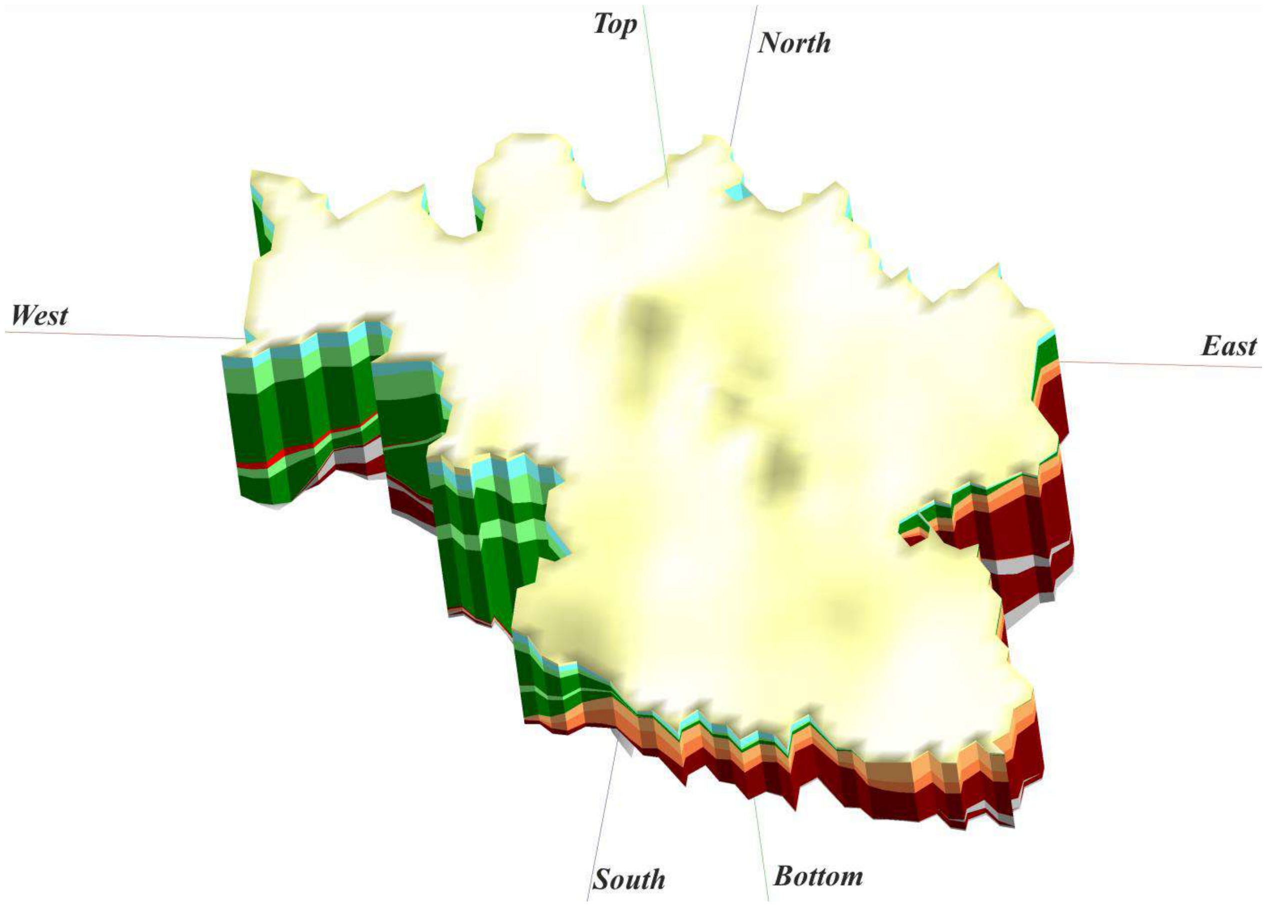




**Fig. 3.9 3-D Model of Aquifer Disposition within the Study Area**

# 4. GROUNDWATER REGIME

## 4.1 Objective

The aim of this chapter is to determine the depth to water level in a shallow aquifer, discern the seasonal variation in depth to water level, analyse their fluctuations, to know the impact of urbanization on groundwater regime and assess the decadal trends.

## 4.2 Methodology

To access the groundwater behaviour, the depth to water level data were systematically collected within the shallow aquifer from 87 monitoring stations, including both dug wells and hand pumps. These stations were strategically distributed across 21 zones to ensure comprehensive coverage of the principal aquifers within the study area **(Fig. 4.1).** Measurements were taken during the pre-monsoon period in May and the post-monsoon period in November 2023 using a sounder. Concurrently, relevant geographical information (latitude, longitude, and elevation) was recorded during field expeditions.

To evaluate the seasonal decadal trends in water levels, data from 11 existing dug wells spanning the years 2013 to 2023 were analysed for both pre-monsoon and post-monsoon seasons. Additionally, to examine the relationship between rainfall and depth to water level, monthly rainfall data for 2023 from three rain gauge stations within the study area were used, along with monthly monitoring data from 10 monitoring stations (DW) for the same year. To assess the impact of urbanization on the groundwater regime, depth to water level maps for the pre-monsoon periods of 2002, 2013, and 2022 were prepared based on data from the existing monitoring stations.

The data was organized using MS-Excel, and ArcGIS 10.3.1 software was employed for data processing and map preparation. Inverse Distance Weighting (IDW) was utilized to estimate attribute values at locations within the range of available data, based on known data values. To assess the seasonal fluctuation of water level in the year 2023, changes in groundwater level were calculated between the pre-monsoon and post-monsoon periods. Fluctuation data was further analysed and processed using MS-Excel. Water level data for pre and post monsoon period along with fluctuation for the year 2023 are presented in **Annexure-III** The graph between rainfall and depth to water level was prepared using Origin 2024 software.

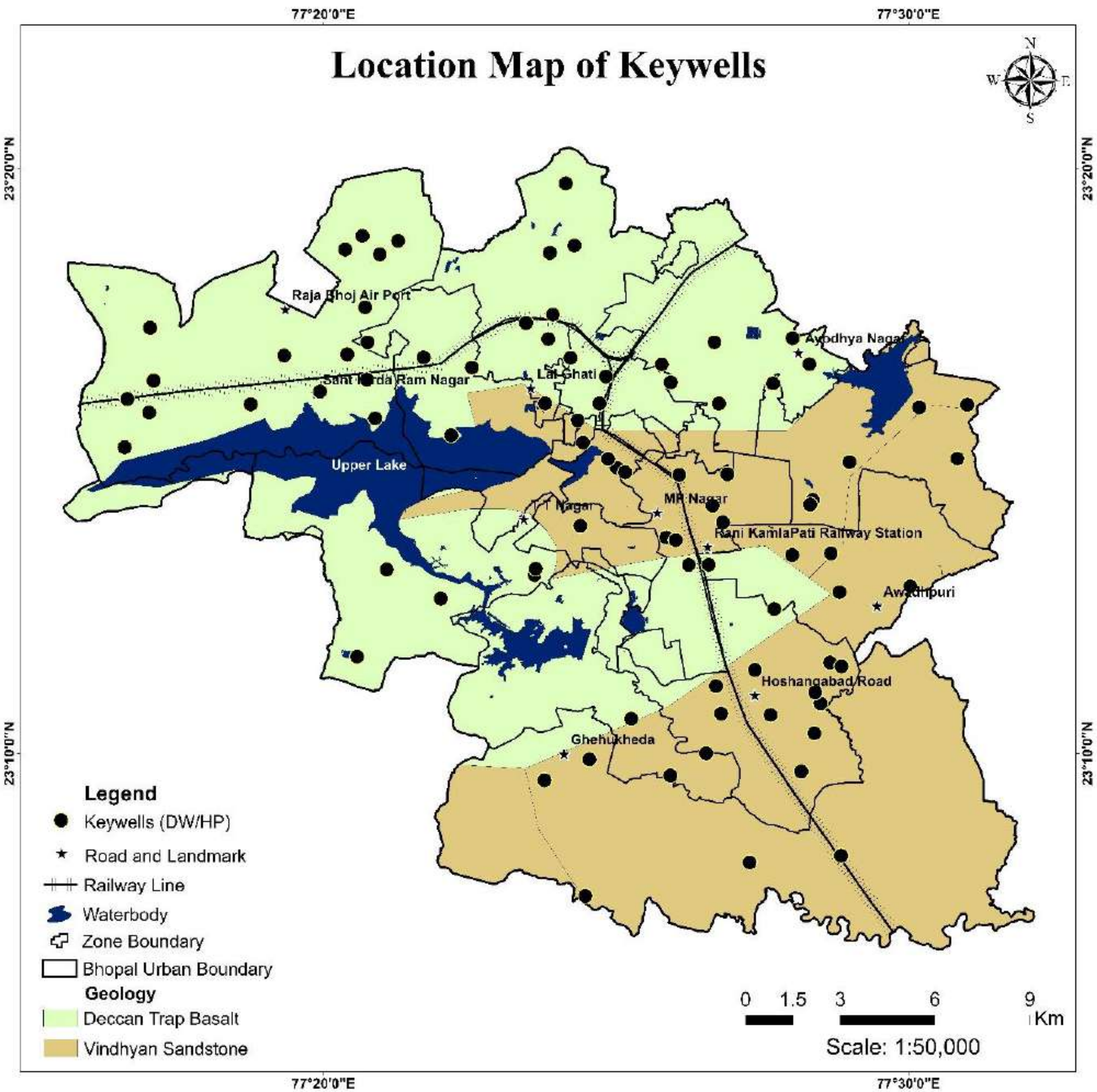



**Fig. 4.1 Location map of Keywells**

### 4.3 Result and Discussion

#### 4.3.1 Pre-Monsoon Depth to Water Level of Shallow Aquifer

Pre-monsoon depth to water level of shallow aquifer is ranging between 0.85 mbgl (Shahpura) to 38 mbgl (Gitti Phoda). Predominantly, the water level is situated within the range of 5-10 mbgl across the major portion of the study area, with localized patches displaying depth spanning from 10-20 mbgl. Shallow water level is observed near upper lake. Pre-Monsoon Depth to water level map is depicted in **Fig.4.2.**

#### 4.3.2. Post-Monsoon Depth to Water Level of Shallow Aquifer

During post-monsoon depth to water level varies between 0.53 mbgl (Shahpura) to 30.54 mbgl (Gitti phoda). Water level between 2-5 mbgl is observed in the area falls in the vicinity of upper lake while 5-10 mbgl are observed in rest part of the study area excluding some patches in North-western, North-Eastern and South-Eastern part of the study area where water level ranges between 10-20 mbgl. Post-Monsoon depth to water level map is depicted in **Fig.4.3**.

#### 4.3.3 Seasonal Water level fluctuation of Shallow Aquifer

The analysis of seasonal water level fluctuations reveals significant variability across the study area. Maximum fluctuation, reaching 7.89 m, is observed at Shivaji Nagar, while minimal fluctuation of 0.05 m is noted at Gandhi Nagar. To categorize these fluctuations, they are grouped into three main zones: low, moderate, and high. The analysis highlights that approximately 44.8% of the wells fall within the low fluctuation zone, indicating good aquifer storage capacity. Conversely, 36.8% of the wells fall within the moderate fluctuation zone, while 18.4% of the wells are categorized under the high fluctuation zone, indicating inadequate aquifer storage. Seasonal water level fluctuation map is shown in **Fig.4.4**.

#### 4.3.4 Groundwater Flow Direction

In the study area, the groundwater flow direction is influenced by the city's topography, where the western and northern regions are elevated compared to the eastern and south-eastern parts, hydrogeology, Influence of Lakes and Water Bodies, Effects of Urbanization, water extraction and Recharge patterns etc. Hence, the general groundwater flow direction is from the higher elevations in the western and northern parts of the city towards the low-lying areas in the eastern, north-eastern and south-eastern directions as shown in **Fig. 4.5.** The groundwater flow direction in the western parts is predominantly towards the Upper Lake.

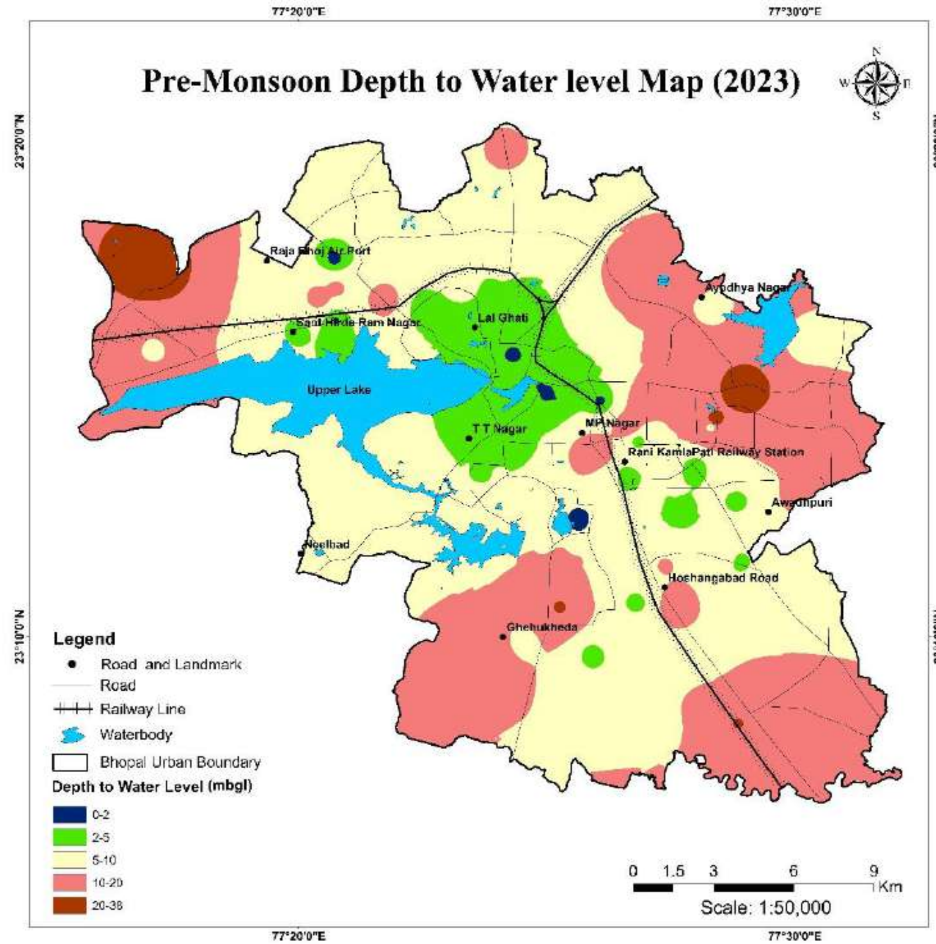



Fig.4.2 Pre-monsoon Depth to water level of shallow Aquifer (2023)

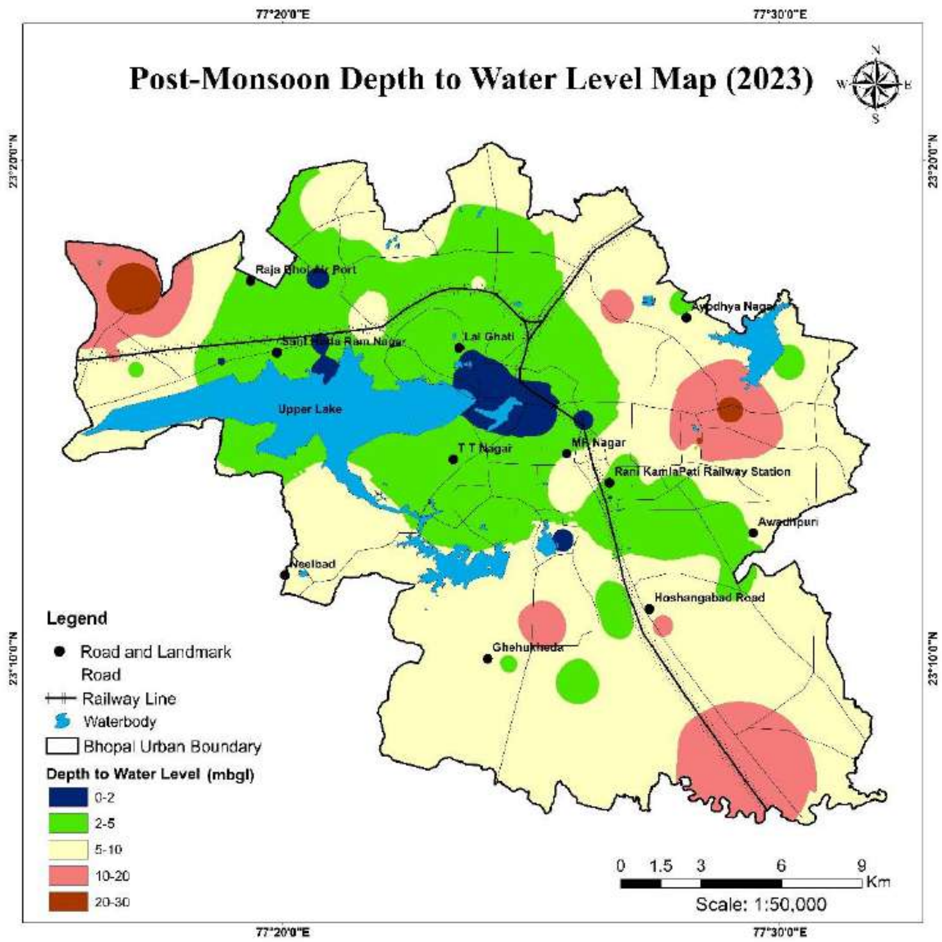
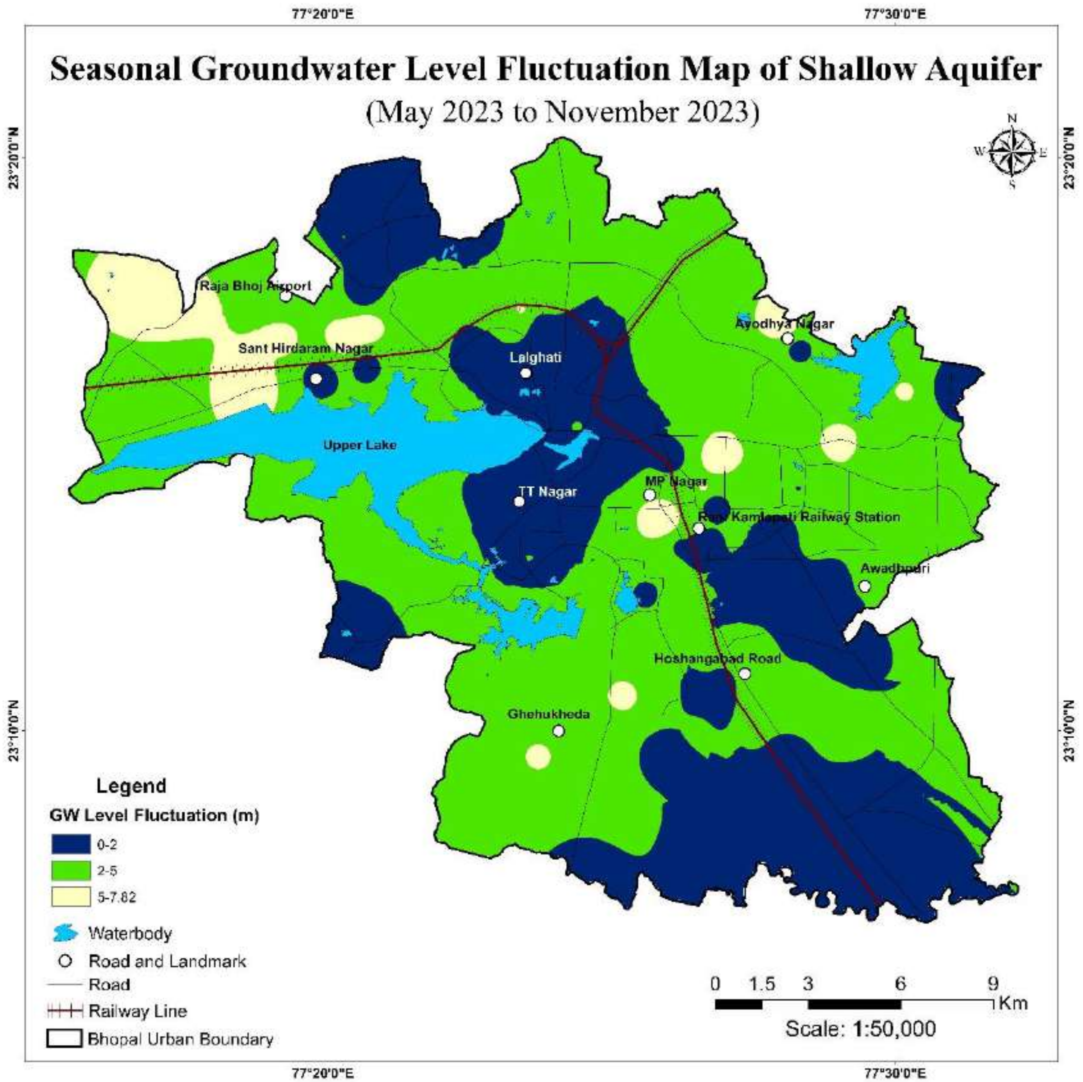
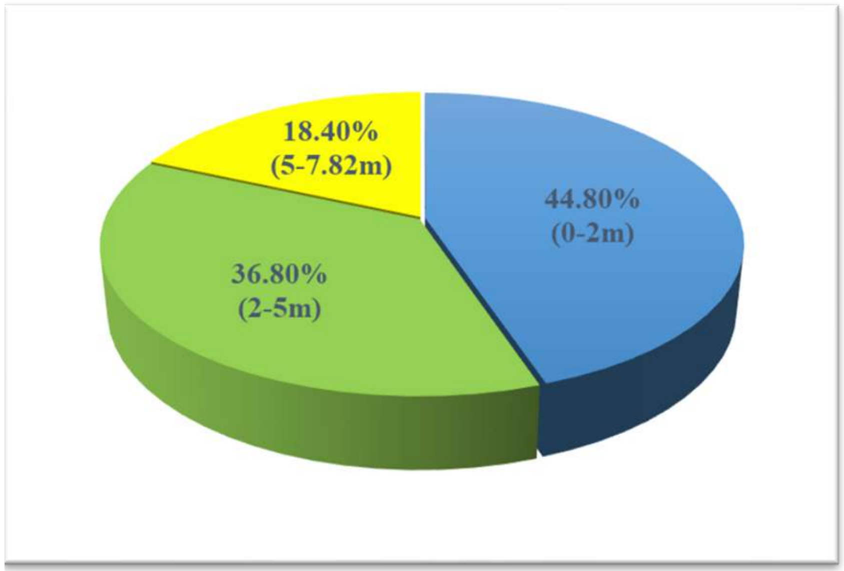



Fig.4.3 Post-monsoon Depth to water level of shallow aquifer (2023)




| Category | No. of Wells | Fluctuation | % of wells |
|---|---|---|---|
| Less Water Level Fluctutation | 39 | 0-2 m | 44.8 |
| Moderate Water Level Fluctutation | 32 | 2-5 m | 36.8 |
| High Water Level Fluctuation | 16 | > 5 m | 18.4 |

**Fig.4.4 Seasonal groundwater level fluctuation map of shallow aquifer (2023)**

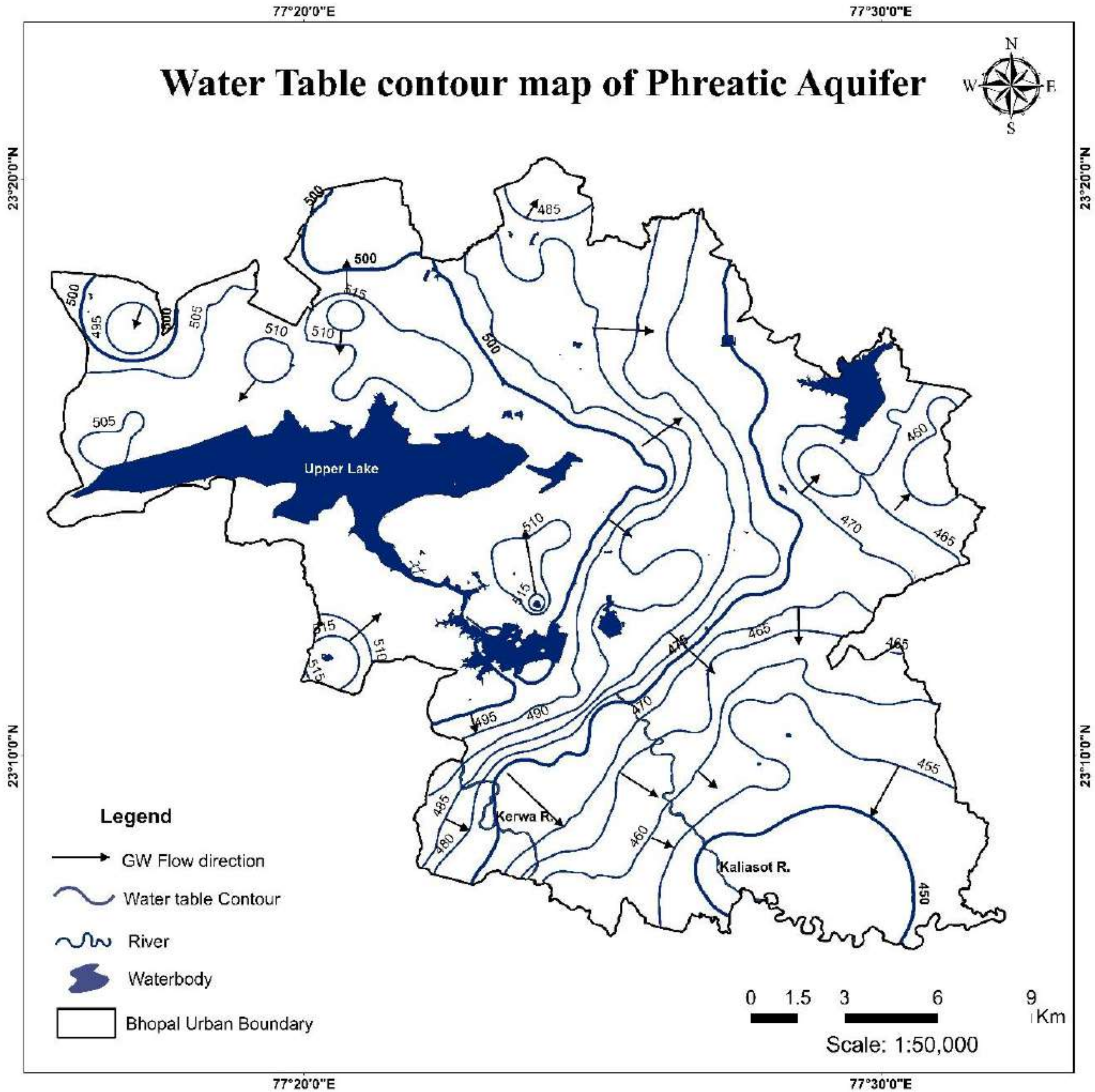



**Fig.4.5 Water table Contour Map of Phreatic Aquifer with flow direction of Groundwater**

### 4.3.5 Water Level Trend of Shallow Aquifer

The trend analysis of water levels spanning from 2013 to 2023 indicates that two number of wells lying in Barkhera and E-2 Nursery showing declining trend of water level with rate ranging between 0-0.15m/year during both pre and post monsoon **(Table: 4.1).** Pre and post monsoon groundwater level trend map of shallow aquifer is depicted in **Fig. 4.6** and **4.7** respectively. The declining trend in water levels may be correlated with an increasing demand for water over the past 11 years, during which the population has grown by 26%. In addition to this, few wells located in the area of Lalghati, Barkheda Pathani and DIG Banglow are showing rising trend of water level with a rate varies from 0.3-0.5 m/year during Pre-monsoon period. It indicates that these areas are prone to water logging condition.

**Table 4.1 Trend of Depth to Water level within shallow aquifer during pre and post monsoon**

| Well | Pre-Monsoon trend | Post-Monsoon trend |
|---|---|---|
| Barkhera | -0.156 | -0.023 |
| Ayodhya Nagar | 0.14 | 0.093 |
| Bairagarh | 0.096 | 0.279 |
| Barkheda Pathani | 0.359 | 0.212 |
| DIG Bangla | 0.502 | 0.134 |
| E- 2 Nursery | -0.096 | -0.138 |
| Lal Ghati | 0.316 | 0.116 |
| Nabibagh | 0.207 | 0.041 |
| Piplani | 0.055 | 0.047 |
| Shahjahana bad | 0.082 | 0.029 |
| South T T Nagar | -0.0005 | 0.054 |

### 4.3.6 Effect of Urbanization on Depth to Water Level of Shallow Aquifer

To assess the impact of urbanization on the groundwater regime, Depth to Water Level maps of the Shallow Aquifer were analysed for the years 2002, 2013, and 2022 **(Fig. 4.8).** In 2002, the average depth to the water level ranged from 5 to 10 mbgl, with localized areas near Shapura Lake exhibiting water levels between 0 and 3 mbgl. By 2013, the average depth had decreased to between 3 and 5 mbgl, and the extent of areas with water levels in the 0-3 mbgl range had expanded. In 2022, the average depth to the water level remained within the 3-5 mbgl range, but the area covered by this depth range increased, and the region showing depths between 0 and 3 mbgl further expanded. This trend indicates a significant influence of urbanization on the groundwater system. The population increased by 58.2% from 2001 (1,458,416) to 2022 (2,308,912), contributing to the growth in urban areas and corresponding changes in groundwater levels.

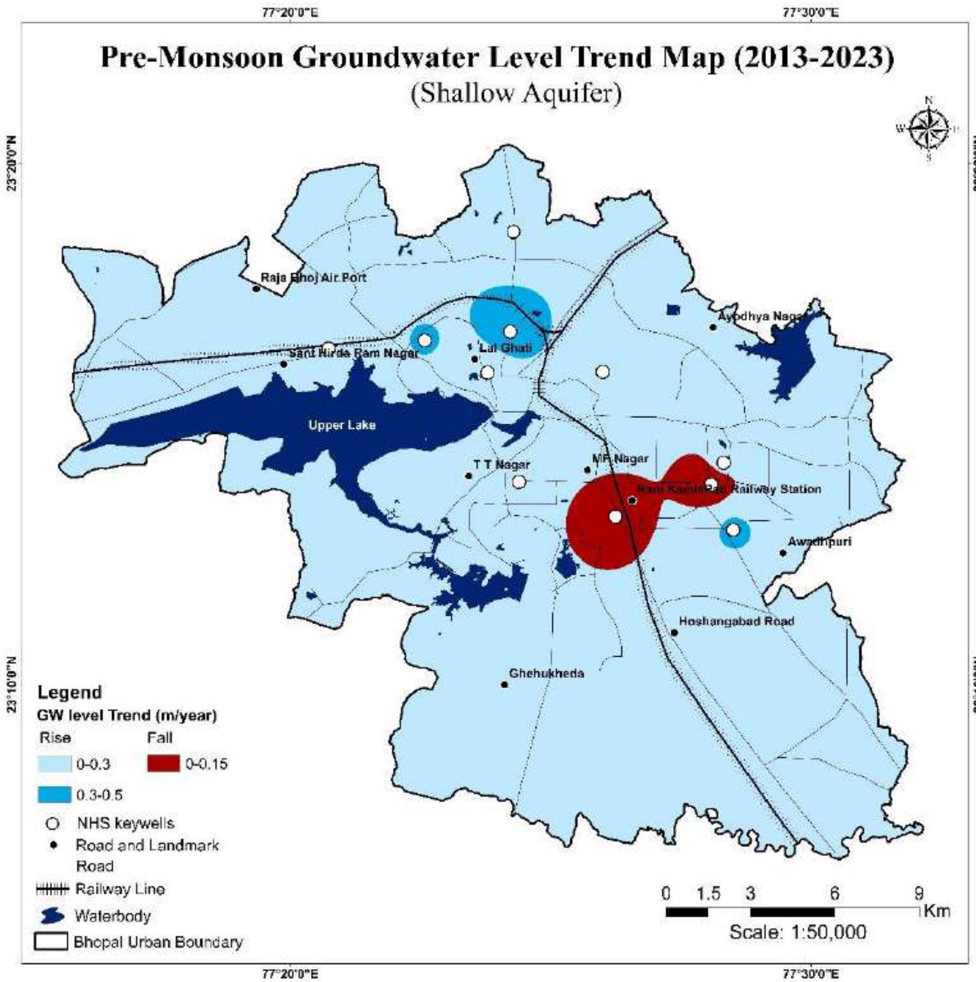



**Fig.4.6 Pre-Monsoon groundwater level trend map of shallow aquifer**

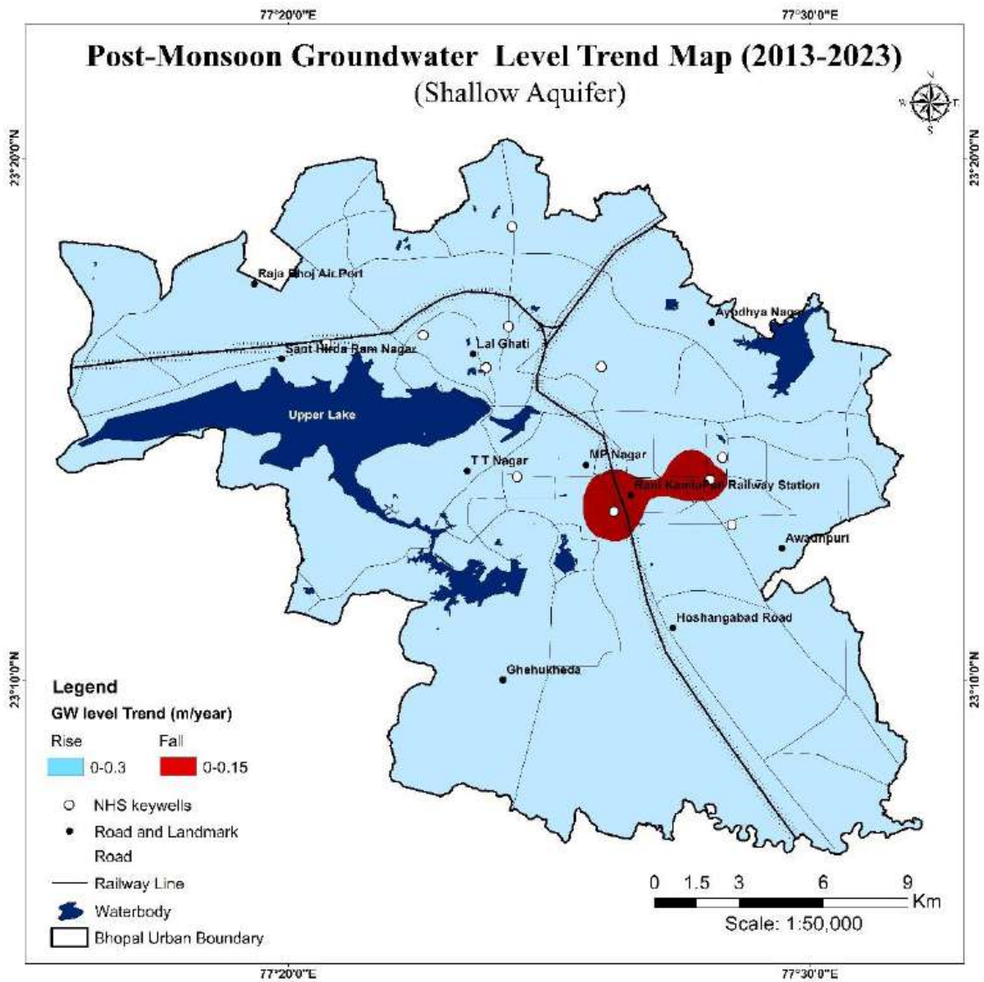



**Fig. 4.7 Post-Monsoon groundwater level trend map of shallow aquifer**

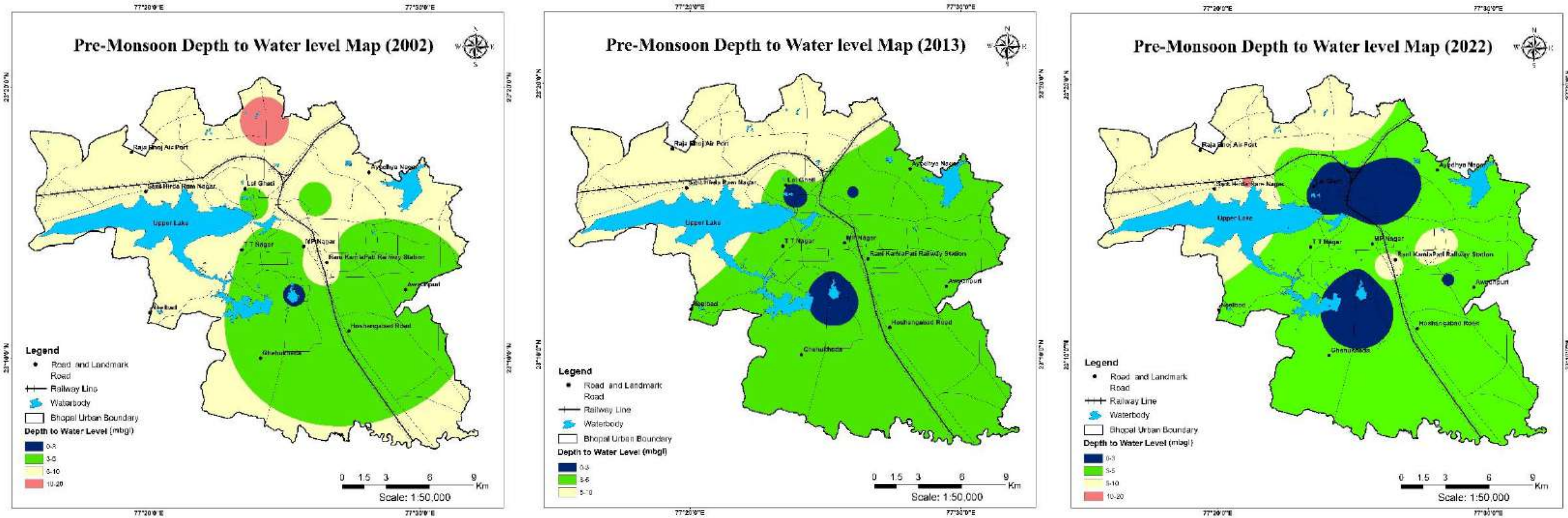
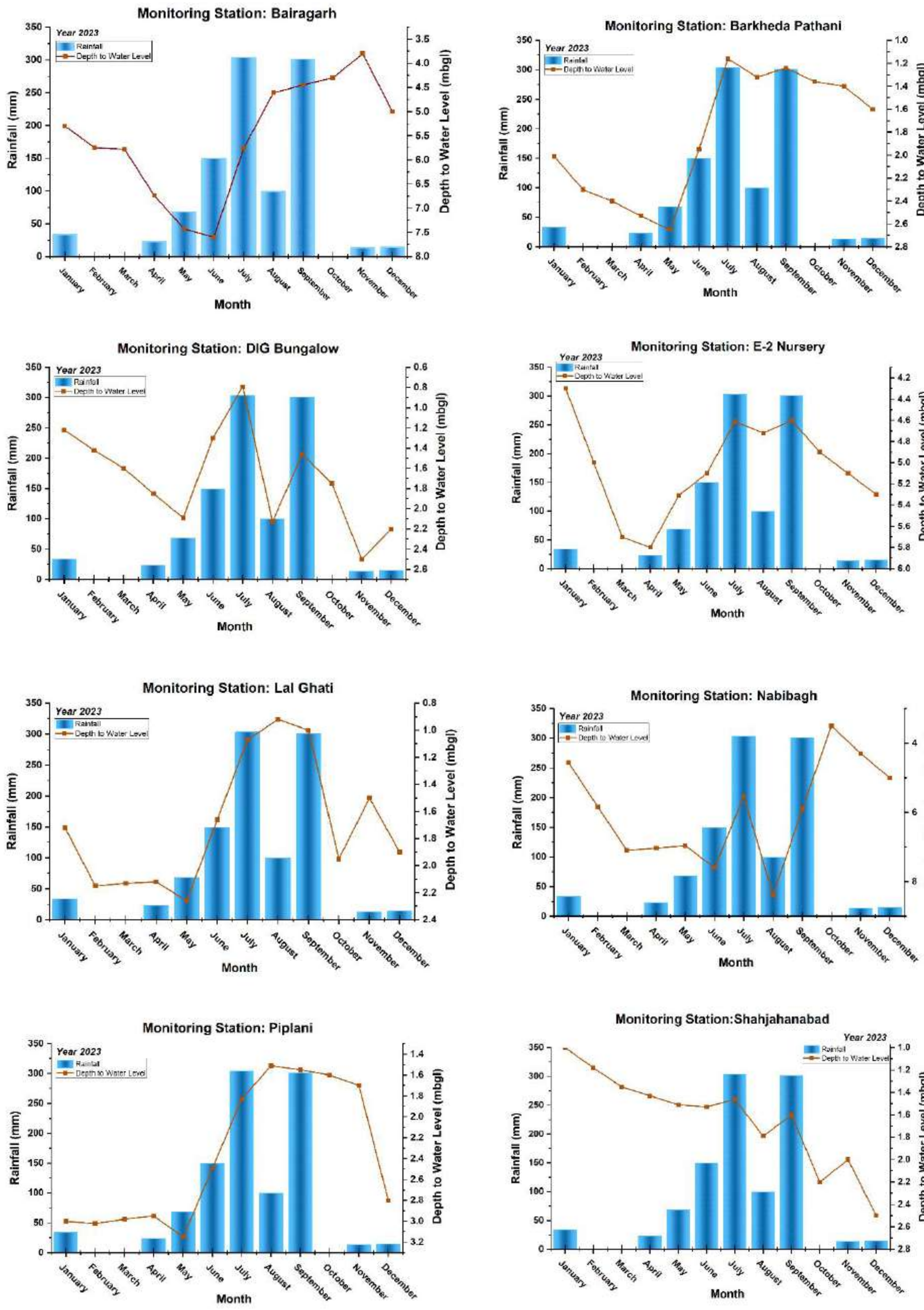



**Fig.4.8 Comparison between Pre-Monsoon Depth to water level map of shallow aquifer for year 2002, 2013 and 2022**

### 4.3.7 Rainfall and Depth to water level of shallow aquifer (2023):

The correlation between rainfall and depth to water level for the year 2023 are depicted in **Fig. 4.9.**



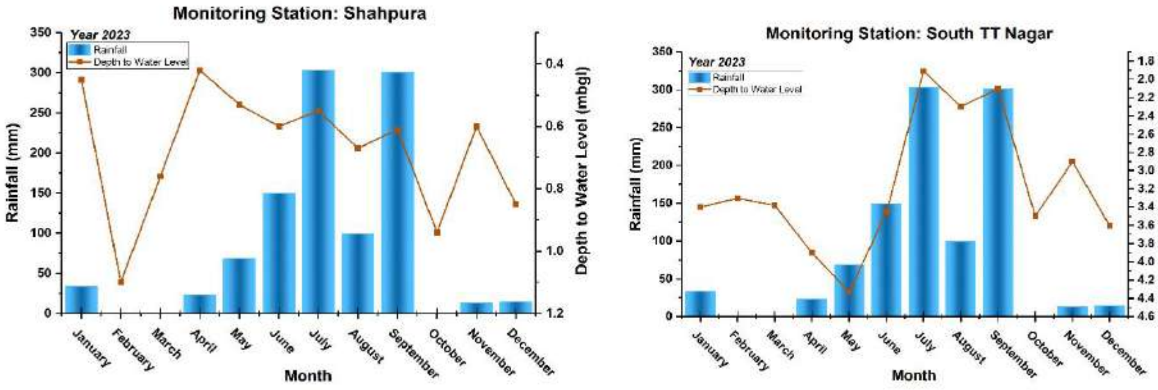



**Fig. 4.9: Graph showing correlation between Rainfall and Depth to water level for the year 2023**

The correlation indicates that rainfall directly impacts groundwater levels, with increased rainfall leading to a rise in groundwater levels and decreased rainfall causing a drop in groundwater levels. It can be concluded that aquifer is highly susceptible to seasonal variability.

# 5. ASSESSMENT OF DYNAMIC GROUNDWATER RESOURCES

## 5.1 Objective

The primary aim of this chapter is to evaluate the Dynamic Groundwater Resources within the study area, which is crucial for the effective management of groundwater resources in accordance with their availability.

## 5.2 Methodology

The Dynamic Groundwater Resource Assessment: 2023 for the State of Madhya Pradesh, including Bhopal Urban, was conducted by CGWB, NCR, Bhopal using the GEC-2015 Methodology within the INDIA - GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES) Software. This assessment includes calculating the Annual Groundwater Recharge and Annual Extractable Groundwater Resources, determining the Total Annual Groundwater Extraction (utilization), and evaluating the percentage of utilization relative to the Annual Extractable Groundwater Resources (Stage of Extraction).

URL of IN-GRES http://ingres.iith.ac.in

The stage of groundwater extraction is defined by.

$$\text{Stage of GW Extraction} = \frac{\text{Existing Gross GW Extraction for all Uses}}{\text{Annual Extractable GW Resources}} * 100$$

### 5.2.1 Categorization of Assessment Unit

The categorization of assessment unit based on stage of groundwater extraction is summarized in the given **table 5.1**;

**Table 5.1: Categorization of Assessment Unit**

| S. No. | Stage of Groundwater Extraction (%) | Category |
|---|---|---|
| 1. | ≤ 70 | Safe |
| 2. | > 70 and ≤90 | Semi-critical |
| 3. | > 90 and ≤100 | Critical |
| 4. | > 100 | Over Exploited |

### 5.3 Result and Discussion

The Dynamic Groundwater resources of Bhopal Urban was calculated for an area of 425 Ha. Details are mentioned in **table 5.2**;

**Table 5.2 Area Details of Bhopal Urban**

| Total Geographical Area (Ha) | | | | |
|---|---|---|---|---|
| Recharge Worthy Area (Ha) | | | Hilly Area (Ha) | Total (Ha) |
| Command Area | Non-Command Area | Total | | |
| 0 | 38293 | 38293 | 4207 | 42500 |

Groundwater recharge scenario within the Bhopal Urban is described in **table 5.3** and **5.4**;

**Table 5.3: Groundwater Recharge Scenario of Bhopal Urban**

| Recharge from Rainfall-Monsoon Season (Ham) | Recharge from Other Sources-Monsoon Season (Ham) | Recharge from Rainfall-Non-Monsoon Season (Ham) | Recharge from Other Sources-Non-Monsoon Season (Ham) | Total Annual Groundwater Recharge (Ham) | Total Natural Discharges (Ham) | Annual Extractable Groundwater Resource (Ham) |
|---|---|---|---|---|---|---|
| 3594.13 | 600.69 | 0 | 1071.53 | 5266.35 | 263.32 | 5003.03 |

**Table 5.4: Recharge from Other Sources in Bhopal Urban**

| Recharge from Canals (in Ham) | Recharge from Surface Water Irrigation (in Ham) | Recharge from Ground Water Irrigation (in Ham) | Recharge due to Tanks and Ponds (in Ham) | Recharge due to Water Conservation Structures (in Ham) | Recharge due to Pipelines (in Ham) | Total Recharge from Other Sources (in Ham ) |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 437.61 | 0.00 | 1234.61 | 1672.22 |

Groundwater extraction for irrigation, industrial and domestic usage along with stage of extraction and categorization are tabulated in **table 5.5**;

**Table 5.5: Groundwater Extraction Scenario Bhopal Urban**

| **Ground Water Extraction for Irrigation Use (Ham)** | **Ground Water Extraction for Industrial Use (Ham)** | **Ground Water Extraction for Domestic Use (Ham)** | **Total Extraction (Ham)** | **Annual GW Allocation for for Domestic Use as on 2025 (Ham)** | **Net Ground Water Availability for future use (Ham)** | **Stage of Ground Water Extraction (%)** | **Categorization** |
|---|---|---|---|---|---|---|---|
| 0.00 | 31.38 | 3727.90 | 3759.27 | 4088.58 | 883.08 | **75.14** | **semi critical** |

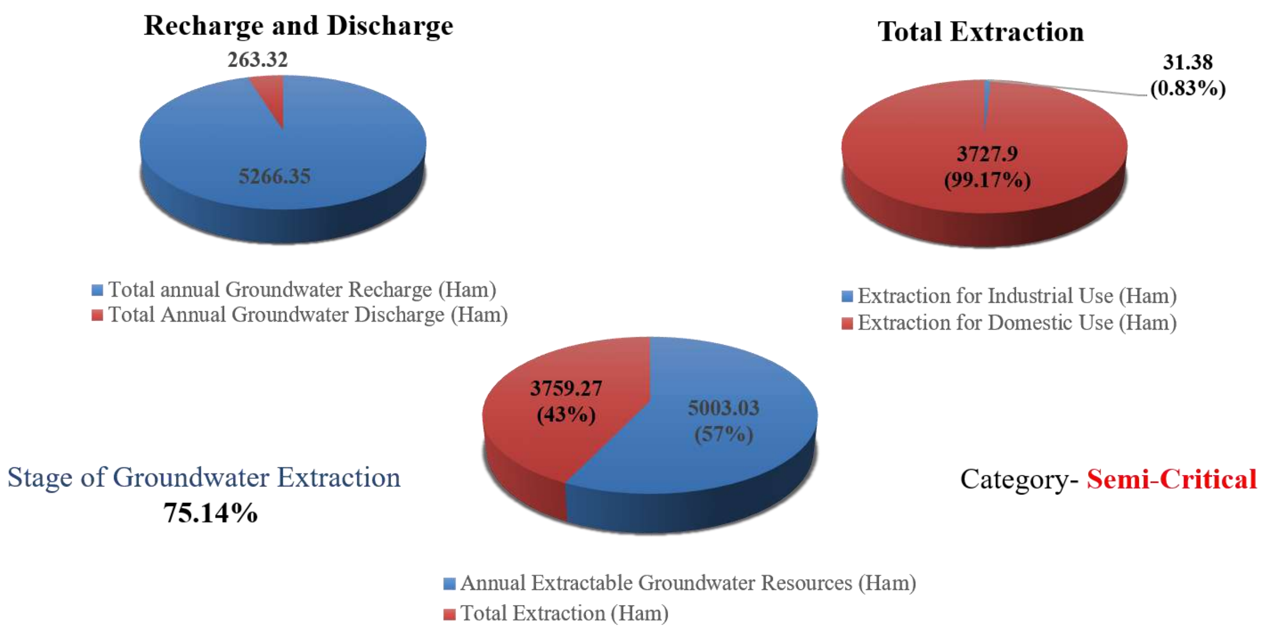



**Fig. 5.1 Dynamic Groundwater Resource Estimation (2023)**

### 5.3.1 Comparison of Dynamic Groundwater Resources of year 2020, 2022 and 2023

The Dynamic Groundwater Resources assessment for the years 2020, 2022, and 2023 have demonstrated a successive increase in annual extractable groundwater resources, accompanied by a rise in total extraction. This trend can be linked to the growing population, which exerts additional pressure on groundwater resources. The comparison is shown in **Table 5.6** and **Fig. 5.2.**

**Table 5.6 Comparison between Dynamic Groundwater Resources of Year 2020, 2022 and 2023**

| Year | Annual Extractable Groundwater Resources (Ham) | Total Extraction (Ham) | Stage of Groundwater Extraction (%) |
|---|---|---|---|
| 2020 | 2859.06 | 2271.72 | 79.46% |
| 2022 | 5181.35 | 3685.39 | 71.13% |
| 2023 | 5003.03 | 3759.27 | 75.14% |

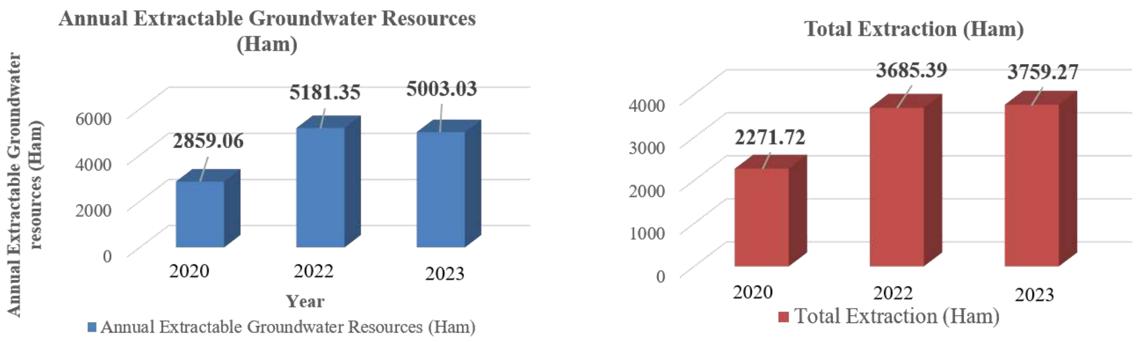



**Fig. 5.2 Comparison between Dynamic Groundwater Resources of Year 2020, 2022 and 2023**

# 6. WATER QUALITY OF BHOPAL URBAN AGGLOMERATE

## 6.1 Objective

The primary objectives of this chapter are to evaluate the quality of both shallow and deep aquifer groundwater, surface water, and rainwater within the study area along with to assess groundwater quality in the vicinity of a large dumping site and the Union Carbide India Limited (UCIL) plant, known for the Bhopal gas tragedy. These objectives aim to provide a comprehensive understanding of water quality in the study area and to identify any potential contamination resulting from industrial activities and waste disposal practices. Through this assessment, effective measures can be developed to mitigate risks and ensure the protection of water resources.

## 6.2 Methodology

Water samples were systematically collected from various sources within the study area. 80 groundwater samples were obtained from key wells representing the shallow aquifer during pre and post-monsoon, 11 from exploratory wells/boreholes representing the deeper aquifer and 8 from surface water sources during pre-monsoon, and 3 from rainwater. Samples were collected using clean double stopper polyethylene bottles. The samples were then analysed for a comprehensive range of water quality parameters, including temperature, pH, electrical conductivity (EC), total hardness, major ions (calcium, magnesium, sodium, potassium), alkalinity (carbonate, bicarbonate), and various contaminants such as chloride, fluoride, nitrate, sulfate, phosphate, silica, as well as trace/heavy metals (copper, iron, zinc, arsenic, chromium, manganese, lead, uranium). Information regarding sampling locations can be found in **Annexures IV and V**, and the spatial distribution is illustrated in **Fig. 6.1**. Additionally, Detailed analytical results for these parameters are provided in **Annexures XVIII and XIX**.

The analysis of the water samples was conducted using various standard methods as outlined in the 23rd edition of the American Public Health Association (APHA) manual. Specifically, measurements were performed using a microprocessor-based pH meter, electrical conductivity meter, UV-VIS spectrophotometer (Shimadzu, UV-1201), and flame photometer (Systronics 128). Analytical grade (AR) reagents were utilized for these analyses. Additionally, the heavy/trace elements were analysed using a Thermo iCAP RQ 01459 inductively coupled plasma mass spectrometer (ICP-MS), which was calibrated to the trace elements standard of Certified Reference Material (CRM) in the Regional Chemical Laboratory of Central Groundwater Board, Northern Region, Lucknow. The assessment of descriptive statistics and correlation matrix for groundwater quality in the Bhopal Urban Agglomerate was performed by comparing observations of different parameters against the Bureau of Indian Standard (BIS – 10500: 2012), as detailed in **Annexures VI and VII**.

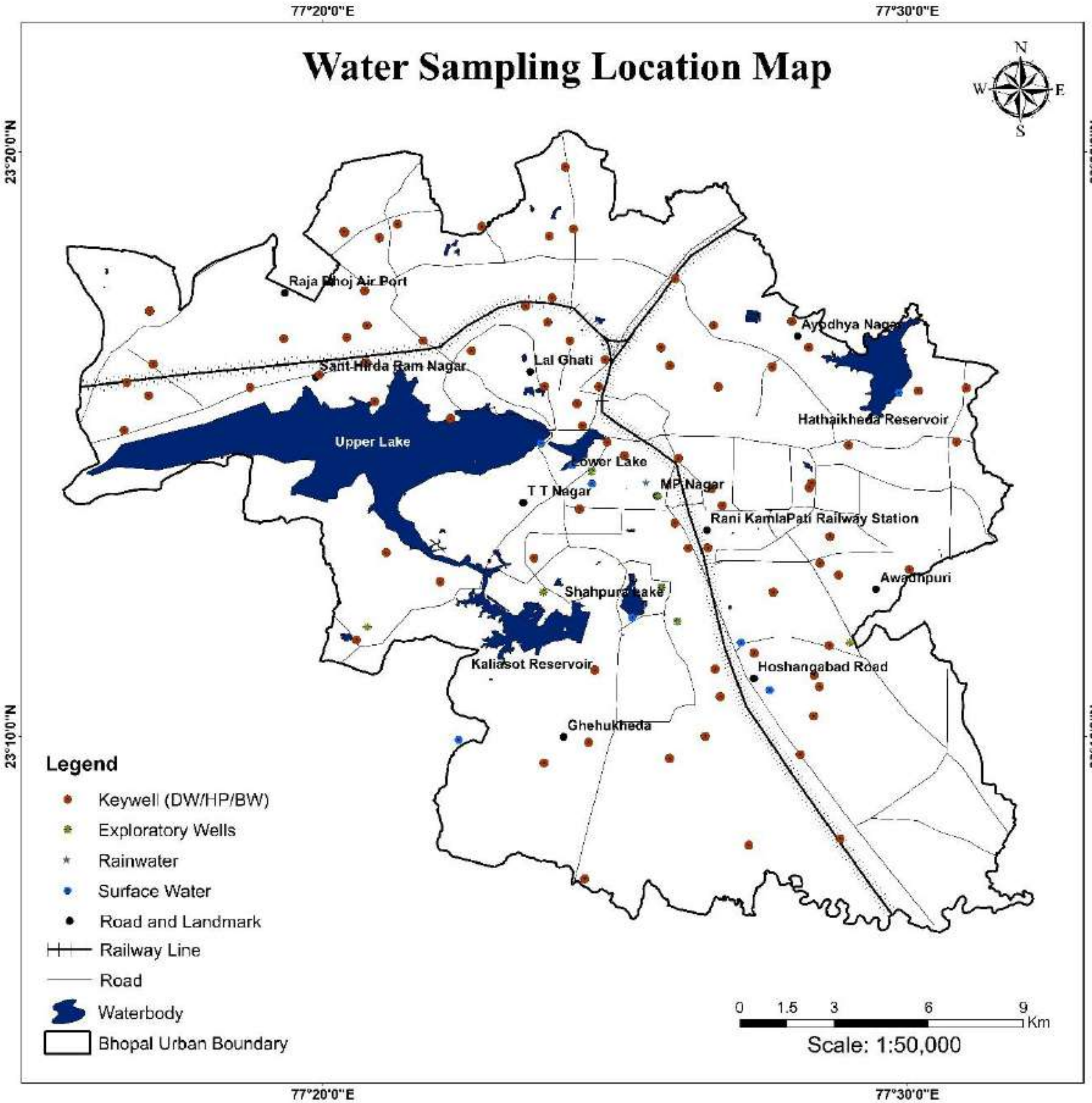



**Fig. 6.1 Water Sampling Location Map**

## 6.3 Result and Discussion

### 6.3.1 Groundwater Quality

**Temperature**

Cool water is generally more palatable than warm water. High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems. In the study area, the water temperature measured during the sampling and observed in between 25.1 to 33.1°C during pre-monsoon while in between 23.7 to 28.6°C during post-monsoon. The maximum temperature observed at Bairagarh Chichli (33.1°C) and at Pallavi Nagar (28.6°C) during pre- and post-monsoon respectively.

**Hydrogen Ion Concentration (pH)**

The hydrogen ion concentration (pH) is a measure of the hydrogen ion concentration in water and indicates whether the water is acidic or alkaline. In the study area, groundwater is within the BIS permissible limit and referred as slightly acidic to neutral in nature.

**Electrical Conductivity (EC)**

The electrical conductance is ability of water to conduct electric current and it depends on the concentration of ions, type of ions, and temperature. Electrical Conductivity (EC) estimates the amount of total dissolved salts (TDS), or determines the level of ions.

The electrical conductivity of groundwater in the study area ranges between 418 to 2105 µS/cm and 525 to 2385 µS/cm at 25°C during pre- and post-monsoon respectively in shallow aquifer. The maximum electrical conductivity observed 2015 µS/cm in pre-monsoon and 2385 µS/cm in post-monsoon at Badwai. In deeper aquifer, observed electrical conductivity ranges between 308 to 1700 µS/cm at 25°C. The maximum electrical conductivity has been observed at Govindpura. The spatial distribution of electrical conductivity of shallow aquifer during pre and post monsoon 2023 is shown in **Fig.6.2 and Fig.6.3** respectively and the frequency distribution is given in **Table 6.1**. On the basis of electrical conductivity, the groundwater Bhopal urban agglomerate is belonging good to moderately saline in nature.

**Table: 6.1: Frequency distribution (in %) of electrical conductivity (µS/cm at 25°C)**

| No. of Samples | Shallow Aquifer | | Deeper Aquifer (Pre-monsoon) |
|---|---|---|---|
| | Pre-monsoon | Post-monsoon | |
| | 80 | 80 | 11 |
| Min. | 418 | 525 | 308 |
| Max. | 2105 | 2385 | 1700 |
| Mean | 1055 | 1061 | 876 |
| < 750 | 15.0 | 16.3 | 45.5 |
| 750- 2250 | 85.0 | 82.5 | 54.5 |
| 2250-3000 | 0.0 | 1.3 | 0.0 |
| > 3000 | 0.0 | 0.0 | 0.0 |

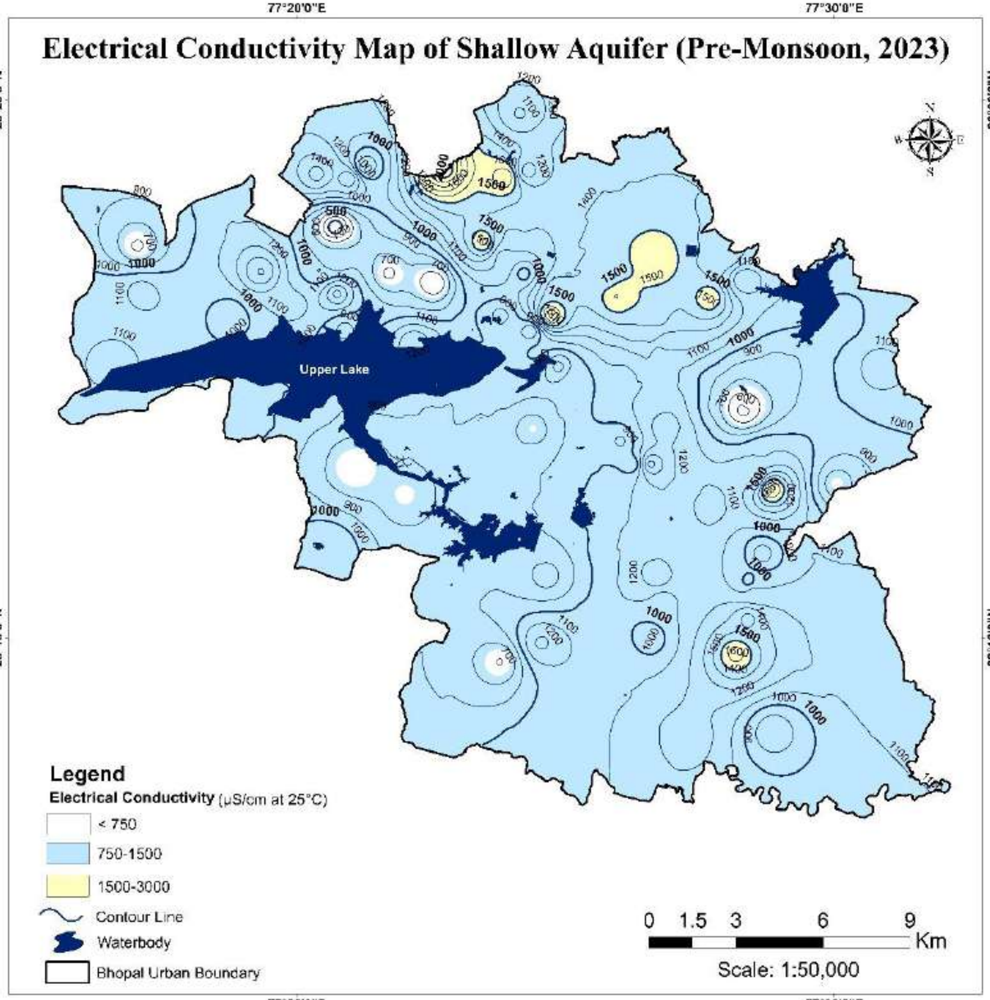



**Fig. 6.2 Spatial distribution of electrical conductivity of shallow aquifer (Pre-Monsoon, 2023)**

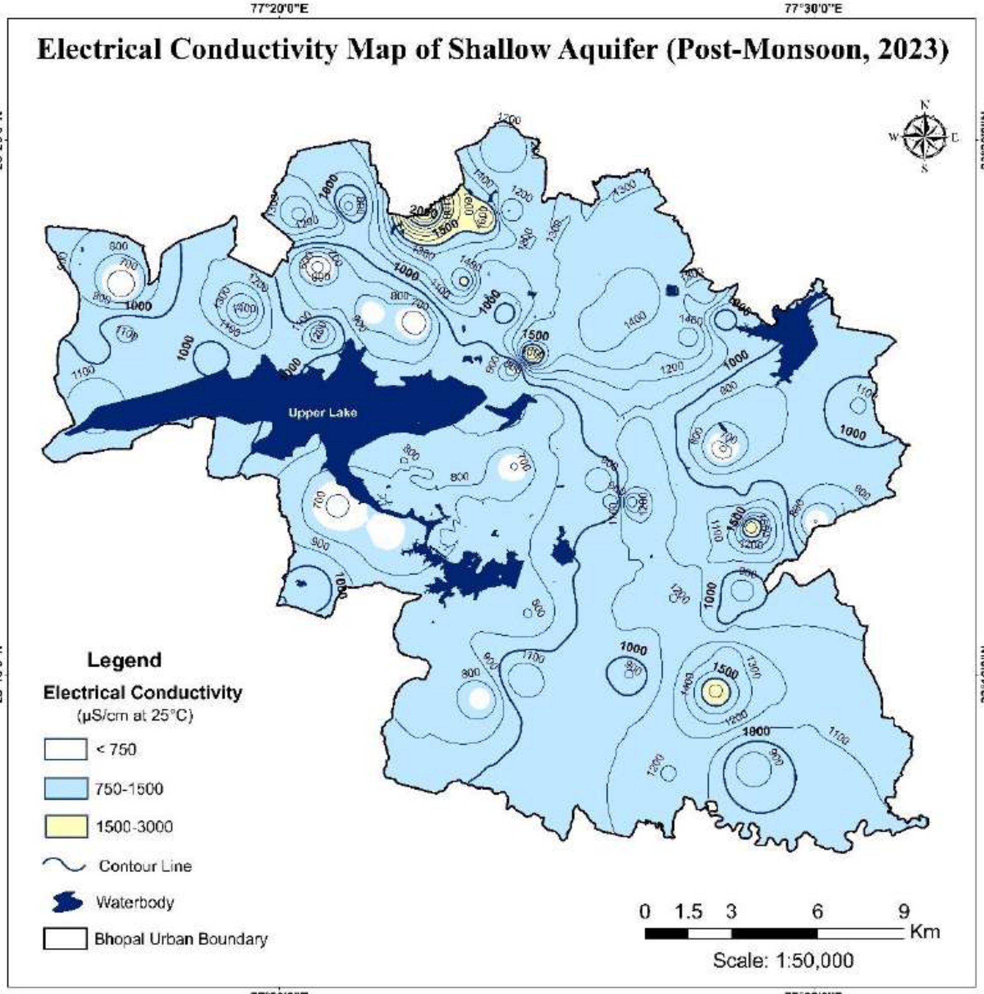



**Fig. 6.3 Spatial distribution of electrical conductivity of shallow aquifer (Post-Monsoon, 2023)**

### Chloride

Chloride is present in all-natural waters, mostly at low concentrations. It is highly soluble in water and moves freely with water through soil and rock. Chloride concentration of shallow aquifer is within the BIS permissible limit and ranges between 20 to 309 mg/l and 25 to 270 mg/l during pre- and post-monsoon respectively. The maximum chloride concentration is observed 309 mg/l during pre-monsoon and 270 mg/l at Badwai during post-monsoon. In deeper aquifer observed chloride concentration ranges between 12 to 297 mg/l. The maximum chloride concentration has been observed at Govindpura i.e. 297 mg/l. The frequency distribution is given in **Table 6.2**.

**Table: 6.2: Frequency distribution (in %) of chloride concentration (mg/l)**

| **No. of Samples** | **Shallow Aquifer** | | **Deeper Aquifer (Pre-monsoon)** |
|---|---|---|---|
| | **Pre-monsoon** | **Post-monsoon** | |
| | 80 | 80 | 11 |
| Min. | 20.0 | 25.0 | 12.5 |
| Max. | 309.4 | 270.0 | 297.5 |
| Mean | 96 | 99 | 112 |
| *<250* | 98.8 | 97.5 | 81.8 |
| *250-1000* | 1.3 | 2.5 | 18.2 |
| *>1000* | 0.0 | 0.0 | 0.0 |

### Fluoride

The fluoride concentration of shallow aquifer within study area ranges between 0.06 to 0.89 mg/l and 0.05 to 0.85 mg/l during pre- and post-monsoon respectively. The maximum concentration of fluoride is observed 0.89 mg/l at South T.T. Nagar during pre-monsoon and 0.85 mg/l during post-monsoon at DIG Bangalow. In deeper aquifer, observed fluoride concentration ranges between 0.07 to 1.48 mg/l. The maximum fluoride concentration has been observed at Neelbad i.e. 1.48 mg/l. Fluoride concentration maps of shallow aquifer for pre- and post- monsoon 2023 are given in **Fig. 6.4** and **Fig.6.5**. The frequency distribution is tabulated in **Table 6.3.**

**Table: 6.3 Frequency distribution (in %) of fluoride concentration (mg/l)**

| **No. of Samples** | **Shallow Aquifer** | | **Deeper Aquifer** |
|---|---|---|---|
| | **Pre-monsoon** | **Post-monsoon** | |
| | 80 | 80 | 11 |
| Min. | 0.06 | 0.05 | 0.07 |
| Max. | 0.89 | 0.85 | 1.48 |
| Mean | 0.35 | 0.33 | 0.44 |
| <1.0 | 100.0 | 100.0 | 90.9 |
| 1-1.5 | 0.0 | 0.0 | 9.1 |
| >1.5 | 0.0 | 0.0 | 0.0 |

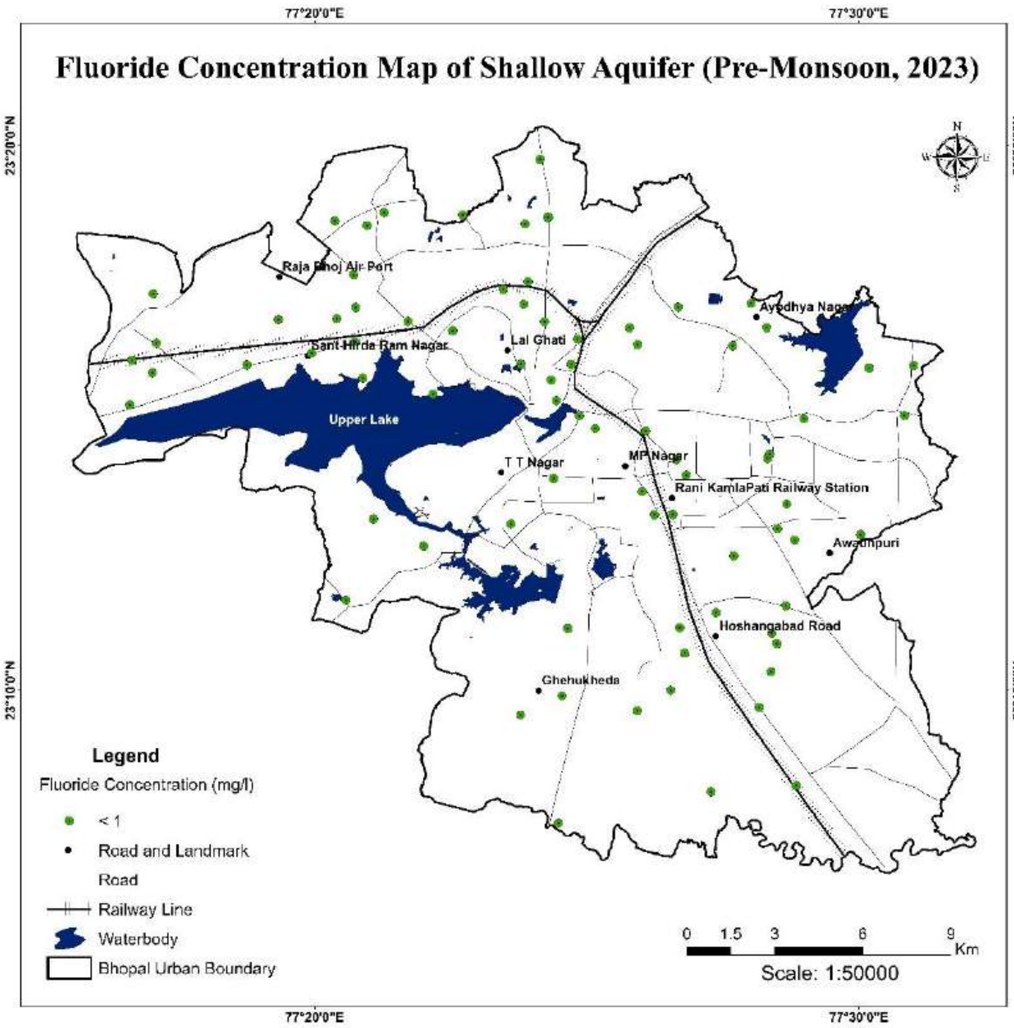



**Fig. 6.4 Fluoride concentration map of shallow aquifer**

**(Pre-Monsoon, 2023)**

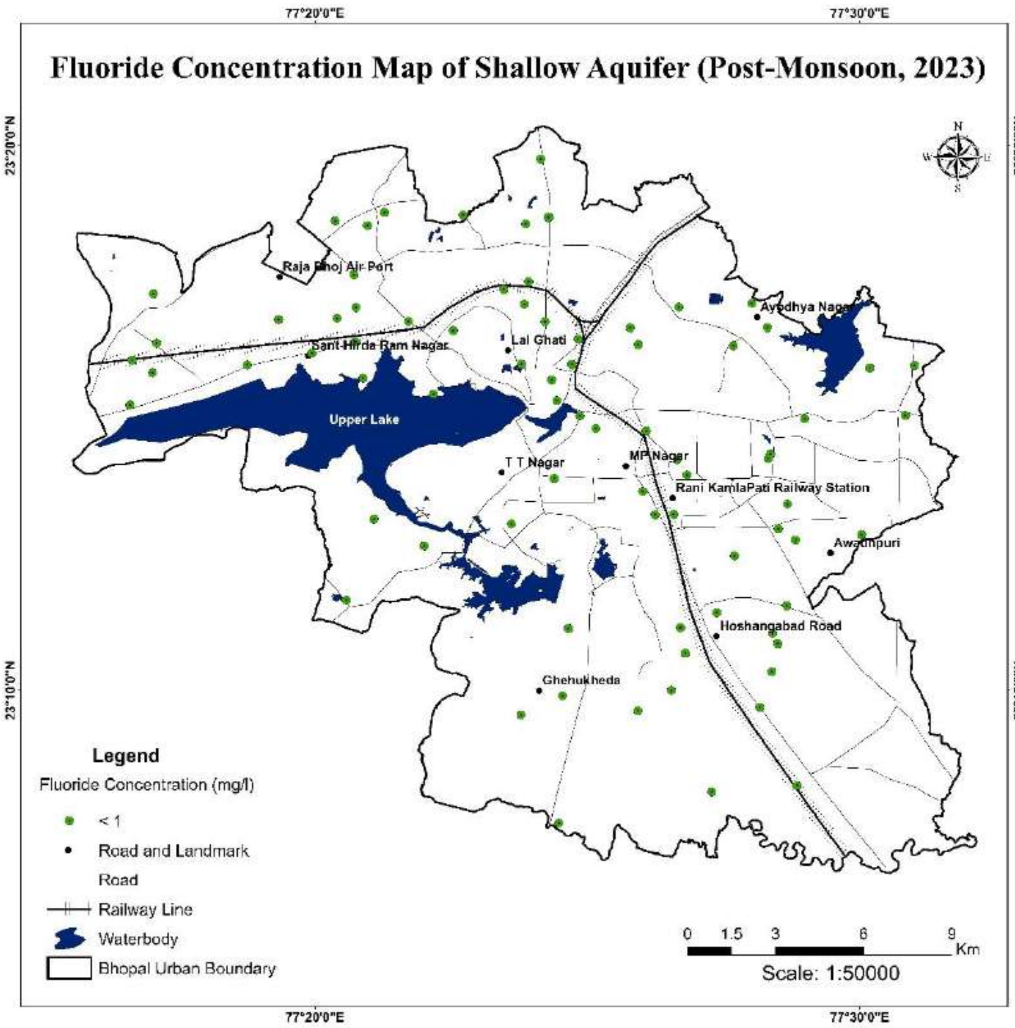



**Fig. 6.5 Fluoride concentration map of shallow aquifer**

**(Post-Monsoon, 2023)**

**Nitrate**

In Bhopal urban agglomerate, nitrate concentration in shallow aquifer ranges between 1 to 186 mg/l during pre-monsoon and about 81.25% groundwater have been recorded nitrate concentration within the acceptable limit while 18.75% water samples recorded more than 45 mg/l as BIS recommendation. The highest concentration of nitrate is observed at Narela Sankari i.e. 186 mg/l. In post-monsoon, the nitrate concentration ranges between 1 to 149 mg/l and 83.75% groundwater have been recorded nitrate concentration within the acceptable limit while 16.25% water samples recorded more than 45 mg/l as BIS recommendation. The highest concentration of nitrate is observed at Narela Sankari i.e. 149 mg/l. In deeper aquifer all groundwater has been recorded nitrate concentration within the acceptable limit of 45 mg/l. The maximum concentration of nitrate concentration has been recorded in the EW of M.P. Nagar Govt. High School i.e. 42 mg/l. The point value maps of nitrate contamination for pre- and post- monsoon-2023 of shallow aquifer are given in **Fig.6.6** and **Fig.6.7**. Nitrate concentration of shallow and deep aquifer is tabulated in **Annexure VIII**.

**Total Hardness**

The hardness in water is derived largely from contact with the soil and rock formations. Hardness can be defined as the capacity of water to precipitate soap caused by presence of calcium and magnesium-bicarbonate, sulfate and chloride ions.

Total hardness of groundwater in the Bhopal urban agglomerate is ranging between 105 to 762 mg/l and 160 to 825 mg/l during pre- and post-monsoon of shallow aquifer. In Deeper aquifer, it ranges between 75 to 579 mg/l. The maximum concentration of total hardness has been observed in shallow aquifer at Plate form No. 6 of Bhopal railway station during both pre-monsoon and post-monsoon i.e. 762 mg /l and 825 mg/l respectively. In deeper aquifer, at Govindpura, observed total hardness was 579 mg/l. The comparative concentration of total hardness of pre- and post-monsoon-2023 are given in **Fig. 6.8** and **Fig. 6.9** respectively and frequency distribution is given in **Table: 6.4** and total hardness more than BIS limit is given in **Annexure IX.**

**Table: 6.4: Frequency distribution (in %) of total hardness (mg/l)**

| | **Shallow Aquifer** | | **Deeper Aquifer (Pre-monsoon)** |
|---|---|---|---|
| | **Pre-monsoon** | **Post-monsoon** | |
| **No. of Samples** | 80 | 80 | 11 |
| Min. | 105 | 160 | 75 |
| Max. | 762 | 825 | 579 |
| Mean | 392 | 389 | 280 |
| <200 | 6.3 | 3.8 | 36.4 |
| 200-600 | 87.5 | 91.3 | 63.6 |
| >600 | 6.3 | 5.0 | 0.0 |

World Health Organization has classified the degree of hardness in water for domestic uses. In the study area 96 to 97% water samples belonging to very hard category in shallow aquifer during pre- and post-monsoon. In deeper aquifer 72% water samples belonging to very hard category. **Table 6.5** shows the categorization of total hardness.

**Table: 6.5 Categorization of Total Hardness**

| Hardness | mg/l as $CaCO_3$ | Pre-monsoon Nos. (%) | Post-monsoon Nos. (%) | Deeper Aquifer (Nos./ %) |
|---|---|---|---|---|
| Soft | 0-60 | Nil | Nil | Nil |
| Moderately hard | 61-120 | 1 (1.25%) | Nil | 1 (9.09%) |
| Hard | 121-180 | 2 (2.5%) | 2 (2.5%) | 2 (18.18%) |
| Very hard | more than 180 | 77 (96.25%) | 78 (97.5%) | 8 (72.72%) |

**Chemistry of Heavy Metals**

Heavy metals, namely Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn), Chromium (Cr) Arsenic (As), Lead (Pb) and Uranium (U) have been analysed in the groundwater and maps of iron and manganese contamination for pre and post-monsoon-2023 are given in **Fig.6.10** and **Fig. 6.11** respectively. The copper (Cu), zinc (Zn), arsenic (As), lead (Pb), chromium (Cr) and uranium (U) concentration in shallow aquifer is recorded within the acceptable limit during pre and post-monsoon.

In shallow aquifer, Iron concentration ranges between BDL to 4.331 mg/l during pre-monsoon whereas in post-monsoon, it is ranging between BDL to 5.120 mg/l. About 15% of groundwater samples belong to shallow aquifer having iron contamination. The maximum concentration has been recorded at Hathaikheda (4.331 mg/l) and at Chhola (5.12 mg/l) during pre-and post-monsoon respectively. The iron concentration in deeper aquifer is under BDL. Frequency distribution of iron concentration is tabulated in **table 6.6.**

**Table 6.6 Frequency distribution of Iron concentration**

| | Shallow Aquifer | | Deeper Aquifer (Pre-Monsoon) |
|---|---|---|---|
| | Pre-Monsoon | Post Monsoon | |
| No. of Samples | 80 | 80 | 11 |
| Min. | 0.00 | 0.00 | 0.00 |
| Max. | 4.33 | 5.12 | 0 |
| Mean | 0.48 | 0.48 | 0.00 |
| <1.0 | 85.0 | 85.0 | 100.0 |
| >1.0 | 15.0 | 15.0 | 0.0 |

The manganese concentration in shallow aquifer ranges between BDL to 0.557 mg/l and 0.020 to 0.95 mg/l during pre- and post-monsoon respectively. Acceptable and permissible limit of manganese in drinking water are 0.10 mg/l and 0.30 mg/l respectively as per BIS. About 2.5% samples during pre-monsoon and 3.8% samples during post-monsoon showed Mn Contamination. The maximum concentration of manganese is observed at HP68 (0.557 mg/l) and HP34 (0.95 mg/l) during pre- and post-monsoon respectively and at BW of Bhanpur Parisar which represent deeper aquifer, Mn concentration is found 0.069 mg/l. Frequency distribution of Manganese concentration is given in **table 6.7.**

| Table: 6.7 Frequency distribution of Manganese concentration | | | |
|---|---|---|---|
| | **Shallow Aquifer** | | **Deeper Aquifer (Pre-Monsoon)** |
| | **Pre-monsoon** | **Post monsoon** | |
| No. of Samples | 80 | 80 | 11 |
| Min. | 0.00 | 0.00 | 0.00 |
| Max. | 0.56 | 0.95 | 0.069 |
| Mean | 0.04 | 0.04 | 0.01 |
| <0.1 | 83.8 | 90.0 | 100.0 |
| 0.1-0.3 | 13.8 | 6.3 | 0.0 |
| >0.3 | 2.5 | 3.8 | 0.0 |

**Mechanisms of Controlling Groundwater Chemistry**

- **Water Type and Relationships (Hydro-chemical Diagrams)**

The Piper trilinear diagram is extensively used to graphically represent the composition of dissolved constituents in natural waters from various sources. According to the Piper-trilinear diagram **(Fig. 6.12 and Annexure-X & XI),** the groundwater in shallow aquifers during the pre-monsoon period predominantly consists of 87.5% (70 samples) as Ca-$HCO_3$ type, 10% (8 samples) as Ca-Mg-Cl type (mixed), and 2.5% (2 samples) as Ca-Na-$HCO_3$ type. Post-monsoon, the composition shifts to 92.5% (74 samples) Ca-$HCO_3$ type, 3.75% (3 samples) Ca-Mg-Cl type, 2.5% (2 samples) Ca-Na-$HCO_3$ type, and 1.25% (1 sample) Ca-Cl type.

During the pre-monsoon, deeper aquifers show 81.8% (9 samples) as Ca-$HCO_3$ type, with 9.1% (1 sample each) as Ca-Mg-Cl and Na-Cl types.

The Ca-$Cl_2$ type indicates permanent hardness in water, while the Ca-Mg-Cl type (alkaline earth-chloride) shows no single cation or anion exceeding 50% of the total, representing permanent hardness. The Na-Cl type reflects saline water, and the Ca-$HCO_3$ type denotes carbonate hardness, also known as temporary hardness. Similarly, the Ca-Na-$HCO_3$ type represents carbonate hardness.

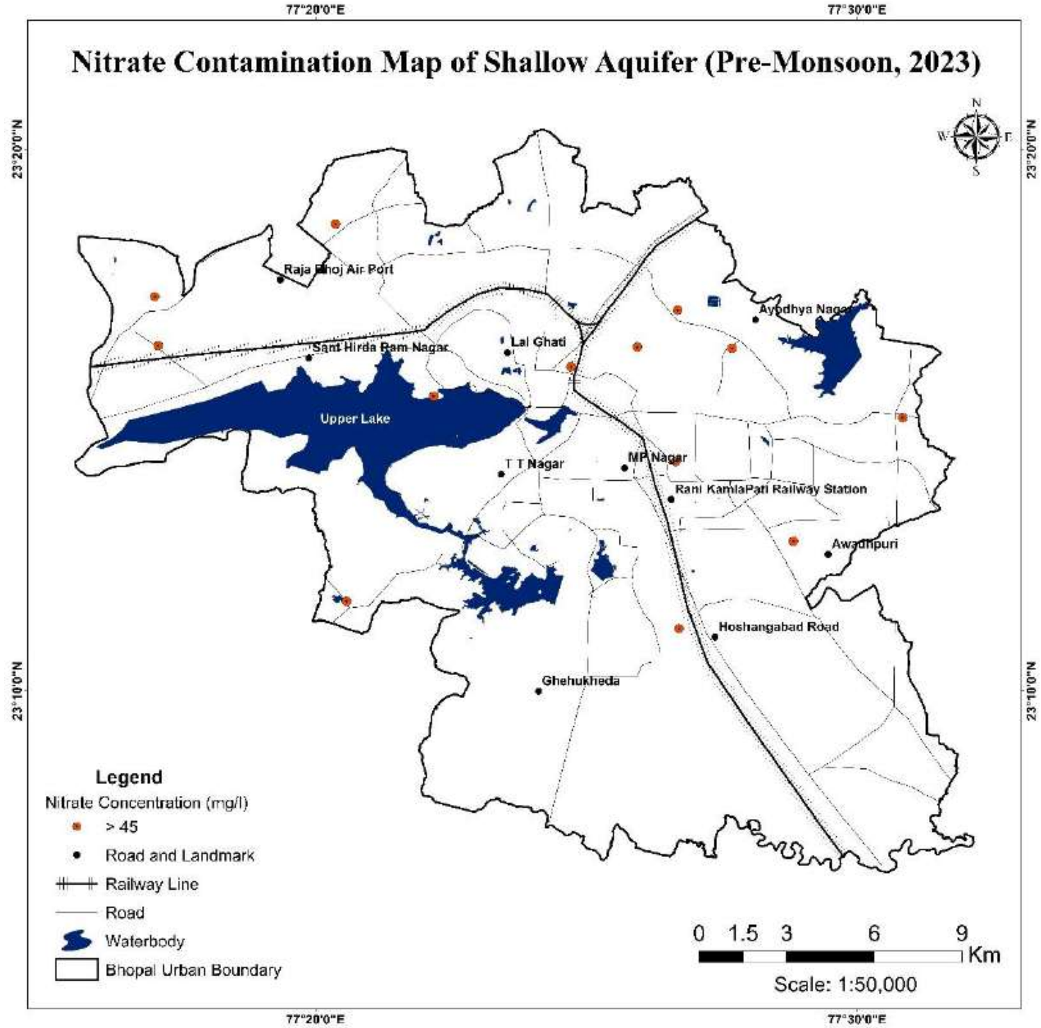



**Fig. 6.6 Nitrate Contamination map of shallow aquifer (Pre-Monsoon, 2023)**

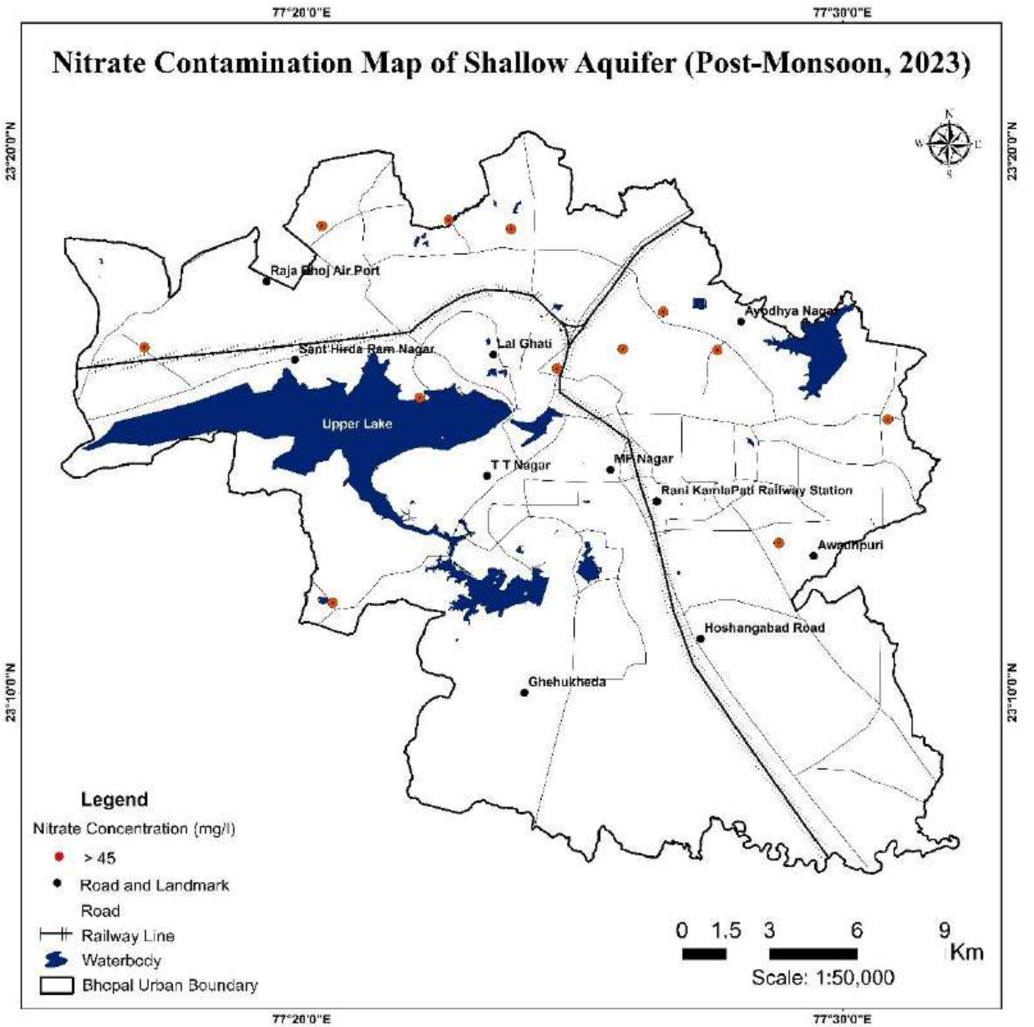



**Fig. 6.7 Nitrate Contamination map of shallow aquifer (Post-Monsoon, 2023)**

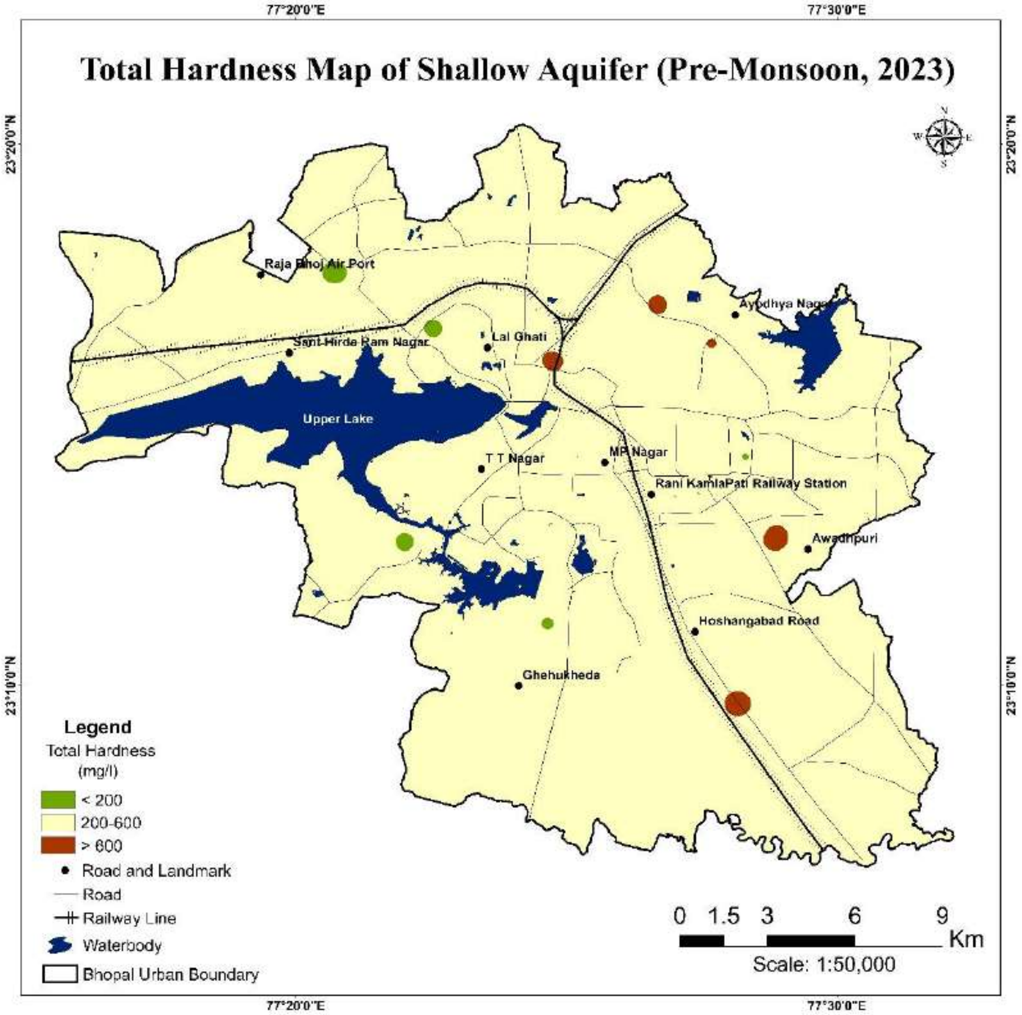



**Fig. 6.8 Total Hardness map of shallow aquifer**

**(Pre-Monsoon, 2023)**

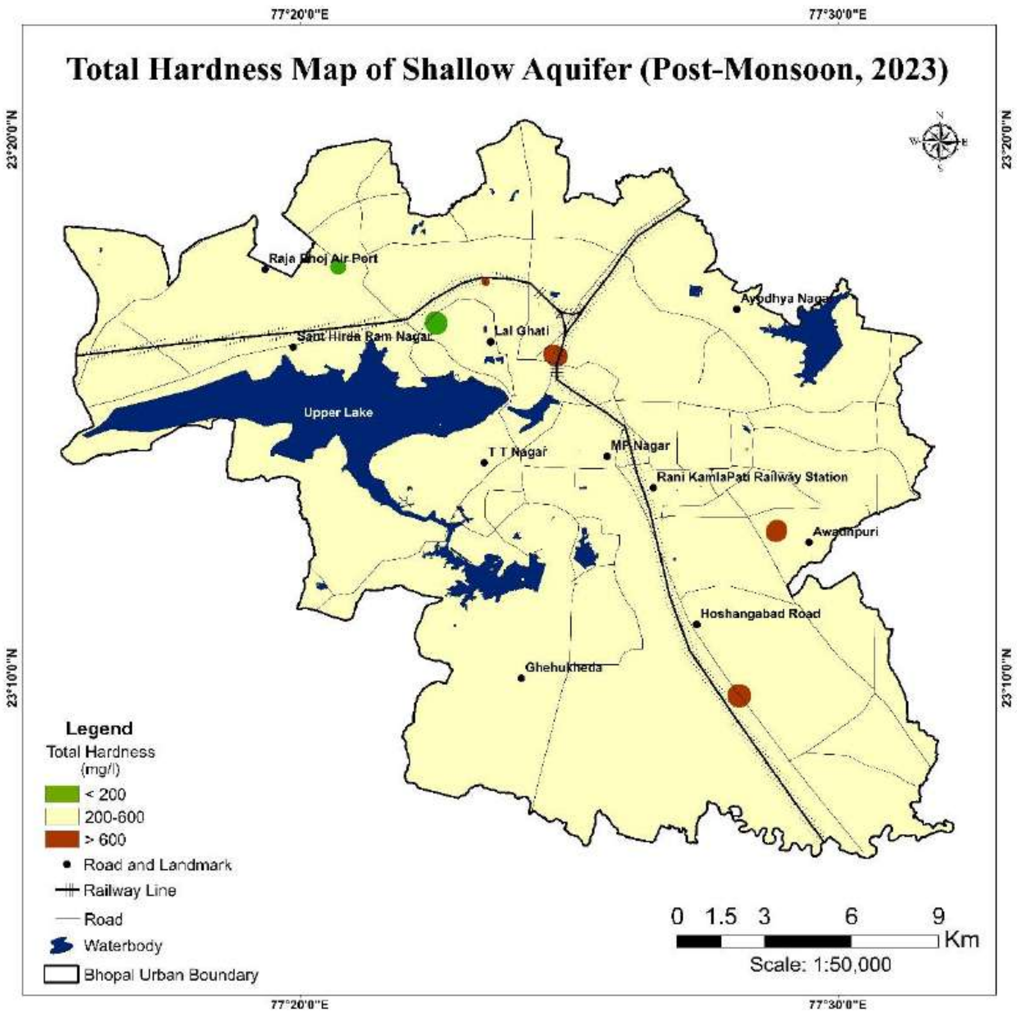



**Fig. 6.9 Total Hardness map of shallow aquifer**

**(Post-Monsoon, 2023)**

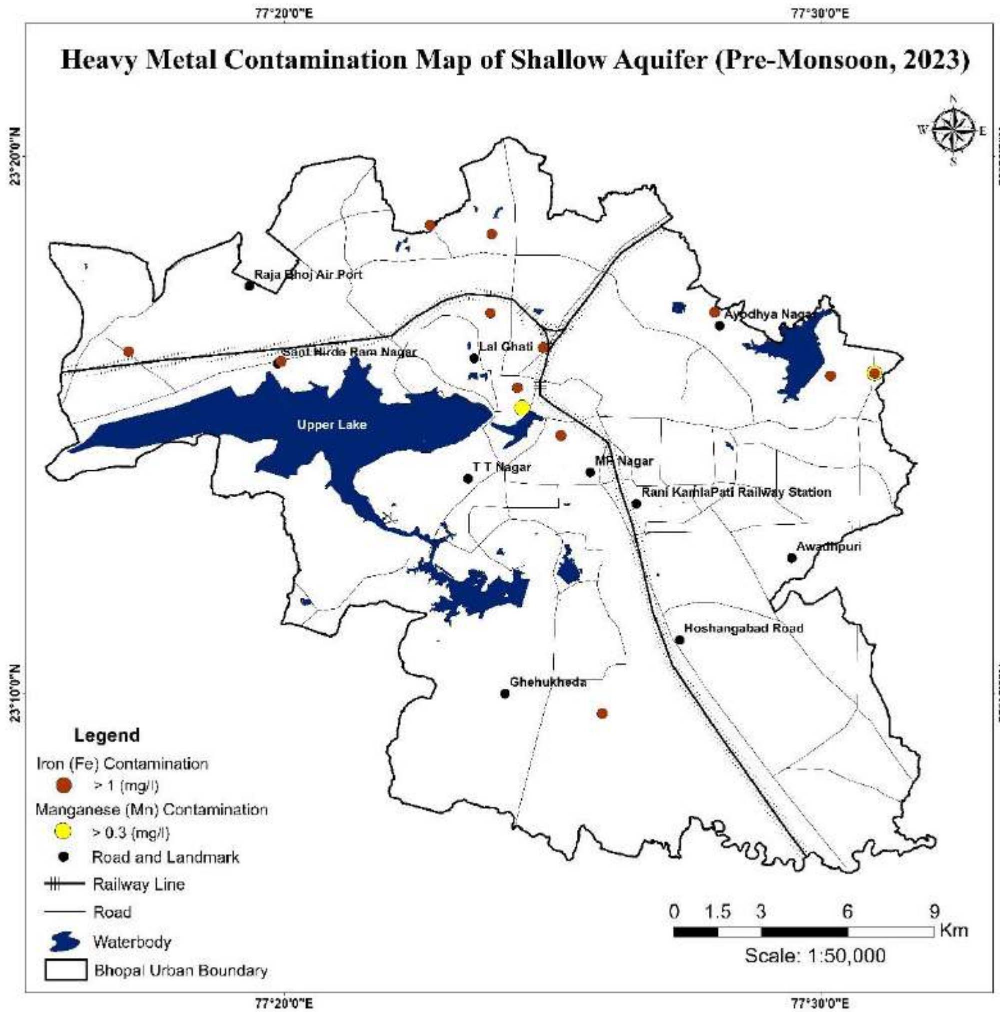



**Fig. 6.10 Heavy Metal (Fe and Mn) contamination map of shallow aquifer (Pre-Monsoon, 2023)**

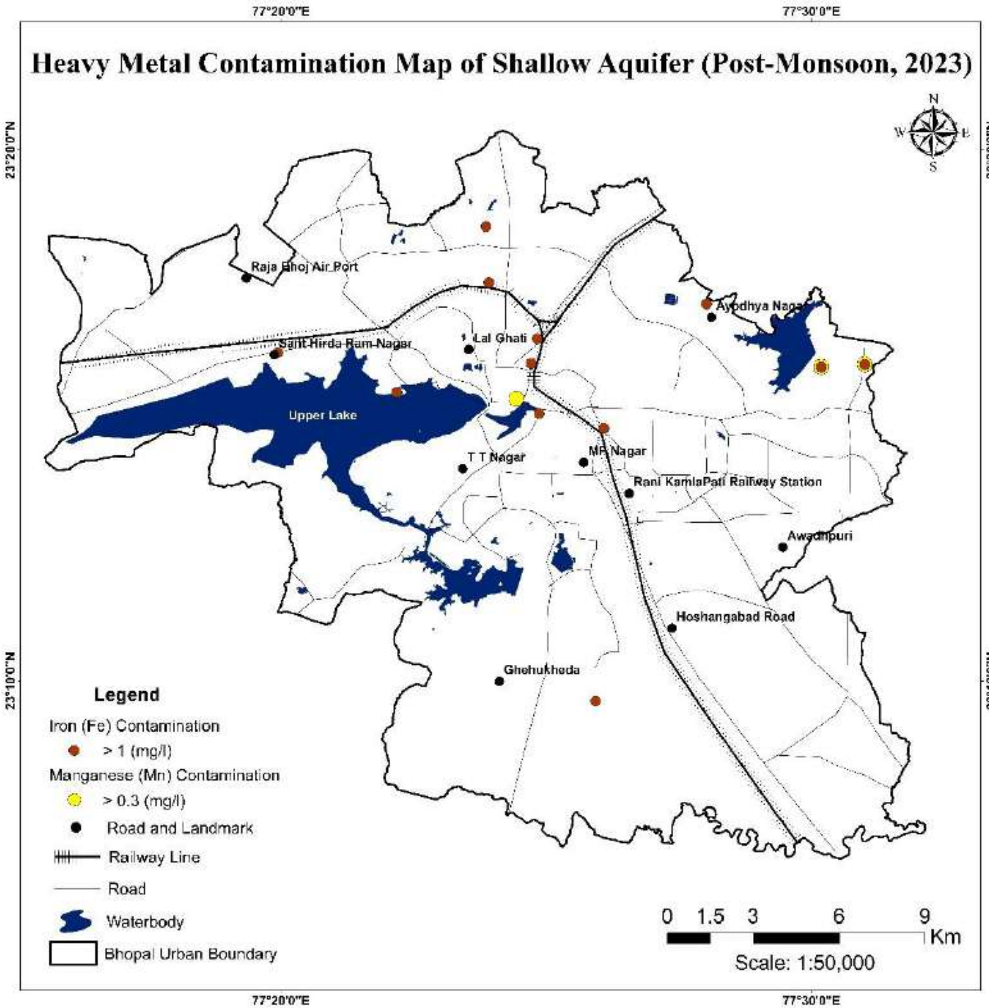



**Fig. 6.11 Heavy Metal (Fe and Mn) contamination map of shallow aquifer (Post-Monsoon, 2023)**

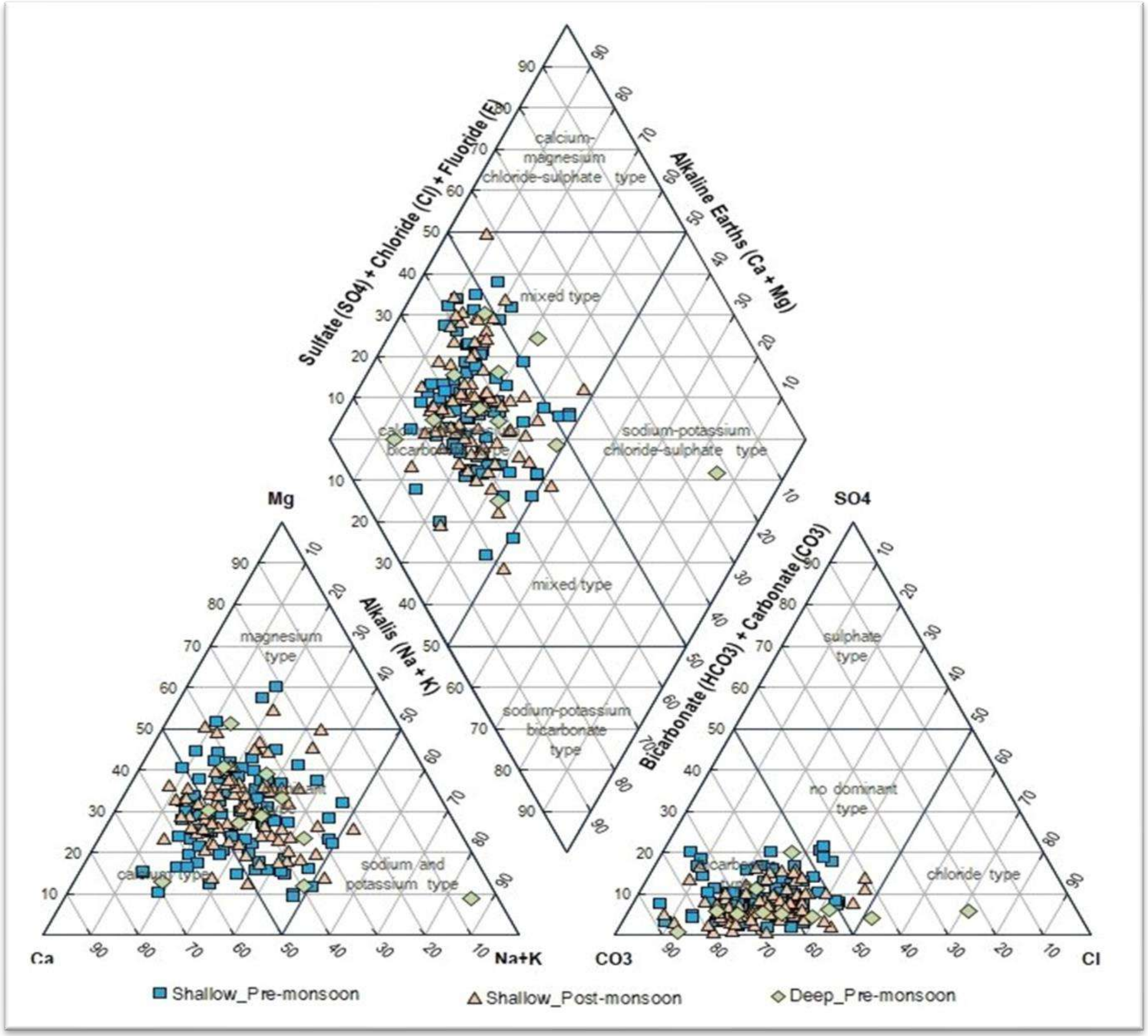



**Fig.6.12 Piper Trilinear diagram for shallow and deep aquifer**

## ➢ Gibbs Diagram and Water–Rock Interaction

To obtain hydro-geochemical processes, Gibbs (1970) has proposed scatter diagram method illustrating three important natural mechanisms controlling the major ion chemistry of the groundwater including water–rock interaction, evaporation and atmospheric precipitation. The TDS concentrations were plotted against the ratios of Na/ (Na + Ca) for cations and Cl/ (Cl + HCO3) for anions **(Fig.6.13).**

It has been found that majority of the samples collected from shallow aquifer falls in evaporation dominance during both pre-monsoon and post-monsoon. The data points on the Gibbs diagram suggests groundwater chemistry of Shallow is controlled principally by evaporation-crystallization factor leads the groundwater quality of the study area is good in nature. Some groundwater samples in pre-monsoon falls into rock dominance. This reflected the significance of water–rock interactions as the major source of dissolved ions controlling the chemical composition of these water are poor in quality (Li et al. 2015; Raju et al. 2015; Subba Rao 2002; Srinivasa Moorthy et al. 2008).

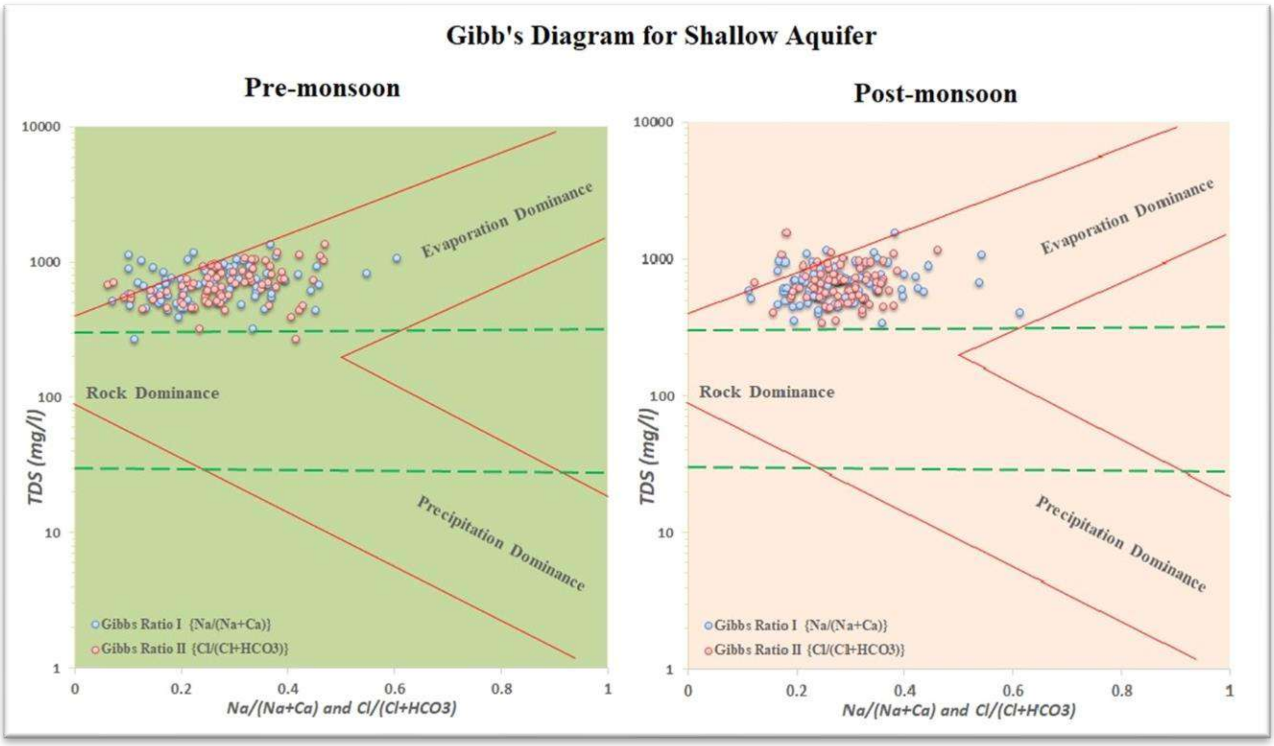



**Fig. 6.13 Gibb's Diagram for shallow Aquifer**

## ➢ Effect of Monsoon on Groundwater Quality of the study area

To examine the effect of monsoon on groundwater quality a paired t-test employed on 80 Number of samples. These collected from the same sample source during pre- and post-monsoon. Results of paired t-test is being given below in Annexure XVII. A t-test is a statistical hypothesis test that is used to determine whether there is a significant difference between the means of two groups. It helps you assess whether any observed differences between the groups are likely to have occurred by chance or if they are statistically significant.

At 95% confidence level and with a degree of freedom 50, outcome of t-test reveals that, mean value of parameter such as temperature, electrical conductivity, sulphate, nitrate, calcium, magnesium, potassium, arsenic, lead and uranium has been changed significantly. While parameter like pH, bi-carbonate, chloride, fluoride, total hardness, sodium, iron, manganese, copper, zinc and chromium remained unchanged after monsoon.

- **Correlation Matrix of Pre- and Post-monsoon water samples representing Shallow Aquifer**

Correlation matrix of Pre- and Post-Monsoon water samples of shallow aquifer are tabulated in **Annexure-XXIV** & **XXV** respectively. Correlation matrix of pre-monsoon suggests that shallow aquifer is largely governed by a few key parameters (like bicarbonate, chloride, calcium, and magnesium) that dictate salinity and hardness. Trace elements like arsenic and manganese are also interrelated, suggesting specific geochemical processes or sources affecting their levels. The weak correlations among other parameters, such as pH, suggest that these are influenced by factors different from those controlling the major ions.

Post-monsoon correlation matrix indicates that groundwater in the shallow aquifer is influenced by strong relationships between major ions such as bicarbonate, chloride, calcium, and magnesium, which affect salinity and hardness. Trace elements like arsenic and uranium are also closely related, suggesting similar geochemical conditions. Mn shows relationship with arsenic points to possible shared sources or processes. In contrast, pH does not significantly influence the concentrations of other parameters, and fluoride appears to be relatively independent of the other ions.

The comparison of pre- and post-monsoon correlation matrices indicates that while major ions like bicarbonate and chloride consistently influence water salinity and hardness, the monsoon season introduces additional significant relationships among trace elements. The strong correlation between arsenic and uranium, and between manganese and arsenic are found during post-monsoon.

**Groundwater Quality for Irrigation:**

- **Residual Sodium Carbonate (RSC)**

The water having high concentration of bicarbonates show the tendency of calcium and magnesium precipitated as carbonates. Quantity of this effect, an experimental parameter termed as residual sodium carbonate was coined by Eaton, 1950. The residual sodium carbonate (RSC) can be calculated by the given equation as follows:

$RSC = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+} + Mg^{2+})$

Where, the concentration of $CO_3^{2-}$, $HCO_3^{-}$, $Ca^{2+}$ and $Mg^{2+}$ ions expressed in meq/l

In the pre-monsoon period, 95% (76 samples) of groundwater from the shallow aquifer has RSC values below 1.25, 3.8% has values between 1.25 and 2.5, and 1.3% (1 sample) has an

RSC value greater than 2.5. These RSC values generally indicate that the water is suitable to marginally suitable for agricultural use, except for one location (DW02) with an RSC value of 2.60, which suggests unsuitability for agriculture **(Annexure-XII & XIII).**

During the post-monsoon period, 96.3% (77 samples) of groundwater has RSC values below 1.25, 2.5% (2 samples) fall between 1.25 and 2.5, and 1.3% (1 sample) has an RSC value greater than 2.5. Water with RSC values up to 2.5 is considered suitable to marginally suitable for agriculture, while one location (DW09) with an RSC value of 2.95 indicates unsuitability for agricultural purposes. In the deeper aquifer, all groundwater samples have RSC values below 1.25, indicating suitability for agricultural use. The frequency distribution of RSC values is detailed in **Table 6.8.**

**Table 6.8: Frequency distribution of RSC Values**

| **Suitability for Irrigation** | | **Shallow Aquifer** | | **Deeper Aquifer (Pre-Monsoon)** |
|---|---|---|---|---|
| | **RSC Value** | **Pre-monsoon** | **Post-monsoon** | |
| Safe | <1.25 | 95.0% (76 nos.) | 96.3% (77 nos.) | 100.0 |
| Marginal suitable | 1.25 - 2.50 | 3.8% (3 nos.) | 2.5% (2 nos.) | 0.0 |
| Unsuitable | >2.50 | 1.3% (1 no.) | 1.3 % (1 no.) | 0.0 |

- **US Salinity Diagram**

The US Salinity Diagram, developed by the U.S. Salinity Laboratory in 1954, classifies water suitability for irrigation based on electrical conductivity (µS/cm at 25°C) and Sodium Adsorption Ratio (SAR). The electrical conductivity and SAR values for the Bhopal urban agglomerate were plotted on this diagram **(Fig. 6.14, Annexure-XII & XIII).**

In the shallow aquifer during the pre-monsoon period, 85.0% (68 samples) of the water falls into the C3-S1 class (high salinity and low SAR), while 15.0% (12 samples) are in the C2-S1 class (medium salinity and low SAR). Post-monsoon, 82.5% (66 samples) remain in the C3-S1 class, 16.25% (13 samples) in the C2-S1 class, and 1.25% (1 sample) shifts to the C4-S2 class (very high salinity and medium SAR). For deeper aquifers, 45.45% (5 samples) are classified as C2-S1, another 45.45% (5 samples) as C3-S1, and 9.09% (1 sample) as C3-S2.

Water with very high salinity and low to moderate SAR can be used for irrigation, provided that good management practices and favourable drainage conditions are in place to control salinity, ensuring satisfactory crop production. The frequency distribution of these classes is detailed in **Table 6.9.**

| Table: 6.9: Frequency distribution of USSL classification of the study area | | | | | |
|---|---|---|---|---|---|
| **Shallow Pre-monsoon** | | **Shallow Post-monsoon** | | **Deeper Aquifer** | |
| Irrigation Class | Nos. (%) | Irrigation Class | Nos. (%) | Irrigation Class | Nos. (%) |
| C2S1 | 12 (15.0%) | C2S1 | 13 (16.25) | C2S1 | 5 (45.45%) |
| C3S1 | 68 (85.0%) | C3S1 | 66 (82.50) | C3S1 | 5 (45.45%) |
| | | C4S2 | 1 (1.25) | C3S2 | 1 (9.09%) |

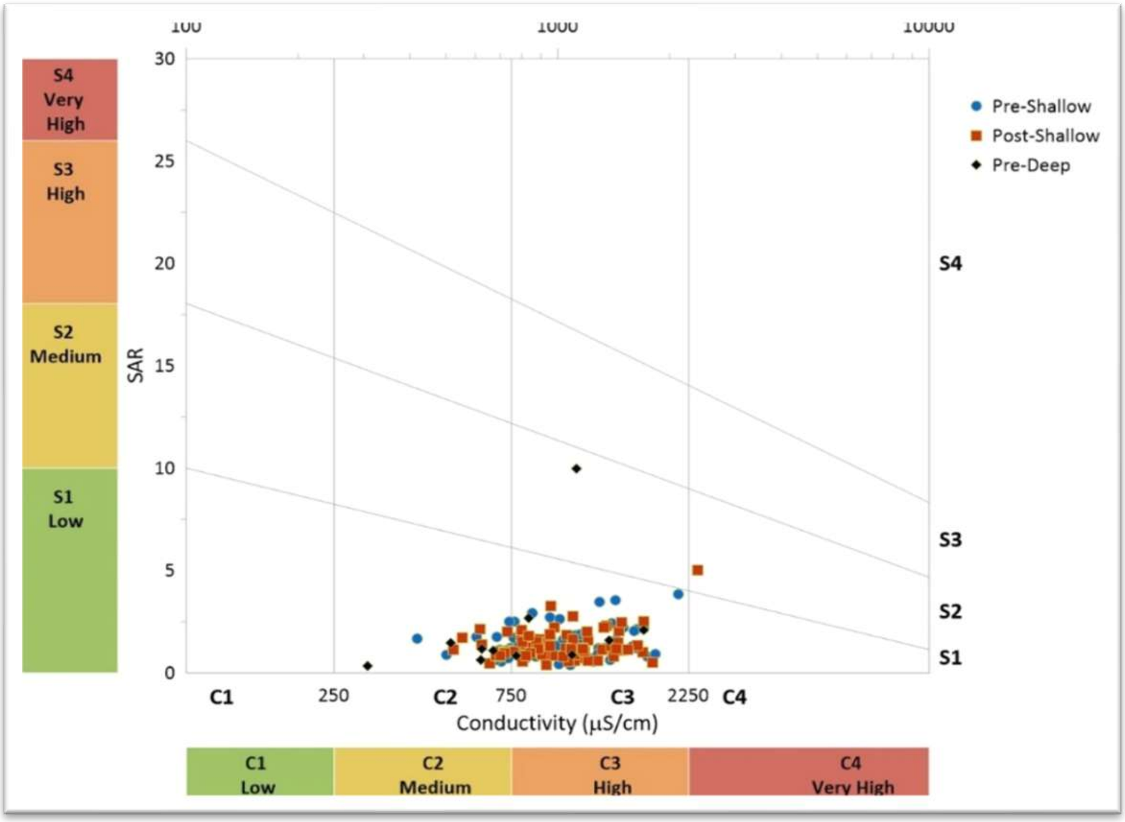



**Fig. 6.14 USSL classification for shallow and deeper aquifer**

### 6.2 Surface Water Quality

Surface water samples in the study area exhibit pH values ranging from 6.67 to 7.53, all within the BIS (IS 10500:2012) permissible range of 6.5 to 8.5, with the maximum pH recorded at Kerwa Dam-Mandora (7.95). This suggests that the surface water is slightly acidic to slightly alkaline in nature. The electrical conductivity of surface water varies between 260 and 650 µS/cm at 25°C, with all samples falling below the 750 µS/cm, indicating good water quality. The highest EC was observed at Kerwa Dam (650 µS/cm).

Fluoride concentrations across the surface water samples remain within the BIS limit of 1.5 mg/l, with the maximum at Kerwa Dam (0.83 mg/l). Nitrate concentrations are well within the acceptable limit of 45 mg/l, with the highest concentration found in Khatlapura Lower Lake (12.2 mg/l). Total hardness (as $CaCO_3$) ranges from 94 to 200 mg/l, all within the acceptable limit, with the maximum value recorded at Kerwa Dam (200 mg/l).

The Piper diagram identifies the surface water in the Bhopal urban agglomerate as Calcium Bicarbonate type, indicative of temporary hardness. According to the US Salinity Diagram, groundwater in the area is classified as C2-S1 (medium salinity and low sodium), suitable for irrigation for most crops.

### 6.3 Water Quality of Rain Water

In Bhopal urban agglomerate three numbers of rain water samples have been collected in the month of July and September. The quality analysis results reveal the pH is in between 6.55 to 6.69 shows that rain water is slightly acidic and electrical conductivity is 15 to 18 µS/cm at 25°C and other parameters are below detectable limit **(Annexure XIX).**

### Conclusions

- The groundwater and surface water in the study area exhibit pH levels ranging from slightly acidic to neutral, with electrical conductivity indicating good to moderately saline conditions. Chloride concentrations in groundwater vary between 20 and 309 mg/l and 25 to 270 mg/l during pre- and post-monsoon respectively for shallow aquifers, while deeper aquifers range from 12 to 297 mg/l. Fluoride concentration remains within BIS permissible limit, with the highest concentrations of 0.89 mg/l at South T.T. Nagar (pre-monsoon) and 0.85 mg/l at DIG Bungalow (post-monsoon).
  Nitrate contamination was found in 18.75% of groundwater samples of shallow aquifer during the pre-monsoon and 16.25% during the post-monsoon, while deeper aquifers and surface water remain within acceptable limits. The highest nitrate concentration in shallow aquifers was recorded at Narela Sankari. Total hardness in groundwater ranges from 105 to 762 mg/l (pre-monsoon) and 160 to 825 mg/l (post-monsoon) for shallow aquifers, with the maximum observed at Platform No. 6 of Bhopal railway station. Deeper aquifers and surface water maintain total hardness within permissible limits.

- The concentrations of copper (Cu), zinc (Zn), arsenic (As), lead (Pb), chromium (Cr), and uranium (U) in all groundwater samples from both shallow and deeper aquifers are within acceptable limits during both pre- and post-monsoon season. However, iron and manganese contamination are found in shallow aquifers. Specifically, 15% of groundwater samples in both seasons show iron concentration above the permissible limit, while deeper aquifers have iron concentrations below detectable limits. Manganese exceeds the permissible limit in 2.5% of samples during pre-monsoon and 3.8% during post-monsoon in shallow aquifers, while deeper aquifers remain within BIS standards.
- The Piper trilinear diagram reveals that groundwater in shallow aquifers predominantly consists of Ca-$HCO_3$ type during both pre-monsoon (87.5%) and post-monsoon (92.5%) periods, with minor variations in Ca-Mg-Cl, Ca-Na-$HCO_3$, and Ca-Cl types. Deeper aquifers primarily show Ca-Na-$HCO_3$ type water (81.8%), with Ca-Mg-Cl and Na-Cl types present in smaller proportions. Gibbs diagram suggests that the groundwater chemistry of shallow aquifers is primarily influenced by evaporation-crystallization, indicating generally good water quality. A few pre-monsoon

groundwater samples fall into the rock dominance category. The Residual Sodium Carbonate (RSC) values indicate that 1.3% of shallow aquifer groundwater samples are unsuitable for irrigation, while 95% are safe, and 3.8% are marginally suitable during both pre- and post-monsoon seasons. Groundwater from deeper aquifers is suitable for agricultural use. According to the USSL diagram, shallow aquifer groundwater is categorized as C3-S1 and C2-S1 in pre-monsoon and C2-S1, C3-S1, and C4-S2 in post-monsoon. Deeper aquifers fall into the C2-S1, C3-S1, and C3-S2 irrigation classes, while surface water is classified as C2-S1. High salinity and low to moderate Sodium Adsorption Ratio (SAR) water can be used for irrigation with appropriate management and drainage.

- To assess the impact of the monsoon on groundwater quality, a paired t-test was conducted on samples from the same sources during pre- and post-monsoon periods. The analysis revealed significant changes in the mean values of parameters such as temperature, electrical conductivity, sulfate, nitrate, calcium, magnesium, potassium, arsenic, lead, and uranium, while other parameters remained unchanged after the monsoon.

## 6.4 Groundwater Quality in and around Bhanpur Khanti (dumping site) and Union Carbide India Limited (UCIL)

### 6.4.1 Bhanpur Khanti

**Background**

Groundwater samples were collected from the Bhanpur Khanti dumping site, formerly utilized by the Bhopal Municipal Corporation (BMC) for the disposal of Municipal Solid Wastes (MSWs) from the entire Bhopal city. Sampling took place in December 2014 during the active period of dumping activity and again in 2023 after the cessation of dumping operations to assess the impact on groundwater contamination. Sampling locations are shown in **Fig. 6.15** This study aims to evaluate changes in groundwater quality over time, specifically in relation to the cessation of dumping activities, providing valuable insights into the environmental repercussions of waste disposal practices in the area.

**Results**

In 2014, the analytical results **(Annexure-XX)** revealed that the pH value of groundwater around Bhanpura dumping site was within the BIS standards. The electrical conductivity in groundwater of around Bhanpura dumping site was moderately saline in nature. The maximum EC was detected in $BW_8$ on Vidisha Road i.e. 2020 µS/cm. The chloride and fluoride concentration around Bhanpura dumping site area were within the BIS standards. The maximum concentration of fluoride was observed in $BW_1$ (0.98 mg/l) on Agricultural Field of Agrawal Jewellers, Ayodhya By Pass road.

The nitrate concentration around Bhanpura dumping sites area were more than BIS acceptable limit of 45 mg/l. The maximum concentration was observed in Front of Naveen Middle School ($DW_1$) i.e. 97 mg/l. In some locations the total hardness was more than BIS permissible limit of 600 mg/l in dumping site area. The maximum concentration of total hardness was observed on Vidisha Road (900 mg/l). The Piper-trilinear diagram of study area shows the groundwater is $CaHCO_3$, Ca-Mg-Cl and CaCl type of water. The USSL diagram indicates the groundwater is in the class of $C_3$-$S_1$ (High Salinity & Low SAR).

In 2023, groundwater sample was collected from the downstream side of the dumping site, revealing key parameters: Electrical Conductivity (EC) measured at 1125 µS/cm, Nitrate concentration at 45 mg/l, and total hardness at 351 mg/l. While all basic parameters fell within the permissible limits set by the BIS, manganese exceeded the permissible limit, registering at 0.581 mg/l. Furthermore, analysis using a Piper-Trilinear Diagram indicated the groundwater type as Ca-HCO3, while the USSL diagram classified it as C3-S1, signifying high salinity and low SAR, rendering it suitable for agricultural purposes.

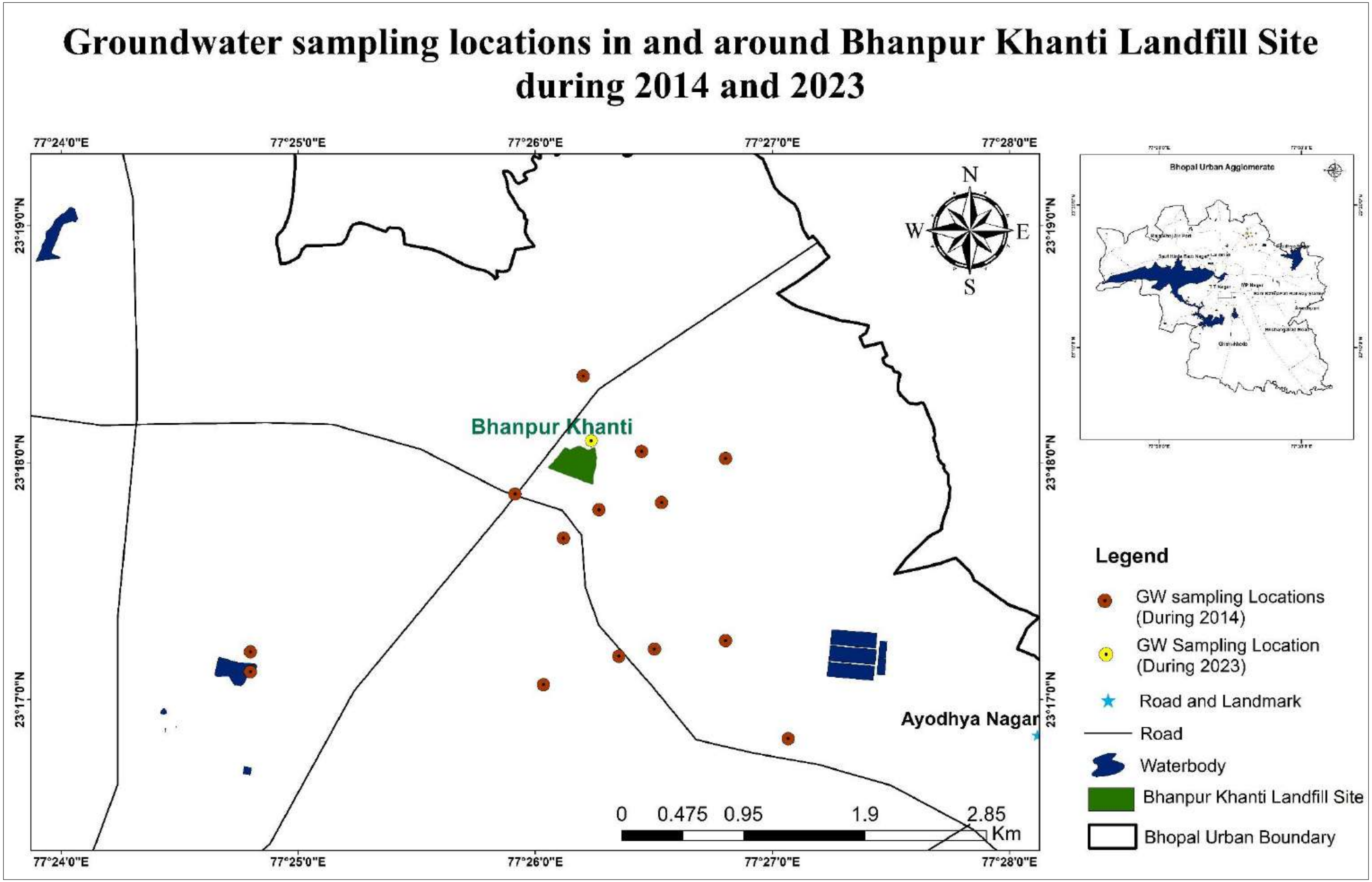



**Fig. 6.15 Groundwater sampling locations in and around Bhanpur Khanti Landfill Site during 2014 and 2023**

### 6.4.2 Union Carbide India Limited (UCIL)

**Background**

In 2011, a study was conducted around the Union Carbide India Limited (UCIL) factory area in Bhopal to assess groundwater quality. Sampling locations are mentioned in **Annexure- XXI** Subsequently, in December 2023, groundwater samples were collected from various directions within a 5 km radius of the UCIL site **(Annexure-XXII** ). This investigation aims to evaluate any changes in groundwater quality over time and assess potential impacts on the environment and surrounding flora and fauna, stemming from the infamous gas leak incident that occurred on the night of December 2nd, 1984. Groundwater sampling locations during 2011 and 2023 are shown in **Fig. 6.17.**

**Results**

The analytical result of chemical analysis **(Annexure- XXI)** during 2011 indicates that pH value was within the BIS standard of 6.50 to 8.50. In some locations electrical conductivity was observed more than 2000 2000 µS/cm at 25 °C. The maximum electrical conductivity was observed 2990 µS/cm in the HP of Chandbad. The chloride concentration was within the BIS permissible limit except hand pump of Sundar Nagar (730 mg/l). The fluoride concentration within the BIS standard. The nitrate concentration around UCIL were more than BIS acceptable limit of 45 mg/l. the maximum concentration was observed at Chandbad (441 mg/l). Total hardness around UCIL area was ranged between 195 to 940 mg/l. In some locations were observed more than BIS permissible limit of 600 mg/l. The maximum concentration of total hardness was observed in Chandbad HP (940 mg/l).

The Piper-trilinear diagram shows the groundwater was $CaHCO_3$ and Ca-Mg-Cl types of water i.e. temporary as well as permanent hardness in the water. The US Salinity Diagram classifies the water were in the class of $C_3$-$S_1$, $C_2$-$S_1$, $C_4$-$S_2$ and $C_4$-$S_1$ class.

The iron concentration was observed more than BIS acceptable limit at some locations namely Geetanjali College (2.68 mg/l), Sunder Nagar (1.225 mg/l), DIG Banglow (0.74 mg/l) and Ashima Colony (0.61 mg/l). The manganese concentration was observed more than the permissible limit at Sundar Nagar (0.232 mg/l).

The analytical results of groundwater quality around UCIL during December 2023 **(Annexure-XXII)** revealed that the pH value of groundwater around UCIL were within acceptable limits. The electrical conductivity of groundwater ranged from 502 to 2497 µS/cm at 25°C. All locations UCIL exhibited EC values below 3000 µS/cm at 25°C. the maximum EC was observed in hand pump of Badwai. The chloride and fluoride concentration were within the BIS permissible limit. The nitrate concentration has been observed between 1 to 142 mg/l. In some location, nitrate concentration was more than BIS acceptable limit. The maximum concentration was observed in the hand pump nearby Bhopal Railway Junction i.e. 142 mg/l. The total hardness ranged from 193 to 827 mg/l. Total hardness in all locations were within the BIS permissible limit except Bhopal Railway Junction ($HP_4$: 827 mg/l), Geetanjali College ($BW_4$: 683 mg/l) and Badwai ($HP_{10}$: 634 mg/l).

These heavy metals analytical results revealed that the concentration of aluminum (Al), zinc (Zn), arsenic (As), silver (Ag), boron (B), molybdenum (Mo), nickel (Ni), copper (Cu), selenium (Se), chromium (Cr), cadmium (Cd), barium (Ba), mercury (Hg), lead (Pb), uranium (U) and Strontium (Sr) were within the BIS standards except iron (Fe) and manganese (Mn). The iron concentration observed between 0 to 11.664 mg/l. The iron concentration observed more than BIS permissible limit in few locations (11 nos.) nearby UCIL. The maximum concentration of iron was recorded at Jhangirabad $HP_{11}$ (11.664 mg/l). The manganese concentration observed between 0 to 0.581 mg/l. The manganese concentration observed more than BIS permissible limit in few locations (3 nos.) nearby UCIL. The maximum concentration of manganese was recorded at Bhanpur $BW_8$ (0.581 mg/l).

As per **Gibb's Diagram (Fig.6.16),** all groundwater samples in and around UCIL are situated within the zone characterized by rock dominance indicating that rock weathering is the primary source that controls groundwater chemistry and its evolution. It implies that, Bhopal gas tragedy has no adverse effect on groundwater quality.

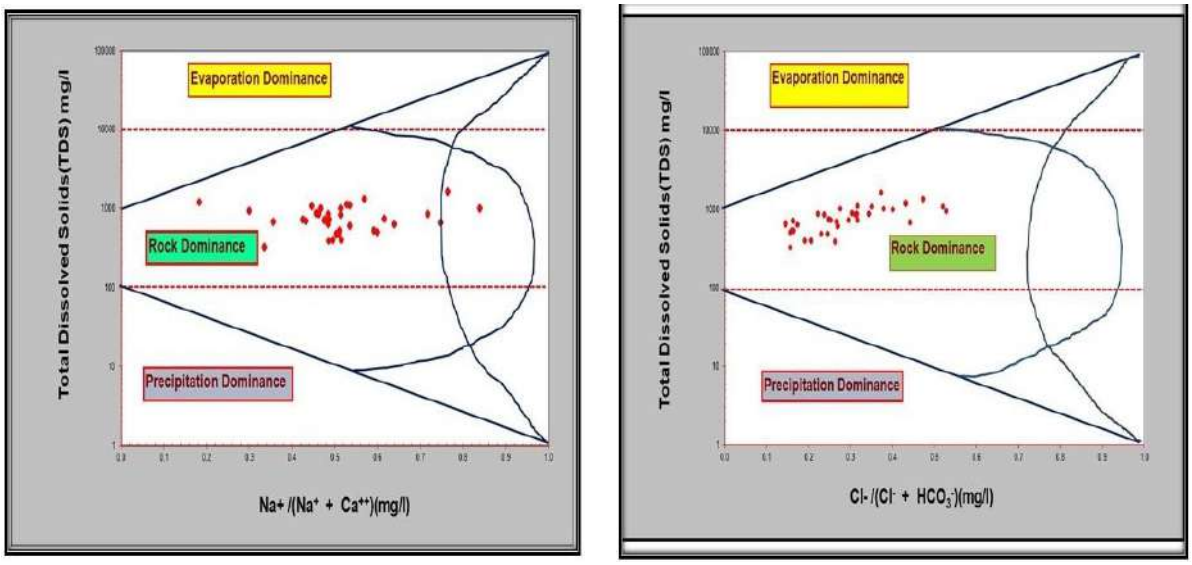



**Fig. 6.16 Gibb's Diagram illustrating groundwater chemistry in and around UCIL**

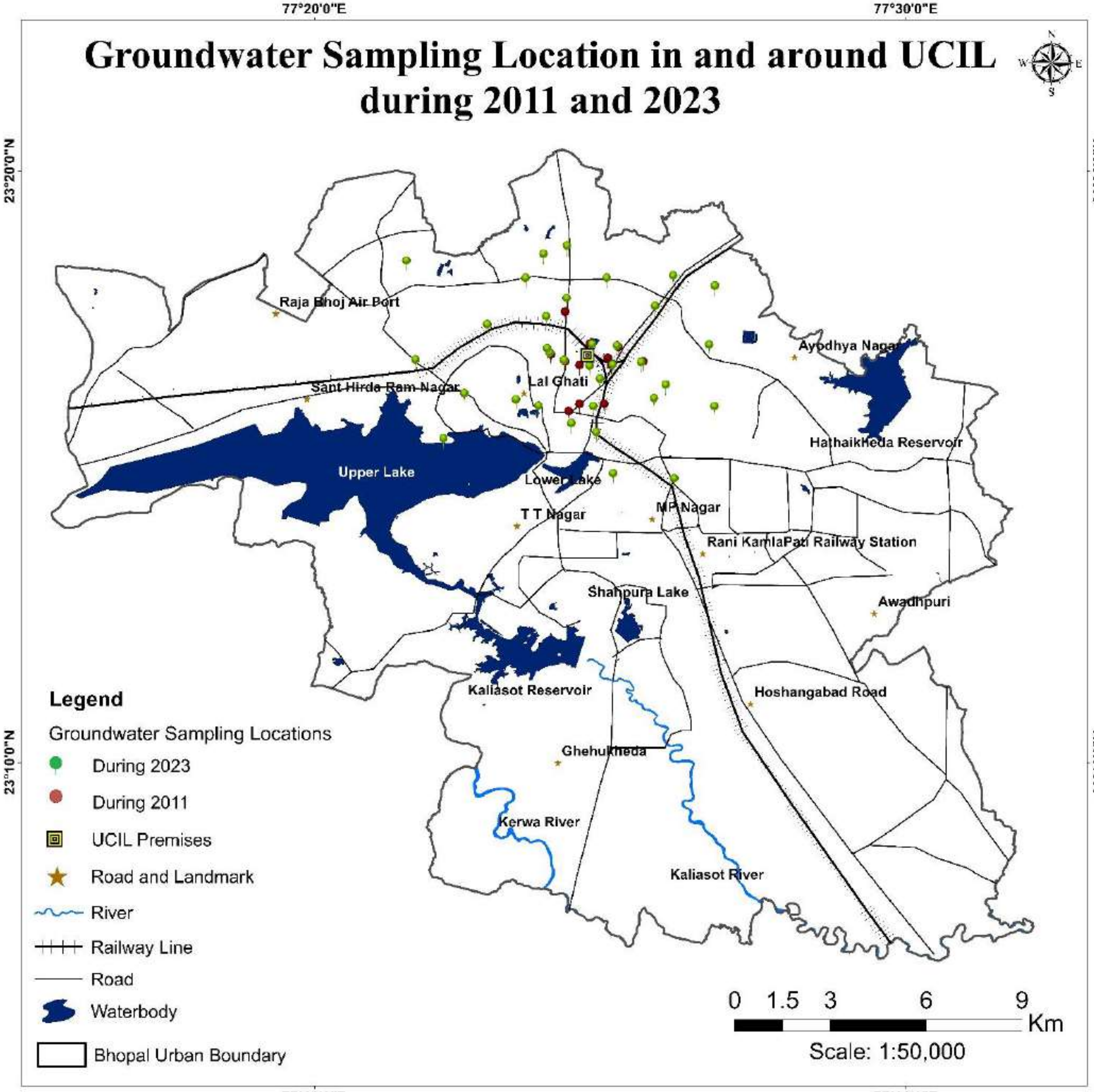



**Fig. 6.17 Groundwater sampling locations in and around UCIL during 2011 and 2023**

# 7. GROUNDWATER RELATED ISSUES

Understanding groundwater-related issues is essential before recommending management interventions. Therefore, extensive fieldwork was conducted in the study area from April 2023 to March 2024. The methodology involved detailed mapping of aquifers, identifying and mapping sources of contamination, collecting and analysing groundwater, surface water and rainwater samples for quality monitoring, conducting well inventories, and monitoring water levels. Additionally, feedback from farmers was collected to provide valuable insights into local groundwater conditions and challenges.

**Farmers Feedback**

During the field study, interactions were conducted with farmers, and 17 feedback responses were collected (Farmers feedback proforma and photographs are given in **Annexure-XXXI**. These interactions provided valuable insights into the challenges and concerns faced by the farmers, encompassing aspects such as agricultural practices, resource utilization, and working conditions. Summary of the feedback collected from the farmers is given below;

- In SE/SW and Southern part farmers predominantly rely on the surface water from river like Kaliasot and Kerwa river for irrigation of their agricultural land.
- Wealthier farmers, whose agricultural land is distant from surface water bodies, typically construct borewells with depths ranging from 400 to 500 feet and discharge rates between 0.5 lps to 5 lps. In contrast, smaller farmers can only afford to construct borewells up to a maximum depth of 300 feet, with discharge rates ranging from 0.5 lps to 2 lps.
- Disruptions in electricity supply hinder the extraction of groundwater source, hence dependency on surface water is more in that area.
- The overall quality of groundwater in the area is suitable for both irrigation and domestic purposes
- In the eastern part, groundwater levels drop below 20 m during the post-monsoon season, and the water table further declines during the pre-monsoon period. Farmers resort to regular interval pumping intervals to extract groundwater.
- In the western tip of the upper lake part, despite rapid urbanization, groundwater levels remain above 20 m. However, the area still experiences significant discharge rates ranging from 0.7 lps to 5.5 lps, indicating both the resilience of the groundwater system and the ongoing demand for water resources in the region.
- In northern/NE area water level is relatively shallow and Crops grown- Kharif season-soyabean, paddy, urad, moong, corn, -Rabi season – gram, wheat, peas.

Based on the field work, farmers feedback and conclusions from chapter 3, 4, 5 and 6, following issues were identified within the study area;

1. **Declining Groundwater level of shallow aquifer**

Groundwater level trend data from observation wells over a ten-year period (2013-2023) have revealed a declining pattern in certain locations **(Fig. 7.1)** with a rate of 0.15 m/year. Management plan for this is given in **Chapter 8.1.**

2. **Nitrate Contamination in Shallow Aquifer**

A groundwater quality study in Bhopal urban area detected nitrate levels exceeding the BIS permissible limit (>45 mg/l) in 13 observation wells **(Fig. 7.1)** representing the shallow aquifer. Details are given in **Chapter 8.2** along with management strategy.

3. **High Value of Total Hardness and Heavy metal Contamination (Fe, Mn) in shallow Aquifer**

The groundwater quality analysis of the study area revealed the presence of temporary hardness and heavy metals contamination, mainly iron and manganese. Iron contamination was detected in 17 wells, while manganese was found in 3 wells. Additional information, including the management plan, is available in **Chapter 8.2**, and point locations are shown in **Fig. 7.1.**

4. **Water logging condition and rising groundwater level**

Waterlogging and increasing water levels were observed in the study area mainly near the waterbodies **(Fig. 7.1). Chapter 8.6** includes further information on issue and the management plan.

5. **Improper Well Design**

The study identified that improper well design in collapsible formation of hard rock terrain was a primary issue, leading to the short-term functionality of wells. Area having collapsible formations are shown in **Fig 7.1.** More information, along with the management plan, is available in **Chapter 8.7.**

6. **Limited thickness of deeper Aquifer**

The study area faced a major issue with the limited thickness of the deeper aquifer **(Fig. 7.1)**, resulting in low yield and sustainability challenges. Additional details, including the management plan, are outlined in **Chapter 8.8.**

7. **Degradation of waterbodies**

The degradation of waterbodies was identified as a growing concern in the study area. Waterbodies receiving untreated wastewater are shown in **Fig.7.1.** Further details, along with the management plan, are provided in **Chapter 8.9.**

8. **Illegal Groundwater extraction**

Illegal groundwater extraction is one of the issues responsible for overexploitation of groundwater. Additional details with management plan are provided in **Chapter 8.10.**

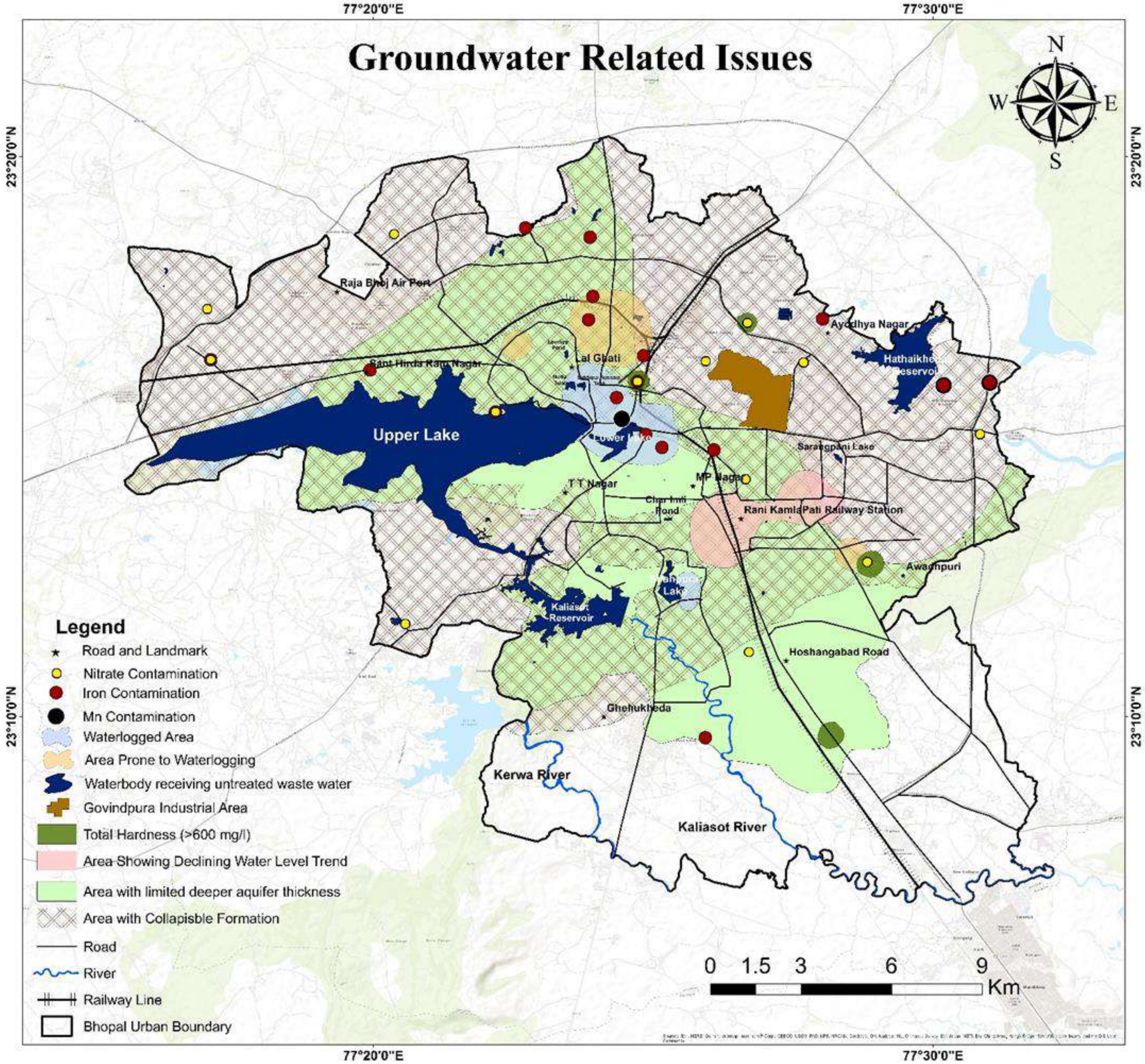



**Fig. 7.1 showing map of groundwater related issues within the study area**

# GROUNDWATER MANAGEMENT PLAN

## 8.1 DELINEATION OF RECHARGE WORTHY AREA AND PROPOSED ARTIFICIAL RECHARGE PLAN

### 8.1.1 Objective

The main objective of this chapter is to identify the recharge worthy zone in and around study area and accordingly prepare the Artificial recharge Plan to counteract the declining groundwater level of shallow aquifer.

### 8.1.2 Methodology

**For delineation of Recharge worthy zone in and around study area**

As the study area and nearby area is covered with hard rock (Vindhyan Sandstone and Deccan Trap basalt), hence recharge worthy zone has only been demarcated for unconfined/shallow aquifer due to limited intake possible for semi confined/ deep aquifers presented in hard rock terrain (Artificial recharge manual by CGWB). For demarcating the recharge worthy zone in and around study area, 3 watersheds have been demarcated, one lies in the study area named urban watershed and other two lie outside the study area namely Kolans watershed and Kerwa watershed. Watershed demarcation outside the study area is based on the fact that Artificial recharge proposed in upstream side, automatically beneficially for downstream. After that following factors have been taken into consideration; namely, Land use/ Land cover, decadal post monsoon depth to water level, Weathering thickness, Rainfall, Slope, Water bodies and Drainage.

- **Waterbodies and Drainage**

Waterbodies and drainage networks significantly influence recharge by modulating surface runoff and infiltration. Lakes, rivers, and wetlands can act as recharge areas by allowing water to infiltrate into the underlying aquifers. Conversely, poorly managed drainage systems can exacerbate runoff, reducing infiltration and recharge potential. Drainage Map was prepared using Digital elevation data and cross checked from toposheet on 1:50,000 scale.

- **Land use/Land cover**

Land Use and Land Cover (LULC) alterations influence recharge by modifying surface properties, evapotranspiration rates, and runoff patterns, ultimately affecting groundwater replenishment. Changes such as urbanization or deforestation can decrease infiltration and increase runoff, potentially diminishing recharge capacity and altering aquifer dynamics. LULC 2022 map was prepared using sentinel data on 10 m resolution and it is estimated that about 46.7% study area is covered with built-up zones.

- **Post-monsoon depth to water level**

Post-monsoon depth to water level plays a very important role for planning demarcating recharge worthy area and planning artificial recharge plan. As per Master plan for artificial recharge prepared by CGWB, 2013, depth to water level for post-monsoon should be below 3 mbgl. It is good to consider decadal water level. Post-monsoon depth to water level above 3 mbgl is not suitable for artificial recharge. Post-monsoon depth to water level data for period of (2013-2023) were used to demarcate areas not suitable for artificial recharge.

- **Weathering Thickness**

The thickness of the weathering zone can significantly influence recharge processes. Variations in weathering thickness directly impact subsurface permeability and storage capacity, fundamentally dictating the efficacy of groundwater recharge. Weathering thickness map was prepared using Vertical electrical sounding data and Exploration data falls within the study area and demarcated watersheds.

- **Rainfall**

Rainfall is directly related to groundwater recharge potential and determines the availability of water to percolate into the subsurface. It is an important factor to delineate the recharge worthy area The monsoonal rainfall occurs in the months from June to September is considered for recharge. There is total 4 rainfall monitoring stations of Indian Meteorological Department (IMD) which are distributed over study area and demarcated watersheds; Bairagarh airport (23.2833,77.35), Bhopal Arera Hills (23.239, 77.4243), Nabibag AET (23.3, 77.4) and Sehore AWS (77.083, 23.200). The study area receives average 1008 mm of rainfall from South-west monsoon during June to September. Theissen polygon method was used to calculate monsoonal rainfall for each watershed.

- **Slope**

Slope plays a crucial role in rainwater infiltration and runoff, making it a significant factor in groundwater recharge potential assessments. Areas with steep slopes experience rapid runoff, leading to shorter retention times for infiltrating water, which are typically deemed less conducive to groundwater recharge due to their limited capacity for water retention. For this study, area having slope greater than 20% is not considered for artificial recharge. Slope map was prepared using Digital elevation data of SRTM on 30 m resolution. Data has been obtained from USGS Earth explorer.

All the layers were prepared in ArcGIS 10.3.1 and integrated to delineate the artificial recharge zone. The layers of waterbodies and drainage, Land use/land cover, post monsoon depth to water level, weathering thickness and slope are shown in **Fig. 8.1.1.**

**For preparation of Artificial Recharge Plan**

Artificial Recharge plan was prepared for the areas suitable for recharge. All three watersheds were taken to propose artificial recharge structures. Two crucial aspects for devising an artificial recharge plan include determining recharge-efficient water and assessing available space. The calculation process for both is outlined below:

➢ **For computing Recharge efficient water:**

- Determine the watershed area and deduct the extent of non-rechargeable zones, if present within the watershed, to compute the effective rechargeable area (Ha.
- Compute the monsoonal rainfall (mm) for the particular watershed using Theissen polygon method. Rainfall should be converted into inches.

- For the computed rainfall, determine the surface runoff coefficient using strange table (Annexure-XXVI).
- Calculate the surface runoff using the following formula;
  **Surface runoff- Area (Ha)* Runoff coefficient* Rainfall (m)**
- Calculate the baseflow which is considered as 25% of surface runoff.
- Compute surplus runoff by deducting baseflow from surface runoff.
- Determine the committed runoff, accounting for 70% of surplus runoff, allocated for non-rechargeable purposes.
- Calculate non-committed runoff, representing 30% of surplus runoff, which is designated for recharge purposes.
- Calculate evaporation losses, equivalent to 25% of non-committed runoff, representing the amount of water lost through evaporation from surface water bodies or soil.
- Recharge-efficient water is determined by subtracting evaporation losses from non-committed runoff, representing the portion of water available for groundwater recharge.

➢ **For assessing available storage for artificial recharge:**

- Determine the specific yield based on the lithology of the watershed according to established standard norms. (Annexure-XXVII)
- Compute the unsaturated thickness by analysing historical depth to post-monsoon water level for each watershed.
- Calculate the available volume for storage using following formula;
  Available storage- Area (Ha)* specific yield* Unsaturated thickness (m).
- The water resource needed to fill the available space is determined by adding 133% to the available space, accounting for losses.

### 8.1.3 Result and Discussion:

The recharge-worthy zone map was created by integrating all the aforementioned layers with particular emphasis placed on slope and post-monsoon depth to water level layer, assigning them greater weightage in the integration process. The map is displayed in **Fig.8.1.4.**

In the delineated three watersheds, Kolans Watershed and Kerwa Watershed, the entirety of the watershed areas is deemed suitable for artificial recharge, except some locations. However, within urban watershed, certain areas are unsuitable for artificial recharge as Post-monsoon water level is below 3 mbgl, and major portion is extensively covered by built-up area. Consequently, rooftop rainwater harvesting with recharge wells is proposed for Watershed 1, while general artificial recharge structures are recommended for the remaining two watersheds. The calculation procedure details are outlined as follows:

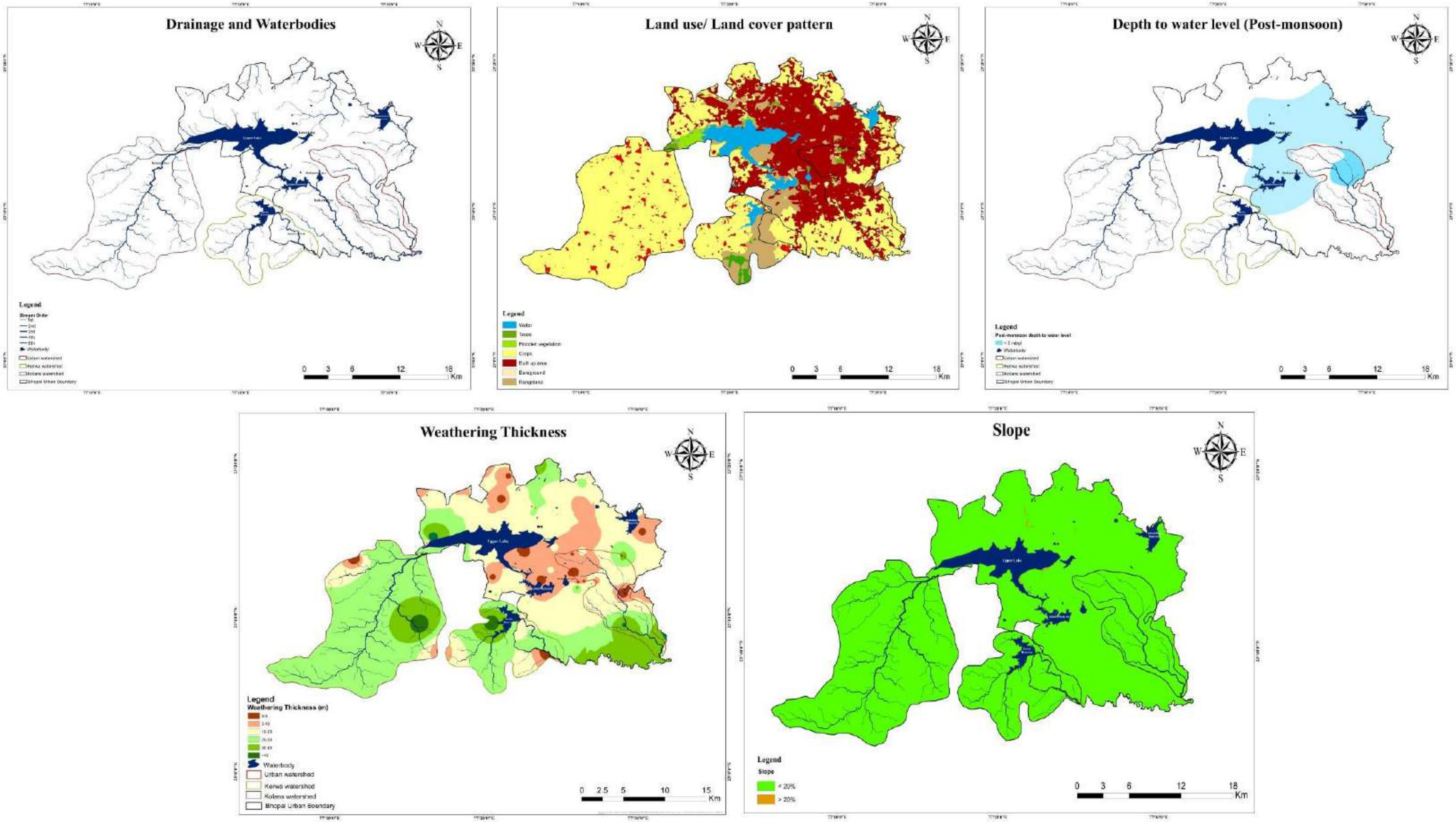



**Fig.8.1.1 Different Layers used to demarcate the recharge worthy zone in and around the study area**

#### 8.1.3.1 Urban Watershed

**Recharge efficient water;**

- Total Area of watershed= 6560.63 Ha
- Non recharge worthy area = 1286.03 Ha
- Recharge worthy area= 5274.6 Ha
- Monsoonal Rainfall= 873.3 mm= 0.8733 m=34.38”
- Surface runoff coefficient= 23.1%, 0.231 (From strange table)
- Surface runoff = A*RC*RF (m)
  =5274.6*0.231*0.8733

  =1064.06 Ha-m

- Baseflow (25% of surface runoff)= 266 Ham
- Surplus runoff (surface runoff-baseflow)= 798.06 Ham
- Committed runoff (70% of surplus runoff)=558.64 Ham
- Non-committed runoff (30% Of surplus runoff)=239.42 Ham
- Evaporation losses (25% of non-committed)=59.85 Ham
- Recharge efficient water= (Non-committed runoff- Evaporation losses); 239.42-59.85= **179.57 Ham**

**Available storage:**

Deccan Trap basalt and Vindhyan Sandstone formations cover Watershed 1, with a specific yield of 1% for both formations according to standard norms. Therefore, a specific yield of 1% is taken for this watershed.

- Specific Yield- 1%- 0.01

Based on the post-monsoon depth to water level data spanning from 2013 to 2023

- Unsaturated thickness for AR= (5.8-3) =2.8 mbgl
- Available storage volume- A*Sy*Unsaturated Thickness= 5274.6*0.01*2.8= 147.69 Ham
- WR Required to fill the available storage volume= 147.69* 1.33= **196.43 Ham**

Since the recharge-efficient water quantity is less than the available storage volume, the proposed total recharge from rooftop rainwater harvesting will be based on the quantity of recharge-efficient water.

**As per Model building bye laws, roof top area of 100 Sq-m or more is suitable for Roof top rainwater harvesting.**

**Consider,**

- Area of Roof top=100 Sq-m
  = 0.01 Ha
- Rainfall= 75 mm, as per norm (maximum amount of daily Rainfall in 2 spells)
  =0.075 m
- Run-off coefficient= 0.85 (CGWA portal)
- Quantum of run-off available= 100* 0.075* 0.85 m3/hr

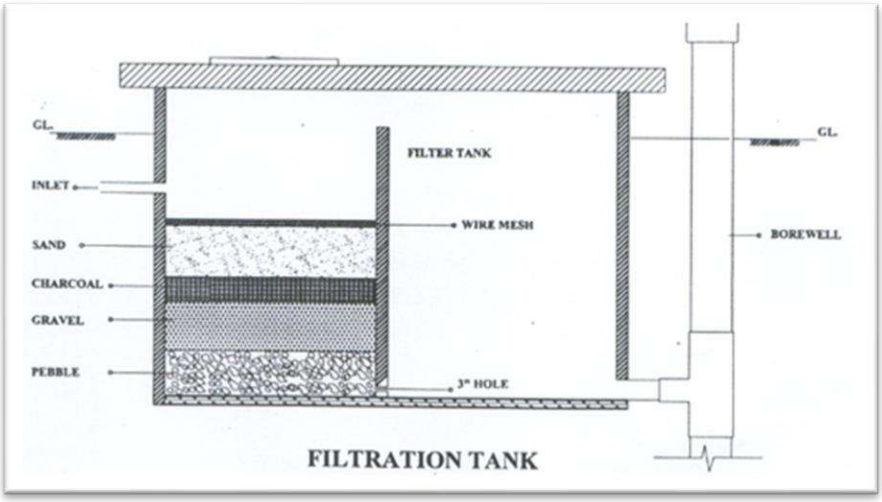
= 6.375 m3/hr
= 0.0006375 Ham/hr

- Average recharge capacity of unconfined quifer within watershed= 0.95 lps
=3.42 m3/hr.

- Water available from 1 rooftop- 6.375 m3/hr
- No. of Borewells= 6.375/3.42= 1.8 (**2 Borewells**)
Proposed depth- (Depth approx. 10 mbgl or as per field condition)
- Minimum size of Filtration tank required,
(Depth-2.5 m, length and width 1.6 m)
- Total recharge efficient water- 179.57 Ham
- No. of house hold required- 1795700/6.375
**- 2,82,000 (approx.)**

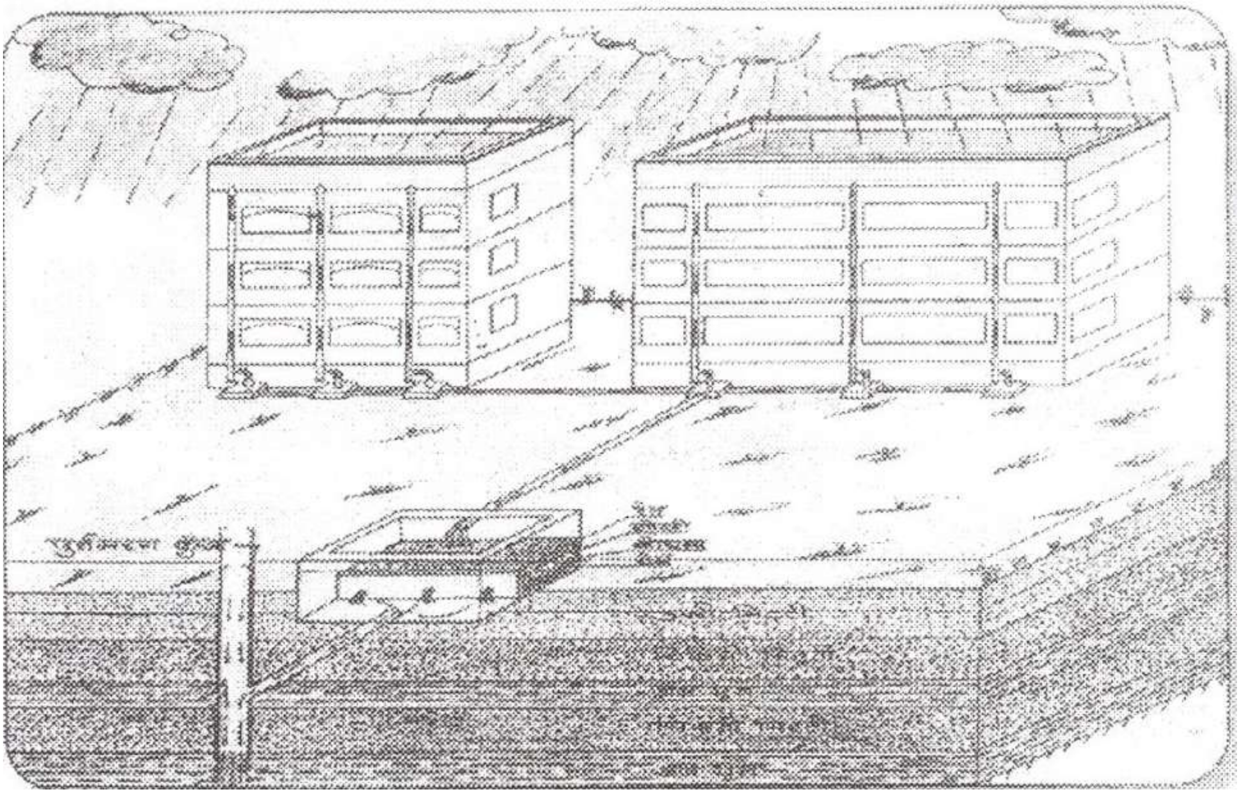
To recharge 179.57 Ham, a total of **2,82,000** households with an average area of 100 sq-m each are needed. Additionally, 1 filtration tanks, with two number of borewells (BW), having a depth of 20 mbgl, are required for this purpose. Schematics of filtration tank and roof top rain water harvesting with recharge well are shown in **Fig.8.1.2 and 8.1.3**.

In addition to this, detailed roof top harvesting plan for Maulana Azad National Institute of Technology was prepared and attached in **Annexure XXXII.**




(Source: MPPCB)

**Fig. 8.1.2 Schematics of Filtration Tank**



(Source- CGWB)

**Fig.8.1.3 depicting Roof top rainwater harvesting with recharge of aquifer system**

**8.1.3.2 Kolans Watershed**

**Recharge efficient water:**

- Total Area of watershed= 20319.7 Ha
- Rainfall= 1084.3 mm= 1.0843m=42.69”
- Surface runoff coefficient= 30.6%, 0.306 (from strange table)
- Surface runoff- A *RC*RF
  =20319.7*0.306*1.0843
  =6742 Ham
- Baseflow (25% of surface runoff)=1685.5 Ham
- Surplus runoff (surface runoff-baseflow)= 5056.5 Ham
- Committed runoff (70% of surplus runoff)= 3539.55 Ham
- Non-committed runoff (30% SR)= 1516.95 Ham
- Evaporation losses (25% of non-committed)= 379.23 Ham
- Recharge efficient water-1516.95-379.23= **1137.72 Ham**

**Available storage:**

Watershed is entirely covered by Deccan trap basalt, Hence

- Specific Yield- 1%- 0.01

Based on the post-monsoon depth to water level data spanning from 2013 to 2023;

- Unsaturated thickness for AR= (5.62-3)= 2.62 mbgl
- Available storage volume- A*Sy*Unsaturated Thickness =20319.7*0.01*2.62 = 532.38 Ham
- Water Resource required to fill the available storage volume= 532.38* 1.33

  = **708.1 Ham**

Since the recharge-efficient water quantity is more than the available storage volume, the proposed total recharge from artificial recharge structures will be based on the quantity of available storage volume.

The number of proposed artificial recharge structures are designed in accordance with field conditions not on the quantity available for recharge. **Table:8.1.1** shows the proposed artificial recharge structures.

**Table: 8.1.1 Proposed Artificial Recharge Structures within Kolans Watershed**

| **Type** | **Water intake capacity** | **Nos.** | **Unit Cost (in lakhs)** | **Total Cost (in lakhs)** | **Total Recharge** |
|---|---|---|---|---|---|
| Check dam (size-15 m (L)* 300m (water spread area)* 1.5 m (H) | 0.7 ham (3 times filling) Total- 2.1 Ham | 78 | 6 | 468 | 163.8 Ham |
| Gully plug (mainly for conservation of soil moisture, infiltration, to stop soil erosion) | 0.001 Ham (3 times filling) Total- 0.003 Ham | 55 | 0.5 | 27.5 | 0.165 Ham |
| Percolation tank | 20 (including 3 times filling) | 4 | 20 | 80 | 80 Ham |
| | | | | Total- 576 | Total Recharge from all Structures= **244 Ham** |

Total 244 Ham recharge is possible through construction of aforementioned structures. Remaining water will contribute to surface water resources for upper lake.

The location of each structure is given in **Annexure-XXVIII** and illustrated on **Fig.8.1.4**.

### 8.1.3.3 Kerwa Watershed

**Recharge efficient water:**

- Total Area of watershed= 7839.78 Ha
- Rainfall= 873.3 mm = 0.8733 m=34.38”
- Surface runoff coefficient- 23.1%, 0.231 (Using strange table)
- Surface runoff= A*RC*RF (m)
  =7839.78*0.231*0.8733

  =1581.53 Ham
- Baseflow (25% of surface runoff)-395.38 Ham
- Surplus runoff (surface runoff-baseflow) = 1186.15 Ham
- Committed runoff (70% of surplus runoff) = 830.3 Ham
- Non-committed runoff (30% of surplus runoff) = 355.85 Ham
- Evaporation losses (25% of non-committed) = 89 Ham
- Recharge efficient water= 355.85-89= **266.85 Ham**

**Available storage:**

Deccan trap basalt cover whole area of Kerwa watershed, Hence specific yield is taken as 1%.

- Specific Yield- 1%- 0.01 (based on lithology)

Based on the post-monsoon depth to water level data spanning from 2013 to 2023;

- Unsaturated thickness for AR= (5.15-3) = 2.15 mbgl
- Available storage volume- A*Sy*Unsaturated Thickness=7839.78*0.01*2.15
  = 168.56 Ham
- Water resource required to fill the available storage volume= 168.56* 1.33
  **= 224.18 Ham**

Since the recharge-efficient water quantity is more than the available storage volume, the proposed total recharge from artificial recharge structures will be based on the quantity of available storage volume and numbers are suggested based on field condition. Proposed artificial recharge structures are tabulated in **Table: 8.1.2.**

**Table:8.1.2 Proposed Artificial Recharge Structures within Kerwa Watershed**

| Type | Water intake capacity | Nos. | Unit Cost (in Lakhs) | Total Cost (in Lakhs) | Total Recharge |
|---|---|---|---|---|---|
| Check dam (size-15 m (L)* 300m (water spread area)*1.5 m (H) | 0.7 ham (3 times filling) Total- 2.1 Ham | 16 | 6 | 96 | 33.6 Ham |
| Gully plug (mainly for conservation of soil moisture, infiltration, to stop soil erosion) | 0.001 Ham (3 times filling) Total- 0.003 Ham | 55 | 0.5 | 27.5 | 0.165 Ham |
| Percolation tank | 20 (including 3 times filling) | 3 | 20 | 60 | 60 Ham |
| | | | | Total-184 | Total Recharge- 94 Ham |

Total 94 Ham recharge is possible through construction of aforementioned structures. Remaining water will contribute to the surface water resources of through Kerwa Reservoir.

The location of each structure is given in **Annexure-XXIX** and illustrated in **Fig.8.1.4**.

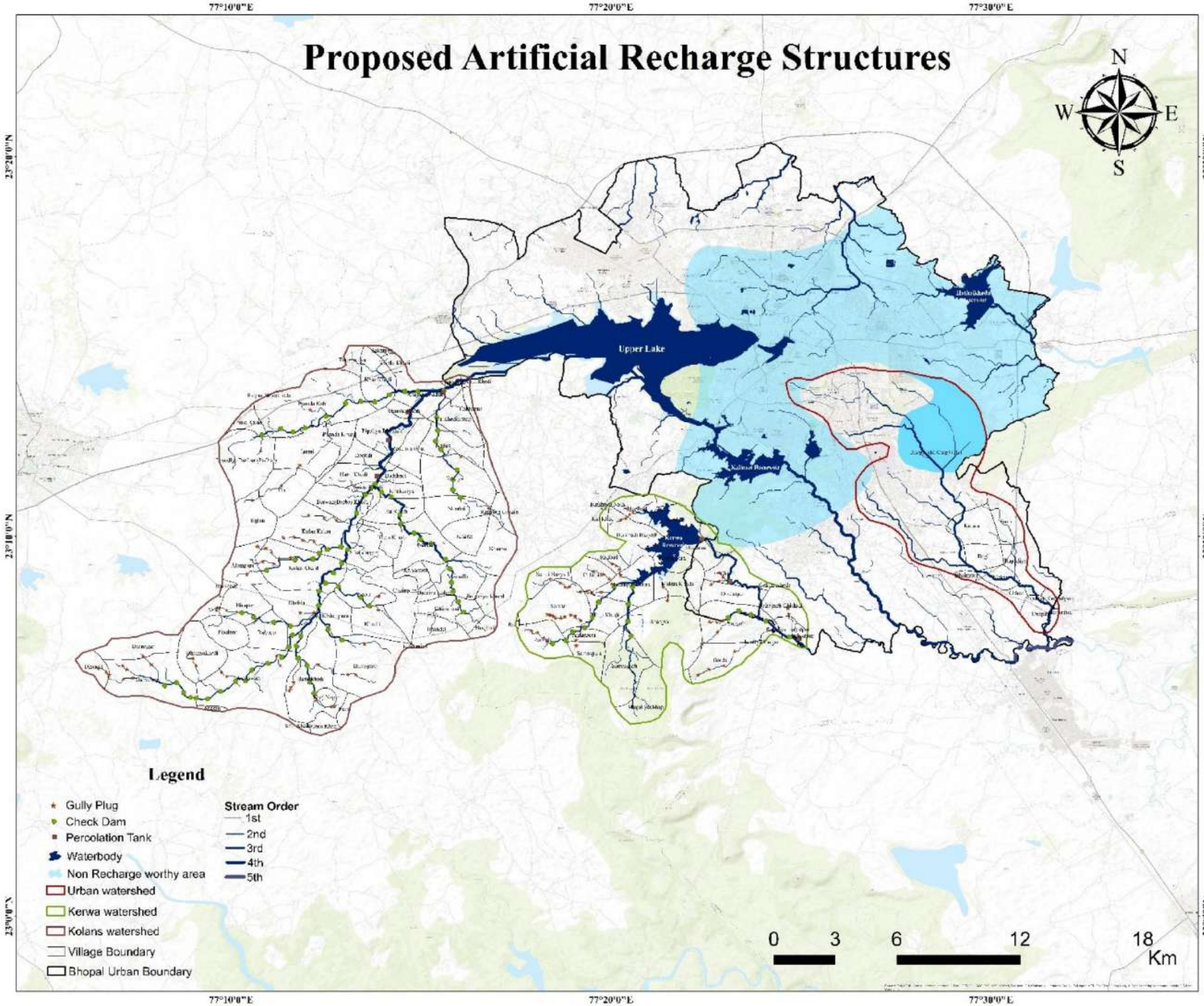



Fig. 8.1.4 Proposed Watershed-wise Artificial Recharge Structures

## 8.2 GROUNDWATER QUALITY MANAGEMENT INTERVENTIONS

### 8.2.1 Objective

The main objective of this chapter is to provide management plan to mitigate groundwater quality related issues which includes nitrate, Total Hardness and Heavy Metal Contamination in Shallow Aquifer.

### 8.2.2 Methodology

Groundwater quality issues were assessed by analysing 83 samples collected from shallow aquifers during both the pre-monsoon and post-monsoon periods of 2023. The analysis was conducted using standard procedures as specified in the 23rd edition of the American Public Health Association (APHA) manual. During field visits, sources of contamination were identified. The management plan was then developed based on these identified issues.

### 8.2.3 Result and Discussion

#### 8.2.3.1 Issue: Nitrate Contamination in Shallow Aquifer

A groundwater quality study in Bhopal urban area detected nitrate levels exceeding the BIS permissible limit (>45 mg/l) in 13 observation wells representing the shallow aquifer. The highest concentration, 186 mg/l, was observed at Narela Shankari. The primary source of nitrate contamination in the study area is attributed to sewerage leakage. This conclusion was drawn from the relationship between nitrate and chloride. Analytical data from Bhopal, plotted on a bivariate plot of $NO_3^-/Cl^-$ vs. $Cl^-$ **(Fig.8.2.1)**, where chloride levels are higher than the $NO_3^-/Cl^-$ ratio, indicate that most nitrate pollution is related to domestic effluent and sewage.

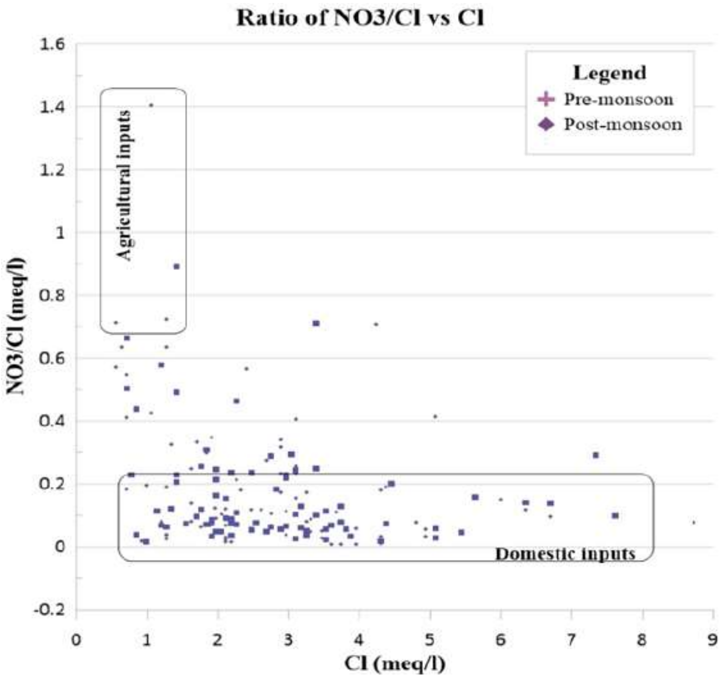



**Fig. 8.2.1 Bivariate plot of $NO_3^-/Cl^-$ vs. $Cl^-$**

**Status of untreated sewage of the study area:**

According to the projected population for 2023, approximately 259 MLD of sewage is generated daily, based on 80% of the daily water requirement as per CPCB report of 2021. The MPPCB report from March 2024 indicates that Bhopal Urban has a total of 16 sewage treatment plants (STPs) **(Table 8.2.1)** with a combined capacity of 177.6 MLD, although the required capacity is 259 MLD. Currently, only 103.22 MLD out of 177.6 MLD capacity is utilized, resulting in a gap of 74.38 MLD. Consequently, around 155 MLD of sewage is discharged untreated.

**Table 8.2.1: Details of operational STP of Bhopal Urban Agglomerate**

| S. No. | Location | Existing STP Capacity (MLD) | Capacity Being Utilized (MLD) |
|---|---|---|---|
| 1 | Bhopal - Maholi Damkhera (Bhoj wet Land) | 35 | 6.18 |
| 2 | Bhopal - Bawariya Kalan | 13.56 | 12.4 |
| 3 | Bhopal - Mata Mandir | 4.51 | 2.5 |
| 4 | Bhopal (BHEL) | 4.5 | 1.19 |
| 5 | Bhopal - Badwai | 16.67 | 15 |
| 6 | Bhopal - Gondarmau | 2.36 | 2.33 |
| 7 | Bhopal - Kotra | 10 | 8 |
| 8 | Bhopal - Ekant Park | 8 | 2 |
| 9 | Bhopal - Shirin River (Kohefiza) (Bhojwetland) | 5 | 4.81 |
| 10 | Bhopal (Char Imli, Shahpura) | 4.5 | 2.76 |
| 11 | Bhopal (Neelbad, Shahpura) | 6 | 3.36 |
| 12 | Bhopal (Sankhedi, Kolar) | 32 | 20.89 |
| 13 | Bhopal (Behind Bansal Hospital,Shahpura) | 9.5 | 4.27 |
| 14 | Bhopal (Professor's Colony, Bhojwetland) | 2 | 1.4 |
| 15 | Bhopal (Jamoniyachhir, Shahpura) | 3.5 | 2.03 |
| 16 | Bhopal (Makshi, Kolar) | 20.5 | 14.1 |

**Management:**

**8.2.3.1 Proper Sewerage disposal to mitigate nitrate contamination and reuse of recycled water:**

As mentioned in **Issue 8.2.3.1**, nitrate contamination in the shallow groundwater aquifer is primarily attributed to the mixing of wastewater and sewage with groundwater. To mitigate the contamination, it is recommended to operate all STPs at full capacity. Furthermore, as per CPCB report of March 2021, 11 STPs with a total capacity of 124 MLD are under construction.

Upon completion, these Sewage Treatment Plants should be effectively utilized. Additionally, It is also crucial to line all unlined sewerage (Like Panchsheel nala near MANIT campus, Unlined sewerage line at Rachna Nagar under bridge and near Ashima Mall etc.) pipelines to reduce nitrate contamination **(Fig.8.2.1).**



Unlined sewerage line near Rachna nagar under bridge, MP nagar

Unlined sewerage line near Ashima Mall


Panchsheel Nala near MANIT Campus

**Fig.8.2.1 shows some unlined sewerage of Bhopal Urban Agglomerate**

**8.2.3.2 Issue: High Value of Total Hardness and Heavy metal Contamination (Fe, Mn) in shallow Aquifer:**

- Groundwater quality analysis of the study area indicates the presence of geogenic temporary hardness. The highest total hardness has been recorded in HP of Platform No. 6 of Bhopal Railway Station, with levels of 762 mg/l during pre-monsoon and 825 mg/l during post-monsoon.
- The study area has detected the presence of heavy metals, specifically iron (Fe) and manganese (Mn). Iron contamination was found in 17 wells, while manganese was found in 3 wells. The highest concentration of iron was recorded at Hathaikheda with 4.331 mg/l during the pre-monsoon period, and at Chhola with 5.12 mg/l during the post-monsoon period. For manganese, the highest concentrations were observed at Transport Nagar with 0.557 mg/l during pre-monsoon, and at Hathaikheda with 0.95 mg/l during post-monsoon. While the primary source of this contamination is geogenic point source, it was observed that wastewater disposal

from automobile service and cleaning centres at Transport Nagar **(Fig.8.2.2)** significantly contributes to the contamination observed in the HP of Transport Nagar.


**Fig.8.2.2 Wastewater disposal from automobile servicing and cleaning at Transport Nagar**

**Management:**

**8.2.3.2 Recommendation for high value of total hardness and Heavy metal contamination in shallow Aquifer:**

In Issue 7.2.3.2, it is noted that the total hardness in the shallow aquifer is geogenic and temporary, and can be reduced by boiling the water. Therefore, it is recommended to boil water before using it for drinking. The list is given in **Table:8.2.2** and locations are marked on map in **Fig. 8.11.** For heavy metal contamination, it is recommended that handpumps showing contamination should not be used for drinking water but may be used for domestic purposes **(refer to Tables 8.2.3** and **8.2.4,** and for marked locations on map, see **Fig. 8.11).** Additionally, in Transport Nagar, wastewater from automobile cleaning should not be disposed of directly. Instead, it should be disposed in systematic manner to prevent heavy metal contamination.

**Table 8.2.2: List of Wells with High Total Hardness (Recommendation: Use water for drinking purpose only After Boiling)**

| S. No. | District | Block | Location | Source | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | Bhopal | Phanda | Barkheda Pathani | Dw | 23.21267 | 77.48037 |
| 2 | Bhopal | Phanda | Daamkheda | HP | 23.28387 | 77.44471 |
| 3 | Bhopal | Phanda | Misrod | HP | 23.16154 | 77.46943 |
| 4 | Bhopal | Phanda | Narela Shankari | HP | 23.27209 | 77.46143 |
| 5 | Bhopal | Phanda | Platform-6, Bhopal Junction | HP | 23.2664 | 77.41194 |
| 6 | Bhopal | Phanda | Prem Nagar | HP | 23.28935 | 77.39106 |

**Table 8.2.3: List of wells contaminated by Iron (Recommendation: To use only for domestic purpose)**

| S. No. | District | Block | Location | Source | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | Bhopal | Phanda | Ayodhya Nagar | HP | 23.28502 | 77.46702 |
| 2 | Bhopal | Phanda | Bairagarh | HP | 23.26982 | 77.332343 |
| 3 | Bhopal | Phanda | Banskhedi | HP | 23.16039 | 77.432157 |
| 4 | Bhopal | Phanda | Chhola | HP | 23.27411 | 77.413787 |
| 5 | Bhopal | Phanda | Hathaikheda | HP | 23.26528 | 77.503083 |
| 6 | Bhopal | Phanda | Jehangirabad | HP | 23.25063 | 77.414403 |
| 7 | Bhopal | Phanda | Khanugaon | HP | 23.25733 | 77.369683 |
| 8 | Bhopal | Phanda | Palasi | HP | 23.30934 | 77.397814 |
| 9 | Bhopal | Phanda | Panna Nagar | HP | 23.29174 | 77.398653 |
| 10 | Bhopal | Phanda | Platform-6, Bhopal Junction | HP | 23.2664 | 77.411942 |
| 11 | Bhopal | Phanda | Subhash Nagar | HP | 23.24605 | 77.434716 |
| 12 | Bhopal | Phanda | Transport Nagar | HP | 23.26607 | 77.516779 |
| 13 | Bhopal | Phanda | Badwai | HP | 23.31212 | 77.378601 |
| 14 | Bhopal | Phanda | Bhonri | HP | 23.27289 | 77.284894 |
| 15 | Bhopal | Phanda | Jinsi | HP | 23.24679 | 77.419247 |
| 16 | Bhopal | Phanda | Mangalwara | HP | 23.2616 | 77.405747 |
| 17 | Bhopal | Phanda | Nariyalkheda | HP | 23.28479 | 77.397395 |

**Table 8.2.4: List of wells contaminated by Manganese (Recommendation: To use only for domestic purpose)**

| S. No. | District | Block | Location | Source | Latitude | Longitude |
|---|---|---|---|---|---|---|
| 1 | Bhopal | Phanda | Budhwara | HP | 23.25528 | 77.40729 |
| 2 | Bhopal | Phanda | Transport Nagar | HP | 23.26607 | 77.51678 |
| 3 | Bhopal | Phanda | Hathaikheda | HP | 23.26528 | 77.50308 |

## 8.3 DEMARCATION OF AQUIFERS SUITABLE FOR DRINKING WATER SUPPLY

### 8.3.1 Objective

The primary aim is to identify aquifers that meet the safety standards for drinking water quality.

### 8.3.2 Materials and methods

Under this study, total 83 numbers of groundwater samples were collected for each basic parameters and heavy metal analysis from shallow aquifer (DW/HP) during pre and post monsoon 2023. 13 exploratory wells were used for collection of water samples for deeper aquifer during pre-monsoon only. Water Quality Index (WQI) was used to describe the aquifer suitability for drinking water usage. It is a metric used to assess the overall quality of water based on multiple parameters. The WQI provides a single value representing the combined influence of various water quality parameters, allowing for a more straightforward interpretation and comparison. The method used for the calculation of the WQI was adapted from Sharma *et al.,* 17 parameters (TDS, $F^-$, $Cl^-$, $NO_3^-$, $SO_4^{2-}$, $HCO_3^-$, $Ca^{2+}$, $Mg^{2+}$, total hardness, Zn, Cr, Uranium, Cu, Fe, Mn, Arsenic, and Lead) were considered to calculate the Water Quality Index. Following four equations has been used for WQI. (Sahu and Sikdar, 2008).

| | |
|---|---|
| $W_i = w_i / \sum_{i=1}^{n} w_i$ ________(1) | Where: |
| | $C_i$- Observed concentration for i^th parameter |
| $q_i = \left(\frac{C_i}{S_i}\right) \times 100$ ________(2) | $W_i$- Relative weight of i^th parameter |
| | $w_i$- Definite weight for i^th parameter |
| $SI_i = W_i \times q_i$ ________(3) | $S_i$-recommended standard limit for i^th parameter |
| $WQI = \sum_{i=1}^{n} SI_i$ ________(4) | $q_i$- Quality rating scale i^th parameter |
| | $SI_i$- Sub-Index i^th parameter |

Each parameter was assigned a definite weight ($w_i$) according to its relative importance on the overall quality of water, ranging from 1 to 5, where 5 was considered most significant while 1 was least significant. In the second step, the relative weight ($W_i$) was computed using equation (1). In the next step, the quality rating scale ($qi$) calculated by comparing the concentration of each parameter in the sample with its respective acceptable limit value, as suggested in the IS 10500:2012. Sub-indices (SI) were calculated to compute the WQI in the next step using equation (3). In final step, the WQI was calculated using equation (4)**.**

### 8.3.3 Results and Discussion

The WQI in shallow aquifer during pre- and post-monsoon of the study area is ranging between 13.3 to 106.9 and 19.6 to 125 respectively whereas in deeper aquifer, it varies between 13.1 to 68.2 during pre-monsoon. The minimum, maximum and mean values of WQI are given below in **Table 8.3.1**; WQI of shallow and deeper aquifer is presented in **Annexure-XV** and **XVI** respectively.

| **Table 8.3.1: The Minimum, Maximum and Mean value of WQI in Shallow and Deeper Aquifer** | | | |
|---|---|---|---|
| Water Quality | Shallow Aquifer | | Deeper Aquifer |
| | Pre-Monsoon | Post-Monsoon | Pre-Monsoon |
| No. of Samples | 80 | 80 | 11 |
| Minimum Value | 13.3 | 19.6 | 13.1 |
| Maximum Value | 106.9 | 125 | 68.2 |
| Mean value | 50.7 | 48.6 | 33.4 |

Sample Calculation for WQI calculation for Groundwater of hand pump (HP 34) located at Hathaikheda village collected during post-monsoon sampling is shown in **Annexure-XIV**. The water quality index for HP 34 has been calculated 125, comes under poor water category as per Yenugu et al. 2020 classification.

In the study area, 98.8% and 96.25% of groundwater samples of shallow aquifer are found as excellent to good water quality in terms WQI during pre- and post-monsoon respectively whereas 100% groundwater samples of deeper aquifer belong to excellent water quality. Maximum WQI (106.9) was recorded from hand pump of Transport Nagar during pre-monsoon and during post- monsoon maximum WQI (125) was observed at HP of Hathaikheda village. The WQI value more than 100 indicates the groundwater is of poor water category. The water quality index classification for shallow and deeper aquifer are given in **Table 8.3.2.**

| **Table 8.3.2: Percent Distribution of water samples in shallow and deeper aquifer based on Yenugu et al. WQI classification.** | | | | |
|---|---|---|---|---|
| **Classification range based on Yenugu et al. 2020** | **Water Quality** | **Shallow Aquifer** | | **Deeper Aquifer** |
| | | **Pre-Monsoon** | **Post-Monsoon** | **Pre-Monsoon** |
| < 50 | Excellent | (47 nos.) 58.8% | (48 nos.) 60% | (9 nos.) 81.82% |
| 50–100 | Good | (32 nos.) 40% | (29 nos.) 36.25% | (2 nos.) 18.18% |
| 101–200 | Poor water | (1 no.) 1.3% | (3 nos.) 3.75% | Nil |
| 201–300 | Very poor | Nil | Nil | Nil |
| > 300 | Unsuitable | Nil | Nil | Nil |

The majority of shallow aquifers meet the standards for drinking water quality, with the exception of a small area in the eastern vicinity near Hathaikheda Dam. In this particular zone, the water quality index indicates that the water is unsuitable for drinking. This anomaly is likely attributed to the disposal of wastewater from service and cleaning centres for automobiles, as observed during field investigations. Water Quality Index maps of shallow aquifer for pre and post-monsoon are given in **Fig.8.3.1 and Fig.8.3.2.**

Water Quality Index (WQI) is a matrix used to assess the overall quality of water based on multiple parameters. The WQI results shows that the 98.8% in pre-monsoon and 96.25% in post-monsoon of shallow and deeper aquifer are found excellent to good water quality.

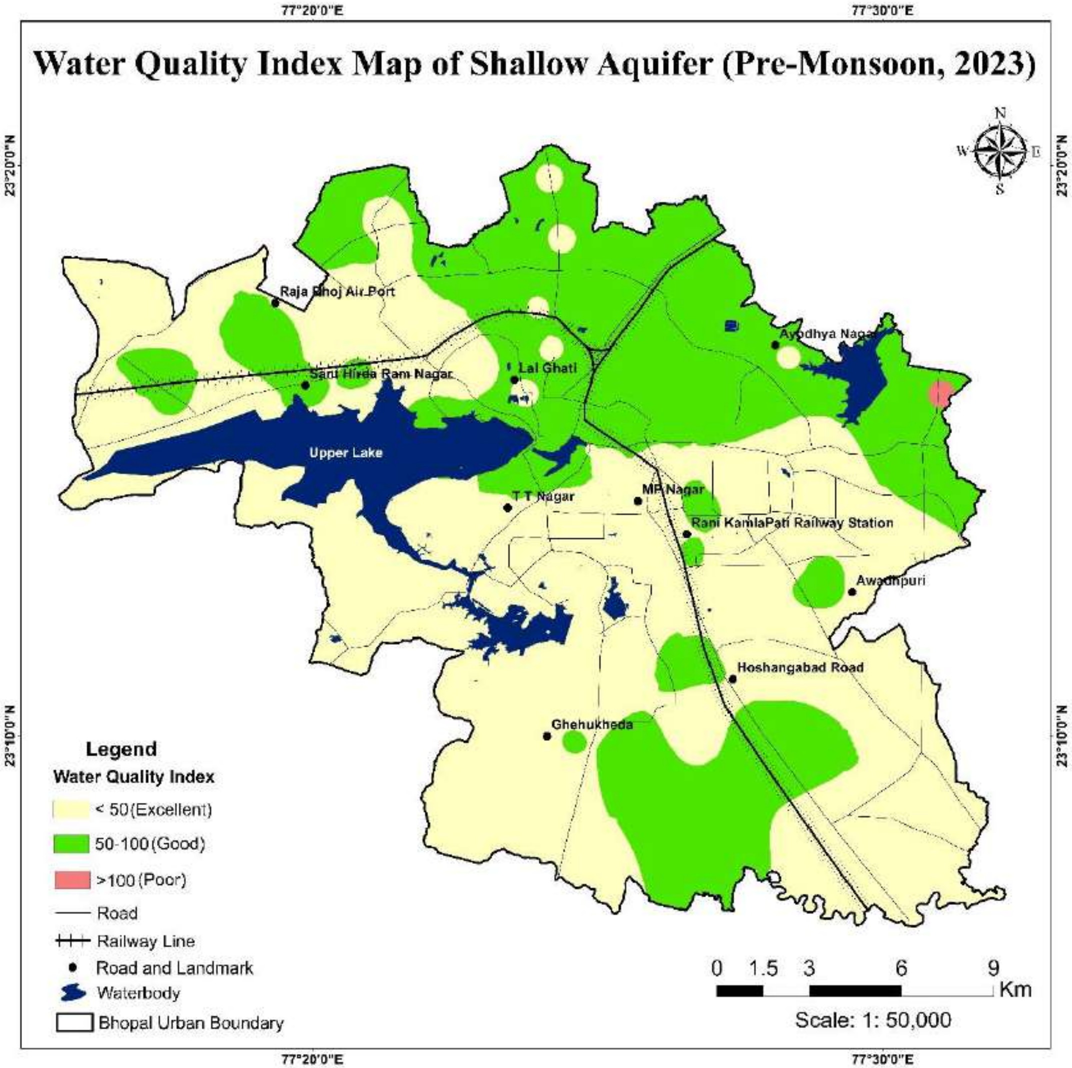



**Fig. 8.3.1 Water Quality Index Map of Shallow aquifer for pre-monsoon (2023)**

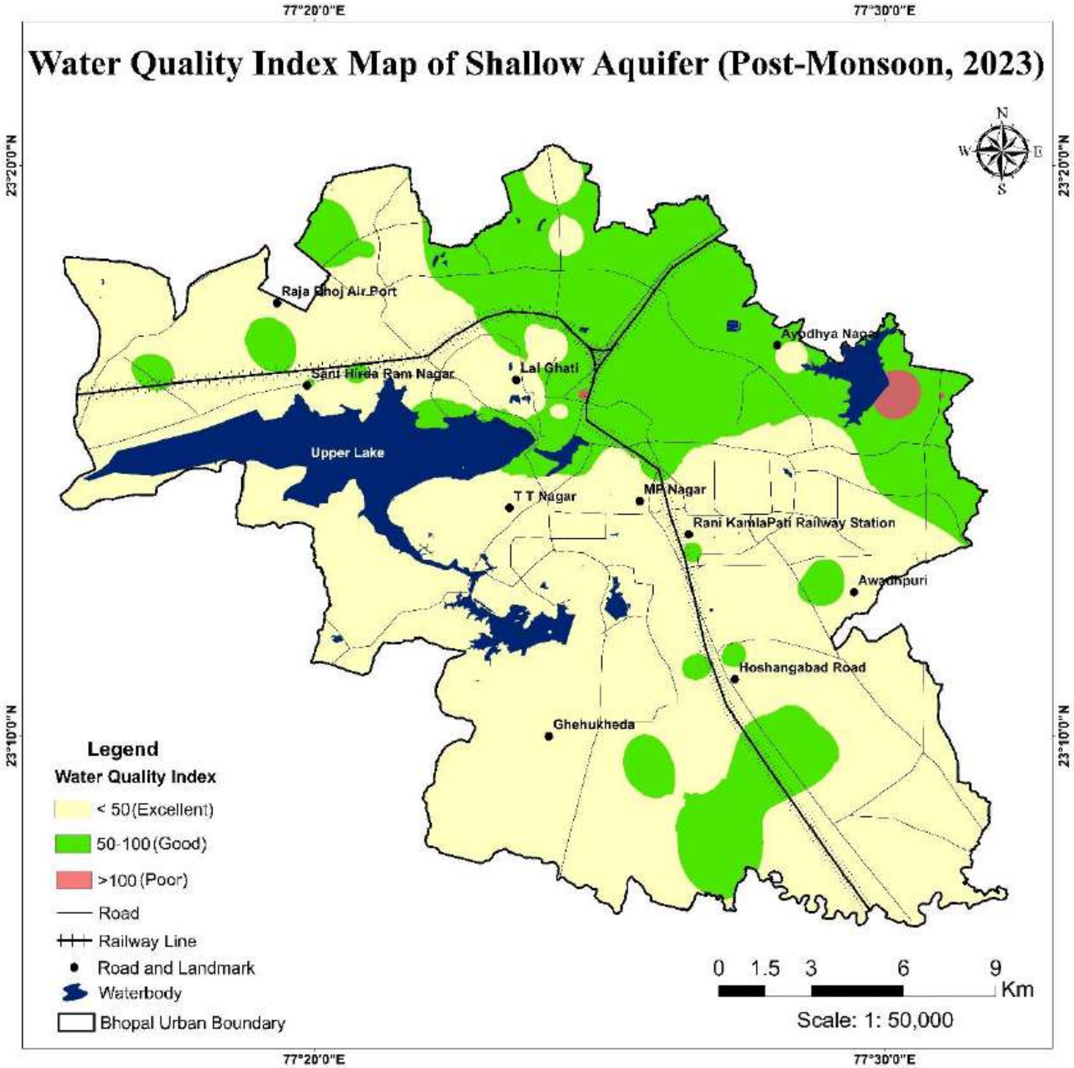



**Fig. 8.3.2 Water Quality Index Map of Shallow aquifer for post-monsoon (2023)**

## 8.4 IDENTIFICATION OF GROUNDWATER POTENTIAL AQUIFER FOR DRINKING WATER SUPPLY

### 8.4.1 Objective

The main objective of this chapter is to demarcate groundwater potential zones for drinking water supply within the study area.

### 8.4.2 Methodology

Groundwater potential zones of the study area have been demarcated using Vertical Electrical Sounding (VES) data. Transverse Resistance & Longitudinal Conductance has been calculated from interpreted VES results.

It can be envisaged that the VES stations with low to moderate S value and high T represents freshwater region. Increasing T values indicate high transmissivity of aquifers (Gupta G, 2015).

The Transverse Resistance (T) and Longitudinal Conductance (S) values are effectively useful for demarcating groundwater potential (Narendra, 2007). Ayolabi, (2005) stated that from the geo-electric parameters such as longitudinal conductance and transverse resistance the coefficient of anisotropy of the overburden material can be determined. Singh, (2003) stated that the transverse resistance (T) and longitudinal conductance (S) are used for better resolution of thin layers of both resistive and conductive properties. The transverse resistance (T) values can be calculated from VES results. The equation is as follows.

$$T = h1 \times \rho 1 + h2 \times \rho 2 \ldots\ldots\ldots + hn \times \rho n \quad in\ ohm.m^2$$

Where, T=Transverse Resistance, h=layer thickness, $\rho$ = layer resistivity.

The Longitudinal conductance (S) values can be derived from VES results. The equation is as follows.

$$S = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} \ldots\ldots\ldots \frac{hn}{\rho n} \quad in \text{ mhos}$$

Where, S= Longitudinal Conductance, h=layer thickness, $\rho$ = layer resistivity.

### 8.4.3 Result and Discussion

In the study area, regions characterized by high transverse resistivity (T) and low longitudinal conductivity (S) have been identified predominantly in the north-eastern and north-western sectors. An average transverse resistivity value of 3000 ohm-$m^2$ and an average longitudinal conductivity value of 4.5 mho have been considered. Groundwater potential zones have been delineated based on these criteria, with the identified areas exhibiting high T and low S indicative of favourable groundwater potential. Conversely, the remaining portions of the study area exhibit lower groundwater potential. The validity of the data is supported by the exploration details obtained from 8 exploratory wells. These wells, having low discharge rates, are situated within regions identified as having low groundwater potential. This confirmation reinforces the accuracy of the assessment, highlighting the consistency of findings across areas characterized by limited groundwater resources. Transverse resistivity, longitudinal conductivity and Groundwater potential zone maps are presented below in **Fig.8.4.1, 8.4.2** and

**8.4.3** respectively**.** The Groundwater Potential zone lie on the North-western and North-eastern portion of the study area. The recommended depth to Borewell is up to 80 mbgl.

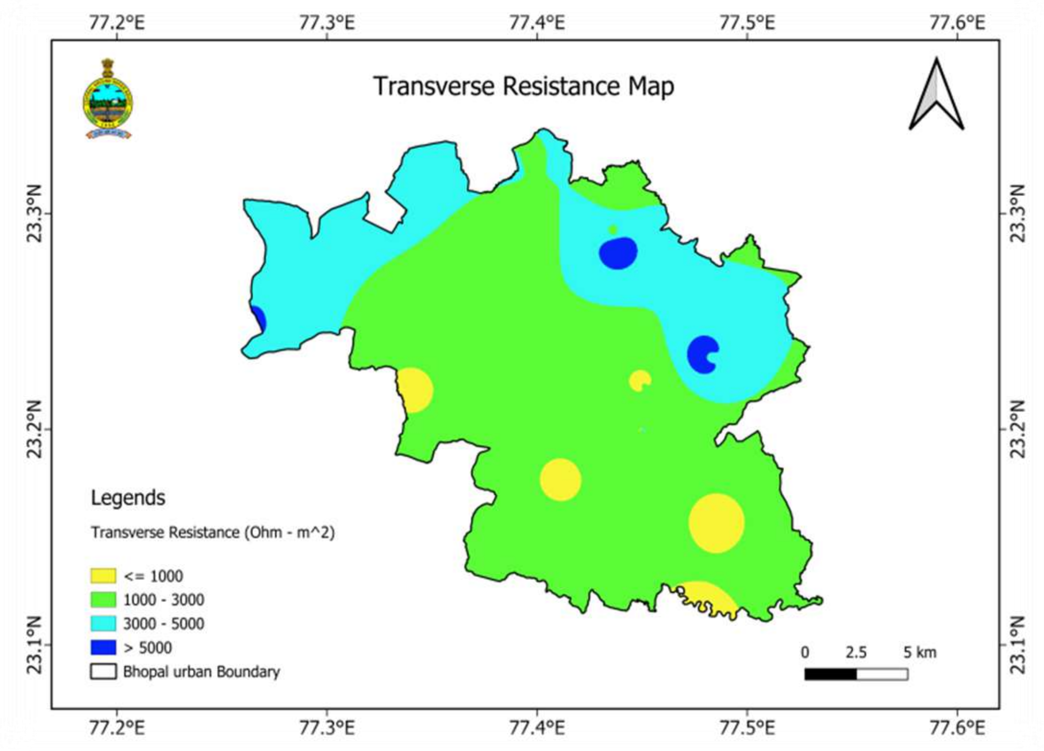



**Fig. 8.4.1 Map of Transverse Resistance**

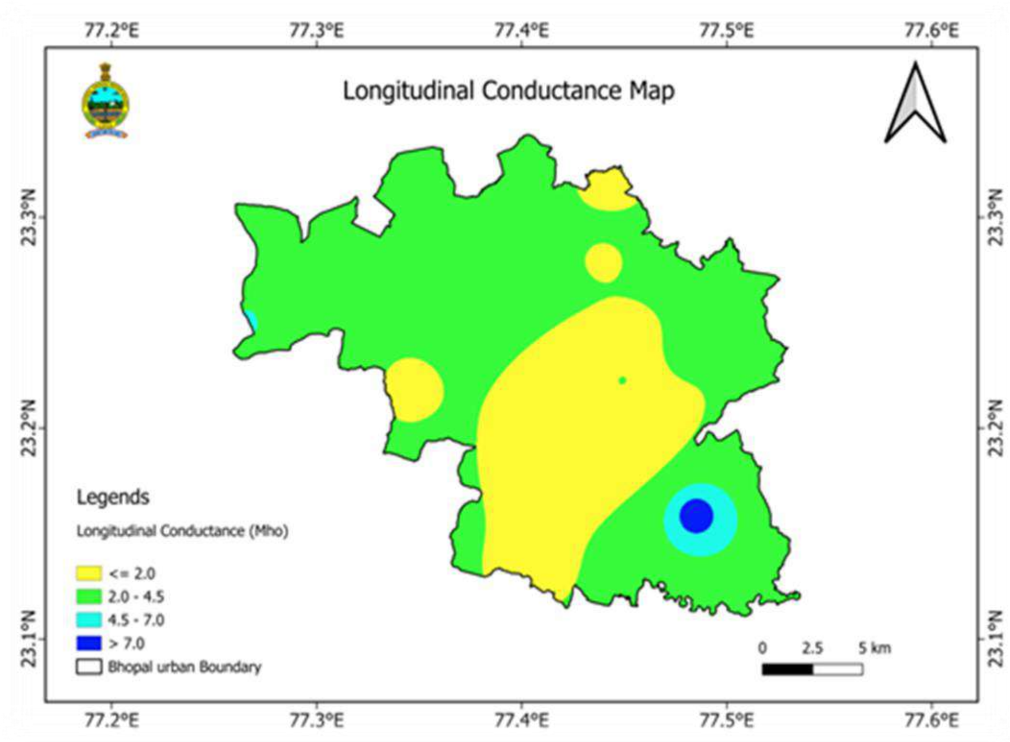



**Fig.8.4.2 Map of Longitudinal Conductance**

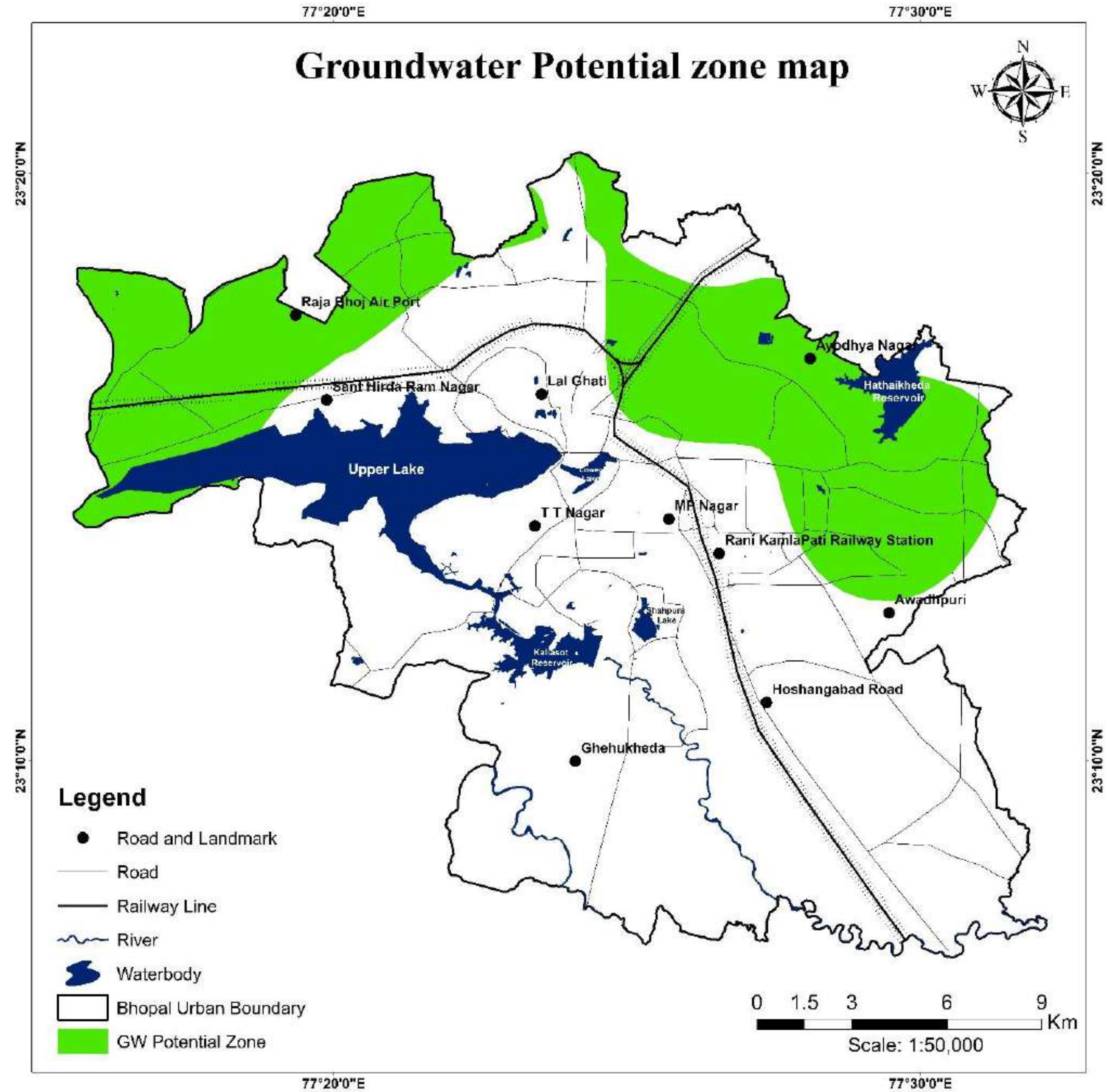



**Fig.8.4.3 Groundwater Potential zone map**

## 8.5 A PLAN FOR DRINKING WATER SOURCE SUSTAINABILITY

### 8.5.1 Objective

The primary objectives of this chapter are to assess the available water resources and water supply within the study area and to develop a comprehensive plan for ensuring the sustainability of drinking water resources.

### 8.5.2 Methodology

To prepare a drinking water source sustainability plan, an assessment on gap between the Demand and supply for drinking water is carried out using the following data: the population as on 2023, the surface water supply managed by the Bhopal Municipal Corporation, and the current demand for drinking water. The projected population for 2023 was derived from the 2011 Census data, using growth rate of 2.3%. To assess the demand for water of total population, per capita requirement of 135 litres was used, then this was multiplied by the total population to ascertain the daily water demand, which was again multiplied by 365 days to compute annual water demand for drinking/domestic usage. The demand-supply gap was quantified by subtracting the total annual water demand from the available surface water supply.

### 8.5.3 Result and Discussion

According to the Bhopal Municipal Corporation, the primary sources of surface water within the study area are the Upper Lake, Narmada River, Kolar and Kerwa Reservoir. The total surface water supply in the area amounts to 427 MLD. However, accounting for a 35% leakage loss, the effective water supply is reduced to 277 MLD. The projected population for 2023, based on 2011 Census data, is 23,50,582. The estimated daily water requirement for drinking and domestic use is approximately 317 MLD, resulting in a supply-demand gap of 40 MLD. Additionally, it is noteworthy that only 67% of the study area is equipped with pipeline distribution systems (Jotwani, 2014), highlighting a significant disparity in water distribution coverage. By, 2040, water requirement would be 464 MLD. The following recommendations are suggested for ensuring drinking water source sustainability.

i) Bhopal Municipal Corporation is advised to establish proper pipelines to extend surface water supply to areas currently lacking it. It is also suggested to maintain the damaged pipelines to prevent leakage losses.

ii) To alleviate pressure on groundwater resources, it is crucial to promote the recycling and reuse of water. Existing Sewage Treatment Plants (STPs) **(Fig. 8.11)** should be operated at full capacity, with treated water redirected for use in industrial purposes, construction projects, or greenbelt development. According to the MPPCB report from March 2024, Bhopal Urban has 16 STPs with a total capacity of 177.6 MLD. Currently, only 103.22 MLD of this capacity is utilized, and merely 20.65 MLD of the treated water is being reused **(Table 8.5.1).** Maximizing the use of these facilities and increasing the volume of reused treated water can significantly reduce the demand on groundwater resources.

**Table 8.5.1: Existing STP location along with quantity of reuse of treated water**

| S. No. | Location | Existing STP Capacity (MLD) | Capacity Being Utilized (MLD) | Reuse of Treated Water (MLD) |
|---|---|---|---|---|
| 1 | Bhopal - Maholi Damkhera (Bhoj wet Land) | 35 | 6.18 | 1.24 |
| 2 | Bhopal - Bawariya Kalan | 13.56 | 12.4 | 2.48 |
| 3 | Bhopal - Mata Mandir | 4.51 | 2.5 | 0.50 |
| 4 | Bhopal (BHEL) | 4.5 | 1.19 | 0.24 |
| 5 | Bhopal - Badwai | 16.67 | 15 | 3.00 |
| 6 | Bhopal - Gondarmau | 2.36 | 2.33 | 0.47 |
| 7 | Bhopal - Kotra | 10 | 8 | 1.60 |
| 8 | Bhopal - Ekant Park | 8 | 2 | 0.40 |
| 9 | Bhopal - Shirin River (Kohefiza) (Bhojwetland) | 5 | 4.81 | 0.96 |
| 10 | Bhopal (Char Imli, Shahpura) | 4.5 | 2.76 | 0.55 |
| 11 | Bhopal (Neelbad, Shahpura) | 6 | 3.36 | 0.67 |
| 12 | Bhopal (Sankhedi, Kolar) | 32 | 20.89 | 4.18 |
| 13 | Bhopal (Behind Bansal Hospital,Shahpura) | 9.5 | 4.27 | 0.85 |
| 14 | Bhopal (Professor's Colony, Bhojwetland) | 2 | 1.40 | 0.28 |
| 15 | Bhopal (Jamoniyachhir, Shahpura) | 3.5 | 2.03 | 0.41 |
| 16 | Bhopal (Makshi, Kolar) | 20.5 | 14.10 | 2.82 |

iii) In addition to this, proper Roof top Rain water harvesting is suggested for sustainable management of water resources. These systems serve to capture rainwater for various uses such as domestic consumption, greenbelt irrigation, and other activities. In assessing the feasibility of such systems, calculations are used to determine the available rainwater from rooftops and the corresponding household demand. Utilizing an assumption of five individuals per household and a water demand of 135 LPCD, alongside average normal monthly rainfall and an assumed roof area of 100 sq-m, the suggested storage capacity aligns with the maximum runoff from rooftops, particularly during peak rainfall months such as August. This scientific approach emphasizes the practicality and efficiency of rooftop rainwater harvesting as a viable solution for augmenting water resources in urban areas. Calculation for deciding storage tank capacity is tabulated in **Table 8.5.2.**

**Table 8.5.2 Calculation for deciding storage tank capacity**

| Month | Rainfall | Rainfall Harvested | Water Demand | Cumulative Rainfall Harvested | Cumulative Water Demand | Difference |
|---|---|---|---|---|---|---|
| Jan | 14.7 | 1.2495 | 20.25 | 1.2495 | 20.25 | -19.0005 |
| Feb | 9.8 | 0.833 | 20.25 | 2.0825 | 40.5 | -38.4175 |
| Mar | 11.9 | 1.0115 | 20.25 | 3.094 | 60.75 | -57.656 |
| Apr | 4.8 | 0.408 | 20.25 | 3.502 | 81 | -77.498 |
| May | 19.8 | 1.683 | 20.25 | 5.185 | 101.25 | -96.065 |
| Jun | 127.9 | 10.8715 | 20.25 | 16.0565 | 121.5 | -105.4435 |
| Jul | 339.6 | 28.866 | 20.25 | 44.9225 | 141.75 | -96.8275 |
| Aug | 352.1 | **29.9285** | 20.25 | 74.851 | 162 | -87.149 |
| Sep | 168.7 | 14.3395 | 20.25 | 89.1905 | 182.25 | -93.0595 |
| Oct | 38.9 | 3.3065 | 20.25 | 92.497 | 202.5 | -110.003 |
| Nov | 11.4 | 0.969 | 20.25 | 93.466 | 222.75 | -129.284 |
| Dec | 10.5 | 0.8925 | 20.25 | 94.3585 | 243 | -148.6415 |

Suggested storage tank capacity- 30 $m^3$

Size of the storage tank- Length* Width* Depth

-3m*3m*3.3 m

Suggested rooftop rainwater harvesting not only meets water demand but also prevents strong runoff and flooding of road during heavy rains. It also reduces pumping cost and stress on groundwater resources. A rooftop rainwater harvesting plan has been designed for one building of Maulana Azad National Institute of Technology as a reference, which incorporating for both water storage and groundwater recharge.

## Roof Top Rainwater Harvesting Plan for Maulana Azad National Institute of Technology

Maulana Azad National Institute of Technology located in Bhopal. It spreads over 610 acres and total available area is about 501 acres as per data provided by MANIT. Total built up area is 288595 Sq-m which is 14.22% of total available area. There is a much scope of Roof top rain water harvesting. In campus, there are several buildings as shown in layout map **(Fig.8.5.1).** The roof top rainwater harvesting is proposed for Building no.40 (shopping complex) having roof top area of 0.53 Ha. Month-wise Surface runoff for building no. 40 is tabulated in **Table 8.5.3.** This surface runoff can be harvested through artificial recharge.

**Table 8.5.3: Month-wise generated runoff for building no. 40.**

| Season | Month | Rainfall (mm) | Rainfall (m) | Run off Coefficient | Runoff (ham) | Run off ($m^3$) |
|---|---|---|---|---|---|---|
| Monsoon Season | Jun-23 | 127.9 | 0.1279 | 0.85 | 0.058 | 576.2 |
| | Jul-23 | 339.6 | 0.3396 | 0.85 | 0.153 | 1529.9 |
| | Aug-23 | 352.1 | 0.3521 | 0.85 | 0.159 | 1586.2 |
| | Sep-23 | 168.7 | 0.1687 | 0.85 | 0.076 | 760.0 |
| | Oct-23 | 38.9 | 0.0389 | 0.85 | 0.018 | 175.2 |
| | Nov-23 | 11.4 | 0.0114 | 0.85 | 0.005 | 51.4 |

| Season | Month | Rainfall (mm) | Rainfall (m) | Run off Coefficient | Runoff (ham) | Run off ($m^3$) |
|---|---|---|---|---|---|---|
| Non-Monsoon Season | Dec-23 | 10.5 | 0.0105 | 0.85 | 0.005 | 47.3 |
| | Jan-23 | 14.7 | 0.0147 | 0.85 | 0.007 | 66.2 |
| | Feb-23 | 9.8 | 0.0098 | 0.85 | 0.004 | 44.1 |
| | Mar-23 | 11.9 | 0.0119 | 0.85 | 0.005 | 53.6 |
| | Apr-23 | 4.8 | 0.0048 | 0.85 | 0.002 | 21.6 |
| | May-23 | 19.8 | 0.0198 | 0.85 | 0.009 | 89.2 |

The total annual available runoff is **5001 $m^3$**, which is recommended to be used for both storage and groundwater recharge.

- **Size of Storage tank**

Based on field conditions, suggested size of storage tank is **125 $m^3$** having dimensions of **5m*5m*5m (Length*Width*Depth).**

- **Available runoff for groundwater recharge:**

After storing 125 $m^3$ of surface runoff, the remaining available runoff for groundwater recharge is calculated as shown in **Table 8.5.4**.

**Table 8.5.4: Month-wise Available Runoff for Recharge after Storage**

| Season | Month | Rainfall (mm) | Run off ($m^3$) | Water for storage ($m^3$) | Water available for recharge ($m^3$) |
|---|---|---|---|---|---|
| Monsoon Season | Jun-23 | 127.9 | 576.2 | 125.0 | 451.2 |
| | Jul-23 | 339.6 | 1529.9 | 125.0 | 1404.9 |
| | Aug-23 | 352.1 | 1586.2 | 125.0 | 1461.2 |
| | Sep-23 | 168.7 | 760.0 | 125.0 | 635.0 |
| Non-Monsoon Season | Oct-23 | 38.9 | 175.2 | 125.0 | 50.2 |
| | Nov-23 | 11.4 | 51.4 | 125.0 | -73.6 |
| | Dec-23 | 10.5 | 47.3 | 125.0 | -77.7 |
| | Jan-23 | 14.7 | 66.2 | 125.0 | -58.8 |
| | Feb-23 | 9.8 | 44.1 | 125.0 | -80.9 |
| | Mar-23 | 11.9 | 53.6 | 125.0 | -71.4 |
| | Apr-23 | 4.8 | 21.6 | 125.0 | -103.4 |
| | May-23 | 19.8 | 89.2 | 125.0 | -35.8 |

Total amount of runoff available for groundwater recharge is estimated as **4003 $m^3$.**

**(Note:** Artificial recharge is focused on shallow aquifers due to the limited extent of deeper aquifers in hard rock terrain.)

A borewell with a depth of 10 mbgl along with filtration pit is proposed, corresponding to the thickness of the shallow aquifer in the area. Filtration pit to ensure that the recharged water is free from contaminants

- **For calculation of size of filtration pit**:

The maximum possible rainfall in one hour is 150 mm, but it is divided into two spells. Therefore, the maximum rainfall for a single spell is 75 mm.

| Building No | Area (Ha) | Rainfall (m) | Run off Coeff. | Rainfall Run off (Ham) | Rainfall Runoff ($m^3$) |
|---|---|---|---|---|---|
| 40 | 0.53 | 0.075 | 0.85 | 0.034 | 337.875 |

The maximum possible runoff generated in one hour is 338 $m^3$. The runoff available for recharge is calculated by subtracting the storage tank capacity:

Runoff Available for Recharge=Total Runoff−Storage Tank Capacity=338 $m^3$−125 $m^3$

=213 $m^3$

Hence, recommended size of the filtration pit is - **5 (Depth)* 6.5 (Width)* 6.5 (Length).**

The same method can be used to develop rooftop rainwater harvesting plans for other buildings.

iv) Existing dug wells, currently unused and filled with garbage, such as those identified in Barkheda (23.23056, 77.46806) and Peepalner (23.31029, 77.3395), can be effectively converted into recharge wells. The dugwells that fall inside the recharge worthy area, can be transformed into recharge wells. The process involves diverting surface runoff from fields into these wells, through a filtration chamber to prevent the entry of dust, impurities, and other contaminants.

- ❖ **Suggested Design (Fig. 8.5.2):** The proposed filtration chamber has dimensions of 2.5 m in width, 2 m in length, and 2 m in height. It is divided into two sections: a desilting chamber and a filter media chamber. The initial runoff water enters the desilting chamber, where larger particles settle. Subsequently, the water flows into the filter media chamber, which have dimensions of 1.5 m (width), 2 m (height), and 2 m (depth). This chamber contains layers of coarse sand (1.5-2 mm) and gravel (5-10 mm), which further filter the water. The filtered water is then directed to the bottom of the dug well, ensuring that the bottom is not disturbed and preventing the formation of air bubbles.

This method enhances the sustainability of drinking water sources by efficiently utilizing existing infrastructure to recharge groundwater.

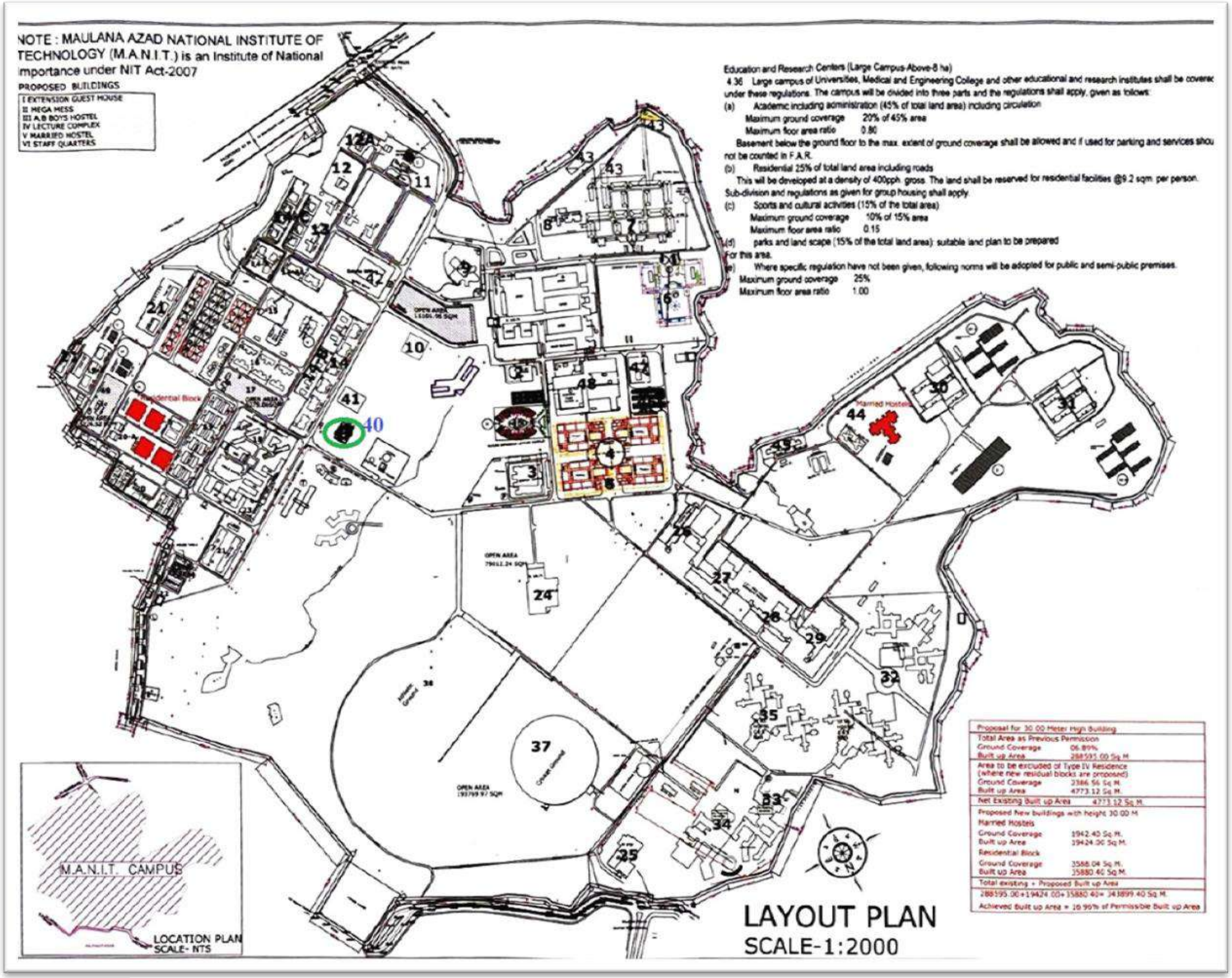



**Fig.8.5.1 Layout of Maulana Azad National Institute of Technology with demarcation of Building No. 40**

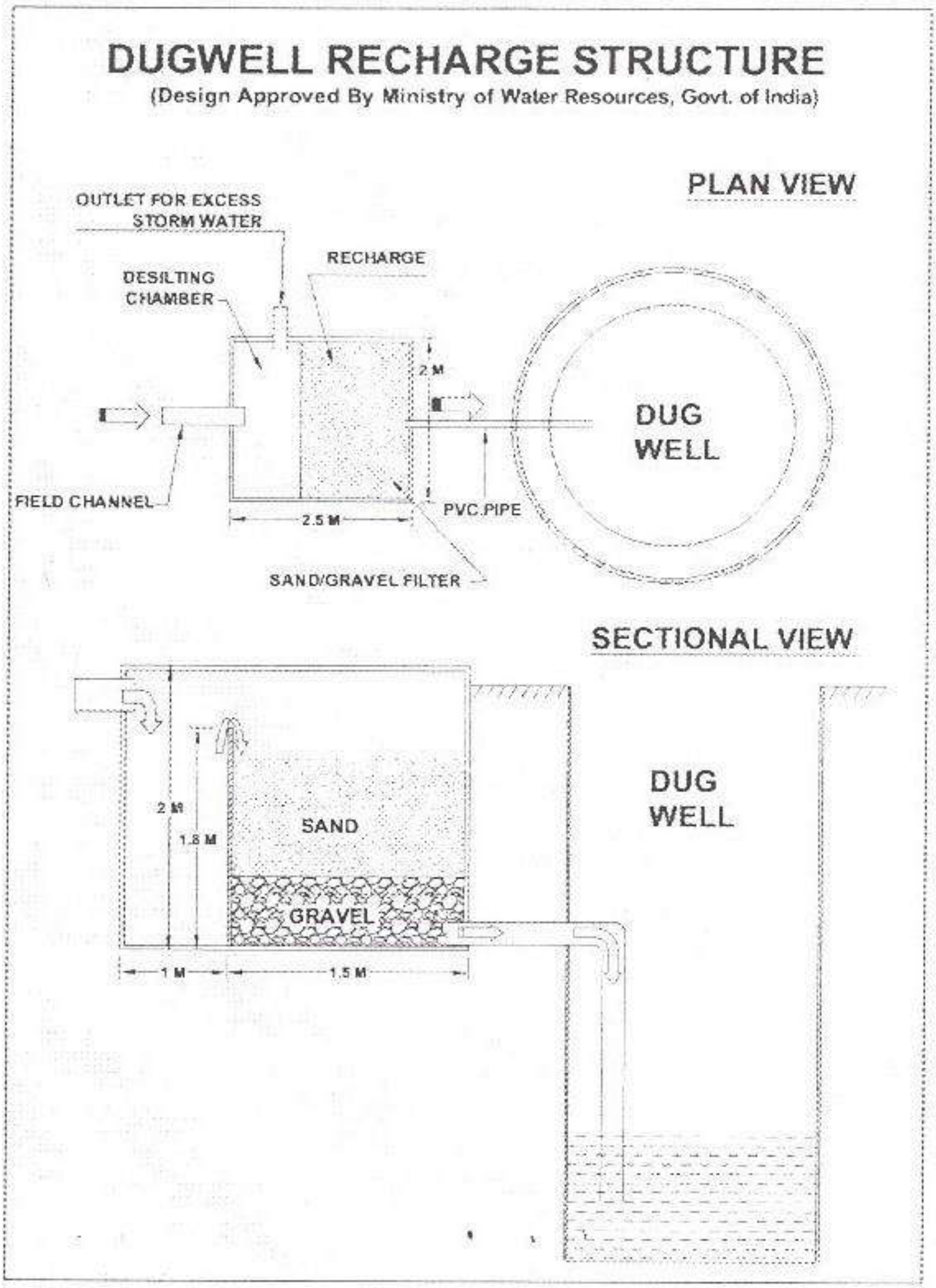



**Fig.8.5.2 Schematics of Dug cum Recharge well**

## 8.6 IDENTIFICATION OF WATERLOGGED CONDITION AND ITS REMEDIATION

### 8.6.1 Objective

Water logging is a widespread issue particularly in urban area due to high impervious surface area, poor drainage system, improper land use planning and presence of waterbodies. The main aim of this chapter is the identification of waterlogged condition and their causes along with the recommendations for tackling the waterlogging.

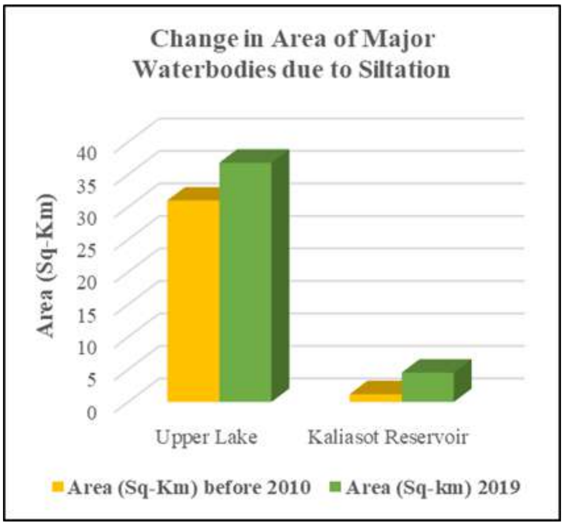
### 8.6.2 Methodology

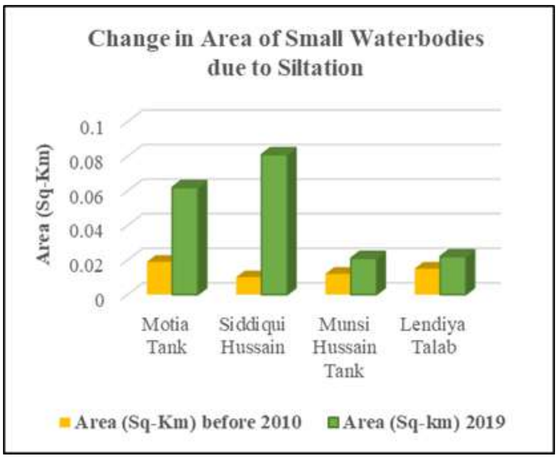
The water logging condition in the study area was identified using pre-monsoon depth to water level data of 2023 from 87 groundwater monitoring stations representing shallow aquifer. Waterlogging condition is identified where the depth to the water level during the pre-monsoon period was above 3 mbgl. Utilizing ArcGIS 10.3.1, the Inverse Distance Weighting (IDW) technique was applied for spatial interpolation, resulting in the production of a map illustrating regions having water logging conditions. To identify areas prone to waterlogging, temporal depth to water level trend data of pre-monsoon period spanning 2013 to 2023 were analysed for 12 existing groundwater monitoring stations. Stations exhibiting an increasing trend in depth to water level at a rate of 0.3 to 0.5 m/year are categorized as prone to waterlogging.

### 8.6.3 Results and discussion

Following the statistical analysis of the existing dataset, it is identified that waterlogged and prone to waterlogging conditions are predominantly observed in areas adjacent to lakes such as Upper Lake, Lower Lake, Shahpura Lake, Kaliasot Reservoir, and smaller ponds such as Motia Tank, Siddiqui Hussain Tank, Munsi Hussain Tank, and Lendiya Pond.

The primary cause of waterlogging in the urban area of Bhopal is linked to these waterbodies because siltation in waterbodies and encroachment around them affect natural recharge and pose waterlogging conditions. Data indicates that the water spread area of Lower Lake and Shahpura Lake has decreased due to encroachment. Conversely, the water spread areas of Upper Lake, Kaliasot Reservoir, Motia Tank, Siddiqui Hussain Tank, Munsi Hussain Tank, and Lendiya Pond have increased significantly. This increase is attributed to reduced depth caused by siltation.



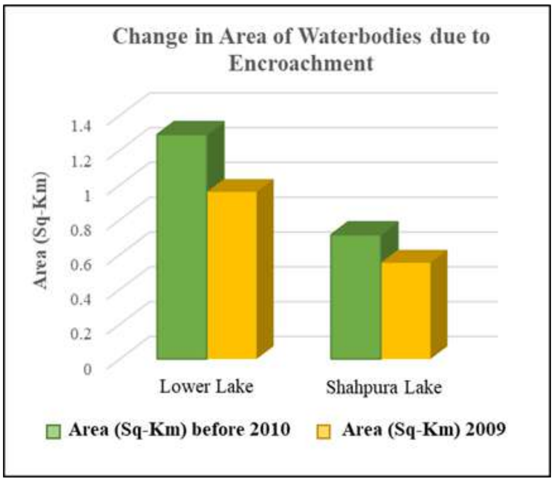



**Fig. 8.6.1 Change in area of waterbodies due to siltation and encroachment**

In addition to this less dependency of groundwater due to availability of surface water supply is one of reasons of water logging in those areas. Hydrographs of monitoring stations located in the area having waterlogged condition show the average depth to water level is less than 3 mbgl in past 10 years (from 2013 to 2023) **(Fig.8.6.2).**

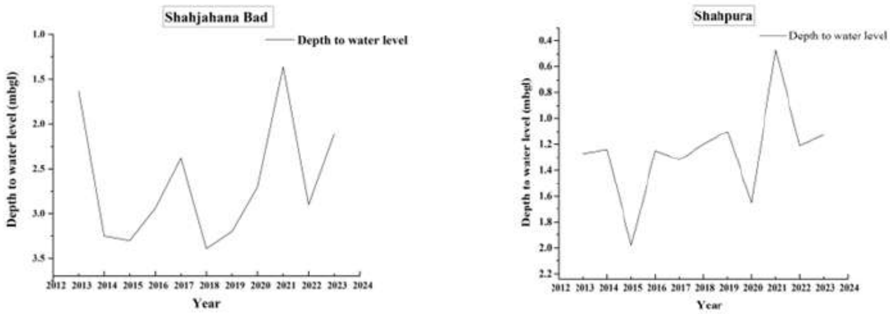



**Fig.8.6.2 Hydrographs of wells located in waterlogged areas**

**Recommendations for tackling waterlogging:**

To mitigate waterlogging condition within the study area, following measures are suggested;

- Desilting of the Upper Lake, Motia tank, Siddiqui Hussain tank, Munsi Hussain tank and Lendiya tank, and Kaliasot Reservoir **(Fig. 8.11)** is recommended to enhance their recharge capacity and to maintain natural groundwater flow direction.
- It is suggested to the Urban Development Authority to take necessary actions to remove encroachments around Lower Lake and Shahpura Lake. It would help in natural infiltration and groundwater recharge and reduce the waterlogging condition.
- It is recommended to abstract groundwater from existing Dugwells and Handpumps in waterlogged areas for irrigation in greenbelt area and for domestic use to mitigate waterlogging condition.

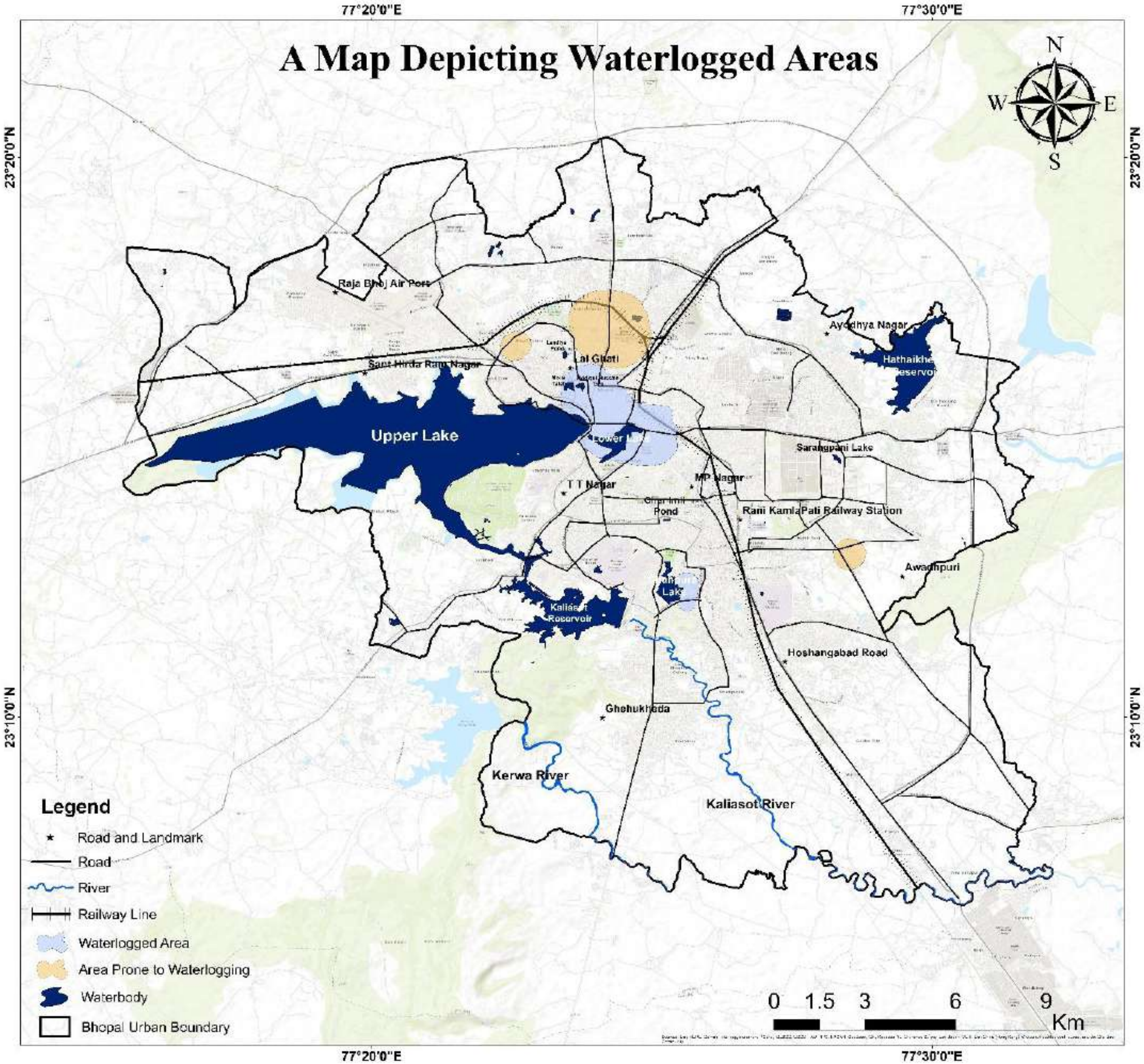



**Fig.8.6.3 illustrate both the waterlogged areas and areas prone to waterlogging conditions**

## 8.7 MANAGEMENT PLAN FOR ENSURING LONG TERM SUSTAINABILITY OF BORE WELLS

### 8.7.1 Objective

The primary objective of this chapter is to provide an optimal design for borewells that ensures their long-term sustainability.

### 8.7.2 Methodology

This involves identifying areas with collapsible formations by analysing litholog data obtained from drilling of exploratory wells within the study area.

### 8.7.3 Result and Discussion

In regions characterized by hard rock formations, casing is typically installed up to a certain depth to penetrate the weathered zone. However, in the study area which is underlain by Deccan Trap basalt and Bhander Group (Vindhyan Supergroup), there are inter-trappean beds, specifically red bole in basaltic areas and contact zone between deccan trap basalt and Vindhyan Sandstone are collapsible in nature. These collapsible layers pose significant challenges to the stability and sustainability of wells. In red bole areas, caving can occur, sealing off the aquifer zone. According to drilling data of CGWB, locations such as Barkheda Pathani, Barakatullah University, Gautam Nagar, Ashoka Society, 6 No. Bus Stop, Char Imli, Shyam Nagar, Gandhi Nagar, Nabibagh, Govindpura and Kolu Kheri and have deeper collapsible zones consisting of red bole/ contact zone.

Management plan involves to provide the **proper well design**. The design of water wells requires careful scientific consideration. Drilling in such areas should be done in telescopic manner. To prevent collapse and maintain well stability, casing must be precisely installed against these collapsible zones specifically against red bole in deccan trap area. It is also noted that contact zone between Deccan trap basalt and Vindhyan Sandstone acts as an aquifer, Hence, slotted pipes should be installed against these zones. This approach is essential for safeguarding the aquifer and ensuring the structural integrity of the well. The design of the well is provided for reference **(Fig.8.7.1).**

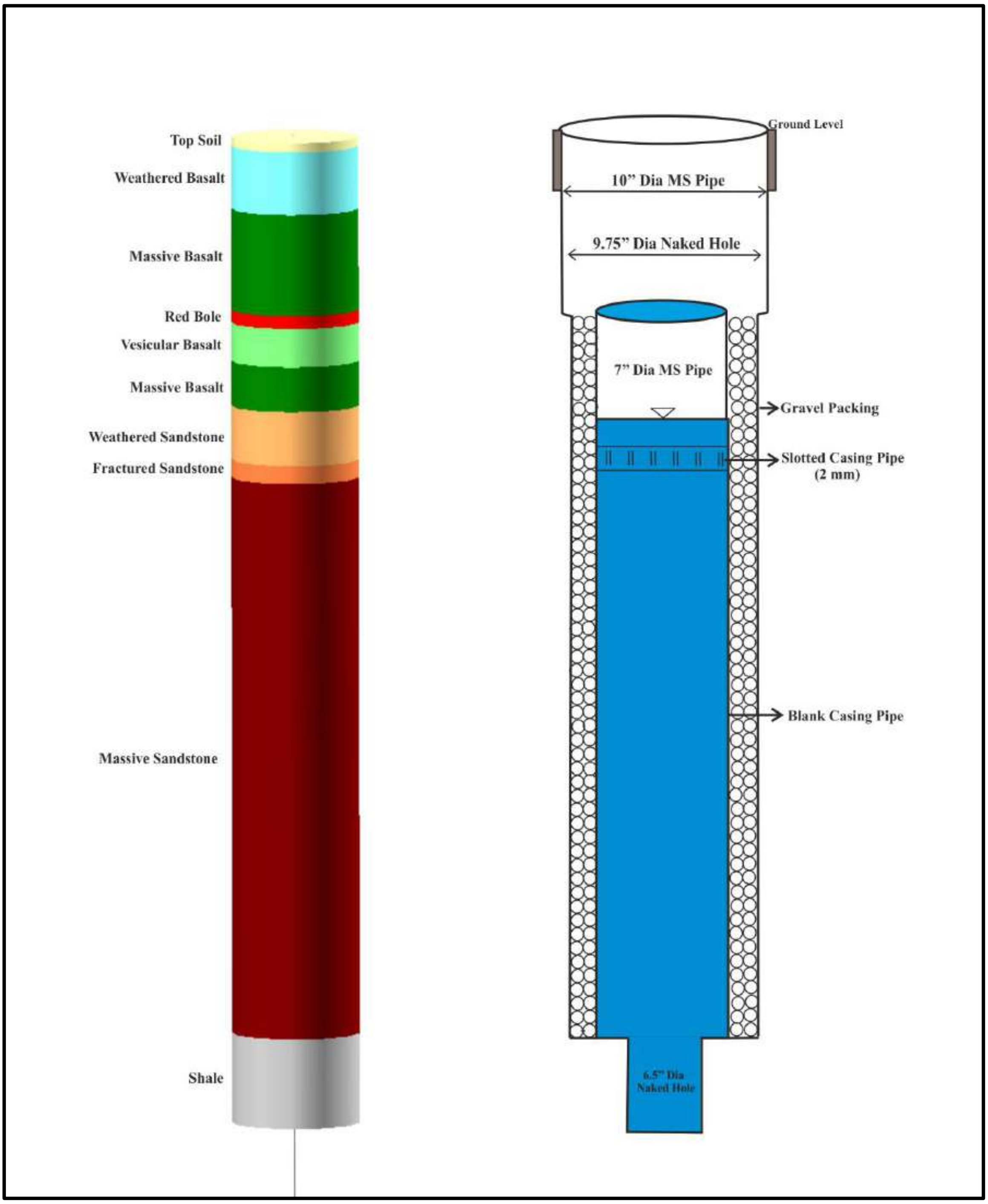



**Fig.8.7.1 Recommended Well Design in areas having collapsible formation**

## 8.8 MANAGEMENT PLAN FOR AREA HAVING LIMITED DEEPER AQUIFER THICKNESS

### 8.8.1 Objective

To identify the areas having limited aquifer thickness and low yield of aquifers and to suggest proper management plan to overcome this issue.

### 8.8.2 Methodology

Exploration details like aquifer thickness, aquifer zones, yield of aquifer are employed to delineate the area having limited aquifer thickness.

### 8.8.3 Result and Discussion

The study area is dominated by hard rock terrain, consisting of Deccan Trap basalt and massive Vindhyan Sandstone. Deeper aquifers in this region are mainly formed by joints and fractures within the hard rock. However, these aquifers have limited regional extent and thickness, which poses a significant challenge for groundwater availability. Exploratory drilling by the Central Groundwater Board (CGWB) has revealed the limited thickness of these deeper aquifers. Areas with restricted aquifer thickness have been mapped which includes Shymala Hills, MP nagar, Char Imli, 1100 Quarters, Arvind Vihar, 6 No. Bus stop, Nehru Nagar, Ashoka Society, Basantkunj, Yatayat Park and Barkheda Pathani.

**Management Plan:**

To maximize well productivity, hydrofracturing can be employed to enhance yield. This process involves lowering a rubber packer to the desired depth in the well and expanding it to seal off the section. Water is then pumped into the sealed portion, creating hydraulic pressure that forces the water to infiltrate the borewell walls. The high pressure can open small joints or fractures, connecting them with adjacent fractures and thereby improving the yield of borewell yield. Hydrofracturing can be effectively implemented in the areas indicated on the map.

## 8.9 MANAGEMENT PLAN FOR ENSURING PROTECTION OF WATERBODIES FROM POLLUTION

### 8.9.1 Objective

The main objective of this chapter is to provide a comprehensive management plan for surface water bodies aimed at preventing pollution and ensuring their long-term sustainability.

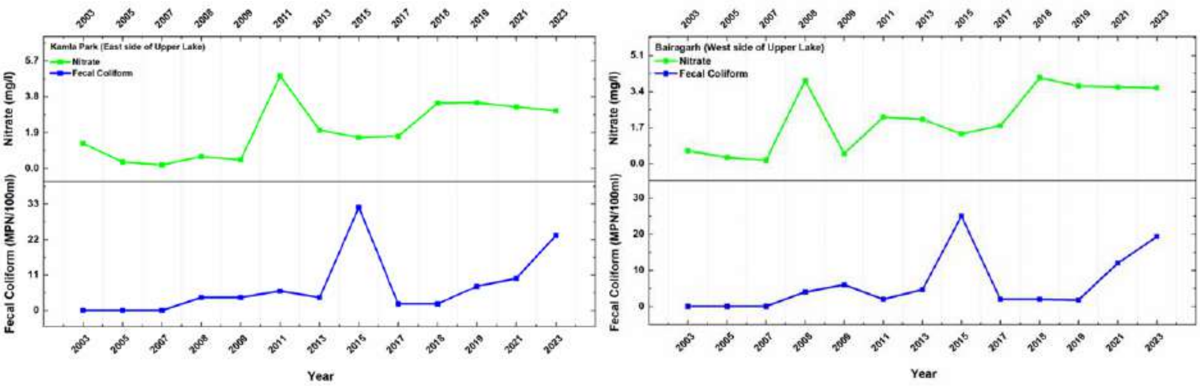
### 8.9.2 Methodology

The approach involves conducting field surveys, reviewing existing literature, and analyzing long-term data on surface water quality from the MPPCB site to assess the condition of surface water bodies within the study area.

### 8.9.3 Result and Discussion

The water bodies in the study area are getting polluted from direct discharge of untreated sewage and wastewater. Upper Lake receives sewerage from areas around the Medical College hostels, Koh-e-Fiza, and south of Van Vihar. Water quality of Lower Lake is deteriorating by unlined sewerage lines and Patra Nala, which carries city's wastewater and drains into lower lake. In addition to this, waste water from Dhobighat, Retghat, Ginnori Bhoipur Nala, Bhagwan Sahai Marg nala, Jahangirabad nala, Police line nala, MVM Nala, Banganga nala is being discharged in the lower lake (CGWB, 1999). Shahpura Lake is significantly impacted by sewage discharge. Siddiqui Hussain Tank has become a swampy area due to siltation and algal growth (CGWB, 2009). Lendiya Pond which was mainly constructed for fisheries activity, now receives sewage from nearby habitation. Sarangpani Lake is polluted by sewage and BHEL factory effluents. Similarly, Char Imli Pond, Laharpur Reservoir, and Hathikheda Reservoir all receive untreated sewage from surrounding areas. As per NGT/OA/ 07/2022 & 12/2022; about 1.25 MLD untreated sewage from 4 fall points is discharged into Kaliasot reservoir.

Data from MPPCB (2013-2023) collected from each side of Upper Lake shows an increasing trend in nitrate concentration, indicating untreated sewage inflow, and rising fecal coliform levels **(Fig.8.9.1)**, confirming animal or human waste disposal in the lake.



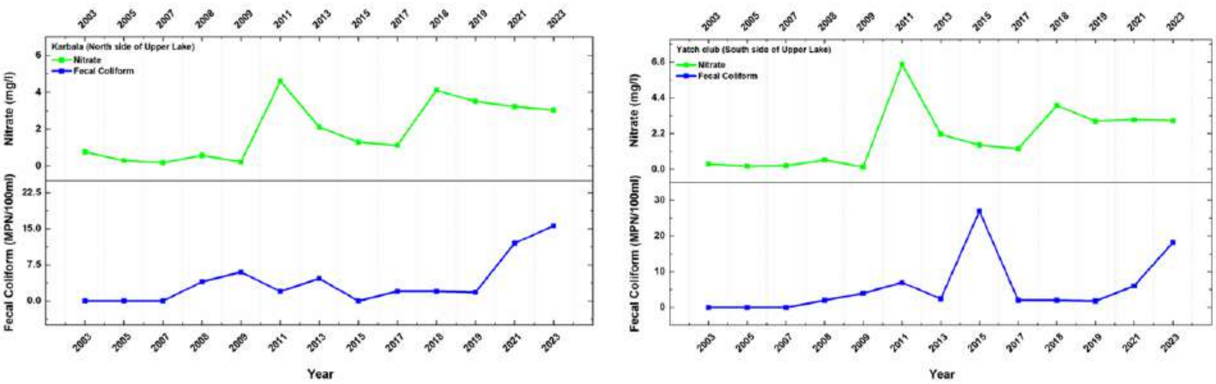



**Fig. 8.9.1 Graph showing increasing Nitrate concentration and fecal coliform in Upper Lake**

**Recommendations for preventing pollution of water bodies and protecting their catchment areas:**

It is recommended that wastewater and sewage should be discharged only after proper treatment and quality assurance to prevent contamination. The implementation of artificial recharge structures in the catchment areas of the Upper Lake and Kerwa Reservoir, as indicated on the map, will enhance groundwater replenishment and protect these areas. To mitigate soil erosion, 55 gully plugs are proposed in each of the Kolans and Kerwa watersheds **(Fig. 8.11).** Additionally, removing encroachments around water bodies and initiating a plantation drive along their perimeters will help stabilize soil and prevent erosion. Routine cleaning and maintenance of these water bodies are also essential for sustaining their health and capacity.

## 8.10 RECOMMENDATIONS OF REGULATION OF GROUNDWATER EXTRACTION

**Illegal Groundwater Extraction**

Central Groundwater Authority has been constituted for the purposes of regulation and control of Groundwater Management and Development. As per guideline dated 24.09.2020, all new/existing industries, industries seeking expansion, infrastructure projects and mining projects abstracting groundwater, unless specifically exempted **(Annexure- XXX),** will be required to seek No Objection Certificate (NOC). It has been observed that numerous firms are extracting groundwater without obtaining a No Objection Certificate from the Central Groundwater Authority, which could lead to overextraction of groundwater.

**Recommendation for Regulation of Groundwater extraction:**

It is suggested to take necessary actions against Groundwater users who withdraw groundwater without obtaining No Objection Certificate (NOC) from Central Groundwater Authority. It would help to regulate and monitor groundwater extraction. List of Firms (as provided by MPPCB) are attached herewith who didn't apply for NOC till date.

**Table:8.10.1 List of firms which didn't apply for NOC for groundwater withdrawal**

| S.No. | Firm Name |
|---|---|
| 1 | MUNICIPAL SOLID WASTE PROCESSING |
| 2 | NAVDUNIA |
| 3 | OJAS ENTERPRISES |
| 4 | ANANTA OF M/S GMV PVT. LTD. |
| 5 | OLLAN OF M/S. GMV PVT. LTD. |
| 6 | PACIFIC BUSINESS CENTREOF M/S SARC INFRASTRUCTURE AND TECHNOLOGY |
| 7 | PRIDE CITY PHASE-1 OF M/S STERLING BALAJEE MEGA VENTURES |
| 8 | PRIDE CITY PHASE-2 OF M/S STERLING BALAJEE MEGA VENTURES |
| 9 | PROPOSED RESIDENTIAL TOWNSHIP OF M/S KAUSHALYA DEVI BUILDERS AND DEVELOPERS |
| 10 | SOUMYA GREENVILLE |
| 11 | STERLING GLOBE GRAND OF M/S STERLING GLOBE BUILDERS |
| 12 | SWASTIK GRAND VILLAS |
| 13 | SWASTIK PARAS ENCLAVE |
| 14 | WHISPERING PALMS OF M/S S. S. REALITY |
| 15 | AVANTEE MEGA FOOD PARK PRIVATE LIMITED |
| 16 | DELIGHT DAIRY LIMITED |
| 17 | KRISHNA FOOD PRODUCTS |
| 18 | Aakriti Greens Phase II, Salaiya |
| 19 | M/S. JAYA HIND MONTUPET PVT. LTD. |
| 20 | Aashima Mall |
| 21 | All India Institute of Medical Sciences |
| 22 | Bansal Hospital |

| | |
|---|---|
| 23 | Aura Mall |
| 24 | Bharat Heavy Electricals Limited |
| 25 | Bhopal Memorial Hospital & Research Centre |
| 26 | Coach Rehabilitation Workshop (West Central Railway) Bhopal |
| 27 | Box Corugators and Offset Printers |
| 28 | Central Forensic Science Laboratory of Directorate of Forensic Science Services, |
| 29 | Bull Mother Farm (A Unit of M.P. State Livestock & Poultry Development Corp.) |
| 30 | Habibganj Coaching Depot (WCR), Bhopal |
| 31 | Habibganj Railway Station |
| 32 | Hamidia Hospital, Bhopal |
| 33 | Himalaya Residency by Himalaya Builders, Bhopal |
| 34 | Indian Institute of Science Education & Research (Institute Works Deptt), |
| 35 | Kasturba Hospital, BHEL, |
| 36 | L.N. Medical College & J.K. Hospital (H.K.Kalchuri Education Trust), Bhopal |
| 37 | MSME Technology Centre, Bhopal |
| 38 | New Bhopal Textile Mills (A unit of NTC (MP) Ltd.), Bhopal |
| 39 | Opal Developers (Shalimar Fort-Leza), Bhopal |
| 40 | Pride City-II (Multistory Group Housing Project)By Sterling Balajee Mega Ventures |
| 41 | RKDF University (Ayushmati Education & Social Society, Bpl) Bhopal |
| 42 | K.D.S.R. Infrastructure Pvt. Ltd.,Address:- Village Khamkhera, Tehsil Hujur, Distt. Bhopal. ,KhamkheraPIN:-462038 |
| 43 | M. H. FOODS & BEVERAGES Address:- KHASRA NO.94/1/1/2, BEHIND SHIVA AUTOMOBILE,OPPOSITE RAKSHA HOSPITAL, BHANPUR ROAD,BHOPALPIN:-462038 |
| 44 | NARMADA FRESH BEVERAGES INDIA LLPAddress:- S.K. Tower, Samantar Road, Behind Alpana ,Cineplex Bhopal M.P.,bhopalPIN:-462001 |
| 45 | OSSIGENO PVT. LTD.Address:- KHASRA NO. 387/1, BAWARIA KALAN, NEAR ,VRINDAVAN DHABHA, HOSHANGABAD ROAD, BHOPAL ,BHOPALPIN:-462026 |
| 46 | Ojus EnterprisesAddress:- J. K.Road, Thesil. Huzur ,BhopalPIN:-462023 |
| 47 | Lal Ion Exchange and Chemicals (P) Ltd.Address:- Plot No. 10 A, Secotor- I, Industrial Area,Govindpura Bhopal M.P.,bhopalPIN:-462023 |
| 48 | Smart EnterprisesAddress:- Khasra No.106-107/2/2-106-107/3/1-106-107/3/2, Gram plashi Karond,BhopalPIN:-462038 |
| 49 | Gurunam BeveragesAddress:- Mansarover garden,indore bhopal, highway,phanda kala,bhopal, madhya pradesh,462030,BHOPAL G.P.O.PIN:-462030 |
| 50 | HONEST PEOPLE BEVERAGES Address:- PATWARI HALKA NO. 25, RIC-03, VILLAGE RAPDIYA ,TEHSIL- HUZUR DISTRICT - BHOPAL M.P.,UNIVERSITY (BHOPAL)PIN:-462026 |

(Source: MPPCB)

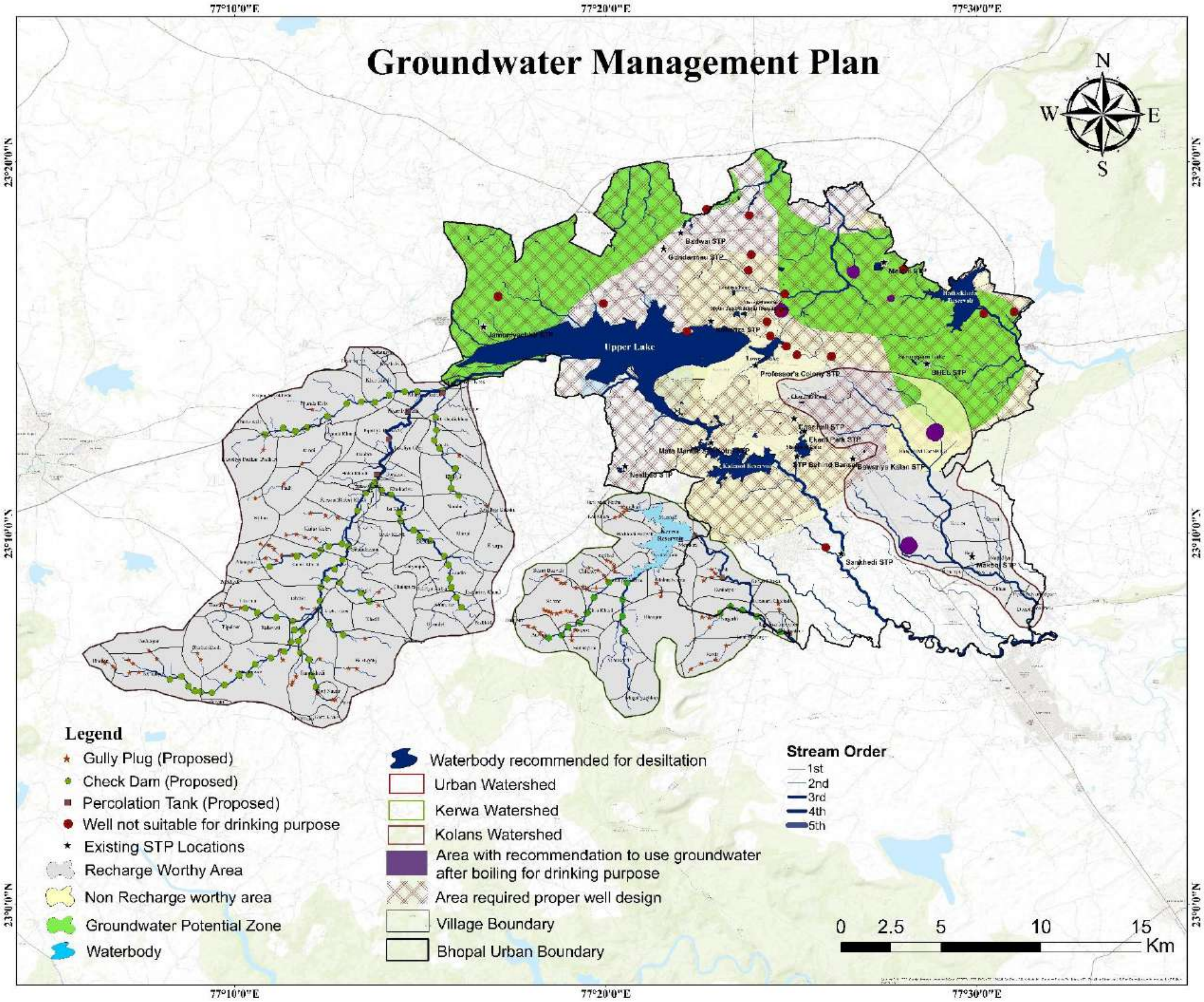



**Fig.8.11 showing map of Groundwater Management Plan within the study**

# 9. CONCLUSIONS AND RECOMMENDATIONS

Bhopal Urban Agglomerates known as "City of lakes" extending over an area of 416 Sq. Km lie in the Phanda block of Bhopal District. It mainly comprises of two hydrogeological units namely Vindhyan Sandstone and Shales (Bhander Group) and Deccan trap basalt.

- Detailed aquifer mapping at a 1:10,000 scale has delineated both horizontal and vertical extents of aquifers within the study area. The mapping indicated that Deccan Trap Basalt dominates the western, northwestern, and northern regions, while Vindhyan Sandstone and Shale are prevalent in the central, eastern, and southeastern areas. Weathered Deccan Trap Basalt and Vindhyan Sandstone serve as unconfined aquifers, whereas vesicular/fractured basalt and fractured sandstone form semi-confined or confined aquifers. The thickness of unconfined aquifer is limited in areas like Bittan Market, MP Nagar, Ashoka Society, Janta Colony, Arvind Vihar, Nehru Nagar, Shyam Nagar, Manav Sangrahalaya, Gandhi Nagar, and near Hathaikheda Dam and maximum in the southeastern part. The yield of unconfined aquifer reaching up to 3.4 lps under favourable conditions. Deeper aquifers within Deccan Trap Basalt generally occur below 30 mbgl, while those in Vindhyan Sandstone are found below 25 mbgl, with yields ranging from 0.1 to 4.75 lps and 0.1 to 10.43 lps, respectively. The contact zone between Deccan Trap Basalt and Vindhyan Sandstone represents a potential aquifer, though its limited thickness poses a challenge. To address this issue, hydrofracturing was recommended to open up the small joints and fractures thereby improving their yield. Additionally, geophysical surveys indicated that the northwestern and northeastern parts of the study area may have notable groundwater potential with recommended depth of borewells upto 80 mbgl.

- To analyse groundwater level behaviour, pre- and post-monsoon water level data of shallow aquifer were examined. The fluctuations typically range from 0 to 2 m, indicating good storage capacity of unconfined aquifer. Decadal data from 2013 to 2023 show a declining trend of water level in some wells, at a rate ranging between 0-0.15 m/year, suggesting increased reliance on groundwater in these areas. Conversely, few wells exhibit rising water level trend at rates of 0.3 to 0.5 m/year, pointing the areas susceptible to waterlogging condition. Areas having waterlogging were identified using pre-monsoon water level data of 2023, and it was observed that those condition are more prevalent near waterbodies. It was identified that siltation in waterbodies and encroachment around them are major factors contributing to waterlogging. To address this, desiltation of waterbodies was recommended, along with the abstraction of groundwater in waterlogged areas. For areas experiencing declining water level, a total 94 check dams, 110 gully plugs, and 7 percolation tanks, with a cumulative recharge capacity of 338 Ham, were proposed in the upstream side of demarcated watersheds which lie outside the study area. Additionally, rooftop rainwater harvesting in urban areas was suggested, offering a recharge potential of 179.57 Ham.

- Groundwater quality assessment was conducted to evaluate its suitability for drinking purposes. The analysis revealed nitrate contamination in the shallow aquifer, primarily due to the mixing of sewage or domestic wastewater with groundwater. Heavy metal (Fe, Mn) contamination was detected at some locations, attributed to geogenic sources, while in Transport Nagar, this contamination was linked to automobile wastewater disposal. Temporary total hardness was also noted in the shallow aquifers. In contrast, all chemical parameters in the deeper aquifer were within BIS permissible limits. To improve groundwater quality in the shallow aquifer, it was recommended to operate all existing Sewage Treatment Plants at full capacity and avoid direct discharge of sewage or wastewater into groundwater, which will help prevent nitrate contamination. Wells with heavy metal contamination should be avoided for drinking purposes, and boiling was recommended to resolve the issue of temporary hardness. The safer aquifer for drinking water has been identified using the Water Quality Index (WQI), with the shallow aquifers generally falling into the safe category, except near Hathaikheda Reservoir. On contrary, all deeper aquifer is falling under safe category. The Gibbs diagram indicates that the groundwater quality in shallow aquifers is primarily influenced by the evaporation-crystallization process, resulting in groundwater that is suitable for drinking.

- The Piper trilinear diagram indicated that groundwater in shallow aquifers is predominantly of the Ca-$HCO_3$ type (87.5% pre-monsoon, 92.5% post-monsoon), with minor occurrences of Ca-Mg-Cl, Ca-Na-$HCO_3$, and Ca-Cl types. This composition suggests a dominant influence of carbonate processes on water chemistry. In deeper aquifers, Ca-Na-$HCO_3$ type water is prevalent (81.8%), with smaller amounts of Ca-Mg-Cl and Na-Cl types, indicating a different geochemical influence.

- Residual Sodium Carbonate (RSC) values indicated that 1.3% of shallow groundwater samples are unsuitable for irrigation, while 95% are suitable and 3.8% are marginally suitable. This indicates that the majority of shallow groundwater is appropriate for agricultural use, with only a small fraction being unsuitable.

- The USSL diagram classified shallow aquifer groundwater as C3-S1 and C2-S1 during the pre-monsoon period, and C2-S1, C3-S1, and C4-S2 during the post-monsoon period. This classification denotes varying levels of salinity and sodium suitability for irrigation. Deeper aquifers are categorized as C2-S1, C3-S1, and C3-S2, while surface water is classified as C2-S1. High salinity and moderate Sodium Adsorption Ratio (SAR) water can be used for irrigation with appropriate management practices and effective drainage to ensure optimal agricultural productivity.

- To determine the effect of monsoon on groundwater quality, paired t-test analysis was conducted which indicates that the monsoon significantly affects certain groundwater quality parameters, including temperature, electrical conductivity, sulphate, nitrate, calcium, magnesium, potassium, arsenic, lead, and uranium, as these showed notable changes between the pre- and post-monsoon periods. Conversely, other parameters like pH, bicarbonate, chloride, fluoride, total hardness, sodium, iron, manganese, copper, zinc, and chromium remained largely unchanged, suggesting that the monsoon does not uniformly influence all aspects of groundwater quality.

- Groundwater quality analysis in the vicinity of Union Carbide India Limited showed the presence of total hardness, nitrate contamination, and heavy metals (Fe and Mn) at certain locations. The Gibbs diagram indicated that all samples fall within a zone dominated by rock influence, suggesting that rock weathering is the primary factor influencing groundwater chemistry and its evolution in the area. There is no relation between UCIL gas leak tragedy and groundwater contamination. Additionally, groundwater quality assessment near the large dumping site at Bhanpur Khanti (now not in use) indicated that the groundwater is of the Ca-HCO3 type and only Mn contamination was found from the dumping site which is geogenic nature.

- Surface water quality in the study area is being deteriorating due to the direct discharge of untreated sewage into water bodies. Although the chemical parameters for surface water bodies such as Lower Lake, Upper Lake, Shahpura Lake, Kerwa Reservoir, and Hathaikheda Reservoir were found within permissible limits, surface water quality data of Upper Lake spanning 2003 to 2023 revealed an increasing trend in nitrate and fecal coliform levels which confirms a deterioration in water quality over time.

- According to the Dynamic Groundwater Resource Estimation 2023 of Bhopal Urban agglomerate, the area falls under semi-critical. To reduce reliance on groundwater, rooftop rainwater harvesting was recommended. Areas that are not suitable for groundwater recharge, it was advised to install a storage tank with a capacity of 30 $m^3$ for households with an average rooftop area of 100 Sq-m. These tanks will collect rainwater from rooftops and can be used for domestic purposes. Additionally, it was recommended to BMC, to increase surface water supply and repair old or leaky pipelines to avoid leakage loss.

- To regulate illegal groundwater extraction, it was suggested to District Administration to take strict action against those who withdraw groundwater without having No Objection Certificate from Central Groundwater Authority.

# 10. REFERENCES


- Anon. (2011). *71-City Water-Excreta Survey, 2005-06*. Centre for Science and Environment, New Delhi.
- APHA. (1922). *Standards methods for the examination of water and wastewater* (24th ed.). Ellen Burton Barun, Terry E. Baxter, & William C. Lipps (Eds.). American Public Health Association. ISBN: 0875532993.
- Ayolabi, E. A. (2005). Geoelectric evaluation of Olushosun landfill site southwest Nigeria and its implication on groundwater. *Journal of Geological Society of India, 66*, 318-322.
- *Before the National Green Tribunal, Central Zonal Bench, Bhopal, OA.07/2022 and OA 12/2022; in the matter of Subhash C. Pandey V/S State of MP & ORS.*
- *Bhopal Municipal Corporation*.
- Bureau of Indian Standards. (2012). *Drinking water specifications (IS 10500)*. Manak Bhawan, Bahadur Shah Zafar Marg, New Delhi.
- *Census of India, Census report, 2011*. Retrieved from https://censusindia.gov.in/
- Central Groundwater Authority. (2016). *Estimation of water requirement for drinking and Domestic use (NBC, 2016-BIS)*.
- Central Groundwater Board (CGWB). (1980). *Report on comprehensive hydrogeological surveys in Bhopal District under Indo-British Betwa groundwater project (1975-1980)*.
- Central Groundwater Board (CGWB). (1990). *Report on systematic hydrogeological surveys in Bhopal district*.
- Central Groundwater Board (CGWB). (1999). *Report on hydrogeological framework for urban development of Bhopal city*.
- Central Groundwater Board (CGWB). (2004). *Report on detailed reappraisal hydrogeological surveys in Bhopal District*.
- Central Groundwater Board (CGWB). (2009). *Report on information of waterbodies of Bhopal City*.
- Central Groundwater Board (CGWB). (2010). *Collaborative Hydrogeological studies in Central Institute of Agriculture Engineering (CIAE) Research Farm area, Nabibagh, Berasia road, Bhopal*.
- Central Groundwater Board (CGWB). (2011). *Groundwater quality report in and around UCIL*.
- Central Groundwater Board (CGWB). (2011). *Report on hydrogeological scenario of Bhopal city*.

- Central Groundwater Board (CGWB). (2013). *District groundwater information booklet, North Central Region*. Ministry of Water Resources, Bhopal.
- Central Groundwater Board (CGWB). (2014). *Groundwater quality report in and around Bhanpur Khanti*.
- Central Groundwater Board (CGWB). (2020). *Report on Dynamic Groundwater resource assessment*.
- Central Groundwater Board (CGWB). (2022). *Groundwater exploration report*.
- Central Groundwater Board (CGWB). (2022). *Report on Dynamic Groundwater resource assessment*.
- Central Groundwater Board (CGWB). (2023). *Report on Dynamic Groundwater resource assessment*.
- Central Groundwater Board (CGWB). *Artificial Recharge Manual*.
- Central Pollution Control Board. (2021). *National Inventories of Sewage Treatment Plant*. Retrieved from https://cpcb.nic.in/uploads/namp/STP.pdf
- *Earth Explorer-USGS*. Retrieved from https://earthexplorer.usgs.gov/
- *ESRI Sentinel-2 Land Cover Explorer*. Retrieved from https://www.esri.com/en-us/arcgis/products/sentinel-2-lander/overview
- Gautam, R. K., Islamuddin, N., More, N., Verma, S., Pandey, S., Mumtaz, N., Kumar, R., & Usama, M. (n.d.). Sewage Generation and Treatment Status for the City of Delhi, its Past, Present and Future Scenario- A Statistical Analysis. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*.
- *Geological Survey of India*. Retrieved from https://www.gsi.gov.in/
- Ghosh, S., & Salla, S. (2014). Limnological studies of lower lake of Bhopal, India. *International Journal of Mathematics and Physics Sciences Research (IJMPSR), 1*(1), 30-37.
- Gibbs, R. J. (1970). Mechanism controlling world water chemistry. *Science, 170*(3962), 1088-1090.
- Gupta, G., Patil, S. N., Padmane, S. T., Erram, V. C., & Mahajan, S. H. (2015). Geoelectric investigation to delineate groundwater potential and recharge zones in Suki river basin, north Maharashtra. *Journal of Earth System Science, 124*(7), 1487-1501. Retrieved from https://www.ias.ac.in/article/fulltext/jess/124/07/1487-1501
- Gupta, P., Keesari, T., & Kamaraj, P. (2021). Assessment of biannual seasonal variations in hydrochemistry of Kerwa reservoir located in hard rock formations of Central India. *Environmental Earth Sciences, 80*(10), 1-15. Retrieved from https://doi.org/10.1007/s12665-021-09668-8
- *Indian Meteorological Department*. Retrieved from https://mausam.imd.gov.in/

- *IN-GRES*. Retrieved from http://ingres.iith.ac.in
- Joshi, D. (2015). *Report on National Aquifer Mapping and Management Plan for Phanda block, Bhopal District*.
- Jotwani, J., Jain, B., & Malik, S. (2014). Assessment of Potability of Different Water Sources at Bhopal city. *International Journal of Environmental Sciences, 4*(5), 890-898.
- Kamat, R. (2019). Urban Flood Vulnerability Assessment of Bhopal, M.P. India. *International Journal of Civil Engineering and Technology (IJCIET), 10*(01), 2956-2977.
- *Madhya Pradesh Industrial Development Corporation*. Retrieved from https://www.mponline.gov.in/portal/Services/MIDC/
- *Madhya Pradesh Pollution Control Board, Water Quality of Upper Lake*. Retrieved from https://www.mppcb.mp.gov.in/
- Narendra, P., & Satyanarayana Tata. (2007). Report on electrical resistivity surveys in the over exploited areas of Morshi and Warud taluks, Amravati district, CGWB technical report.
- Sailaukhanuly, Y., et al. (2024). Health risk assessment of nitrate in drinking water with potential source identification: A case study in Almaty, Kazakhstan. *International Journal of Environmental Research and Public Health, 21*(1), 55. Retrieved from https://doi.org/10.3390/ijerph21010055
- Sattar, G. S., Keramat, M., & Shahid, S. (2014). Deciphering transmissivity and hydraulic conductivity of the aquifer by vertical electrical sounding (VES) experiments in Northwest Bangladesh. *Applied Water Science, 4*(1), 67-77. Retrieved from https://doi.org/10.1007/s13201-014-0203-9
- Sen, A., Sen, N., & Singh, V. (2022). Issues and Challenges of Water Supply System in Bhopal City, Madhya Pradesh. *Bulletin of Pure and Applied Sciences- Geology, 41F*(1), 129-141.
- Singh, K. P. (2003). A new approach for detection of Hidden Aquifer using DC Resistivity data transforms. *Journal of Geological Society of India, 61*, 540-548.
- Tiwari, A., & Mishra, P. K. (2019). A study of urban-landscape characteristics of Bhopal City (India) in a geo-spatial environment. In *Making Cities Resilient* (pp. 207-226). Springer, Cham.
- Town and Country Planning Organization, Ministry of Urban Development. (2016). *Model Building Bye Laws*.
- *Visualization of Earth Observation Data and Archival System*. Retrieved from https://vedas.sac.gov.in/
- Wadwekar, M., & Pandey, R. (2021). Assessing Groundwater recharge potential through rainwater harvesting in Urban Environment: A case of Bhopal City. In *Water*

*Management and Water Governance, Water Science and Technology Library, 96*. Retrieved from https://doi.org/10.1007/978-3-030-58051-3_31

- Yenugu, S. R., Vangala, S., & Badri, S. (2020). Groundwater quality evaluation using GIS and water quality index in and around inactive mines, southwestern parts of Cuddapah basin, Andhra Pradesh, South India. *Hydrology Research, 51*(1), 109-127. Retrieved from https://doi.org/10.1016/j.hydres.2020.11.001

## Annexure-I: Litholog of Exploratory wells

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| **Exploratory wells under NAQUIM 2.0 within the study area** | | | | |
| 1 | Yatayat Park | 0 | 3 | Top Soil |
| | | 3 | 11 | Weathered Sandstone |
| | | 11 | 71 | Compact Sandstone |
| | | 71 | 75 | Fractured Sandstone |
| | | 75 | 87 | Compact Sandstone |
| | | 87 | 90 | Fractured Sandstone |
| | | 90 | 100 | Compact Sandstone |
| 2 | Water Purification Plant (BMC) | 0 | 1 | Top Soil |
| | | 1 | 8.1 | Weathered Sandstone |
| | | 8.1 | 105.7 | Compact Sandstone |
| 3 | Nehru Nagar | 0 | 0.5 | Top Soil |
| | | 0.5 | 3.5 | Weathered Sandstone |
| | | 3.5 | 35.5 | Compact Sandstone |
| | | 35.5 | 38.6 | Fractured Sandstone |
| | | 38.6 | 105.7 | Compact Sandstone |
| 4 | Neelbad EW | 0 | 8.1 | Top Soil |
| | | 8.1 | 20.3 | Weathered Basalt |
| | | 20.3 | 47 | Massive basalt |
| | | 47 | 57 | fractured basalt |
| | | 57 | 105 | Massive basalt |
| | | 105 | 117.9 | Weathered basalt |
| | | 117.9 | 200 | Massive basalt |
| 5 | MP Nagar | 0 | 4.5 | Weathered Sandstone |
| | | 4.5 | 38.6 | Compact Sandstone |
| | | 38.6 | 69.1 | Shale |
| | | 69.1 | 148.1 | Compact Sandstone |
| 6 | Basantkunj | 0 | 35.7 | Weathered Basalt |
| | | 35.7 | 38.8 | fractured basalt |
| | | 38.8 | 52 | Weathered Basalt |
| | | 52 | 78.4 | Massive basalt |
| | | 78.4 | 99.8 | Compact Sandstone |
| 7 | Arvind Vihar | 0 | 2 | Top Soil |
| | | 2 | 23.3 | Compact Sandstone |
| | | 23.3 | 26.4 | Fractured Sandstone |
| | | 26.4 | 69.1 | Shale |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| | | 69.1 | 78.2 | Compact Sandstone |
| | | 78.2 | 84.3 | Fractured Sandstone |
| | | 84.3 | 160.7 | Compact Sandstone |
| | | 160.7 | 200 | Shale |
| 8 | 1100 Quarters | 0 | 6 | Weathered Basalt |
| | | 6 | 26.4 | Massive basalt |
| | | 26.4 | 90.4 | Compact Sandstone |
| | | 90.4 | 102.6 | Shale |
| | | 102.6 | 105.6 | Compact Sandstone |
| **Exploratory wells under NAQUIM 2.0 lie outside the study area** | | | | |
| 9 | Phanda Kalan | 0 | 2 | Top Soil |
| | | 2 | 17.5 | Weathered Basalt |
| | | 17.5 | 44.7 | Massive basalt |
| | | 44.7 | 47 | Fractured basalt |
| | | 47 | 56.9 | Massive basalt |
| | | 56.9 | 75.2 | clay |
| **Existing Exploratory wells lie within the study area** | | | | |
| 10 | Barkheda Pathani | 0 | 1 | Top Soil |
| | | 1 | 11 | Weathered Basalt |
| | | 11 | 35 | Massive basalt |
| | | 35 | 47 | Weathered Sandstone |
| | | 47 | 48 | Fractured Sandstone |
| | | 48 | 65 | Compact Sandstone |
| | | 65 | 66 | Fractured Sandstone |
| | | 66 | 158 | Compact Sandstone |
| | | 158 | 198 | Shale |
| | | 198 | 199 | Fractured Sandstone |
| | | 199 | 200 | Shale |
| 11 | Neelbad | 0 | 1 | Top Soil |
| | | 1 | 5 | Weathered Basalt |
| | | 5 | 128 | Massive basalt |
| | | 128 | 129 | Vesicular/fractured basalt |
| | | 129 | 200 | Massive basalt |
| 12 | Barkatullah University | 0 | 1 | Top Soil |
| | | 1 | 4.5 | Vesicular / fractured basalt |
| | | 4.5 | 31.9 | Massive basalt |
| | | 31.9 | 35 | Vesicular / fractured basalt |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| | | 35 | 61 | Massive basalt |
| | | 61 | 65 | Fractured Sandstone |
| | | 65 | 128.5 | Compact Sandstone |
| | | 128.5 | 141.7 | Fractured Sandstone |
| | | 141.7 | 178.3 | Compact Sandstone |
| | | 178.3 | 184.4 | Shale |
| 13 | Manav Sanghralaya | 0 | 105 | Compact Sandstone |
| | | 105 | 190 | Shale |
| | | 190 | 270 | Compact Sandstone |
| | | 270 | 372 | Shale |
| | | 372 | 430 | Compact Sandstone |
| | | 430 | 458 | Fractured Sandstone |
| 14 | Nabibagh | 0 | 1 | Top Soil |
| | | 1 | 14.5 | Weathered Basalt |
| | | 14.5 | 19.3 | Massive basalt |
| | | 19.3 | 20.7 | Red Bole |
| | | 20.7 | 22.8 | Vesicular / fractured basalt |
| | | 22.8 | 23.7 | Massive basalt |
| | | 23.7 | 25.8 | Weathered Sandstone |
| | | 25.8 | 26.5 | Fractured Sandstone |
| | | 26.5 | 96.3 | Compact Sandstone |
| | | 96.3 | 122.41 | Shale |
| 15 | Gandhi Nagar | 0 | 3.2 | Weathered Basalt |
| | | 3.2 | 8.8 | Vesicular basalt |
| | | 8.8 | 51.5 | Massive basalt |
| | | 51.5 | 54.6 | Red Bole |
| | | 54.6 | 57.6 | Vesicular / fractured basalt |
| | | 57.6 | 91.17 | Massive basalt |
| 16 | GSI | 0 | 2.3 | Top Soil |
| | | 2.3 | 6.17 | Massive basalt |
| | | 6.17 | 13.75 | Vesicular / fractured basalt |
| | | 13.75 | 15.75 | Massive basalt |
| | | 15.75 | 20.35 | Shale |
| | | 20.35 | 61.35 | Compact Sandstone |
| | | 61.35 | 72.55 | Fractured Sandstone |
| | | 72.55 | 91.75 | Shale |
| | | 91.75 | 98 | Compact Sandstone |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| 17 | Gautam nagar | 0 | 2.5 | Top Soil |
| | | 2.5 | 12.5 | Weathered Basalt |
| | | 12.5 | 15 | Compact Sandstone |
| | | 15 | 28 | Fractured Sandstone |
| | | 28 | 33 | Compact Sandstone |
| | | 33 | 45 | Fractured Sandstone |
| | | 45 | 54 | Compact Sandstone |
| | | 54 | 61 | Shale |
| 18 | Shivaji Nagar (6 no. bus stop) | 0 | 2 | Top Soil |
| | | 2 | 8 | Weathered Basalt |
| | | 8 | 31 | Compact Sandstone |
| | | 31 | 34.4 | Fractured Sandstone |
| | | 34.4 | 70 | Shale |
| | | 70 | 76.42 | Compact Sandstone |
| 19 | Janta colony | 0 | 21.3 | Massive basalt |
| | | 21.3 | 51.9 | Compact Sandstone |
| 20 | Ashoka society (E-7 ) | 0 | 23.3 | Massive basalt |
| | | 23.3 | 26.9 | Red Bole |
| | | 26.9 | 30.9 | Vesicular / fractured basalt |
| | | 30.9 | 38.5 | Massive basalt |
| | | 38.5 | 76.5 | Compact Sandstone |
| 21 | Baghira apartment (E-5) | 0 | 15.5 | Massive basalt |
| | | 15.5 | 16.3 | Red Bole |
| | | 16.3 | 68.8 | Compact Sandstone |
| | | 68.8 | 110.4 | Shale |
| | | 110.4 | 122 | Compact Sandstone |
| 22 | Shyam nagar | 0 | 2.6 | Weathered Basalt |
| | | 2.6 | 10.7 | Massive basalt |
| | | 10.7 | 18.8 | Vesicular / fractured basalt |
| | | 18.8 | 35 | Compact Sandstone |
| | | 35 | 57.3 | Fractured Sandstone |
| | | 57.3 | 93 | Shale |
| 23 | Char Imli | 0 | 6.15 | Weathered Basalt |
| | | 6.15 | 9.8 | Red Bole |
| | | 9.8 | 21.3 | Weathered Sandstone |
| | | 21.3 | 30.5 | Compact Sandstone |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| 24 | M.A.C.T | 0 | 11.15 | Weathered Basalt |
| | | 11.15 | 23.2 | Massive basalt |
| | | 23.2 | 28 | Vesicular / fractured basalt |
| | | 28 | 34.5 | Fractured Sandstone |
| | | 34.5 | 91.62 | Compact Sandstone |
| 25 | Govindpura | 0 | 0.5 | Top Soil |
| | | 0.5 | 7 | Weathered Sandstone |
| | | 7 | 9 | Fractured Sandstone |
| | | 9 | 15 | Compact Sandstone |
| | | 15 | 27 | Shale |
| | | 27 | 62 | Compact Sandstone |
| | | 62 | 68 | Shale |
| | | 68 | 87 | Compact Sandstone |
| | | 87 | 100 | Fractured Sandstone |
| 26 | Kolu Kheri | 0 | 25.2 | Weathered/ Vesicular basalt |
| | | 25.2 | 62.8 | Massive basalt |
| | | 62.8 | 75.1 | fractured basalt |
| | | 75.1 | 87.3 | Massive basalt |
| | | 87.3 | 93.4 | Vesicular Basalt |
| | | 93.4 | 105.6 | Massive basalt |
| | | 105.6 | 111.7 | Vesicular Basalt |
| | | 111.7 | 142.3 | Massive basalt |
| **Existing Exploratory wells lie outside the study area** | | | | |
| 27 | Ratibad | 0 | 0.9 | Top Soil |
| | | 0.9 | 4.5 | Weathered Basalt |
| | | 4.5 | 17.5 | Massive basalt |
| | | 17.5 | 37.9 | Vesicular / fractured basalt |
| | | 37.9 | 84.5 | Massive basalt |
| | | 84.5 | 108.3 | Amygdular basalt |
| | | 108.3 | 128.7 | Massive basalt |
| | | 128.7 | 129.7 | Fractured basalt |
| | | 129.7 | 153 | Massive basalt |
| | | 153 | 154 | Fractured basalt |
| | | 154 | 242 | Massive basalt |
| 28 | Bakaniya | 0 | 1.3 | Top Soil |
| | | 1.3 | 20.2 | Weathered Basalt |
| | | 20.2 | 50.9 | Vesicular / fractured basalt |
| | | 50.9 | 62.9 | Massive basalt |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| | | 62.9 | 70 | fractured basalt |
| | | 70 | 83 | Red Bole |
| | | 83 | 93 | Vesicular / fractured basalt |
| | | 93 | 184 | Massive basalt |
| 29 | Barjhiri | 0 | 38.4 | Weathered / fractured basalt |
| | | 38.4 | 84.2 | Massive basalt |
| | | 84.2 | 86 | Red Bole |
| | | 86 | 111.7 | Vesicular / fractured basalt |
| | | 111.7 | 238.8 | Massive basalt |
| 30 | Barkhera Nathu | 0 | 38.4 | Vesicular / fractured basalt |
| | | 38.4 | 133 | Massive basalt |
| | | 133 | 136 | Vesicular / fractured basalt |
| | | 136 | 264.1 | Massive basalt |
| | | 264.1 | 267.2 | fractured basalt |
| | | 267.2 | 300.7 | Massive basalt |
| 31 | Nandini | 0 | 32.4 | Vesicular / fractured basalt |
| | | 32.4 | 64.9 | Massive basalt |
| | | 64.9 | 68 | Red Bole |
| | | 68 | 77 | Vesicular / fractured basalt |
| | | 77 | 80.2 | Vesicular Basalt |
| | | 80.2 | 81.4 | Massive basalt |
| 32 | Berkhedi Kalan | 0 | 1 | Top Soil |
| | | 1 | 17.5 | Weathered Basalt |
| | | 17.5 | 43 | Vesicular / fractured basalt |
| | | 43 | 59 | Massive basalt |
| | | 59 | 79 | Vesicular / fractured basalt |
| | | 79 | 99 | Massive basalt |
| | | 99 | 100 | fractured basalt |
| | | 100 | 200 | Massive basalt |
| 33 | Sarwar | 0 | 2.3 | Weathered Basalt |
| | | 2.3 | 15.7 | Massive basalt |
| | | 15.7 | 27 | Vesicular basalt |
| | | 27 | 31 | Massive basalt |
| | | 31 | 64 | Vesicular / fractured basalt |
| | | 64 | 118.12 | Massive basalt |

| S.No. | Site Name | Depth from (mbgl) | Depth to (mbgl) | Litholog |
|---|---|---|---|---|
| 34 | Kaamkheda | 0 | 1 | Top Soil |
| | | 1 | 11 | Weathered Basalt |
| | | 11 | 26 | Vesicular / fractured basalt |
| | | 26 | 164 | Compact Sandstone |
| | | 164 | 200 | Shale |

## Annexure-II: Vertical Electrical Sounding data in and around study area

| S. No. | Village | Latitude | Longitude | Elevation (m amsl) | Rho1 (ohm -m) | H1 (m) | Rho2 (ohm -m) | H2 (m) | Rho3 (ohm -m) | H3 (m) | Rho4 (ohm -m) | H4 (m) | Rho5 (ohm -m) | Weathering Thickness (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | N-2 | 23.221766 | 77.449742 | 491 | 211 | 0.75 | 14.5 | 1.24 | 2.3 | 5.41 | 49 | | | 7.4 |
| 2 | Jamuri maidan | 23.233655 | 77.48009 | 486 | 9.7 | 0.5 | 48.4 | 3.18 | 201 | 13.9 | 58.5 | 125 | 3219 | 3.7 |
| 3 | Badhada | 23.218022 | 77.319021 | 516 | 16.6 | 0.5 | 108 | 0.629 | 5.43 | 26.8 | 63.8 | | | 28 |
| 4 | Mungaliya Cchhap | 23.21689 | 77.291716 | 523 | 2.73 | 0.724 | 10.5 | 24.8 | 429 | 42.4 | 3.8 | | | 25 |
| 5 | Sukhi sewaniya | 23.376954 | 77.457351 | 484 | 10.8 | 0.5 | 4.54 | 2.62 | 2113 | | | | | 3.1 |
| 6 | Khinchital | 23.4160102 | 77.428064 | 487 | 30.5 | 0.75 | 7.27 | 6.2 | 487 | | | | | 7 |
| 7 | kamkheda | 23.385464 | 77.424504 | 482 | 21.4 | 0.75 | 65200 | 6.4 | 76.4 | | | | | 0.75 |
| 8 | Khamakheda | 23.38135 | 77.40766 | 483 | 37.2 | 0.75 | 12 | 2.93 | 53.6 | 12.8 | 724 | 15.3 | 44.7 | 16.5 |
| 9 | gohargunj | 23.244553 | 77.591955 | 449 | 52.3 | 0.75 | 155609 | 3.1 | 19.1 | | | | | 0.75 |
| 10 | Phandakalan | 23.2317112 | 77.19348 | 522 | 38.8 | 0.75 | 127 | 1.2 | 11 | 61.9 | 1647 | | | 0.75 |
| 11 | hatai khedi | 23.203022 | 77.216469 | 522 | 155 | 1 | 12.4 | 9.02 | 10.3 | 19.7 | 158 | | | 29.7 |
| 12 | Jamoniyakalan | 23.2085 | 77.568578 | 444 | 56.8 | 0.75 | 820 | 0.527 | 2.26 | 2.52 | 137 | | | 3.8 |
| 13 | Jhangariya Khurd | 23.195059 | 77.514802 | 455 | 30.9 | 0.75 | 256 | 9.72 | 7356 | 12.2 | 62.3 | | | 0.75 |
| 14 | New sewaniya | 23.111787 | 77.471546 | 452 | 5.93 | 4.22 | 11.8 | 39.3 | 187 | | | | | 43.5 |
| 15 | Parwaliya soni | 23.329199 | 77.390327 | 495 | 5.51 | 1.52 | 13.8 | 41.2 | 6270 | | | | | 42.7 |
| 16 | Barkheda modor | 23.316804 | 77.291706 | 513 | 5.02 | 4.83 | 41.2 | 90.2 | 6270 | | | | | 4.85 |
| 17 | kardai | 23.377125 | 77.346866 | 506 | 14 | 1.34 | 70.1 | 16.2 | 53 | 203 | 2172 | | | 1.34 |
| 18 | Mungaliya Cchhap | 23.358644 | 77.263924 | 518 | 6.45 | 0.5 | 121 | 4.99 | 22.2 | 30.4 | 146 | | | 22.7 |
| 19 | Kolkhedi | 23.250358 | 77.266553 | 509 | 28.6 | 1.22 | 7.1 | 28.4 | 77.3 | 77.7 | 2831 | | | 29.6 |
| 20 | Amrod | 23.246775 | 77.205868 | 525 | 15.5 | 2.79 | 34.9 | 31.9 | 105 | | | | | 34.7 |
| 21 | Fatepur Dobra | 23.161652 | 77.341797 | 516 | 8.03 | 1.67 | 45.2 | 3.22 | 17.6 | 39.3 | 80.8 | | | 44.2 |
| 22 | Badjhiri amla | 23.131112 | 77.286227 | 547 | 6.18 | 3.92 | 132 | 19.9 | 8.56 | 25.6 | 9416 | | | 3.92 |
| 23 | Moondla | 23.159417 | 77.264521 | 524 | 5.68 | 8.38 | 42.3 | 36.3 | 217 | | | | | 44.7 |
| 24 | Misrod | 23.158944 | 77.484725 | 453 | 9.37 | 2.34 | 4.37 | 38.3 | 122 | | | | | 40.6 |
| 25 | Kolar | 23.132498 | 77.404973 | 464 | 4.25 | 0.5 | 181 | 10.5 | 22.4 | 13.5 | 3768 | | | 24.46 |
| 26 | Gehun Khed | 23.176965 | 77.411539 | 488 | 49 | 1.2 | 118 | 0.451 | 21.2 | 10.3 | 41.2 | | | 11.9 |
| 27 | Abbas Nagar | 23.319821 | 77.359894 | 509 | 29.6 | 0.521 | 7.13 | 3.51 | 2424 | 9.89 | 4.29 | | | 4 |

| S. No. | Village | Latitude | Longitude | Elevation (m amsl) | Rho1 (ohm -m) | H1 (m) | Rho2 (ohm -m) | H2 (m) | Rho3 (ohm -m) | H3 (m) | Rho4 (ohm -m) | H4 (m) | Rho5 (ohm -m) | Weathering Thickness (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | Malikhedi | 23.311559 | 77.439937 | 483 | 149 | 0.5 | 2206 | 0.446 | 59.1 | 11.8 | 6.96 | 8.58 | 7184 | 21.3 |
| 29 | Nishatpura | 23.284507 | 77.438048 | 486 | 7.47 | 7.81 | 159 | 48 | 8.39 | | | | | 7.81 |
| 30 | Patelnagar | 23.259523 | 77.504272 | 472 | 59.2 | 1.33 | 8.73 | 2.91 | 154 | 7.81 | 33.3 | 62.4 | 4516 | 4.24 |
| 31 | Bhopal | 23.233527 | 77.481145 | 484 | 5 | 1 | 80 | 4.8 | 29 | 50.7 | 380 | | | 56.5 |
| 32 | Kalyanpur | 23.329608 | 77.501901 | 513 | 8 | 1.2 | 5 | 16.6 | 590 | | | | | 17.8 |
| 33 | Bankhedi | 23.225107 | 77.575255 | 444 | 18 | 1.8 | 6 | 12.7 | 40 | 92.1 | 206 | | | 14.5 |
| 34 | Padariya Jat | 23.192538 | 77.561976 | 444 | 38 | 0.5 | 8 | 14.6 | 291 | 113.7 | 140 | | | 15.1 |
| 35 | Bagarauda | 23.156603 | 77.539072 | 452 | 42 | 1.5 | 5 | 6.6 | 15 | 45.9 | Very High | | | 54 |
| 36 | Bhopal (M Corp +OG) | 23.291744 | 77.436242 | 488 | 10 | 0.6 | 25 | 5.4 | 156 | 11.9 | 15 | 45.6 | 634 | 6 |
| 37 | Neelbad | 23.307572 | 77.250786 | 520 | 18 | 0.8 | 154 | 16.4 | 26 | 37.2 | 152 | | | 1 |
| 38 | Doobadi | 23.208243 | 77.228528 | 515 | 16 | 2.1 | 6 | 11.5 | 132 | 56.7 | Very High | | | 13.6 |
| 39 | Khori | 23.256841 | 77.223619 | 526 | 8 | 0.3 | 19 | 1.9 | 100 | 12.7 | 30 | 51.4 | 67 | 2.2 |
| 40 | Kodi | 23.104347 | 77.477632 | 452 | 15 | 0.3 | 10 | 27.7 | 253 | | | | | 28 |
| 41 | Kalapani | 23.088802 | 77.395749 | 469 | 16 | 1.9 | 12 | 45.9 | 20 | | | | | 47.8 |
| 42 | Samasgarh | 23.080294 | 77.340633 | 546 | 22 | 0.4 | 14 | 4.7 | | Very high | | | | 5.1 |
| 43 | Mundla | 23.159483 | 77.261904 | 526 | 11 | 1.6 | 5 | 5.6 | 28 | 22.1 | 215 | | | 29.3 |
| 44 | Parewa Kheda | 23.328525 | 77.389804 | 493 | 8 | 2.1 | 22 | 23.3 | 61 | 74.6 | Very High | | | 25.4 |
| 45 | Rolukhedi | 23.216286 | 77.288921 | 522 | 17 | 1.6 | 21 | 11.2 | 15 | 15.9 | 110 | 56.6 | 9999 | 28.7 |
| 46 | Rojibeg | 23.379385 | 77.344594 | 513 | 18 | 1.9 | 509 | 7.3 | 42 | 97 | 275 | | | 2 |
| 47 | Ratibad | 23.154885 | 77.341781 | 516 | 17.3 | 1.1 | 9 | 17.3 | 52 | 79 | 357 | | | 18.4 |
| 48 | Anwala | 23.127377 | 77.282607 | 546 | 10 | 2.1 | 57 | 15.4 | 19 | 44.2 | 103 | | | 17.5 |
| 49 | Bhopal (M Corp+OG) | 23.218144 | 77.339923 | 519 | 36 | 2.6 | 10 | 5.9 | 371 | | | | | 8.5 |
| 50 | Bhopal (M Corp+OG) | 23.220537 | 77.450625 | 488 | 9 | 0.6 | 24 | 1.5 | 9 | 5.5 | 50 | 22.9 | 180 | 7.6 |
| 51 | Sukhi Sewaniya | 23.356555 | 77.475743 | 507 | 7 | 1.5 | 364 | 12 | Very high | | | | | 1.5 |
| 52 | Bhopal (M Corp+OG) | 23.356564 | 77.475733 | 507 | 22 | 1.5 | 96 | 4.1 | 20 | 25.7 | 259 | | | 1.5 |

| S. No. | Village | Latitude | Longitude | Elevation (m amsl) | Rho1 (ohm -m) | H1 (m) | Rho2 (ohm -m) | H2 (m) | Rho3 (ohm -m) | H3 (m) | Rho4 (ohm -m) | H4 (m) | Rho5 (ohm - m) | Weathering Thickness (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | Play Ground (Barkhatullah University) | 23.199689 | 77.447995 | 484 | 11 | 4.8 | 55 | 12 | 115 | 12 | 80 | | | 16.8 |
| 54 | Opp. To Check Post in Play Ground (Barkhatullah University) | 23.199624 | 77.448004 | 484 | 6 | 4 | 21 | 4.8 | 60 | | | | | 8.8 |
| 55 | Opp. To Munshi Premchand Hostel (Barkhatullah University) | 23.199354 | 77.44811 | 483 | 23 | 3.2 | 35 | 54.4 | 75 | | | | | 57.6 |
| 56 | 80 m “S” of Jawahar Hostel (Barkhatullah University) | 23.199462 | 77.448329 | 484 | 40 | 2.8 | 20 | 3.6 | 54 | | | | | 6.4 |
| 57 | Perpendicular to VES 4 (Barkhatullah University) | 23.199616 | 77.448175 | 484 | 18 | 3 | 14 | 21 | 30 | 20.4 | 90 | | | 24 |
| 58 | Parallel to Road towards Hostel (Barkhatullah University) | 23.200073 | 77.449508 | 482 | 23 | 4.8 | 81 | 5.7 | 32 | | | | | 4.8 |
| 59 | (Barkhatullah University) 40 m “W” of Engineering College | 23.19984 | 77.450462 | 481 | 33 | 3 | 165 | 27 | 60 | | | | | 3 |
| 60 | Phanda | 23.232749 | 77.191229 | 528 | 6 | 6.8 | 17 | 6 | 70 | 6.1 | 440 | 11.7 | 289 | 18.9 |
| 61 | Phanda2 | 23.2281 | 77.20954 | 523 | 50 | 1 | 7 | 5.7 | 2 | 1 | 4.8 | 3.1 | 218 | 10.8 |
| 62 | Khajuri | 23.242726 | 77.241654 | 522 | 32 | 7.3 | 75 | 6.6 | 20 | 20.7 | 43 | 30.6 | 3675 | 65.2 |

| S. No. | Village | Latitude | Longitude | Elevation (m amsl) | Rho1 (ohm -m) | H1 (m) | Rho2 (ohm -m) | H2 (m) | Rho3 (ohm -m) | H3 (m) | Rho4 (ohm -m) | H4 (m) | Rho5 (ohm -m) | Weathering Thickness (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 63 | kolukheri | 23.25286 | 77.277145 | 511 | 7 | 1 | 3.4 | 2 | 4.7 | 13.5 | 85 | 35.5 | 236 | 52 |
| 64 | SILines9Green | 23.2892 | 77.3885 | 498 | 18 | 1 | 12 | 3.92 | 5 | 22.7 | 770 | 41 | 2382 | 27.6 |
| 65 | SILines6Fairwa | 23.28698 | 77.38565 | 503 | 1695 | 17.3 | 224 | 15.5 | 62 | 7.3 | 315 | 26.4 | 6500 | 0.5 |
| 66 | SILines15Green | 23.2824 | 77.394 | 497 | 9 | 6.2 | 41 | 3.7 | 435 | 3.9 | 6850 | 26.3 | 855 | 9.9 |
| 67 | SILPumpHno5 | 23.2878 | 77.3887 | 503 | 8 | 4 | 2 | 5.9 | 9 | 6.9 | 6500 | 25.4 | 5285 | 16.8 |
| 68 | SILines9Green | 23.286 | 77.3886 | 502 | 18 | 1 | 12 | 3.9 | 5 | 22.7 | 770 | 41 | 2380 | 27.6 |
| 69 | SILines9Green | 23.2858 | 77.3886 | 503 | 12 | 3.6 | 6 | 15.6 | 18 | 6.4 | 62 | 15.5 | 2585 | 41.1 |

**Annexure-III: Pre- and Post-Monsoon Groundwater Level and Fluctuation for year 2023 of Bhopal Urban**

| S. No. | Village/zone | Pre-Monsoon WL (mbgl) | Post-Monsoon WL (mbgl) | Fluctuation (m) |
|---|---|---|---|---|
| 1 | 116/ 19 Shivaji Nagar | 13.76 | 5.87 | 7.89 |
| 2 | Adarsh Nagar | 10.56 | 7.47 | 3.09 |
| 3 | Shivaji Nagar | 14.84 | 8.62 | 6.22 |
| 4 | Subhash Nagar | 1.45 | 1 | 0.45 |
| 5 | Vikas Nagar | 15 | 9.75 | 5.25 |
| 6 | Budhwara | 2.85 | 0.6 | 2.25 |
| 7 | Khanugaon | 7.15 | 3.82 | 3.33 |
| 8 | BDA Awadhpuri | 11.14 | 7.04 | 4.1 |
| 9 | Indira Nagar | 8.96 | 5.21 | 3.75 |
| 10 | Bagmugliya | 9.13 | 6.68 | 2.45 |
| 11 | Deeksha Nagar | 8.51 | 6.41 | 2.1 |
| 12 | Laharpur | 7.34 | 6.81 | 0.53 |
| 13 | Laharpur | 3.16 | 2.36 | 0.8 |
| 14 | Pallavi Nagar | 5.62 | 3.44 | 2.18 |
| 15 | Bawadiya Kalan | 3.49 | 3.33 | 0.16 |
| 16 | Salaiya | 8.63 | 6.44 | 2.19 |
| 17 | Guradi ghat | 8.97 | 8.35 | 0.62 |
| 18 | Ratanpur | 20.25 | 18.79 | 1.46 |
| 19 | Misrod | 7.54 | 6.1 | 1.44 |
| 20 | Jaatkhedi | 9.6 | 5.87 | 3.73 |
| 21 | Deepak Nagar | 15.66 | 12.25 | 3.41 |
| 22 | Shiv nagar | 29.46 | 23.5 | 5.96 |
| 23 | Bajrang Nagar, Khajuri Khurd | 10.12 | 8.12 | 2 |
| 24 | Transport Nagar | 8.31 | 7.99 | 0.32 |
| 25 | Hathaikheda | 8.05 | 2.76 | 5.29 |
| 26 | Pipalia Pendekhan | 3.7 | 3.23 | 0.47 |
| 27 | Barkheda Pathani | 4 | 2.57 | 1.43 |
| 28 | Narela Shankari | 10.76 | 7.53 | 3.23 |
| 29 | Govindpura | 12.4 | 4.99 | 7.41 |
| 30 | Barkheda | 2.69 | 2.01 | 0.68 |
| 31 | Gandhi Market | 30.33 | 25.74 | 4.59 |
| 32 | Bairagarh | 3.88 | 3.67 | 0.21 |
| 33 | Bairagarh Kalan | 8.27 | 2.68 | 5.59 |
| 34 | Bhainskhedi | 8.95 | 1.89 | 7.06 |
| 35 | Kalukhedi | 12.64 | 8.37 | 4.27 |
| 36 | Jamuniya cheer | 7.64 | 3.58 | 4.06 |
| 37<br>38 | Chhe Ghara<br>Bhonri | 13.87<br>13.37 | 10.43<br>9.65 | 3.44<br>3.72 |
| 39 | Gitti phoda | 38 | 30.54 | 7.46 |
| 40 | Peepalner | 5.63 | 3.62 | 2.01 |
| 41 | Godar Mau | 7.51 | 6.33 | 1.18 |
| 42 | Gandhi Nagar | 6.28 | 4.86 | 1.42 |

| S. No. | Village/zone | Pre-Monsoon WL (mbgl) | Post-Monsoon WL (mbgl) | Fluctuation (m) |
|---|---|---|---|---|
| 43 | Abbaas Nagar | 6.07 | 5.55 | 0.52 |
| 44 | Lau Khedi | 11.19 | 3.8 | 7.39 |
| 45 | C.T.O Bairagarh | 12.62 | 4.95 | 7.67 |
| 46 | Shrinagar Choli | 13.29 | 8.31 | 4.98 |
| 47 | Bairagarh | 1.65 | 1.27 | 0.38 |
| 48 | Borvan | 3.05 | 1.05 | 2 |
| 49 | Ahirpura | 1.68 | 1.38 | 0.3 |
| 50 | Jinsi | 1.98 | 1.23 | 0.75 |
| 51 | Jehangirabad | 1.94 | 1.37 | 0.57 |
| 52 | Kotra, Sultanabad | 5.96 | 3.66 | 2.3 |
| 53 | Ganga Nagar | 4.31 | 3.82 | 0.49 |
| 54 | Suraj Nagar | 9.47 | 5.62 | 3.85 |
| 55 | Gaura Gaon | 9 | 6.35 | 2.65 |
| 56 | Neelbud | 8.56 | 8.48 | 0.08 |
| 57 | Ayodhya Nagar | 7.5 | 6.41 | 1.09 |
| 58 | Ayodhya Nagar | 11.19 | 3.93 | 7.26 |
| 59 | Garib Nagar | 8.83 | 4.5 | 4.33 |
| 60 | Bairagarh Chichli | 13.85 | 8.63 | 5.22 |
| 61 | Inayatpur | 9.68 | 8.35 | 1.33 |
| 62 | Banjari | 20.77 | 15.13 | 5.64 |
| 63 | Amarnath Enclave | 10.37 | 3.79 | 6.58 |
| 64 | Banskhedi | 3.51 | 2.51 | 1 |
| 65 | Panna Nagar | 8.92 | 5.6 | 3.32 |
| 66 | Palasi | 6.26 | 3.43 | 2.83 |
| 67 | Badwai | 8.43 | 7.19 | 1.24 |
| 68 | Lambakheda | 11.46 | 7.52 | 3.94 |
| 69 | Karariya farm | 7.47 | 4.67 | 2.8 |
| 70 | Semra Kalan | 6.76 | 3.65 | 3.11 |
| 71 | Daamkheda | 17.06 | 12.92 | 4.14 |
| 72 | Platform-6, BJ | 4.7 | 3.68 | 1.02 |
| 73 | Mangalwara | 1.39 | 1.16 | 0.23 |
| 74 | Chhola | 3.74 | 3.09 | 0.65 |
| 75 | Nariyalkheda | 3.62 | 2.91 | 0.71 |
| 76 | Prem Nagar | 8.7 | 3.4 | 5.3 |
| 77 | Vishwakarma Nagar | 2.41 | 1.86 | 0.55 |
| 78 | Anna nagar | 3.48 | 3.12 | 0.36 |
| 79 | DIG bangla | 2.29 | 2.07 | 0.22 |
| 80 | E-2 nursery | 6.39 | 4.9 | 1.49 |
| 81 | Gandhi Nagar | 0.9 | 0.85 | 0.05 |
| 82 | Lalghati | 2.41 | 2.1 | 0.31 |
| 83 | Nabibagh | 7.5 | 4.9 | 2.6 |
| 84 | Piplani | 3.42 | 2 | 1.42 |
| 85 | South TT nagar | 4.26 | 3.1 | 1.16 |
| 86 | Shahjahana bad | 2.19 | 1.8 | 0.39 |
| 87 | Shahpura | 0.85 | 0.53 | 0.32 |

**Annexure-IV: Groundwater Samples collected from key wells stations during pre-monsoon and post-monsoon season under NAQUIM 2.0 (2023-24)**

| S. No. | District | Block | Location | Source | Source Code |
|---|---|---|---|---|---|
| 1 | Bhopal | Phanda | BhanpurParisar | Bore Well | BW01 |
| 2 | Bhopal | Phanda | Govindpura | Bore Well | BW02 |
| 3 | Bhopal | Phanda | PeepalnerBw | Bore Well | BW03 |
| 4 | Bhopal | Phanda | Barkheda Pathani | Dug Well | DW01 |
| 5 | Bhopal | Phanda | DIG Bangla | Dug Well | DW02 |
| 6 | Bhopal | Phanda | Eatkhedi | Dug Well | DW03 |
| 7 | Bhopal | Phanda | Gandhi Nagar | Dug Well | DW04 |
| 8 | Bhopal | Phanda | Lalghati | Dug Well | DW05 |
| 9 | Bhopal | Phanda | Nabibagh | Dug Well | DW06 |
| 10 | Bhopal | Phanda | Piplani | Dug Well | DW07 |
| 11 | Bhopal | Phanda | Sarvar | Dug Well | DW08 |
| 12 | Bhopal | Phanda | ShahiahanaBad | Dug Well | DW09 |
| 13 | Bhopal | Phanda | South TT nagar | Dug Well | DW10 |
| 14 | Bhopal | Phanda | Vishwakarma Nagar | Dug Well | DW11 |
| 15 | Bhopal | Phanda | Abbaas Nagar | Hand Pump | HP01 |
| 16 | Bhopal | Phanda | Adarsh Nagar | Hand Pump | HP02 |
| 17 | Bhopal | Phanda | Amarnath Enclave | Hand Pump | HP03 |
| 18 | Bhopal | Phanda | Anna nagar | Hand Pump | HP04 |
| 19 | Bhopal | Phanda | Ayodhya Nagar | Hand Pump | HP05 |
| 20 | Bhopal | Phanda | Ayodhya Nagar | Hand Pump | HP06 |
| 21 | Bhopal | Phanda | Badwai | Hand Pump | HP07 |
| 22 | Bhopal | Phanda | Bagmugliya | Hand Pump | HP08 |
| 23 | Bhopal | Phanda | Bairagarh | Hand Pump | HP09 |
| 24 | Bhopal | Phanda | Bairagarh | Hand Pump | HP10 |
| 25 | Bhopal | Phanda | BairagarhChichli | Hand Pump | HP11 |
| 26 | Bhopal | Phanda | Bairagarh Kalan | Hand Pump | HP12 |
| 27 | Bhopal | Phanda | Bajrang Nagar, Khajuri Khurd | Hand Pump | HP13 |
| 28 | Bhopal | Phanda | Banskhedi | Hand Pump | HP14 |
| 29 | Bhopal | Phanda | Barkheda Pathani | Hand Pump | HP15 |
| 30 | Bhopal | Phanda | Bawadiya Kalan | Hand Pump | HP16 |

| S. No. | District | Block | Location | Source | Source Code |
|---|---|---|---|---|---|
| 31 | Bhopal | Phanda | BDA Awadhpuri | Hand Pump | HP17 |
| 32 | Bhopal | Phanda | Bhainskhedi | Hand Pump | HP18 |
| 33 | Bhopal | Phanda | Bhonri | Hand Pump | HP19 |
| 34 | Bhopal | Phanda | Borvan | Hand Pump | HP20 |
| 35 | Bhopal | Phanda | Budhwara | Hand Pump | HP21 |
| 36 | Bhopal | Phanda | C.T.O Bairagarh | Hand Pump | HP22 |
| 37 | Bhopal | Phanda | ChheGhara | Hand Pump | HP23 |
| 38 | Bhopal | Phanda | Chhola | Hand Pump | HP24 |
| 39 | Bhopal | Phanda | Daamkheda | Hand Pump | HP25 |
| 40 | Bhopal | Phanda | Deeksha Nagar | Hand Pump | HP26 |
| 41 | Bhopal | Phanda | E-2 Nursery | Hand Pump | HP27 |
| 42 | Bhopal | Phanda | Gandhi Market | Hand Pump | HP28 |
| 43 | Bhopal | Phanda | Gandhi Nagar | Hand Pump | HP29 |
| 44 | Bhopal | Phanda | Garib Nagar | Hand Pump | HP30 |
| 45 | Bhopal | Phanda | Gaura Gaon | Hand Pump | HP31 |
| 46 | Bhopal | Phanda | Gittiphoda | Hand Pump | HP32 |
| 47 | Bhopal | Phanda | Guradi ghat | Hand Pump | HP33 |
| 48 | Bhopal | Phanda | Hathaikheda | Hand Pump | HP34 |
| 49 | Bhopal | Phanda | Inayatpur | Hand Pump | HP35 |
| 50 | Bhopal | Phanda | Indira Nagar | Hand Pump | HP36 |
| 51 | Bhopal | Phanda | Jaatkhedi | Hand Pump | HP37 |
| 52 | Bhopal | Phanda | Jamuniya cheer | Hand Pump | HP38 |
| 53 | Bhopal | Phanda | Jehangirabad | Hand Pump | HP39 |
| 54 | Bhopal | Phanda | Jinsi | Hand Pump | HP40 |
| 55 | Bhopal | Phanda | Kalukhedi | Hand Pump | HP41 |
| 56 | Bhopal | Phanda | Karariya farm | Hand Pump | HP42 |
| 57 | Bhopal | Phanda | Khanugaon | Hand Pump | HP43 |
| 58 | Bhopal | Phanda | Kotra, Sultanabad | Hand Pump | HP44 |
| 59 | Bhopal | Phanda | Laharpur | Hand Pump | HP45 |
| 60 | Bhopal | Phanda | Lambakheda | Hand Pump | HP46 |
| 61 | Bhopal | Phanda | Lau Khedi | Hand Pump | HP47 |
| 62 | Bhopal | Phanda | Mangalwara | Hand Pump | HP48 |

| S. No. | District | Block | Location | Source | Source Code |
|---|---|---|---|---|---|
| 63 | Bhopal | Phanda | Misrod | Hand Pump | HP49 |
| 64 | Bhopal | Phanda | Narela Shankari | Hand Pump | HP50 |
| 65 | Bhopal | Phanda | Nariyalkheda | Hand Pump | HP51 |
| 66 | Bhopal | Phanda | Neelbud | Hand Pump | HP52 |
| 67 | Bhopal | Phanda | Palasi | Hand Pump | HP53 |
| 68 | Bhopal | Phanda | Pallavi Nagar | Hand Pump | HP54 |
| 69 | Bhopal | Phanda | Panna Nagar | Hand Pump | HP55 |
| 70 | Bhopal | Phanda | Peepalner | Hand Pump | HP56 |
| 71 | Bhopal | Phanda | PipaliaPendekhan | Hand Pump | HP57 |
| 72 | Bhopal | Phanda | Platform-6, Bhopal Junction | Hand Pump | HP58 |
| 73 | Bhopal | Phanda | Prem Nagar | Hand Pump | HP59 |
| 74 | Bhopal | Phanda | Ratanpur | Hand Pump | HP60 |
| 75 | Bhopal | Phanda | Salaiya | Hand Pump | HP61 |
| 76 | Bhopal | Phanda | Semra Kalan | Hand Pump | HP62 |
| 77 | Bhopal | Phanda | Shiv nagar | Hand Pump | HP63 |
| 78 | Bhopal | Phanda | Shivaji Nagar | Hand Pump | HP64 |
| 79 | Bhopal | Phanda | Shrinagar Choli | Hand Pump | HP65 |
| 80 | Bhopal | Phanda | Subhash Nagar | Hand Pump | HP66 |
| 81 | Bhopal | Phanda | Suraj Nagar | Hand Pump | HP67 |
| 82 | Bhopal | Phanda | Transport Nagar | Hand Pump | HP68 |
| 83 | Bhopal | Phanda | Vikas Nagar | Hand Pump | HP69 |

**Annexure-V: Water Samples collected from Surface waterbodies, Rain Water and Exploratory wells stations under NAQUIM 2.0 (2023-24)**

| S. No. | District | Block | Location | Source | Source Code |
|---|---|---|---|---|---|
| 1 | Bhopal | Phanda | Kerwa Dam (Mandora) | Surface water | SW01 |
| 2 | Bhopal | Phanda | Shahpura Lake (Manisha Market) | Surface water | SW02 |
| 3 | Bhopal | Phanda | Hatai Kheda Dam | Surface water | SW03 |
| 4 | Bhopal | Phanda | Narmada Water Supply, Ahmedpura, MCD, Bhopal | Surface water | SW04 |
| 5 | Bhopal | Phanda | Shalimar 7 garden | Tap Water | TW01 |

| S. No. | District | Block | Location | Source | Source Code |
|---|---|---|---|---|---|
| 6 | Bhopal | Phanda | Sheetal Das Garden (Upper lake) | Surface Water | SW05 |
| 7 | Bhopal | Phanda | Khatlapur (Lower Lake) | Surface Water | SW06 |
| 8 | Bhopal | Phanda | MBSR | Surface Water | SW07 |
| 1 | Bhopal | Phanda | CGWB, NCR, Bhopal Office | Rain Water | RW01 |
| 2 | Bhopal | Phanda | CGWB, NCR, Bhopal Office | Rain Water | RW02 |
| 3 | Bhopal | Phanda | CGWB, NCR, Bhopal Office | Rain Water | RW03 |
| 1 | Bhopal | Phanda | Yatayat Park | EW | EW01 |
| 2 | Bhopal | Phanda | Vasant Kunj | EW (Depth 100.8 m) | EW02 |
| 3 | Bhopal | Phanda | MP Nagar Police Station | EW During drilling | EW03 |
| 4 | Bhopal | Phanda | 1100 Quarters | Pz | EW04 |
| 5 | Bhopal | Phanda | Nehru Nagar | Pz (During drilling) | EW05 |
| 6 | Bhopal | Phanda | Maharana Pratap Nagar, Govt. High School | EW | EW06 |
| 7 | Bhopal | Phanda | Arvind Vihar | EW | EW07 |
| 8 | Bhopal | Phanda | Neelbad | EW | EW08 |

**Annexure-VI: Statistical outline of the measured water quality parameters of pre- and post-monsoon in shallow aquifer with comparison to Indian Standards for drinking water**

| Parameters | Unit | Mean | | Standard Deviation | | Range | | Pre-monsoon | | Post-monsoon | | BIS 10500: 2012 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Pre** | **Post** | **Pre** | **Post** | **Pre** | **Post** | **Min** | **Max** | **Min** | **Max** | **Acceptable Limit** | **Permissible Limit (in absence of alternate source)** |
| Temp (°C) | (°C) | 28.4 | 26.1 | 1.39 | 1.08 | 8 | 4.9 | 25.1 | 33.1 | 23.7 | 28.6 | | |
| pH at 25°C | | 7.28 | 7.31 | 0.28 | 0.23 | 1.22 | 1.26 | 6.62 | 7.84 | 6.72 | 7.98 | **6.5 - 8.5** | **No relaxation** |
| EC at 25°C | µS/cm at 25°C | 1090 | 1061 | 327 | 325 | 1687 | 1860 | 418 | 2105 | 525 | 2385 | **-** | **-** |
| HCO3 | mg/l | 399 | 394 | 114 | 114 | 537 | 659 | 110 | 647 | 146 | 805 | **-** | **-** |
| Cl | mg/l | 96 | 99 | 54 | 52 | 289 | 245 | 20 | 309 | 25 | 270 | **250** | **1000** |
| SO4 | mg/l | 42 | 36 | 21 | 18 | 85 | 82 | 10 | 95 | 3 | 85 | **200** | **400** |
| NO3 | mg/l | 27 | 25 | 30 | 25 | 185 | 148 | 1 | 186 | 1 | 149 | **45** | **No relaxation** |
| F | mg/l | 0.35 | 0.33 | 0.17 | 0.17 | 0.83 | 0.80 | 0.06 | 0.89 | 0.05 | 0.85 | **1** | **1.50** |
| PO4 | mg/l | 0.02 | 0.03 | 0.07 | 0.16 | 0.43 | 1.37 | 0.00 | 0.43 | 0.00 | 1.37 | **-** | **-** |
| SiO2 | mg/l | 33 | 35 | 13 | 11 | 74 | 55 | 4 | 78 | 10 | 65 | **-** | **-** |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TH | mg/l | 392 | 389 | 136 | 130 | 657 | 665 | 105 | 762 | 160 | 825 | **200** | **600** |
| Ca | mg/l | 94 | 89 | 38 | 32 | 214 | 180 | 32 | 246 | 20 | 200 | **75** | **200** |
| Mg | mg/l | 38 | 40 | 20 | 18 | 113 | 96 | 5 | 118 | 12 | 108 | **30** | **100** |
| Na | mg/l | 63 | 60 | 32 | 34 | 192 | 257 | 20 | 212 | 18 | 275 | **-** | **-** |
| K | mg/l | 5.7 | 5.0 | 5.7 | 5.7 | 31.7 | 32.8 | 1.3 | 33.0 | 1.2 | 34.0 | **-** | **-** |
| TDS | mg/l | 708 | 689 | 213 | 211 | 1097 | 1209 | 272 | 1368 | 341 | 1550 | **500** | **2000** |
| Fe (mg/l) | mg/l | 0.480 | 0.477 | 0.737 | 0.862 | 4.331 | 5.120 | BDL | 4.331 | BDL | 5.120 | **1** | **No relaxation** |
| Mn (mg/l) | mg/l | 0.039 | 0.036 | 0.097 | 0.135 | 0.557 | 0.950 | BDL | 0.557 | BDL | 0.950 | **0.1** | **0.3** |
| Cu (mg/l) | mg/l | BDL | BDL | BDL | BDL | BDL | 0.002 | BDL | BDL | BDL | 0.002 | **0.05** | **1.5** |
| Zn (mg/l) | mg/l | 0.368 | 0.229 | 1.437 | 0.852 | 11.805 | 6.245 | BDL | 11.805 | BDL | 6.245 | **5** | **15** |
| As (ppb) | µg/l | 0.3 | 0.0 | 1.0 | 0.4 | 6.8 | 3.5 | BDL | 6.8 | BDL | 3.5 | **0.01** | **No relaxation** |
| Pb (ppb) | µg/l | 1.2 | 0.5 | 1.0 | 0.7 | 7.3 | 6.3 | BDL | 7.3 | BDL | 6.3 | **0.05** | **No relaxation** |
| Cr (ppb) | µg/l | 0.0 | 0.0 | 0.1 | 0.1 | 1.0 | 0.5 | BDL | 1.0 | BDL | 0.5 | **0.05** | **No relaxation** |
| U (ppb) | µg/l | 0.6 | 0.2 | 1.7 | 1.0 | 9.0 | 7.2 | BDL | 9.0 | BDL | 7.2 | **0.03** | **No relaxation** |

**Annexure-VII: Statistical outline of the measured water quality parameters in deeper aquifer with comparison to Indian Standards for drinking water**

| **Parameters** | **Unit** | **Mean** | **Standard Deviation** | **Range** | **Minimum** | **Maximum** | **BIS 10500: 2012** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | **Acceptable Limit** | **Permissible Limit (in absence of alternate source)** |
| pH at 25°C | | 7.64 | 0.40 | 1.27 | 6.85 | 8.12 | 6.5 - 8.5 | No relaxation |
| EC at 25°C | µS/cm at 25°C | 876 | 408 | 1392 | 308 | 1700 | - | - |
| HCO3 | mg/l | 274 | 103 | 311 | 140 | 451 | - | - |
| Cl | mg/l | 112 | 95 | 285 | 12 | 297 | 250 | 1000 |
| SO4 | mg/l | 27 | 20 | 78 | 1 | 79 | 200 | 400 |
| NO3 | mg/l | 11 | 14 | 41 | 1 | 42 | 45 | No relaxation |
| F | mg/l | 0.44 | 0.40 | 1.41 | 0.07 | 1.48 | 1 | 1.50 |
| PO4 | mg/l | 0.02 | 0.08 | 0.26 | 0 | 0.26 | - | - |
| SiO2 | mg/l | 28 | 15 | 58 | 12 | 70 | - | - |
| TH | mg/l | 280 | 161 | 504 | 75 | 579 | 200 | 600 |
| Ca | mg/l | 64 | 36 | 123 | 12 | 135 | 75 | 200 |
| Mg | mg/l | 29 | 20 | 55 | 10 | 64 | 30 | 100 |
| Na | mg/l | 64 | 55 | 189 | 9 | 199 | - | - |
| K | mg/l | 6.6 | 5.3 | 15.8 | 1.2 | 17 | - | - |
| TDS | mg/l | 569 | 266 | 905 | 200 | 1105 | 500 | 2000 |

| Parameters | Unit | Mean | Standard Deviation | Range | Minimum | Maximum | BIS 10500: 2012 | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Acceptable Limit | Permissible Limit (in absence of alternate source) |
| Fe (mg/l) | mg/l | BDL | BDL | BDL | BDL | BDL | 1 | No relaxation |
| Mn (mg/l) | mg/l | 0.006 | 0.021 | 0.069 | 0.000 | 0.069 | 0.1 | 0.3 |
| Cu (mg/l) | mg/l | BDL | BDL | BDL | BDL | BDL | 0.05 | 1.5 |
| Zn (mg/l) | mg/l | BDL | BDL | BDL | BDL | BDL | 5 | 15 |
| As (ppb) | µg/l | 0.354 | 1.174 | 3.895 | BDL | 3.895 | 0.01 | No relaxation |
| Pb (ppb) | µg/l | 0.208 | 0.369 | 1.011 | BDL | 1.011 | 0.05 | No relaxation |
| Cr (ppb) | µg/l | BDL | BDL | BDL | BDL | BDL | 0.05 | No relaxation |
| U (ppb) | µg/l | 1.104 | 3.661 | 12.142 | BDL | 12.142 | 0.03 | No relaxation |

**Annexure-VIII: The maximum concentration of nitrate (mg/l) in shallow aquifer of Bhopal urban agglomerate during pre-monsoon and post-monsoon**

| S. No. | Location | Source Code | Nitrate concentration (mg/l) | |
|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon |
| 1 | Eatkhedi | DW03 | 92 | 78 |
| 2 | Sarvar | DW08 | 50 | 43 |
| 3 | Badwai | HP07 | 43 | 47 |
| 4 | Bajrang Nagar, Khajuri Khurd | HP13 | 61 | 52 |
| 5 | Barkheda Pathani | HP15 | 56 | 55 |
| 6 | Bhonri | HP19 | 84 | 65 |
| 7 | Daamkheda | HP25 | 47 | 55 |
| 8 | Gittiphoda | HP32 | 57 | 43 |
| 9 | Khanugaon | HP43 | 48 | 47 |
| 10 | Narela Shankari | HP50 | 186 | 149 |
| 11 | Neelbud | HP52 | 78 | 55 |
| 12 | Palasi | HP53 | 40 | 57 |
| 13 | Pallavi Nagar | HP54 | 49 | 36 |
| 14 | Peepalner | HP56 | 57 | 49 |
| 15 | Platform-6, Bhopal Junction | HP58 | 130 | 132 |
| 16 | Semra Kalan | HP62 | 52 | 55 |
| 17 | Vikas Nagar | HP69 | 46 | 42 |
| | | | | |

| Annexure-IX: The maximum concentration of total hardness (mg/l) in shallow aquifer of Bhopal urban agglomerate during pre-monsoon and post-monsoon | | | | |
|---|---|---|---|---|
| **S. No.** | **Location** | **Source Code** | **Nitrate concentration (mg/l)** | |
| | | | **Pre-monsoon** | **Post-monsoon** |
| 1 | Barkheda Pathani | HP15 | 743 | 710 |
| 2 | Daamkheda | HP25 | 614 | 590 |
| 3 | Misrod | HP49 | 654 | 645 |
| 4 | Narela Shankari | HP50 | 609 | 540 |
| 5 | Platform-6, Bhopal Junction | HP58 | 762 | 825 |
| 6 | Prem Nagar | HP59 | 550 | 625 |

**Annexure-X: Type of groundwater of shallow aquifer on the basis of Piper Trilinear Diagram in pre-monsoon and post-monsoon of Bhopal urban agglomerate under NAQUIM 2.0**

| S. No. | Location | Source Code | Type of Water | |
|---|---|---|---|---|
| | | | **Pre-Shallow** | **Post-Shallow** |
| 1 | Barkheda Pathani | DW01 | CaHCO3 | CaHCO3 |
| 2 | DIG Bangla | DW02 | CaHCO3 | CaHCO3 |
| 3 | Eatkhedi | DW03 | CaHCO3 | CaHCO3 |
| 4 | Gandhi Nagar | DW04 | Ca-Mg-Cl | CaHCO3 |
| 5 | Lalghati | DW05 | Ca-Mg-Cl | Ca-Mg-Cl |
| 6 | Nabibagh | DW06 | CaHCO3 | CaHCO3 |
| | | | | |
| 7 | Piplani | DW07 | CaHCO3 | CaHCO3 |
| 8 | Sarvar | DW08 | CaHCO3 | CaHCO3 |
| 9 | Shahiahanabad | DW09 | Ca-Na-HCO3 | Ca-Na-HCO3 |
| 10 | South TT nagar | DW10 | CaHCO3 | CaHCO3 |
| 11 | Vishwakarma Nagar | DW11 | CaHCO3 | CaHCO3 |
| 12 | Abbaas Nagar | HP01 | CaHCO3 | CaHCO3 |
| 13 | Adarsh Nagar | HP02 | CaHCO3 | CaHCO3 |
| 14 | Amarnath Enclave | HP03 | CaHCO3 | CaHCO3 |
| 15 | Anna nagar | HP04 | CaHCO3 | CaHCO3 |
| 16 | Ayodhya Nagar | HP05 | CaHCO3 | CaHCO3 |
| 17 | Ayodhya Nagar | HP06 | CaHCO3 | CaHCO3 |
| 18 | Badwai | HP07 | Ca-Mg-Cl | Ca-Na-HCO3 |
| 19 | Bagmugliya | HP08 | Ca-Mg-Cl | CaHCO3 |
| 20 | Bairagarh | HP09 | CaHCO3 | CaHCO3 |
| 21 | Bairagarh | HP10 | CaHCO3 | CaHCO3 |
| 22 | BairagarhChichli | HP11 | CaHCO3 | CaHCO3 |
| 23 | Bairagarh Kalan | HP12 | CaHCO3 | CaHCO3 |

| S. No. | Location | Source Code | Type of Water | |
|---|---|---|---|---|
| | | | Pre-Shallow | Post-Shallow |
| 24 | Bajrang Nagar, Khajuri Khurd | HP13 | CaHCO3 | CaHCO3 |
| 25 | Banskhedi | HP14 | CaHCO3 | CaHCO3 |
| 26 | Barkheda Pathani | HP15 | CaHCO3 | CaHCO3 |
| 27 | Bawadiya Kalan | HP16 | CaHCO3 | CaHCO3 |
| 28 | BDA Awadhpuri | HP17 | CaHCO3 | CaHCO3 |
| 29 | Bhainskhedi | HP18 | CaHCO3 | CaHCO3 |
| 30 | Bhonri | HP19 | CaHCO3 | CaHCO3 |
| 31 | Borvan | HP20 | CaHCO3 | Ca-Mg-Cl |
| 32 | Budhwara | HP21 | CaHCO3 | CaHCO3 |
| 33 | C.T.O Bairagarh | HP22 | CaHCO3 | CaHCO3 |
| 34 | ChheGhara | HP23 | CaHCO3 | CaHCO3 |
| 35 | Chhola | HP24 | CaHCO3 | CaHCO3 |
| 36 | Daamkheda | HP25 | Ca-Mg-Cl | Ca-Mg-Cl |
| 37 | Deeksha Nagar | HP26 | CaHCO3 | CaHCO3 |
| 38 | E-2 Nursery | HP27 | CaHCO3 | CaHCO3 |
| 39 | Gandhi Market | HP28 | CaHCO3 | CaHCO3 |
| 40 | Gandhi Nagar | HP29 | CaHCO3 | CaHCO3 |
| 41 | Garib Nagar | HP30 | CaHCO3 | CaHCO3 |
| 42 | Gaura Gaon | HP31 | CaHCO3 | CaHCO3 |
| 43 | Gittiphoda | HP32 | CaHCO3 | CaHCO3 |
| 44 | Guradi ghat | HP33 | CaHCO3 | CaHCO3 |
| 45 | Hathaikheda | HP34 | CaHCO3 | CaHCO3 |
| 46 | Inayatpur | HP35 | CaHCO3 | CaHCO3 |
| 47 | Indira Nagar | HP36 | CaHCO3 | CaHCO3 |
| 48 | Jaatkhedi | HP37 | CaHCO3 | CaHCO3 |
| 49 | Jamuniya cheer | HP38 | CaHCO3 | CaHCO3 |
| 50 | Jehangirabad | HP39 | CaHCO3 | CaHCO3 |
| 51 | Jinsi | HP40 | CaHCO3 | CaHCO3 |
| 52 | Kalukhedi | HP41 | CaHCO3 | CaHCO3 |
| 53 | Karariya farm | HP42 | CaHCO3 | CaHCO3 |
| 54 | Khanugaon | HP43 | CaHCO3 | CaHCO3 |
| 55 | Kotra, Sultanabad | HP44 | CaHCO3 | CaHCO3 |
| 56 | Laharpur | HP45 | CaHCO3 | CaHCO3 |
| 57 | Lambakheda | HP46 | CaHCO3 | CaHCO3 |
| 58 | Lau Khedi | HP47 | CaHCO3 | CaHCO3 |
| 59 | Mangalwara | HP48 | CaHCO3 | CaHCO3 |
| 60 | Misrod | HP49 | CaHCO3 | CaHCO3 |
| 61 | Narela Shankari | HP50 | CaHCO3 | CaHCO3 |
| 62 | Nariyalkheda | HP51 | CaHCO3 | CaHCO3 |

| S. No. | Location | Source Code | Type of Water | |
|---|---|---|---|---|
| | | | Pre-Shallow | Post-Shallow |
| 63 | Neelbud | HP52 | CaHCO3 | CaHCO3 |
| 64 | Palasi | HP53 | Ca-Mg-Cl | CaHCO3 |
| 65 | Pallavi Nagar | HP54 | CaHCO3 | CaHCO3 |
| 66 | Panna Nagar | HP55 | Ca-Na-HCO3 | CaHCO3 |
| 67 | Peepalner | HP56 | CaHCO3 | CaHCO3 |
| 68 | PipaliaPendekhan | HP57 | CaHCO3 | CaHCO3 |
| 69 | Platform-6, Bhopal Junction | HP58 | CaHCO3 | Ca-Cl2 |
| 70 | Prem Nagar | HP59 | CaHCO3 | CaHCO3 |
| 71 | Ratanpur | HP60 | CaHCO3 | CaHCO3 |
| 72 | Salaiya | HP61 | CaHCO3 | CaHCO3 |
| 73 | Semra Kalan | HP62 | CaHCO3 | CaHCO3 |
| 74 | Shiv nagar | HP63 | CaHCO3 | CaHCO3 |
| 75 | Shivaji Nagar | HP64 | CaHCO3 | CaHCO3 |
| 76 | Shrinagar Choli | HP65 | Ca-Mg-Cl | CaHCO3 |
| 77 | Subhash Nagar | HP66 | CaHCO3 | CaHCO3 |
| 78 | Suraj Nagar | HP67 | Ca-Mg-Cl | CaHCO3 |
| 79 | Transport Nagar | HP68 | CaHCO3 | CaHCO3 |
| 80 | Vikas Nagar | HP69 | CaHCO3 | CaHCO3 |

**Annexure-XI: Type of groundwater of deeper aquifer on the basis of Piper Trilinear Diagram of Bhopal urban agglomerate under NAQUIM 2.0**

| S. No. | Locations | Source Code | Type of water |
|---|---|---|---|
| 1 | BhanpurParisar | BW01 | Ca-HO3 |
| 2 | Govindpura | BW02 | Ca-Mg-Cl |
| 3 | PeepalnerBw | BW03 | Ca-HO3 |
| 4 | Yatayat Park | EW01 | Ca-HO3 |
| 5 | Vasant Kunj | EW02 | Ca-HO3 |
| 6 | MP Nagar Police Station | EW03 | Ca-HO3 |
| 7 | 1100 Quarters | EW04 | Ca-HO3 |
| 8 | Nehru Nagar | EW05 | Ca-HO3 |
| 9 | Maharana Pratap Nagar, Govt. High School | EW06 | Ca-HO3 |
| 10 | Arvind Vihar | EW07 | Ca-HO3 |
| 11 | Neelbad | EW08 | NaCl |

**Annexure-XII: Irrigation Class in Shallow Aquifer in pre-monsoon and post-monsoon of Bhopal urban agglomerate under NAQUIM 2.0**

| S.No. | Location | Source Code | USSL Classification | | RSC Classification | |
|---|---|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon | RSC_Pre-monsoon | RSC-Post-monsoon |
| 1 | Barkheda Pathani | DW01 | C3S1 | C3S1 | Suitable | Suitable |
| 2 | DIG Bangla | DW02 | C3S1 | C3S1 | Unsuitable | Suitable |
| 3 | Eatkhedi | DW03 | C3S1 | C2S1 | Suitable | Suitable |
| 4 | Gandhi Nagar | DW04 | C2S1 | C2S1 | Suitable | Suitable |
| 5 | Lalghati | DW05 | C2S1 | C2S1 | Suitable | Suitable |
| 6 | Nabibagh | DW06 | C3S1 | C3S1 | Suitable | Suitable |
| 7 | Piplani | DW07 | C2S1 | C2S1 | Suitable | Suitable |
| 8 | Sarvar | DW08 | C2S1 | C2S1 | Suitable | Suitable |
| 9 | Shahiahanabad | DW09 | C3S1 | C3S1 | Marginal Suitable | Unsuitable |
| 10 | South TT nagar | DW10 | C2S1 | C2S1 | Suitable | Suitable |
| 11 | Vishwakarma Nagar | DW11 | C3S1 | C3S1 | Suitable | Suitable |
| 12 | Abbaas Nagar | HP01 | C3S1 | C3S1 | Suitable | Suitable |
| 13 | Adarsh Nagar | HP02 | C3S1 | C3S1 | Suitable | Suitable |
| 14 | Amarnath Enclave | HP03 | C3S1 | C3S1 | Suitable | Suitable |
| 15 | Anna nagar | HP04 | C3S1 | C3S1 | Suitable | Suitable |
| 16 | Ayodhya Nagar | HP05 | C3S1 | C3S1 | Suitable | Suitable |
| 17 | Ayodhya Nagar | HP06 | C3S1 | C3S1 | Suitable | Suitable |
| 18 | Badwai | HP07 | C3S1 | C4S2 | Suitable | Marginal Suitable |
| 19 | Bagmugliya | HP08 | C3S1 | C3S1 | Suitable | Suitable |
| 20 | Bairagarh | HP09 | C3S1 | C3S1 | Suitable | Suitable |
| 21 | Bairagarh | HP10 | C3S1 | C3S1 | Suitable | Suitable |
| 22 | BairagarhChichli | HP11 | C2S1 | C2S1 | Suitable | Suitable |
| 23 | Bairagarh Kalan | HP12 | C3S1 | C3S1 | Suitable | Suitable |
| 24 | Bajrang Nagar, Khajuri Khurd | HP13 | C3S1 | C3S1 | Suitable | Suitable |
| 25 | Banskhedi | HP14 | C3S1 | C3S1 | Suitable | Suitable |
| 26 | Barkheda Pathani | HP15 | C3S1 | C3S1 | Suitable | Suitable |
| 27 | Bawadiya Kalan | HP16 | C3S1 | C3S1 | Suitable | Suitable |
| 28 | BDA Awadhpuri | HP17 | C2S1 | C2S1 | Suitable | Suitable |
| 29 | Bhainskhedi | HP18 | C3S1 | C3S1 | Suitable | Suitable |
| 30 | Bhonri | HP19 | C3S1 | C3S1 | Suitable | Suitable |
| 31 | Borvan | HP20 | C3S1 | C3S1 | Suitable | Suitable |
| 32 | Budhwara | HP21 | C3S1 | C3S1 | Suitable | Suitable |
| 33 | C.T.O Bairagarh | HP22 | C3S1 | C3S1 | Suitable | Suitable |
| 34 | ChheGhara | HP23 | C3S1 | C3S1 | Suitable | Suitable |
| 35 | Chhola | HP24 | C3S1 | C3S1 | Suitable | Suitable |
| 36 | Daamkheda | HP25 | C3S1 | C3S1 | Suitable | Suitable |

| S.No. | Location | Source Code | USSL Classification | | RSC Classification | |
|---|---|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon | RSC_Pre-monsoon | RSC-Post-monsoon |
| 37 | Deeksha Nagar | HP26 | C3S1 | C3S1 | Suitable | Suitable |
| 38 | E-2 Nursery | HP27 | C3S1 | C3S1 | Suitable | Suitable |
| 39 | Gandhi Market | HP28 | C2S1 | C3S1 | Suitable | Suitable |
| 40 | Gandhi Nagar | HP29 | C3S1 | C3S1 | Suitable | Suitable |
| 41 | Garib Nagar | HP30 | C3S1 | C3S1 | Suitable | Suitable |
| 42 | Gaura Gaon | HP31 | C2S1 | C2S1 | Suitable | Suitable |
| 43 | Gittiphoda | HP32 | C2S1 | C2S1 | Suitable | Suitable |
| 44 | Guradi ghat | HP33 | C3S1 | C3S1 | Suitable | Suitable |
| 45 | Hathaikheda | HP34 | C3S1 | C3S1 | Suitable | Suitable |
| 46 | Inayatpur | HP35 | C3S1 | C3S1 | Marginal Suitable | Marginal Suitable |
| 47 | Indira Nagar | HP36 | C3S1 | C3S1 | Suitable | Suitable |
| 48 | Jaatkhedi | HP37 | C3S1 | C3S1 | Suitable | Suitable |
| 49 | Jamuniya cheer | HP38 | C3S1 | C3S1 | Suitable | Suitable |
| 50 | Jehangirabad | HP39 | C3S1 | C3S1 | Suitable | Suitable |
| 51 | Jinsi | HP40 | C3S1 | C3S1 | Suitable | Suitable |
| 52 | Kalukhedi | HP41 | C3S1 | C3S1 | Suitable | Suitable |
| 53 | Karariya farm | HP42 | C3S1 | C3S1 | Suitable | Suitable |
| 54 | Khanugaon | HP43 | C3S1 | C3S1 | Suitable | Suitable |
| 55 | Kotra, Sultanabad | HP44 | C3S1 | C3S1 | Suitable | Suitable |
| 56 | Laharpur | HP45 | C3S1 | C3S1 | Suitable | Suitable |
| 57 | Lambakheda | HP46 | C3S1 | C3S1 | Suitable | Suitable |
| 58 | Lau Khedi | HP47 | C3S1 | C3S1 | Suitable | Suitable |
| 59 | Mangalwara | HP48 | C3S1 | C2S1 | Suitable | Suitable |
| 60 | Misrod | HP49 | C3S1 | C3S1 | Suitable | Suitable |
| 61 | Narela Shankari | HP50 | C3S1 | C3S1 | Suitable | Suitable |
| 62 | Nariyalkheda | HP51 | C3S1 | C3S1 | Suitable | Suitable |
| 63 | Neelbud | HP52 | C3S1 | C3S1 | Suitable | Suitable |
| 64 | Palasi | HP53 | C3S1 | C3S1 | Suitable | Suitable |
| 65 | Pallavi Nagar | HP54 | C3S1 | C3S1 | Suitable | Suitable |
| 66 | Panna Nagar | HP55 | C3S1 | C3S1 | Marginal Suitable | Suitable |
| 67 | Peepalner | HP56 | C3S1 | C3S1 | Suitable | Suitable |
| 68 | PipaliaPendekhan | HP57 | C3S1 | C3S1 | Suitable | Suitable |
| 69 | Platform-6, Bhopal Junction | HP58 | C3S1 | C3S1 | Suitable | Suitable |
| 70 | Prem Nagar | HP59 | C3S1 | C3S1 | Suitable | Suitable |
| 71 | Ratanpur | HP60 | C3S1 | C3S1 | Suitable | Suitable |
| 72 | Salaiya | HP61 | C3S1 | C3S1 | Suitable | Suitable |
| 73 | Semra Kalan | HP62 | C3S1 | C3S1 | Suitable | Suitable |
| 74 | Shiv nagar | HP63 | C3S1 | C3S1 | Suitable | Suitable |

| S.No. | Location | Source Code | USSL Classification | | RSC Classification | |
|---|---|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon | RSC_Pre-monsoon | RSC-Post-monsoon |
| 75 | Shivaji Nagar | HP64 | C3S1 | C3S1 | Suitable | Suitable |
| 76 | Shrinagar Choli | HP65 | C2S1 | C2S1 | Suitable | Suitable |
| 77 | Subhash Nagar | HP66 | C3S1 | C3S1 | Suitable | Suitable |
| 78 | Suraj Nagar | HP67 | C2S1 | C2S1 | Suitable | Suitable |
| 79 | Transport Nagar | HP68 | C3S1 | C3S1 | Suitable | Suitable |
| 80 | Vikas Nagar | HP69 | C3S1 | C3S1 | Suitable | Suitable |

## Annexure-XIII: Irrigation Class in Deeper Aquifer of Bhopal urban agglomerate under NAQUIM 2.0

| Locations | Source Code | USSL Classification | RSC Classification |
|---|---|---|---|
| BhanpurParisar | BW01 | C3S1 | Suitable |
| Govindpura | BW02 | C3S1 | Suitable |
| PeepalnerBw | BW03 | C3S1 | Suitable |
| Yatayat Park | EW01 | C2S1 | Suitable |
| Vasant Kunj | EW02 | C2S1 | Suitable |
| MP Nagar Police Station | EW03 | C2S1 | Suitable |
| 1100 Quarters | EW04 | C3S1 | Suitable |
| Nehru Nagar | EW05 | C2S1 | Suitable |
| M. P. Nagar, Govt. High School | EW06 | C3S1 | Suitable |
| Arvind Vihar | EW07 | C2S1 | Suitable |
| Neelbad | EW08 | C3S2 | Suitable |

## Annexure-XIV: Sample calculation of WQI for Groundwater of HP 34 represented shallow aquifer during post-monsoon

| S. No | Parameter | Unit | Acceptable limit ($S_i$) | Observed concentration ($c_i$) | Definite Weight ($w_i$) | Relative Weight ($W_i$) | Quality rating Scale ($q_i$) | Sub Index ($SI_i$) | WQI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HCO3 | mg/L | ***244*** | 372.1 | **3** | 0.0469 | 153 | 7.1 | 125 |
| 2 | Cl | mg/L | ***250*** | 70 | **3** | 0.0469 | 28 | 1.3 | |
| 3 | SO4 | mg/L | ***200*** | 45 | **3** | 0.0469 | 23 | 1.1 | |
| 4 | NO3 | mg/L | ***45*** | 20 | **4** | 0.0625 | 44 | 2.8 | |
| 5 | F | mg/L | ***1*** | 0.62 | **5** | 0.0781 | 62 | 4.8 | |
| 6 | TH | mg/L | ***200*** | 330 | **3** | 0.0469 | 165 | 7.7 | |
| 7 | Ca | mg/L | ***75*** | 66 | **2** | 0.0313 | 88 | 2.8 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | Mg | mg/L | ***30*** | 40 | **2** | 0.0313 | 134 | 4.2 | |
| 9 | TDS | mg/L | ***500*** | 611 | **4** | 0.0625 | 122 | 7.6 | |
| 10 | Fe | mg/L | *1* | 3.220 | **5** | 0.0781 | 322 | 25.2 | |
| 11 | Mn | mg/L | *0.1* | 0.950 | **4** | 0.0625 | 950 | 59.4 | |
| 12 | Cu | mg/L | *0.5* | 0.000 | **3** | 0.0469 | 0 | 0.0 | |
| 13 | Zn | mg/L | *5* | 0.000 | **3** | 0.0469 | 0 | 0.0 | |
| 14 | As | µg/L | *10* | 0.0 | **5** | 0.0781 | 0 | 0.0 | |
| 15 | Pb | µg/L | *10* | 1.3 | **5** | 0.0781 | 13 | 1.0 | |
| 16 | Cr | µg/L | *50* | 0.0 | **5** | 0.0781 | 0 | 0.0 | |
| 17 | U | µg/L | *30* | 0.0 | **5** | 0.0781 | 0 | 0.0 | |
| | | | | | 64 | 1.0000 | | 125 | |

### Annexure-XV: WQI Values for Shallow Aquifer groundwater in pre-monsoon and post-monsoon sources of Study Area

| S. No. | Location | LAB ID | WQI | |
|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon |
| 1 | Barkheda Pathani | DW01 | 41.5 | 40.3 |
| 2 | DIG Bangla | DW02 | 44.0 | 36.6 |
| 3 | Eatkhedi | DW03 | 40.0 | 37.7 |
| 4 | Gandhi Nagar | DW04 | 13.3 | 19.9 |
| 5 | Lalghati | DW05 | 25.0 | 19.6 |
| 6 | Nabibagh | DW06 | 42.4 | 39.2 |
| 7 | Piplani | DW07 | 18.7 | 20.5 |
| 8 | Sarvar | DW08 | 34.1 | 32.2 |
| 9 | Shahiahanabad | DW09 | 44.0 | 40.5 |
| 10 | South TT nagar | DW10 | 43.2 | 32.3 |
| 11 | Vishwakarma Nagar | DW11 | 54.6 | 54.5 |
| 12 | Abbaas Nagar | HP01 | 39.1 | 33.2 |
| 13 | Adarsh Nagar | HP02 | 48.8 | 51.6 |
| 14 | Amarnath Enclave | HP03 | 30.9 | 33.4 |
| 15 | Anna nagar | HP04 | 55.6 | 49.4 |
| 16 | Ayodhya Nagar | HP05 | 42.3 | 40.9 |
| 17 | Ayodhya Nagar | HP06 | 78.5 | 62.8 |
| 18 | Badwai | HP07 | 95.0 | 82.0 |
| 19 | Bagmugliya | HP08 | 48.1 | 45.7 |
| 20 | Bairagarh | HP09 | 54.5 | 50.3 |

| S. No. | Location | LAB ID | WQI | |
|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon |
| 21 | Bairagarh | HP10 | 60.4 | 55.6 |
| 22 | BairagarhChichli | HP11 | 32.6 | 31.6 |
| 23 | Bairagarh Kalan | HP12 | 65.7 | 59.3 |
| 24 | Bajrang Nagar, Khajuri Khurd | HP13 | 52.5 | 51.5 |
| 25 | Banskhedi | HP14 | 64.2 | 55.9 |
| 26 | Barkheda Pathani | HP15 | 73.2 | 71.1 |
| 27 | Bawadiya Kalan | HP16 | 43.8 | 43.0 |
| 28 | BDA Awadhpuri | HP17 | 32.8 | 31.0 |
| 29 | Bhainskhedi | HP18 | 43.0 | 41.3 |
| 30 | Bhonri | HP19 | 65.1 | 58.9 |
| 31 | Borvan | HP20 | 41.1 | 40.6 |
| 32 | Budhwara | HP21 | 76.9 | 59.5 |
| 33 | C.T.O Bairagarh | HP22 | 33.8 | 32.3 |
| 34 | ChheGhara | HP23 | 44.9 | 40.9 |
| 35 | Chhola | HP24 | 72.9 | 88.3 |
| 36 | Daamkheda | HP25 | 77.5 | 62.3 |
| 37 | Deeksha Nagar | HP26 | 39.1 | 36.6 |
| 38 | E-2 Nursery | HP27 | 40.2 | 33.5 |
| 39 | Gandhi Market | HP28 | 28.2 | 36.8 |
| 40 | Gandhi Nagar | HP29 | 55.5 | 52.2 |
| 41 | Garib Nagar | HP30 | 51.3 | 47.1 |
| 42 | Gaura Gaon | HP31 | 30.5 | 27.2 |
| 43 | Gittiphoda | HP32 | 33.1 | 28.1 |
| 44 | Guradi ghat | HP33 | 58.8 | 54.3 |
| 45 | Hathaikheda | HP34 | 85.6 | 125.0 |
| 46 | Inayatpur | HP35 | 45.6 | 43.6 |
| 47 | Indira Nagar | HP36 | 44.2 | 40.3 |
| 48 | Jaatkhedi | HP37 | 56.4 | 53.4 |
| 49 | Jamuniya cheer | HP38 | 49.5 | 47.7 |
| 50 | Jehangirabad | HP39 | 48.7 | 58.4 |
| 51 | Jinsi | HP40 | 45.0 | 40.0 |
| 52 | Kalukhedi | HP41 | 45.2 | 45.2 |
| 53 | Karariya farm | HP42 | 57.4 | 57.0 |
| 54 | Khanugaon | HP43 | 67.8 | 69.0 |
| 55 | Kotra, Sultanabad | HP44 | 38.2 | 32.8 |
| 56 | Laharpur | HP45 | 33.4 | 31.8 |
| 57 | Lambakheda | HP46 | 48.3 | 44.8 |
| 58 | Lau Khedi | HP47 | 39.2 | 34.0 |
| 59 | Mangalwara | HP48 | 61.0 | 43.3 |

| S. No. | Location | LAB ID | WQI | |
|---|---|---|---|---|
| | | | Pre-monsoon | Post-monsoon |
| 60 | Misrod | HP49 | 67.4 | 66.3 |
| 61 | Narela Shankari | HP50 | 86.4 | 75.6 |
| 62 | Nariyalkheda | HP51 | 51.6 | 47.4 |
| 63 | Neelbud | HP52 | 47.3 | 44.1 |
| 64 | Palasi | HP53 | 75.8 | 77.9 |
| 65 | Pallavi Nagar | HP54 | 61.3 | 52.5 |
| 66 | Panna Nagar | HP55 | 46.1 | 55.3 |
| 67 | Peepalner | HP56 | 66.0 | 63.6 |
| 68 | PipaliaPendekhan | HP57 | 42.8 | 40.3 |
| 69 | Platform-6, Bhopal Junction | HP58 | 93.5 | 106.2 |
| 70 | Prem Nagar | HP59 | 63.6 | 63.1 |
| 71 | Ratanpur | HP60 | 34.2 | 35.4 |
| 72 | Salaiya | HP61 | 40.5 | 39.2 |
| 73 | Semra Kalan | HP62 | 64.1 | 63.3 |
| 74 | Shiv nagar | HP63 | 37.1 | 36.0 |
| 75 | Shivaji Nagar | HP64 | 38.4 | 35.1 |
| 76 | Shrinagar Choli | HP65 | 37.5 | 34.3 |
| 77 | Subhash Nagar | HP66 | 44.6 | 52.0 |
| 78 | Suraj Nagar | HP67 | 26.7 | 25.3 |
| 79 | Transport Nagar | HP68 | 106.9 | 100.3 |
| 80 | Vikas Nagar | HP69 | 50.9 | 49.8 |
| Red coloured highlighted value comes under poor quality category groundwater. | | | | |

## Annexure-XVI: WQI Values for Deeper Aquifer groundwater sources of Study Area

| S. No. | Locations | Source Code | WQI |
|---|---|---|---|
| 1 | BhanpurParisar | BW01 | 56.0 |
| 2 | Govindpura | BW02 | 68.2 |
| 3 | PeepalnerBw | BW03 | 25.7 |
| 4 | Yatayat Park | EW01 | 26.2 |
| 5 | Vasant Kunj | EW02 | 13.1 |
| 6 | MP Nagar Police Station | EW03 | 21.6 |
| 7 | 1100 Quarters | EW04 | 32.9 |
| 8 | Nehru Nagar | EW05 | 19.9 |
| 9 | Maharana Pratap Nagar, Govt. High School | EW06 | 48.1 |
| 10 | Arvind Vihar | EW07 | 23.6 |

| S. No. | Locations | Source Code | WQI |
|---|---|---|---|
| 11 | Neelbad | EW08 | 32.5 |

**Annexure-XVII: Paired Sample t-test for significance of concentration difference in pre-monsoon and post-monsoon samples, Sample Size (N) = 51, Degree of Freedom = 50, and confidence level 95.**

| Parameter | Sampling Period | Mean | SD | ±Std.Error | $t_{cal.}$ | $t_{ref.}$ | Result |
|---|---|---|---|---|---|---|---|
| Temp (°C) | Post-Monsoon | 26.106 | 1.081 | 0.121 | 11.21 | 1.9904 | S |
| | Pre-Monsoon | 28.402 | 1.392 | 0.156 | | | |
| pH | Post-Monsoon | 7.315 | 0.231 | 0.0258 | 1.60 | 1.9904 | NS |
| | Pre-Monsoon | 7.274 | 0.278 | 0.0311 | | | |
| EC | Post-Monsoon | 1060.5 | 324.962 | 36.332 | 3.44 | 1.9904 | S |
| | Pre-Monsoon | 1089.975 | 327.43 | 36.608 | | | |
| $HCO_3$ | Post-Monsoon | 393.646 | 114.203 | 12.768 | 0.96 | 1.9904 | NS |
| | Pre-Monsoon | 398.65 | 114.117 | 12.759 | | | |
| Cl | Post-Monsoon | 98.625 | 52.44 | 5.863 | 1.55 | 1.9904 | NS |
| | Pre-Monsoon | 95.513 | 54.248 | 6.065 | | | |
| $SO_4$ | Post-Monsoon | 36 | 18.455 | 2.063 | 4.97 | 1.9904 | S |
| | Pre-Monsoon | 41.587 | 20.662 | 2.31 | | | |
| $NO_3$ | Post-Monsoon | 24.7 | 25.436 | 2.844 | 2.68 | 1.9904 | S |
| | Pre-Monsoon | 27.113 | 29.552 | 3.304 | | | |
| F | Post-Monsoon | 0.331 | 0.165 | 0.0185 | 1.58 | 1.9904 | NS |
| | Pre-Monsoon | 0.345 | 0.17 | 0.019 | | | |
| TH | Post-Monsoon | 388.788 | 130.434 | 14.583 | 0.77 | 1.9904 | NS |
| | Pre-Monsoon | 392.475 | 136.141 | 15.221 | | | |
| Ca | Post-Monsoon | 89.237 | 31.757 | 3.551 | 2.56 | 1.9904 | S |
| | Pre-Monsoon | 94.35 | 37.967 | 4.245 | | | |
| Mg | Post-Monsoon | 40.325 | 18.4 | 2.057 | 2.07 | 1.9904 | S |
| | Pre-Monsoon | 38.013 | 20.539 | 2.296 | | | |
| Na | Post-Monsoon | 59.888 | 34.305 | 3.835 | 1.64 | 1.9904 | NS |
| | Pre-Monsoon | 62.725 | 32.442 | 3.627 | | | |
| K | Post-Monsoon | 5.033 | 5.715 | 0.639 | 4.02 | 1.9904 | S |
| | Pre-Monsoon | 5.692 | 5.687 | 0.636 | | | |
| Fe | Post-Monsoon | 0.477 | 0.862 | 0.0964 | 0.03 | 1.9904 | NS |
| | Pre-Monsoon | 0.48 | 0.737 | 0.0824 | | | |
| Mn | Post-Monsoon | 0.0365 | 0.135 | 0.0151 | 0.20 | 1.9904 | NS |
| | Pre-Monsoon | 0.0388 | 0.0968 | 0.0108 | | | |
| Cu | Post-Monsoon | 0.0000625 | 0.000291 | 0.0000325 | 1.92 | 1.9904 | NS |
| | Pre-Monsoon | 0 | 0 | 0 | | | |

| Parameter | Sampling Period | Mean | SD | ±Std.Error | $t_{cal.}$ | $t_{ref.}$ | Result |
|---|---|---|---|---|---|---|---|
| Zn | Post-Monsoon | 0.229 | 0.852 | 0.0953 | 1.95 | 1.9904 | NS |
| | Pre-Monsoon | 0.368 | 1.437 | 0.161 | | | |
| As | Post-Monsoon | 0.0475 | 0.391 | 0.0438 | 2.70 | 1.9904 | S |
| | Pre-Monsoon | 0.329 | 0.978 | 0.109 | | | |
| Pb | Post-Monsoon | 0.511 | 0.748 | 0.0836 | 6.05 | 1.9904 | S |
| | Pre-Monsoon | 1.214 | 0.964 | 0.108 | | | |
| Cr | Post-Monsoon | 0.0313 | 0.104 | 0.0116 | 0.43 | 1.9904 | NS |
| | Pre-Monsoon | 0.0225 | 0.142 | 0.0159 | | | |
| U | Post-Monsoon | 0.184 | 0.971 | 0.109 | 2.37 | 1.9904 | S |
| | Pre-Monsoon | 0.645 | 1.745 | 0.195 | | | |
| $t_{ref.}$ – Reference value from student t table at 95% CL, $t_{cal.}$- t value calculated from raw data. | | | | | | | |
| S- Statistically Significant, NS- Statistically not significant | | | | | | | |

## Annexure-XVIII: Groundwater quality data of Bhopal urban agglomerate of shallow aquifer under NAQUIM 2.0

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BW01 | Pre-monsoon | P-1 | 28.8 | 7.32 | 1372 | 0 | 451 | 182 | 28 | 20 | 0.31 | BDL | 23 | 495 | 92 | 64 | 82 | 6.5 | 892 | BDL | 0.069 | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 1 | BW01 | Post-monsoon | P-2 | 28.1 | 7.45 | 1325 | 0 | 476 | 162 | 22 | 12 | 0.23 | BDL | 20 | 505 | 84 | 72 | 68 | 5.2 | 861 | BDL | BDL | BDL | BDL | BDL | 0.3 | BDL | BDL |
| 2 | BW02 | Pre-monsoon | P-1 | 27.7 | 7.52 | 1700 | 0 | 437 | 297 | 32 | 30 | 0.40 | BDL | 28 | 579 | 135 | 59 | 115 | 11.9 | 1105 | BDL | BDL | BDL | BDL | 3.9 | 1.0 | BDL | 12.1 |
| 2 | BW02 | Post-monsoon | P-2 | 26.2 | 7.22 | 1492 | 0 | 415 | 230 | 40 | 35 | 0.12 | BDL | 33 | 490 | 128 | 41 | 110 | 7.8 | 970 | BDL | BDL | BDL | BDL | 5.1 | 0.3 | 0.4 | BDL |
| 3 | BW03 | Pre-monsoon | P-1 | 28.4 | 7.95 | 835 | 0 | 262 | 77 | 79 | 3 | 0.07 | BDL | 12 | 215 | 66 | 12 | 90 | 6.0 | 543 | BDL | BDL | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 3 | BW03 | Post-monsoon | P-2 | 24.9 | 7.82 | 810 | 0 | 275 | 75 | 65 | 5 | 0.12 | BDL | 18 | 230 | 60 | 19 | 77 | 4.8 | 527 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 4 | DW01 | Pre-monsoon | P-1 | 30.2 | 7.35 | 1145 | 0 | 415 | 117 | 32 | 18 | 0.13 | BDL | 34 | 405 | 90 | 44 | 70 | 4.3 | 744 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 4 | DW01 | Post-monsoon | P-2 | 26 | 7.45 | 1095 | 0 | 403 | 115 | 25 | 10 | 0.16 | BDL | 32 | 415 | 92 | 45 | 55 | 3.5 | 712 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 5 | DW02 | Pre-monsoon | P-1 | 27.5 | 7.54 | 950 | 0 | 464 | 45 | 22 | 2 | 0.75 | BDL | 23 | 250 | 40 | 36 | 99 | 5.5 | 618 | BDL | 0.113 | BDL | BDL | 0.7 | 1.1 | BDL | BDL |
| 5 | DW02 | Post-monsoon | P-2 | 26 | 7.65 | 898 | 0 | 397 | 72 | 5 | 6 | 0.85 | BDL | 36 | 298 | 85 | 21 | 65 | 2.6 | 584 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | DW03 | Pre-monsoon | P-1 | 30.8 | 7.84 | 778 | 0 | 259 | 37 | 20 | 92 | 0.33 | BDL | 20 | 267 | 63 | 26 | 50 | 2.5 | 506 | BDL | BDL | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 6 | DW03 | Post-monsoon | P-2 | 25 | 7.87 | 735 | 0 | 262 | 50 | 16 | 78 | 0.29 | BDL | 25 | 275 | 60 | 30 | 42 | 2.1 | 478 | BDL | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |
| 7 | DW04 | Pre-monsoon | P-1 | 29.3 | 6.97 | 418 | 0 | 110 | 45 | 38 | 3 | 0.16 | BDL | 5 | 105 | 34 | 5 | 40 | 6.5 | 272 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 7 | DW04 | Post-monsoon | P-2 | 25.8 | 7.12 | 552 | 0 | 201 | 40 | 42 | 8 | 0.24 | BDL | 10 | 160 | 44 | 12 | 50 | 6.0 | 359 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 8 | DW05 | Pre-monsoon | P-1 | 26.8 | 6.93 | 604 | 0 | 177 | 70 | 38 | 11 | 0.06 | BDL | 4 | 175 | 48 | 13 | 53 | 7.4 | 393 | BDL | 0.059 | BDL | BDL | BDL | 1.7 | BDL | BDL |
| 8 | DW05 | Post-monsoon | P-2 | 27.2 | 7.02 | 619 | 0 | 146 | 95 | 40 | 8 | 0.12 | BDL | 10 | 160 | 40 | 15 | 62 | 6.2 | 402 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 9 | DW06 | Pre-monsoon | P-1 | 29.3 | 7.48 | 1150 | 0 | 384 | 140 | 42 | 2 | 0.49 | BDL | 37 | 395 | 80 | 47 | 78 | 5.0 | 748 | BDL | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |
| 9 | DW06 | Post-monsoon | P-2 | 28.5 | 7.38 | 1095 | 0 | 378 | 110 | 35 | 5 | 0.38 | BDL | 32 | 375 | 84 | 40 | 62 | 4.1 | 712 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 10 | DW07 | Pre-monsoon | P-1 | 29.3 | 7.74 | 500 | 0 | 183 | 32 | 35 | 1 | 0.15 | BDL | 17 | 175 | 36 | 21 | 27 | 5.0 | 325 | BDL | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 10 | DW07 | Post-monsoon | P-2 | 27 | 7.70 | 525 | 0 | 189 | 45 | 38 | 5 | 0.20 | BDL | 20 | 185 | 36 | 23 | 35 | 4.0 | 341 | BDL | BDL | BDL | BDL | BDL | 0.4 | BDL | BDL |
| 11 | DW08 | Pre-monsoon | P-1 | 27.2 | 7.35 | 705 | 0 | 268 | 45 | 15 | 50 | 0.33 | BDL | 47 | 290 | 78 | 23 | 22 | 3.8 | 458 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 11 | DW08 | Post-monsoon | P-2 | 26.8 | 7.38 | 655 | 0 | 256 | 42 | 12 | 43 | 0.35 | BDL | 42 | 280 | 70 | 26 | 18 | 2.5 | 426 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 12 | DW09 | Pre-monsoon | P-1 | 27.8 | 6.96 | 855 | 0 | 354 | 67 | 10 | 8 | 0.36 | 0.16 | 19 | 210 | 64 | 12 | 98 | 2.1 | 556 | 0.204 | 0.197 | BDL | BDL | 1.9 | 0.8 | BDL | BDL |
| 12 | DW09 | Post-monsoon | P-2 | 25.5 | 7.56 | 956 | 0 | 458 | 67 | 3 | 4 | 0.56 | 0.1 | 42 | 227 | 65 | 16 | 113 | 1.2 | 621 | 0.200 | 0.102 | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 13 | DW10 | Pre-monsoon | P-1 | 29.8 | 7.43 | 745 | 0 | 305 | 45 | 35 | 3 | 0.89 | BDL | 20 | 260 | 56 | 29 | 45 | 3.9 | 484 | 0.403 | 0.114 | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 13 | DW10 | Post-monsoon | P-2 | 26 | 7.28 | 695 | 0 | 293 | 42 | 28 | 5 | 0.75 | BDL | 25 | 250 | 58 | 26 | 38 | 4.2 | 452 | 0.250 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 14 | DW11 | Pre-monsoon | P-1 | 26.9 | 7.53 | 1430 | 0 | 505 | 170 | 28 | 23 | 0.40 | BDL | 43 | 366 | 81 | 40 | 156 | 3.9 | 930 | BDL | 0.101 | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 14 | DW11 | Post-monsoon | P-2 | 25.4 | 7.33 | 1465 | 0 | 519 | 180 | 30 | 18 | 0.49 | BDL | 38 | 495 | 94 | 63 | 106 | 2.6 | 952 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 15 | HP01 | Pre-monsoon | P-1 | 27.1 | 7.26 | 795 | 0 | 320 | 60 | 15 | 35 | 0.27 | BDL | 26 | 317 | 111 | 10 | 33 | 2.7 | 517 | 0.250 | BDL | BDL | 1.832 | BDL | 1.6 | BDL | BDL |
| 15 | HP01 | Post-monsoon | P-2 | 26.5 | 7.42 | 762 | 0 | 329 | 62 | 10 | 13 | 0.24 | BDL | 30 | 290 | 82 | 21 | 41 | 1.5 | 495 | 0.220 | BDL | BDL | 0.980 | BDL | 0.7 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | HP02 | Pre-monsoon | P-1 | 27.2 | 7.58 | 1115 | 0 | 382 | 110 | 42 | 45 | 0.69 | BDL | 32 | 371 | 89 | 36 | 82 | 2.3 | 725 | 0.114 | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 16 | HP02 | Post-monsoon | P-2 | 26.6 | 7.35 | 1205 | 0 | 445 | 105 | 46 | 40 | 0.58 | BDL | 35 | 430 | 84 | 54 | 76 | 1.5 | 783 | 0.089 | BDL | BDL | BDL | BDL | 0.3 | BDL | BDL |
| 17 | HP03 | Pre-monsoon | P-1 | 32.6 | 7.63 | 765 | 0 | 265 | 57 | 58 | 8 | 0.26 | BDL | 31 | 193 | 53 | 14 | 80 | 3.1 | 497 | 0.477 | BDL | BDL | 1.085 | BDL | 1.3 | BDL | BDL |
| 17 | HP03 | Post-monsoon | P-2 | 25.2 | 7.25 | 796 | 0 | 287 | 67 | 50 | 10 | 0.28 | BDL | 30 | 250 | 80 | 12 | 65 | 2.8 | 517 | 0.420 | BDL | BDL | 0.925 | BDL | 1.0 | BDL | BDL |
| 18 | HP04 | Pre-monsoon | P-1 | 27.8 | 7.55 | 1288 | 0 | 512 | 102 | 30 | 42 | 0.18 | BDL | 62 | 495 | 96 | 62 | 62 | 3.0 | 837 | 0.308 | BDL | BDL | BDL | BDL | 1.2 | BDL | BDL |
| 18 | HP04 | Post-monsoon | P-2 | 25.9 | 7.28 | 1164 | 0 | 458 | 100 | 34 | 32 | 0.24 | BDL | 56 | 450 | 94 | 52 | 59 | 2.3 | 757 | 0.205 | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 19 | HP05 | Pre-monsoon | P-1 | 27.3 | 7.50 | 1000 | 0 | 431 | 70 | 30 | 6 | 0.34 | BDL | 42 | 366 | 87 | 36 | 59 | 3.3 | 650 | 0.336 | BDL | BDL | 0.177 | 0.6 | 1.5 | BDL | BDL |
| 19 | HP05 | Post-monsoon | P-2 | 25.8 | 7.26 | 915 | 0 | 409 | 55 | 32 | 7 | 0.53 | BDL | 54 | 355 | 76 | 40 | 45 | 3.0 | 595 | 0.258 | BDL | BDL | 0.120 | BDL | 1.2 | BDL | BDL |
| 20 | HP06 | Pre-monsoon | P-1 | 27.9 | 7.34 | 1400 | 0 | 567 | 122 | 40 | 6 | 0.34 | 0.29 | 55 | 431 | 97 | 46 | 115 | 9.0 | 910 | 1.619 | 0.257 | BDL | 0.616 | 1.0 | 0.7 | BDL | BDL |
| 20 | HP06 | Post-monsoon | P-2 | 25 | 7.26 | 1350 | 0 | 573 | 115 | 32 | 8 | 0.31 | 1.37 | 52 | 425 | 100 | 43 | 110 | 10.0 | 878 | 1.025 | 0.120 | BDL | 0.125 | BDL | 0.2 | BDL | BDL |
| 21 | HP07 | Pre-monsoon | P-1 | 26.8 | 7.27 | 2105 | 0 | 604 | 309 | 78 | 43 | 0.49 | BDL | 30 | 569 | 109 | 72 | 212 | 16.2 | 1368 | 1.591 | 0.154 | BDL | 0.081 | BDL | 0.7 | BDL | 3.1 |
| 21 | HP07 | Post-monsoon | P-2 | 25.4 | 7.23 | 2385 | 0 | 805 | 270 | 75 | 47 | 0.48 | 0.10 | 49 | 565 | 104 | 74 | 275 | 18.1 | 1550 | 0.401 | 0.020 | BDL | 0.120 | BDL | 0.3 | 0.2 | BDL |
| 22 | HP08 | Pre-monsoon | P-1 | 27.5 | 7.29 | 1133 | 0 | 277 | 130 | 85 | 25 | 0.27 | BDL | 35 | 421 | 75 | 57 | 55 | 2.7 | 736 | 0.105 | 0.055 | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 22 | HP08 | Post-monsoon | P-2 | 26.8 | 7.48 | 1135 | 0 | 372 | 120 | 70 | 21 | 0.23 | BDL | 36 | 450 | 96 | 51 | 52 | 2.8 | 738 | 0.095 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 23 | HP09 | Pre-monsoon | P-1 | 29.8 | 6.95 | 1140 | 0 | 437 | 105 | 30 | 21 | 0.20 | BDL | 30 | 406 | 117 | 28 | 70 | 3.2 | 741 | 1.429 | BDL | BDL | 0.668 | BDL | 0.8 | BDL | BDL |
| 23 | HP09 | Post-monsoon | P-2 | 26.5 | 7.23 | 1100 | 0 | 433 | 97 | 36 | 11 | 0.17 | BDL | 32 | 405 | 94 | 41 | 65 | 2.0 | 715 | 1.220 | BDL | BDL | 0.250 | BDL | 0.1 | BDL | BDL |
| 24 | HP10 | Pre-monsoon | P-1 | 28 | 7.43 | 1330 | 0 | 499 | 132 | 52 | 2 | 0.13 | BDL | 52 | 520 | 129 | 48 | 63 | 3.3 | 865 | 0.344 | 0.063 | BDL | 4.991 | BDL | 1.5 | BDL | BDL |
| 24 | HP10 | Post-monsoon | P-2 | 25.7 | 7.26 | 1320 | 0 | 470 | 152 | 48 | 5 | 0.19 | BDL | 56 | 525 | 126 | 51 | 59 | 2.3 | 858 | 0.300 | BDL | BDL | 4.200 | BDL | 0.7 | BDL | BDL |
| 25 | HP11 | Pre-monsoon | P-1 | 33.1 | 7.55 | 695 | 0 | 296 | 25 | 45 | 18 | 0.55 | BDL | 46 | 252 | 50 | 31 | 42 | 2.0 | 452 | BDL | BDL | BDL | BDL | 0.6 | 1.4 | 1.0 | BDL |
| 25 | HP11 | Post-monsoon | P-2 | 25.2 | 7.40 | 715 | 0 | 275 | 50 | 40 | 20 | 0.45 | BDL | 34 | 275 | 80 | 18 | 38 | 2.0 | 465 | BDL | BDL | BDL | BDL | BDL | 0.9 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | HP12 | Pre-monsoon | P-1 | 28.8 | 7.00 | 1410 | 0 | 548 | 115 | 48 | 35 | 0.23 | BDL | 37 | 545 | 164 | 33 | 58 | 14.8 | 917 | 0.654 | 0.070 | BDL | BDL | BDL | 1.6 | BDL | BDL |
| 26 | HP12 | Post-monsoon | P-2 | 25.2 | 7.17 | 1452 | 0 | 543 | 132 | 52 | 30 | 0.2 | BDL | 29 | 545 | 154 | 39 | 72 | 17.2 | 944 | 0.550 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 27 | HP13 | Pre-monsoon | P-1 | 28.3 | 6.87 | 1155 | 0 | 357 | 102 | 62 | 61 | 0.26 | BDL | 30 | 451 | 123 | 35 | 50 | 3.0 | 751 | 0.202 | BDL | BDL | 0.933 | BDL | 0.8 | BDL | BDL |
| 27 | HP13 | Post-monsoon | P-2 | 26.8 | 7.27 | 1112 | 0 | 354 | 120 | 49 | 52 | 0.22 | BDL | 36 | 490 | 116 | 49 | 31 | 2.1 | 723 | 0.098 | BDL | BDL | 1.000 | BDL | 0.2 | BDL | BDL |
| 28 | HP14 | Pre-monsoon | P-1 | 30.1 | 7.47 | 1095 | 0 | 462 | 72 | 45 | 13 | 0.33 | BDL | 46 | 446 | 87 | 55 | 45 | 3.4 | 712 | 1.322 | 0.111 | BDL | 0.787 | 1.2 | 1.1 | BDL | BDL |
| 28 | HP14 | Post-monsoon | P-2 | 25.3 | 7.41 | 1030 | 0 | 445 | 60 | 35 | 10 | 0.29 | BDL | 38 | 410 | 84 | 49 | 40 | 2.5 | 670 | 1.010 | 0.100 | BDL | 0.524 | BDL | 0.8 | BDL | BDL |
| 29 | HP15 | Pre-monsoon | P-1 | 31.3 | 6.92 | 1745 | 0 | 505 | 212 | 80 | 56 | 0.19 | 0.13 | 43 | 743 | 246 | 31 | 51 | 3.2 | 1134 | 0.332 | BDL | BDL | 0.146 | BDL | 0.7 | BDL | BDL |
| 29 | HP15 | Post-monsoon | P-2 | 26.8 | 7.22 | 1692 | 0 | 525 | 200 | 78 | 55 | 0.11 | 0.03 | 44 | 710 | 186 | 60 | 62 | 2.8 | 1100 | 0.289 | BDL | BDL | 0.110 | BDL | 0.3 | BDL | BDL |
| 30 | HP16 | Pre-monsoon | P-1 | 29.4 | 7.26 | 1058 | 0 | 444 | 87 | 10 | 9 | 0.40 | BDL | 36 | 431 | 83 | 54 | 33 | 1.9 | 688 | BDL | BDL | BDL | 0.400 | BDL | 1.0 | BDL | BDL |
| 30 | HP16 | Post-monsoon | P-2 | 24.5 | 7.12 | 1075 | 0 | 464 | 75 | 18 | 12 | 0.32 | BDL | 33 | 430 | 100 | 44 | 42 | 2.0 | 699 | BDL | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 31 | HP17 | Pre-monsoon | P-1 | 29.5 | 6.70 | 735 | 0 | 240 | 80 | 20 | 30 | 0.19 | BDL | 24 | 297 | 77 | 25 | 28 | 2.5 | 478 | 0.117 | BDL | BDL | 0.368 | BDL | 0.7 | BDL | BDL |
| 31 | HP17 | Post-monsoon | P-2 | 27.8 | 7.16 | 698 | 0 | 232 | 77 | 15 | 32 | 0.22 | BDL | 28 | 275 | 76 | 21 | 30 | 1.9 | 454 | 0.082 | BDL | BDL | 0.420 | BDL | 0.1 | BDL | BDL |
| 32 | HP18 | Pre-monsoon | P-1 | 26.8 | 7.28 | 925 | 0 | 394 | 47 | 32 | 27 | 0.32 | BDL | 27 | 381 | 77 | 46 | 29 | 3.4 | 601 | 0.260 | BDL | BDL | BDL | BDL | 1.4 | BDL | BDL |
| 32 | HP18 | Post-monsoon | P-2 | 26.8 | 7.51 | 952 | 0 | 415 | 62 | 19 | 28 | 0.25 | BDL | 30 | 370 | 62 | 52 | 47 | 2.9 | 619 | 0.125 | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |
| 33 | HP19 | Pre-monsoon | P-1 | 29.6 | 7.03 | 1175 | 0 | 444 | 85 | 20 | 84 | 0.34 | BDL | 30 | 490 | 119 | 47 | 38 | 2.4 | 764 | 1.077 | BDL | BDL | 0.242 | BDL | 0.9 | BDL | BDL |
| 33 | HP19 | Post-monsoon | P-2 | 27.1 | 7.12 | 1135 | 0 | 458 | 80 | 15 | 65 | 0.29 | BDL | 37 | 460 | 104 | 49 | 44 | 2.0 | 738 | 0.892 | BDL | BDL | 0.300 | BDL | 0.4 | BDL | BDL |
| 34 | HP20 | Pre-monsoon | P-1 | 28.5 | 7.20 | 873 | 0 | 320 | 75 | 53 | 3 | 0.19 | BDL | 57 | 347 | 99 | 24 | 35 | 6.6 | 567 | 0.567 | 0.050 | BDL | BDL | BDL | 1.3 | BDL | BDL |
| 34 | HP20 | Post-monsoon | P-2 | 26.8 | 6.89 | 920 | 0 | 281 | 125 | 45 | 5 | 0.15 | BDL | 52 | 370 | 96 | 32 | 39 | 5.9 | 598 | 0.520 | 0.030 | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 35 | HP21 | Pre-monsoon | P-1 | 28.6 | 6.95 | 1012 | 0 | 444 | 97 | 15 | 18 | 0.25 | BDL | 40 | 302 | 89 | 19 | 105 | 3.5 | 658 | 0.693 | 0.460 | BDL | BDL | 6.8 | 1.5 | BDL | BDL |
| 35 | HP21 | Post-monsoon | P-2 | 24.8 | 7.10 | 978 | 0 | 409 | 77 | 20 | 12 | 0.21 | BDL | 38 | 290 | 70 | 28 | 87 | 2.8 | 636 | 0.458 | 0.350 | BDL | BDL | BDL | 0.6 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | HP22 | Pre-monsoon | P-1 | 27.3 | 7.38 | 898 | 0 | 345 | 75 | 41 | 4 | 0.37 | BDL | 27 | 312 | 103 | 13 | 52 | 11.0 | 584 | BDL | BDL | BDL | BDL | BDL | 1.4 | BDL | BDL |
| 36 | HP22 | Post-monsoon | P-2 | 24 | 7.37 | 905 | 0 | 317 | 87 | 38 | 8 | 0.28 | BDL | 30 | 310 | 100 | 15 | 52 | 8.4 | 588 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 37 | HP23 | Pre-monsoon | P-1 | 28.7 | 7.13 | 1005 | 0 | 327 | 115 | 43 | 16 | 0.38 | BDL | 27 | 441 | 89 | 53 | 21 | 2.2 | 653 | 0.081 | BDL | BDL | 0.224 | BDL | 2.2 | BDL | BDL |
| 37 | HP23 | Post-monsoon | P-2 | 26.4 | 7.28 | 932 | 0 | 311 | 112 | 35 | 12 | 0.29 | BDL | 32 | 425 | 76 | 57 | 18 | 1.8 | 606 | 0.054 | BDL | BDL | 0.120 | BDL | 1.1 | BDL | BDL |
| 38 | HP24 | Pre-monsoon | P-1 | 29 | 7.38 | 1500 | 0 | 616 | 127 | 40 | 2 | 0.39 | BDL | 15 | 490 | 113 | 51 | 112 | 7.7 | 975 | 1.849 | 0.051 | BDL | 0.192 | BDL | 1.0 | BDL | 8.4 |
| 38 | HP24 | Post-monsoon | P-2 | 27.2 | 7.12 | 1334 | 0 | 519 | 137 | 32 | 8 | 0.27 | BDL | 23 | 425 | 106 | 39 | 105 | 5.7 | 867 | 5.120 | 0.035 | BDL | 0.250 | BDL | BDL | 0.5 | BDL |
| 39 | HP25 | Pre-monsoon | P-1 | 28.4 | 7.50 | 1585 | 0 | 444 | 225 | 50 | 47 | 0.30 | BDL | 17 | 614 | 131 | 70 | 69 | 15.4 | 1030 | 0.052 | 0.135 | BDL | BDL | 1.5 | 3.0 | BDL | 9.0 |
| 39 | HP25 | Post-monsoon | P-2 | 25.1 | 7.37 | 1482 | 0 | 390 | 225 | 52 | 55 | 0.39 | BDL | 20 | 590 | 128 | 66 | 60 | 14.0 | 963 | BDL | BDL | BDL | BDL | BDL | 0.9 | BDL | BDL |
| 40 | HP26 | Pre-monsoon | P-1 | 27.4 | 7.56 | 960 | 0 | 296 | 92 | 50 | 19 | 0.35 | BDL | 28 | 352 | 79 | 37 | 42 | 5.0 | 624 | 0.158 | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 40 | HP26 | Post-monsoon | P-2 | 24.8 | 7.76 | 905 | 0 | 287 | 105 | 42 | 12 | 0.28 | BDL | 33 | 355 | 70 | 44 | 38 | 4.3 | 588 | 0.120 | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |
| 41 | HP27 | Pre-monsoon | P-1 | 30.3 | 7 | 922 | 0 | 366 | 69 | 40 | 15 | 0.52 | BDL | 43 | 335 | 98 | 22 | 53 | 8 | 599 | BDL | BDL | BDL | BDL | 2.0 | 1.1 | BDL | 2.7 |
| 41 | HP27 | Post-monsoon | P-2 | 23.7 | 7.98 | 823 | 0 | 342 | 90 | 3 | 12 | 0.65 | 0.10 | 32 | 258 | 65 | 23 | 65 | 11.2 | 535 | BDL | BDL | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 42 | HP28 | Pre-monsoon | P-1 | 28.7 | 6.75 | 712 | 0 | 277 | 45 | 32 | 15 | 0.11 | BDL | 28 | 262 | 71 | 20 | 35 | 2.4 | 463 | BDL | BDL | BDL | BDL | 0.6 | 1.1 | BDL | BDL |
| 42 | HP28 | Post-monsoon | P-2 | 26.5 | 7.02 | 822 | 0 | 305 | 75 | 32 | 20 | 0.19 | BDL | 37 | 300 | 76 | 27 | 50 | 2.0 | 534 | BDL | BDL | BDL | BDL | BDL | 6.3 | BDL | BDL |
| 43 | HP29 | Pre-monsoon | P-1 | 27.1 | 6.78 | 1385 | 0 | 481 | 140 | 72 | 14 | 0.29 | BDL | 31 | 589 | 194 | 25 | 35 | 11.3 | 900 | 0.124 | BDL | BDL | BDL | BDL | 1.2 | BDL | BDL |
| 43 | HP29 | Post-monsoon | P-2 | 27 | 7.05 | 1283 | 0 | 439 | 132 | 68 | 18 | 0.35 | BDL | 28 | 550 | 160 | 36 | 32 | 12.5 | 834 | BDL | BDL | BDL | BDL | BDL | 0.8 | BDL | BDL |
| 44 | HP30 | Pre-monsoon | P-1 | 28.6 | 7.36 | 1218 | 0 | 444 | 125 | 62 | 4 | 0.28 | BDL | 78 | 545 | 123 | 58 | 39 | 3.1 | 792 | 0.185 | BDL | BDL | BDL | BDL | 1.3 | BDL | BDL |
| 44 | HP30 | Post-monsoon | P-2 | 27.7 | 7.48 | 1185 | 0 | 439 | 115 | 55 | 7 | 0.3 | BDL | 62 | 505 | 134 | 41 | 38 | 2.0 | 770 | BDL | BDL | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 45 | HP31 | Pre-monsoon | P-1 | 29.3 | 7.25 | 702 | 0 | 290 | 35 | 35 | 12 | 0.16 | BDL | 51 | 262 | 81 | 14 | 35 | 5.2 | 456 | 0.304 | BDL | BDL | 0.136 | BDL | 1.7 | BDL | BDL |
| 45 | HP31 | Post-monsoon | P-2 | 25.2 | 7.33 | 682 | 0 | 311 | 35 | 26 | 1 | 0.06 | BDL | 46 | 265 | 64 | 26 | 31 | 3.2 | 443 | 0.240 | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | HP32 | Pre-monsoon | P-1 | 29.3 | 6.92 | 685 | 0 | 197 | 45 | 55 | 57 | 0.17 | BDL | 24 | 203 | 32 | 30 | 58 | 2.7 | 445 | 0.057 | BDL | BDL | BDL | 2.2 | 1.4 | BDL | BDL |
| 46 | HP32 | Post-monsoon | P-2 | 26 | 7.15 | 625 | 0 | 183 | 50 | 40 | 43 | 0.22 | BDL | 28 | 200 | 20 | 36 | 45 | 2.0 | 406 | 0.025 | BDL | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 47 | HP33 | Pre-monsoon | P-1 | 26.5 | 7.18 | 1248 | 0 | 450 | 152 | 10 | 9 | 0.26 | BDL | 39 | 550 | 93 | 77 | 30 | 1.3 | 811 | 0.942 | BDL | BDL | 0.065 | BDL | 0.8 | BDL | 3.2 |
| 47 | HP33 | Post-monsoon | P-2 | 26.1 | 7.37 | 1204 | 0 | 427 | 135 | 34 | 13 | 0.31 | BDL | 32 | 520 | 92 | 71 | 32 | 1.6 | 783 | 0.680 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 48 | HP34 | Pre-monsoon | P-1 | 27.2 | 7.10 | 960 | 0 | 364 | 75 | 40 | 16 | 0.66 | BDL | 27 | 317 | 85 | 25 | 70 | 2.9 | 624 | 4.331 | 0.150 | BDL | 0.052 | BDL | 5.4 | BDL | BDL |
| 48 | HP34 | Post-monsoon | P-2 | 26.3 | 7.62 | 940 | 0 | 372 | 70 | 45 | 20 | 0.62 | BDL | 25 | 330 | 66 | 40 | 64 | 2.1 | 611 | 3.220 | 0.950 | BDL | BDL | BDL | 1.3 | BDL | BDL |
| 49 | HP35 | Pre-monsoon | P-1 | 28.8 | 7.50 | 1050 | 0 | 518 | 20 | 35 | 25 | 0.40 | BDL | 37 | 347 | 53 | 52 | 78 | 3.0 | 683 | 0.211 | BDL | BDL | 0.224 | BDL | 1.0 | BDL | 3.4 |
| 49 | HP35 | Post-monsoon | P-2 | 26.6 | 7.53 | 1055 | 0 | 543 | 27 | 25 | 11 | 0.49 | BDL | 40 | 350 | 44 | 58 | 80 | 2.5 | 683 | 0.180 | BDL | BDL | 0.120 | BDL | 0.7 | BDL | BDL |
| 50 | HP36 | Pre-monsoon | P-1 | 27.8 | 7.13 | 1095 | 0 | 444 | 20 | 95 | 20 | 0.32 | BDL | 33 | 416 | 133 | 20 | 46 | 3.3 | 712 | 0.115 | BDL | BDL | 0.083 | BDL | 0.7 | BDL | BDL |
| 50 | HP36 | Post-monsoon | P-2 | 25.2 | 7.08 | 985 | 0 | 409 | 30 | 72 | 23 | 0.25 | BDL | 25 | 390 | 106 | 30 | 38 | 2.5 | 640 | BDL | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |
| 51 | HP37 | Pre-monsoon | P-1 | 28.9 | 7.21 | 1435 | 0 | 573 | 122 | 42 | 11 | 0.26 | BDL | 45 | 510 | 79 | 76 | 84 | 2.6 | 933 | 0.308 | BDL | BDL | BDL | BDL | 0.7 | BDL | 2.7 |
| 51 | HP37 | Post-monsoon | P-2 | 25.8 | 7.23 | 1390 | 0 | 537 | 127 | 38 | 15 | 0.32 | BDL | 40 | 525 | 84 | 77 | 68 | 2.0 | 904 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 52 | HP38 | Pre-monsoon | P-1 | 28.8 | 7.26 | 1078 | 0 | 351 | 87 | 75 | 18 | 0.25 | BDL | 29 | 480 | 107 | 52 | 20 | 3.3 | 701 | 0.549 | BDL | BDL | 0.070 | BDL | 0.8 | BDL | BDL |
| 52 | HP38 | Post-monsoon | P-2 | 27.6 | 7.33 | 1071 | 0 | 366 | 110 | 56 | 20 | 0.2 | BDL | 33 | 470 | 118 | 43 | 27 | 2.1 | 696 | 0.452 | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |
| 53 | HP39 | Pre-monsoon | P-1 | 29.2 | 7.10 | 762 | 0 | 296 | 57 | 35 | 14 | 0.48 | BDL | 12 | 228 | 67 | 14 | 60 | 13.9 | 495 | BDL | 0.298 | BDL | BDL | BDL | 1.2 | BDL | BDL |
| 53 | HP39 | Post-monsoon | P-2 | 25.8 | 7.12 | 800 | 0 | 342 | 65 | 10 | 8 | 0.25 | 0.01 | 30 | 220 | 46 | 26 | 72 | 15.0 | 520 | 3.240 | 0.085 | BDL | 0.058 | BDL | 0.5 | BDL | BDL |
| 54 | HP40 | Pre-monsoon | P-1 | 28.3 | 7.35 | 955 | 0 | 388 | 75 | 28 | 2 | 0.59 | BDL | 20 | 297 | 89 | 18 | 71 | 13.6 | 621 | 1.163 | BDL | BDL | 0.282 | BDL | 1.2 | BDL | BDL |
| 54 | HP40 | Post-monsoon | P-2 | 24.8 | 7.25 | 875 | 0 | 354 | 77 | 22 | 5 | 0.45 | BDL | 23 | 290 | 70 | 28 | 60 | 10.5 | 569 | 0.852 | BDL | BDL | BDL | BDL | 0.9 | BDL | BDL |
| 55 | HP41 | Pre-monsoon | P-1 | 28.5 | 7.14 | 1145 | 0 | 407 | 152 | 15 | 3 | 0.34 | 0.14 | 31 | 465 | 101 | 52 | 45 | 3.6 | 744 | BDL | BDL | BDL | BDL | 0.6 | 1.0 | BDL | BDL |
| 55 | HP41 | Post-monsoon | P-2 | 27 | 7.44 | 1182 | 0 | 378 | 180 | 12 | 9 | 0.34 | 0.12 | 36 | 470 | 108 | 49 | 52 | 3.0 | 768 | BDL | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | HP42 | Pre-monsoon | P-1 | 27.2 | 7.62 | 1460 | 0 | 555 | 110 | 62 | 30 | 0.23 | BDL | 21 | 569 | 135 | 57 | 60 | 15.3 | 949 | BDL | BDL | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 56 | HP42 | Post-monsoon | P-2 | 26.5 | 7.54 | 1415 | 0 | 543 | 125 | 55 | 25 | 0.18 | BDL | 25 | 590 | 124 | 68 | 45 | 14.1 | 920 | BDL | BDL | BDL | BDL | BDL | 0.6 | BDL | BDL |
| 57 | HP43 | Pre-monsoon | P-1 | 28.1 | 7.50 | 1300 | 0 | 413 | 152 | 30 | 48 | 0.21 | 0.43 | 36 | 505 | 147 | 34 | 55 | 18.2 | 845 | 0.535 | BDL | BDL | 11.805 | BDL | 1.0 | BDL | BDL |
| 57 | HP43 | Post-monsoon | P-2 | 24.8 | 7.10 | 950 | 0 | 293 | 110 | 15 | 47 | 0.21 | 0.15 | 29 | 270 | 76 | 19 | 72 | 22.1 | 618 | 2.547 | 0.120 | BDL | 6.245 | BDL | 0.3 | BDL | BDL |
| 58 | HP44 | Pre-monsoon | P-1 | 28.1 | 7.50 | 872 | 0 | 388 | 42 | 42 | 6 | 0.56 | BDL | 53 | 287 | 67 | 29 | 65 | 3.0 | 567 | 0.367 | BDL | BDL | 0.106 | BDL | 1.4 | BDL | BDL |
| 58 | HP44 | Post-monsoon | P-2 | 25.5 | 7.42 | 805 | 0 | 336 | 47 | 38 | 10 | 0.48 | BDL | 47 | 275 | 62 | 29 | 57 | 2.1 | 523 | BDL | BDL | BDL | BDL | BDL | 1.1 | BDL | BDL |
| 59 | HP45 | Pre-monsoon | P-1 | 27.9 | 7.70 | 842 | 0 | 425 | 25 | 12 | 8 | 0.20 | BDL | 27 | 312 | 59 | 40 | 45 | 2.7 | 547 | BDL | BDL | BDL | 0.358 | BDL | 0.9 | BDL | BDL |
| 59 | HP45 | Post-monsoon | P-2 | 28.5 | 7.55 | 812 | 0 | 409 | 30 | 12 | 2 | 0.24 | BDL | 24 | 315 | 66 | 36 | 37 | 1.5 | 528 | BDL | BDL | BDL | 0.300 | BDL | 0.2 | BDL | BDL |
| 60 | HP46 | Pre-monsoon | P-1 | 26.1 | 7.42 | 1090 | 0 | 376 | 102 | 55 | 31 | 0.22 | BDL | 38 | 416 | 103 | 39 | 55 | 3.9 | 709 | 0.521 | BDL | BDL | 0.066 | BDL | 1.1 | BDL | BDL |
| 60 | HP46 | Post-monsoon | P-2 | 25 | 7.32 | 1100 | 0 | 390 | 112 | 43 | 25 | 0.17 | BDL | 36 | 400 | 110 | 30 | 68 | 3.0 | 715 | 0.420 | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 61 | HP47 | Pre-monsoon | P-1 | 28.5 | 7.07 | 818 | 0 | 376 | 37 | 15 | 28 | 0.21 | BDL | 29 | 337 | 89 | 28 | 28 | 2.7 | 532 | 0.428 | BDL | BDL | 0.051 | BDL | 1.1 | BDL | BDL |
| 61 | HP47 | Post-monsoon | P-2 | 25.9 | 7.12 | 802 | 0 | 305 | 70 | 20 | 26 | 0.15 | BDL | 31 | 340 | 84 | 32 | 23 | 2.1 | 521 | BDL | BDL | BDL | 0.032 | BDL | 0.3 | BDL | BDL |
| 62 | HP48 | Pre-monsoon | P-1 | 28.8 | 7.35 | 795 | 0 | 296 | 62 | 35 | 7 | 0.14 | 0.22 | 37 | 223 | 65 | 14 | 58 | 28.7 | 517 | 3.150 | 0.111 | BDL | 0.234 | 3.1 | 1.5 | BDL | BDL |
| 62 | HP48 | Post-monsoon | P-2 | 26.4 | 7.22 | 721 | 0 | 268 | 80 | 13 | 10 | 0.12 | BDL | 43 | 255 | 60 | 26 | 35 | 20.0 | 469 | 0.452 | 0.166 | 0.002 | 0.036 | 3.5 | 0.3 | 0.3 | 0.4 |
| 63 | HP49 | Pre-monsoon | P-1 | 29.1 | 7.34 | 1645 | 0 | 647 | 175 | 15 | 17 | 0.19 | 0.2 | 43 | 654 | 67 | 118 | 70 | 2.0 | 1069 | 0.234 | BDL | BDL | 0.093 | BDL | 0.8 | 0.8 | 4.1 |
| 63 | HP49 | Post-monsoon | P-2 | 27.8 | 7.51 | 1642 | 0 | 659 | 155 | 18 | 20 | 0.33 | 0.02 | 48 | 645 | 80 | 108 | 78 | 1.8 | 1067 | 0.220 | BDL | BDL | 0.100 | BDL | 0.1 | BDL | BDL |
| 64 | HP50 | Pre-monsoon | P-1 | 29.9 | 7.12 | 1585 | 0 | 462 | 150 | 34 | 186 | 0.38 | BDL | 40 | 609 | 192 | 31 | 73 | 10.3 | 1030 | 0.786 | BDL | BDL | BDL | BDL | 0.7 | BDL | BDL |
| 64 | HP50 | Post-monsoon | P-2 | 26.2 | 7.17 | 1452 | 0 | 470 | 120 | 42 | 149 | 0.33 | BDL | 42 | 540 | 138 | 47 | 78 | 9.2 | 944 | 0.598 | BDL | BDL | BDL | BDL | 0.3 | BDL | BDL |
| 65 | HP51 | Pre-monsoon | P-1 | 26.6 | 7.34 | 1150 | 0 | 505 | 77 | 35 | 2 | 0.37 | BDL | 28 | 376 | 91 | 36 | 85 | 3.8 | 748 | 1.058 | BDL | BDL | 0.205 | BDL | 1.8 | BDL | 3.6 |
| 65 | HP51 | Post-monsoon | P-2 | 26.8 | 7.21 | 1098 | 0 | 488 | 70 | 29 | 6 | 0.28 | BDL | 25 | 375 | 86 | 39 | 73 | 2.5 | 714 | 0.850 | BDL | BDL | 0.200 | BDL | 1.1 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | HP52 | Pre-monsoon | P-1 | 29.8 | 6.90 | 1100 | 0 | 333 | 110 | 45 | 78 | 0.16 | BDL | 51 | 391 | 105 | 31 | 68 | 3.2 | 715 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 66 | HP52 | Post-monsoon | P-2 | 27.2 | 7.05 | 1052 | 0 | 336 | 107 | 35 | 55 | 0.21 | BDL | 42 | 395 | 104 | 33 | 55 | 2.5 | 684 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 67 | HP53 | Pre-monsoon | P-1 | 26.6 | 7.40 | 1700 | 0 | 481 | 237 | 62 | 40 | 0.42 | BDL | 35 | 574 | 107 | 75 | 120 | 4.8 | 1105 | 1.396 | BDL | BDL | 0.319 | BDL | 1.4 | BDL | BDL |
| 67 | HP53 | Post-monsoon | P-2 | 25.9 | 7.22 | 1705 | 0 | 525 | 237 | 28 | 57 | 0.30 | BDL | 43 | 545 | 110 | 66 | 135 | 5.8 | 1108 | 1.310 | 0.036 | 0.001 | 0.484 | 0.1 | 0.6 | 0.4 | 3.4 |
| 68 | HP54 | Pre-monsoon | P-1 | 28.9 | 7.58 | 1283 | 0 | 499 | 110 | 23 | 49 | 0.51 | BDL | 42 | 520 | 63 | 88 | 49 | 2.4 | 834 | 0.400 | BDL | BDL | BDL | BDL | 1.0 | BDL | BDL |
| 68 | HP54 | Post-monsoon | P-2 | 28.6 | 7.58 | 1165 | 0 | 476 | 87 | 30 | 36 | 0.51 | BDL | 48 | 450 | 76 | 63 | 57 | 1.9 | 757 | 0.280 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 69 | HP55 | Pre-monsoon | P-1 | 27.1 | 7.54 | 1295 | 0 | 481 | 117 | 52 | 10 | 0.45 | BDL | 33 | 317 | 71 | 34 | 142 | 3.6 | 842 | 0.328 | BDL | BDL | BDL | BDL | 1.1 | BDL | 2.7 |
| 69 | HP55 | Post-monsoon | P-2 | 25.8 | 7.42 | 1097 | 0 | 390 | 125 | 28 | 12 | 0.32 | BDL | 42 | 300 | 80 | 24 | 110 | 3.2 | 713 | 1.879 | 0.034 | 0.001 | 0.064 | 0.1 | 1.0 | 0.3 | 3.7 |
| 70 | HP56 | Pre-monsoon | P-1 | 27.1 | 7.12 | 1443 | 0 | 561 | 102 | 50 | 57 | 0.50 | BDL | 28 | 579 | 121 | 67 | 59 | 3.2 | 938 | 0.148 | BDL | BDL | 0.777 | BDL | 1.4 | BDL | BDL |
| 70 | HP56 | Post-monsoon | P-2 | 27 | 7.40 | 1440 | 0 | 604 | 97 | 45 | 49 | 0.55 | BDL | 35 | 575 | 122 | 66 | 65 | 2.0 | 936 | 0.058 | BDL | BDL | 0.280 | BDL | 0.2 | BDL | BDL |
| 71 | HP57 | Pre-monsoon | P-1 | 26.7 | 7.50 | 1052 | 0 | 333 | 105 | 82 | 7 | 0.32 | 0.07 | 30 | 436 | 111 | 39 | 34 | 3.1 | 684 | 0.107 | BDL | BDL | BDL | BDL | 1.1 | BDL | BDL |
| 71 | HP57 | Post-monsoon | P-2 | 26.8 | 7.48 | 1032 | 0 | 323 | 102 | 75 | 10 | 0.28 | BDL | 25 | 420 | 104 | 39 | 37 | 2.8 | 671 | BDL | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |
| 72 | HP58 | Pre-monsoon | P-1 | 28.1 | 7.24 | 1825 | 0 | 505 | 180 | 95 | 130 | 0.59 | BDL | 20 | 762 | 198 | 65 | 60 | 3.8 | 1186 | 0.715 | BDL | BDL | BDL | BDL | 1.1 | BDL | 5.2 |
| 72 | HP58 | Post-monsoon | P-2 | 27.2 | 7.05 | 1800 | 0 | 403 | 260 | 85 | 132 | 0.60 | 0.01 | 25 | 825 | 200 | 79 | 33 | 2.0 | 1170 | 1.657 | 0.039 | 0.001 | 0.018 | 0.1 | 0.8 | 0.5 | 7.2 |
| 73 | HP59 | Pre-monsoon | P-1 | 29.5 | 7.48 | 1628 | 0 | 592 | 175 | 50 | 10 | 0.31 | BDL | 61 | 550 | 121 | 60 | 115 | 3.5 | 1058 | 0.602 | BDL | BDL | 0.108 | BDL | 1.0 | BDL | 3.5 |
| 73 | HP59 | Post-monsoon | P-2 | 25.4 | 7.32 | 1541 | 0 | 531 | 192 | 46 | 15 | 0.3 | BDL | 65 | 625 | 124 | 77 | 65 | 2.4 | 1002 | 0.425 | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |
| 74 | HP60 | Pre-monsoon | P-1 | 28.1 | 7.84 | 822 | 0 | 327 | 22 | 65 | 25 | 0.34 | 0.24 | 28 | 258 | 59 | 26 | 62 | 3.2 | 534 | 0.082 | BDL | BDL | 0.063 | BDL | 1.5 | BDL | BDL |
| 74 | HP60 | Post-monsoon | P-2 | 26.7 | 7.74 | 835 | 0 | 354 | 25 | 63 | 29 | 0.42 | 0.20 | 32 | 270 | 48 | 36 | 68 | 2.9 | 543 | 0.009 | BDL | BDL | BDL | BDL | 0.4 | BDL | BDL |
| 75 | HP61 | Pre-monsoon | P-1 | 26.9 | 7.35 | 900 | 0 | 364 | 25 | 65 | 24 | 0.48 | BDL | 30 | 312 | 59 | 40 | 55 | 2.8 | 585 | 0.187 | BDL | BDL | 0.144 | BDL | 2.0 | BDL | BDL |
| 75 | HP61 | Post-monsoon | P-2 | 26.2 | 7.68 | 889 | 0 | 390 | 25 | 55 | 22 | 0.48 | BDL | 32 | 330 | 54 | 47 | 49 | 2.0 | 578 | 0.100 | BDL | BDL | BDL | BDL | 0.2 | BDL | BDL |

| S. No. | Source Code | Season | Category | Temp (°C) | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | As (ppb) | Pb (ppb) | Cr (ppb) | U (ppb) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | HP62 | Pre-monsoon | P-1 | 26.7 | 7.30 | 1605 | 0 | 536 | 155 | 72 | 52 | 0.44 | BDL | 21 | 545 | 145 | 45 | 111 | 3.8 | 1043 | 0.125 | BDL | BDL | BDL | BDL | 1.4 | BDL | BDL |
| 76 | HP62 | Post-monsoon | P-2 | 24.9 | 7.05 | 1486 | 0 | 512 | 157 | 45 | 55 | 0.42 | 0.02 | 25 | 470 | 136 | 32 | 124 | 2.2 | 966 | 0.580 | 0.025 | BDL | BDL | BDL | 0.4 | 0.2 | BDL |
| 77 | HP63 | Pre-monsoon | P-1 | 27.5 | 7.14 | 865 | 0 | 339 | 75 | 30 | 9 | 0.54 | BDL | 18 | 332 | 67 | 40 | 42 | 1.9 | 562 | BDL | BDL | BDL | BDL | 0.5 | 1.1 | BDL | BDL |
| 77 | HP63 | Post-monsoon | P-2 | 24.2 | 7.26 | 845 | 0 | 323 | 67 | 46 | 9 | 0.61 | BDL | 20 | 330 | 86 | 28 | 41 | 2.1 | 549 | BDL | BDL | BDL | BDL | BDL | 0.5 | BDL | BDL |
| 78 | HP64 | Pre-monsoon | P-1 | 29.7 | 7.72 | 882 | 0 | 388 | 57 | 12 | 25 | 0.33 | BDL | 25 | 337 | 91 | 26 | 43 | 2.1 | 573 | 0.155 | BDL | BDL | 0.228 | BDL | 0.7 | BDL | BDL |
| 78 | HP64 | Post-monsoon | P-2 | 26.7 | 7.65 | 823 | 0 | 378 | 50 | 10 | 18 | 0.30 | BDL | 28 | 330 | 84 | 29 | 35 | 1.8 | 535 | 0.100 | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 79 | HP65 | Pre-monsoon | P-1 | 28.9 | 6.71 | 682 | 0 | 160 | 67 | 59 | 41 | 0.07 | BDL | 32 | 277 | 79 | 19 | 24 | 2.8 | 443 | 0.921 | BDL | BDL | 0.103 | BDL | 1.2 | BDL | BDL |
| 79 | HP65 | Post-monsoon | P-2 | 25.6 | 6.75 | 700 | 0 | 207 | 65 | 46 | 35 | 0.05 | BDL | 28 | 275 | 74 | 22 | 32 | 2.1 | 455 | 0.580 | BDL | BDL | BDL | BDL | 0.9 | BDL | BDL |
| 80 | HP66 | Pre-monsoon | P-1 | 27.5 | 7.43 | 1070 | 0 | 419 | 70 | 33 | 20 | 0.54 | BDL | 35 | 317 | 91 | 22 | 65 | 33.0 | 696 | 0.568 | BDL | BDL | BDL | BDL | 1.1 | BDL | BDL |
| 80 | HP66 | Post-monsoon | P-2 | 24.3 | 7.25 | 1085 | 0 | 427 | 77 | 35 | 10 | 0.35 | BDL | 22 | 365 | 100 | 28 | 52 | 34.0 | 705 | 1.250 | 0.045 | BDL | BDL | BDL | 0.5 | 0.1 | BDL |
| 81 | HP67 | Pre-monsoon | P-1 | 29.6 | 6.62 | 742 | 0 | 191 | 82 | 60 | 26 | 0.16 | BDL | 41 | 193 | 63 | 8 | 80 | 2.7 | 482 | BDL | BDL | BDL | BDL | BDL | 1.5 | BDL | BDL |
| 81 | HP67 | Post-monsoon | P-2 | 23.8 | 6.72 | 732 | 0 | 232 | 80 | 48 | 15 | 0.11 | BDL | 40 | 215 | 56 | 18 | 68 | 3.0 | 476 | BDL | BDL | BDL | BDL | BDL | 0.1 | BDL | BDL |
| 82 | HP68 | Pre-monsoon | P-1 | 25.1 | 6.76 | 1033 | 0 | 444 | 65 | 22 | 34 | 0.64 | BDL | 22 | 337 | 105 | 18 | 69 | 14.5 | 671 | 2.634 | 0.557 | BDL | 1.034 | 3.0 | 7.3 | BDL | BDL |
| 82 | HP68 | Post-monsoon | P-2 | 27.9 | 7.15 | 955 | 0 | 390 | 70 | 25 | 30 | 0.65 | BDL | 25 | 340 | 68 | 41 | 55 | 10.9 | 621 | 1.987 | 0.660 | BDL | 0.950 | BDL | 1.5 | BDL | BDL |
| 83 | HP69 | Pre-monsoon | P-1 | 29.1 | 7.18 | 1185 | 0 | 450 | 95 | 15 | 46 | 0.74 | BDL | 38 | 386 | 109 | 28 | 88 | 3.5 | 770 | 0.124 | BDL | BDL | 0.078 | BDL | 1.1 | BDL | BDL |
| 83 | HP69 | Post-monsoon | P-2 | 26.4 | 7.25 | 1200 | 0 | 476 | 105 | 20 | 42 | 0.65 | BDL | 40 | 400 | 102 | 35 | 92 | 3.0 | 780 | BDL | BDL | BDL | BDL | BDL | 0.4 | BDL | BDL |

**Annexure-XIX: Groundwater quality data of Bhopal urban agglomerate of Surface water, Rain water and Exploratory Wells under NAQUIM 2.0**

| S. No. | Source Code | pH at 25°C | EC µS/cm at 25°C | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SW01 | 7.53 | 650 | 0 | 244 | 55 | 14 | 6.6 | 0.83 | BDL | 32.08 | 200 | 38 | 26 | 55 | 1.2 | 423 |
| 2 | SW02 | 6.90 | 545 | 0 | 207 | 42 | 15 | 11.2 | 0.48 | 0.94 | 14.37 | 190 | 46 | 18 | 32 | 7.0 | 354 |
| 3 | SW03 | 7.18 | 615 | 0 | 201 | 80 | 7 | 5 | 0.60 | BDL | 14.94 | 165 | 44 | 13 | 54 | 8.7 | 400 |
| 4 | SW04 | 7.20 | 260 | 0 | 79 | 17 | 20 | 8 | 0.10 | BDL | 20.28 | 105 | 32 | 6 | 8 | 2.0 | 169 |
| 5 | TW01 | 7.24 | 300 | 0 | 134 | 15 | 6 | 1 | 0.48 | BDL | 17.83 | 120 | 30 | 11 | 10.5 | 1.9 | 195 |
| 6 | SW05 | 6.72 | 285 | 0 | 117 | 25 | 1 | 6 | 0.34 | 0.3 | 4.27 | 94 | 28 | 6 | 18 | 3.2 | 185 |
| 7 | SW06 | 6.67 | 430 | 0 | 154 | 40 | 3 | 12.2 | 0.24 | 1.09 | 4.84 | 134 | 38 | 10 | 30 | 2.5 | 280 |
| 8 | SW07 | 7.42 | 265 | 0 | 92 | 15 | 10 | 4 | 0.19 | BDL | 21.6 | 99 | 28 | 7 | 8 | 1.4 | 172 |
| 9 | RW01 | 6.55 | 18 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 10 | RW02 | 6.65 | 16 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 11 | RW03 | 6.69 | 15 | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 12 | EW01 | 7.70 | 670 | 0 | 259 | 55 | 36 | 7 | 0.36 | 0 | 24 | 235 | 59 | 21 | 39 | 4.2 | 436 |
| 13 | EW02 | 8.06 | 308 | 0 | 146 | 12 | 1 | 7 | 0.07 | 0.26 | 29 | 135 | 22 | 19 | 9.1 | 1.2 | 200 |
| 14 | EW03 | 6.85 | 625 | 0 | 222 | 67 | 15 | 1 | 0.22 | BDL | 14 | 198 | 40 | 24 | 37.5 | 13.7 | 406 |
| 15 | EW04 | 7.30 | 775 | 0 | 339 | 47 | 21 | 2 | 0.69 | BDL | 32 | 302 | 75 | 28 | 33 | 1.9 | 504 |
| 16 | EW05 | 8.12 | 515 | 0 | 216 | 40 | 12 | 1 | 0.52 | BDL | 70 | 144 | 34 | 14 | 40 | 17.0 | 335 |
| 17 | EW06 | 7.42 | 1090 | 0 | 317 | 147 | 30 | 42 | 0.52 | BDL | 25 | 445 | 90 | 54 | 42 | 2.9 | 709 |
| 18 | EW07 | 7.74 | 620 | 0 | 228 | 56 | 15 | 6 | 0.19 | BDL | 25 | 253 | 85 | 10 | 23 | 5.2 | 403 |
| 19 | EW08 | 8.09 | 1125 | 0 | 140 | 252 | 29 | 2 | 1.48 | BDL | 29 | 75 | 12 | 11 | 198.5 | 2.5 | 731 |

**Annexure-XX: Chemical analysis results showing major ions concentrations in and around Bhanpur Khanti study area of Bhopal in Decmber-2014**

| S.No. | Address | Source Code | pH | EC | CO3 | HCO3 | Cl | SO4 | NO3 | F | PO4 | TH | Ca | Mg | Na | K | SiO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 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 | Agricultural Field of Agrawal Jewellers, Ayodya By Pass | $BW_1$ | 7.9 | 850 | 0 | 397 | 60 | 5 | 13 | 0.98 | 0.1 | 380 | 90 | 38 | 22 | 1 | 23 |
| 2 | In the Premises TripatiAbhinabh Homes, Ayodya By pass | $BW_2$ | 7.56 | 1060 | 0 | 366 | 117 | 33 | 37 | 0.94 | 0.05 | 430 | 110 | 38 | 47 | 0.4 | 20 |
| 3 | House of Om Prakash | $BW_3$ | 7.52 | 1065 | 0 | 366 | 110 | 25 | 59 | 0.71 | 0.07 | 445 | 120 | 35 | 39 | 0.5 | 20 |
| 4 | In front of Govt. Primary School, Ayodya By Pass | $HP_1$ | 7.69 | 1018 | 0 | 445 | 74 | 7 | 38 | 0.75 | 0.01 | 450 | 116 | 39 | 28 | 1.3 | 23 |
| 5 | Agricultural Field of Basant Patel | $BW_6$ | 7.29 | 1235 | 0 | 366 | 177 | 18 | 60 | 0.52 | 0.3 | 530 | 120 | 56 | 40 | 1.4 | 27 |
| 6 | Akshra Infra State, BhanpurKahnti Bridge | $BW_{10}$ | 7.13 | 1320 | 0 | 366 | 188 | 50 | 49 | 0.42 | 0.11 | 550 | 100 | 73 | 48 | 2.3 | 23 |
| 7 | House of Jalam Singh S/o Shri Mohar Singh | $BW_5$ | 7.61 | 1355 | 0 | 445 | 202 | 15 | 11 | 0.51 | 0.1 | 560 | 104 | 73 | 36 | 34 | 11 |
| 8 | Bhanpur Pump House of BNC at Bhanpur Crossing | $BW_9$ | 7.35 | 1320 | 0 | 391 | 181 | 32 | 62 | 0.41 | 0.11 | 580 | 114 | 72 | 35 | 1 | 35 |
| 9 | Agricultural Field of Munna Seth | $BW_4$ | 7.24 | 1650 | 0 | 427 | 259 | 50 | 71 | 0.67 | 0.06 | 660 | 190 | 45 | 74 | 2.3 | 23 |
| 10 | House of Sunder Lal, Vidisha Road | $BW_7$ | 7.12 | 1540 | 0 | 537 | 206 | 36 | 1 | 0.18 | 0.43 | 670 | 128 | 85 | 43 | 1 | 18 |
| 11 | House of Baliram | $BW_{11}$ | 7.26 | 1480 | 0 | 348 | 230 | 100 | 30 | 0.26 | 0.096 | 735 | 182 | 68 | 3 | 0.5 | 40 |
| 12 | House of Rajesh Sharma | $BW_{12}$ | 7.23 | 1508 | 0 | 366 | 227 | 108 | 19 | 0.21 | 0.224 | 740 | 186 | 67 | 4 | 3.2 | 32 |
| 13 | House of Suresh S/O Shri Baliram | $BW_{13}$ | 7.26 | 1640 | 0 | 390 | 255 | 128 | 6 | 0.24 | 0.884 | 795 | 210 | 66 | 6 | 8.6 | 31 |
| 14 | In Front of Naveen Middle School | $DW_1$ | 7.62 | 1770 | 0 | 360 | 319 | 60 | 97 | 0.76 | 0.09 | 810 | 210 | 69 | 34 | 1.5 | 32 |
| 15 | Kushwaha Auto Part & Service Centre, Vidisha Road | $BW_8$ | 7.01 | 2020 | 0 | 537 | 337 | 70 | 83 | 0.31 | 0.11 | 900 | 144 | 131 | 70 | 1.1 | 25 |

**Annexure- XXI: Chemical analysis results showing major ions concentrations in and around Union Carbide India Limited (UCIL), Bhopal 2011**

| S. No. | District | Location | Source | pH | EC | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | F | TH | Ca | Mg | Na | K | Fe | Mn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 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 | **Bhopal** | Chandbad | HP | 6.96 | 2990 | 0 | 348 | 422 | 250 | 441 | 0.17 | 940 | 332 | 27 | 228 | 48 | 0.29 | 0.023 | 0.615 |
| 2 | **Bhopal** | Rail Coach Factory | TW | 7.05 | 1280 | 0 | 403 | 163 | 35 | 52 | 0.34 | 405 | 144 | 11 | 107 | 1 | 0 | 0 | 0.252 |
| 3 | **Bhopal** | Chhola Dashera Maidan | TW | 6.8 | 1980 | 0 | 427 | 344 | 75 | 95 | 0.28 | 715 | 236 | 30 | 125 | 2.5 | 0 | 0 | 0.293 |
| 4 | **Bhopal** | Shankar Nagar | TW | 6.94 | 1242 | 0 | 317 | 177 | 38 | 85 | 0.25 | 500 | 156 | 27 | 54 | 1.5 | 0.067 | 0.009 | 0.28 |
| 5 | **Bhopal** | Sundar Nagar | HP | 7.06 | 2785 | 0 | 238 | 730 | 70 | 117 | 0.82 | 735 | 224 | 43 | 296 | 10.1 | 1.225 | 0.232 | 0.143 |
| 6 | **Bhopal** | Chhola Naka | TW | 6.76 | 2215 | 0 | 512 | 330 | 124 | 113 | 0.38 | 895 | 230 | 78 | 95 | 3.2 | 0.11 | 0 | 0.742 |
| 7 | **Bhopal** | J.P. Nagar | TW | 7.06 | 1030 | 0 | 329 | 96 | 45 | 77 | 0.6 | 405 | 94 | 41 | 50 | 0.7 | 0.026 | 0 | 0.055 |
| 8 | **Bhopal** | DIG Banglow | DW | 7.31 | 835 | 0 | 262 | 67 | 45 | 74 | 0.54 | 305 | 86 | 22 | 45 | 11.1 | 0.74 | 0 | 0.045 |
| 9 | **Bhopal** | Ashima Colony | HP | 7.16 | 1315 | 0 | 354 | 216 | 11 | 64 | 0.66 | 460 | 114 | 43 | 90 | 2 | 0.61 | 0 | 0.246 |
| 10 | **Bhopal** | Geetanjali College | HP | 7.04 | 1060 | 0 | 415 | 78 | 32 | 54 | 0.52 | 380 | 104 | 29 | 67 | 2.3 | 2.68 | 0.02 | 1.975 |
| 11 | **Bhopal** | Phoota Makabara | HP | 7 | 695 | 0 | 214 | 60 | 58 | 33 | 0.43 | 285 | 72 | 26 | 25 | 6.8 | 0.134 | 0 | 0.368 |
| 12 | **Bhopal** | Nadra Bus Stand | HP | 7.24 | 465 | 0 | 201 | 25 | 20 | 15 | 0.26 | 195 | 60 | 11 | 12.5 | 8.9 | 0.11 | 0 | 0.09 |

**Annexure: XXII: Showing Groundwater Quality Results for basic parameters of areas surrounding Union Carbide India limited, Bhopal, 2023**

| S. No. | Parameters Analysed | | pH | EC | CO3 | HCO3 | Cl | SO4 | NO3 | Fluoride | PO4 | SiO2 | TH | Ca | Mg | Na | K | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acceptable and Permissible limits of BIS standards | | 6.5 - 7.5 | | | 200 to 600 | 250 to 1000 | 200 to 400 | 45 to No relaxation | 1.0 to 1.5 | | | 200 to 600 | 75 to 200 | 30 to 100 | | | 500 to 2000 |
| | Location | Sources | at 25°C | µS/cm at 25°C | mg/l | | | | | | | | | | | | | |
| 1 | Subhash Nagar | HP | 7.10 | 1106 | 0 | 421 | 82 | 40 | 13 | 0.41 | 0.03 | 13 | 342 | 107 | 18 | 57 | 40.0 | 719 |
| 2 | Govindpura | BW | 7.25 | 1544 | 0 | 378 | 252 | 44 | 36 | 0.34 | 0.04 | 35 | 480 | 119 | 45 | 117 | 8.4 | 1004 |
| 3 | Semra Kalan | HP | 6.96 | 1554 | 0 | 470 | 178 | 52 | 66 | 0.39 | 0.02 | 28 | 460 | 156 | 17 | 134 | 2.9 | 1010 |
| 4 | Railway Coach Factory | BW | 7.11 | 1332 | 0 | 378 | 198 | 72 | 6 | 0.10 | 0.03 | 23 | 351 | 137 | 2 | 126 | 2.2 | 866 |
| 5 | Chhola | HP | 7.02 | 1354 | 0 | 494 | 141 | 36 | 11 | 0.31 | 0.04 | 20 | 421 | 135 | 20 | 109 | 6.8 | 880 |
| 6 | Bhopal Railway Junction | HP | 6.94 | 1845 | 0 | 378 | 287 | 95 | 142 | 0.57 | 0.02 | 22 | 827 | 212 | 72 | 45 | 2.6 | 1199 |
| 7 | Mangalwara | HP | 7.13 | 745 | 0 | 275 | 89 | 18 | 9 | 0.05 | 2.33 | 43 | 262 | 67 | 23 | 45 | 23.1 | 484 |
| 8 | Khanugaon | HP | 6.86 | 936 | 0 | 268 | 99 | 20 | 58 | 0.16 | 0.21 | 26 | 257 | 83 | 12 | 69 | 26.5 | 608 |
| 9 | Lalghati | HP | 6.86 | 502 | 0 | 214 | 40 | 18 | 5 | 0.05 | 0.09 | 68 | 203 | 53 | 17 | 24 | 2.9 | 326 |
| 10 | Gufa Mandir | DW | 6.74 | 605 | 0 | 201 | 72 | 44 | 8 | 0.05 | 0.11 | 8 | 203 | 61 | 12 | 51 | 7.0 | 393 |
| 11 | Gitanjali College (S) | BW | 6.91 | 812 | 0 | 378 | 72 | 14 | 8 | 0.30 | 0.08 | 17 | 243 | 85 | 7 | 87 | 2.3 | 528 |
| 12 | Geetanjali College (D) | BW | 6.93 | 2051 | 0 | 519 | 465 | 34 | 8 | 0.44 | 0.08 | 22 | 683 | 135 | 84 | 175 | 2.5 | 1333 |
| 13 | DIG Bunglow | DW | 7.54 | 972 | 0 | 397 | 67 | 26 | 1 | 0.70 | 0.25 | 29 | 238 | 55 | 24 | 92 | 6.1 | 632 |
| 14 | JP Nagar | BW | 7.04 | 1301 | 0 | 519 | 161 | 12 | 1 | 0.41 | 0.08 | 24 | 406 | 113 | 30 | 116 | 3.4 | 846 |
| 15 | KenchiChhola | BW | 6.88 | 1669 | 0 | 458 | 248 | 48 | 104 | 0.22 | 0.07 | 23 | 545 | 182 | 22 | 142 | 4.5 | 1085 |
| 16 | Shankar Nagar | BW | 6.90 | 1332 | 0 | 403 | 186 | 36 | 44 | 0.22 | 0.54 | 20 | 421 | 133 | 22 | 108 | 6.3 | 866 |
| 17 | Bhanpur | BW | 7.16 | 1125 | 0 | 409 | 139 | 18 | 10 | 0.28 | 0.1 | 25 | 351 | 131 | 6 | 93 | 3.5 | 731 |
| 18 | Daamkheda | HP | 7.17 | 1358 | 0 | 415 | 181 | 20 | 114 | 0.44 | 0.09 | 27 | 465 | 145 | 25 | 106 | 15.5 | 883 |
| 19 | Nabibagh | DW | 7.33 | 1074 | 0 | 354 | 129 | 20 | 24 | 0.52 | 0.1 | 48 | 351 | 99 | 25 | 71 | 4.3 | 698 |
| 20 | Panna Nagar | HP | 7.30 | 1155 | 0 | 415 | 136 | 34 | 11 | 0.40 | 0.09 | 38 | 307 | 81 | 25 | 126 | 4.0 | 751 |
| 21 | Badwai | HP | 7.14 | 2497 | 0 | 683 | 406 | 88 | 54 | 0.56 | 0.15 | 56 | 634 | 103 | 92 | 314 | 19.6 | 1623 |

| S. No. | Parameters Analysed | | pH | EC | $CO_3$ | $HCO_3$ | Cl | $SO_4$ | $NO_3$ | Fluoride | $PO_4$ | $SiO_2$ | TH | Ca | Mg | Na | K | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Acceptable and Permissible limits of BIS standards** | | **6.5 - 7.5** | | | **200 to 600** | **250 to 1000** | **200 to 400** | **45 to No relaxation** | **1.0 to 1.5** | | | **200 to 600** | **75 to 200** | **30 to 100** | | | **500 to 2000** |
| | **Location** | **Sources** | **at 25°C** | **µS/cm at 25°C** | **mg/l** | | | | | | | | | | | | | |
| 22 | RGPV University | BW | 7.33 | 612 | 0 | 220 | 57 | 30 | 14 | 0.35 | 0.16 | 74 | 193 | 55 | 13 | 50 | 4.4 | 398 |
| 23 | Navri | BW | 6.75 | 1056 | 0 | 256 | 203 | 26 | 4 | 0.16 | 0.09 | 25 | 366 | 143 | 2 | 75 | 3.8 | 686 |
| 24 | Golghar Museum | BW | 7.37 | 745 | 0 | 275 | 82 | 22 | 15 | 0.31 | 1.09 | 20 | 228 | 71 | 12 | 58 | 16.2 | 484 |
| 25 | Shahjahanabad | DW | 7.07 | 615 | 0 | 262 | 62 | 16 | 2 | 0.19 | 0.31 | 24 | 198 | 61 | 11 | 47 | 18.1 | 400 |
| 26 | Sundar Nagar | BW | 7.10 | 1685 | 0 | 336 | 364 | 36 | 3 | 0.91 | 0.1 | 18 | 475 | 131 | 36 | 145 | 5.2 | 1095 |
| 27 | Ashoka Garden | BW | 7.61 | 1126 | 0 | 342 | 144 | 38 | 32 | 0.42 | 0.08 | 23 | 322 | 113 | 10 | 98 | 4.7 | 732 |
| 28 | Jhangirabad | HP | 6.97 | 777 | 0 | 336 | 62 | 9 | 2 | 0.31 | 0.09 | 24 | 208 | 59 | 14 | 69 | 19.6 | 505 |
| 29 | Bharat Talkies | BW | 7.10 | 983 | 0 | 390 | 82 | 10 | 3 | 0.12 | 0.34 | 37 | 297 | 83 | 22 | 60 | 18.2 | 639 |
| 30 | Murli Nagar | BW | 7.39 | 1030 | 0 | 409 | 69 | 32 | 9 | 0.76 | 0.13 | 56 | 223 | 40 | 30 | 112 | 5.2 | 670 |
| 31 | Palasi Village | BW | 7.17 | 1731 | 0 | 488 | 225 | 32 | 67 | 0.36 | 0.1 | 48 | 485 | 133 | 37 | 142 | 6.4 | 1125 |
| 32 | Karond | BW | 7.31 | 1322 | 0 | 415 | 188 | 36 | 21 | 0.52 | 0.12 | 56 | 332 | 61 | 43 | 151 | 4.9 | 859 |
| 33 | Bhopal Memorial Hospital | BW | 7.57 | 1563 | 0 | 415 | 252 | 46 | 6 | 0.11 | 0.09 | 44 | 262 | 44 | 37 | 222 | 5.3 | 1016 |
| 34 | Bhanpur | BW | 7.07 | 1125 | 0 | 354 | 163 | 26 | 36 | 0.32 | 0.11 | 30 | 351 | 109 | 19 | 98 | 5.5 | 731 |
| 35 | Khejda | BW | 7.04 | 1456 | 0 | 275 | 307 | 34 | 32 | 0.31 | 0.11 | 38 | 515 | 194 | 7 | 78 | 5.2 | 946 |
| 36 | Barkhedi | BW | 6.97 | 812 | 0 | 342 | 67 | 12 | 6 | 0.34 | 0.18 | 16 | 213 | 67 | 11 | 75 | 22.1 | 528 |

## Annexure-XXIII: Showing Groundwater Quality Results for heavy metals of areas surrounding Union Carbide India limited, Bhopal, 2023

| S. No. | Parameters Analysed | | B | Al | Cr | Mn | Fe | Ni | Cu | Zn | As | Se | Sr | Mo | Ag | Cd | Ba | Hg | Pb | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acceptable and Permissible limits of BIS standards | | 0.5 to 1.0 | 0.03 to 0.2 | 0.05 to No relaxation | 0.1 to 0.3 | 1.0 to No relaxation | 0.02 to No relaxation | 0.05 to 1.50 | 5 to 15 | 0.01 to No relaxation | 0.01 to No relaxation | | 0.07 to No relaxation | 0.1 to No relaxation | 0.003 to No relaxation | 0.7 to No relaxation | 0.001 to No relaxation | 0.05 to No relaxation | 0.03 to No relaxation |
| | Locations | Sources | 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 | mg/L |
| 1 | Subhash Nagar | HP | 0.122 | 0.011 | 0.000 | 0.071 | 1.436 | 0.001 | 0.006 | 0.059 | 0.002 | 0.000 | 0.320 | 0.008 | 0.001 | 0.000 | 0.082 | 0.000 | 0.008 | 0.006 |
| 2 | Govindpura | BW | 0.110 | 0.018 | 0.000 | 0.001 | 0.042 | 0.001 | 0.004 | 0.011 | 0.005 | 0.006 | 1.107 | 0.007 | 0.018 | 0.000 | 0.151 | 0.000 | 0.002 | 0.014 |
| 3 | Semra Kalan | HP | 0.050 | 0.022 | 0.000 | 0.062 | 1.023 | 0.002 | 0.004 | 0.031 | 0.000 | 0.000 | 0.757 | 0.006 | 0.025 | 0.000 | 0.098 | 0.000 | 0.003 | 0.002 |
| 4 | Railway Coach Factory | BW | 0.025 | 0.051 | 0.000 | 0.020 | 0.425 | 0.001 | 0.001 | 0.031 | 0.000 | 0.000 | 0.806 | 0.005 | 0.026 | 0.000 | 0.099 | 0.000 | 0.020 | 0.003 |
| 5 | Chhola | HP | 0.062 | 0.004 | 0.000 | 0.082 | 5.383 | 0.002 | 0.006 | 0.340 | 0.000 | 0.000 | 1.070 | 0.000 | 0.000 | 0.000 | 0.099 | 0.000 | 0.003 | 0.010 |
| 6 | Bhopal Railway Junction | HP | 0.072 | 0.016 | 0.000 | 0.039 | 1.657 | 0.002 | 0.001 | 0.018 | 0.000 | 0.000 | 1.895 | 0.001 | 0.019 | 0.000 | 0.171 | 0.000 | 0.001 | 0.007 |
| 7 | Mangalwara | HP | 0.041 | 0.016 | 0.000 | 0.166 | 0.452 | 0.002 | 0.002 | 0.036 | 0.004 | 0.000 | 0.208 | 0.007 | 0.012 | 0.000 | 0.078 | 0.000 | 0.001 | 0.000 |
| 8 | Khanugaon | HP | 0.038 | 0.019 | 0.001 | 0.260 | 4.707 | 0.007 | 0.005 | 8.373 | 0.001 | 0.000 | 0.247 | 0.004 | 0.009 | 0.001 | 0.096 | 0.000 | 0.005 | 0.000 |
| 9 | Lalghati | HP | 0.000 | 0.006 | 0.001 | 0.115 | 10.073 | 0.001 | 0.012 | 0.219 | 0.000 | 0.000 | 0.214 | 0.001 | 0.005 | 0.000 | 0.013 | 0.000 | 0.005 | 0.000 |
| 10 | Gufa Mandir | DW | 0.004 | 0.022 | 0.000 | 0.240 | 0.149 | 0.003 | 0.002 | 0.118 | 0.000 | 0.000 | 0.203 | 0.002 | 0.007 | 0.000 | 0.116 | 0.000 | 0.001 | 0.000 |
| 11 | Gitanjali College (S) | BW | 0.133 | 0.041 | 0.000 | 0.164 | 0.414 | 0.002 | 0.002 | 0.058 | 0.000 | 0.000 | 2.223 | 0.004 | 0.031 | 0.000 | 0.146 | 0.000 | 0.001 | 0.007 |
| 12 | Geetanjali College (D) | BW | 0.012 | 0.016 | 0.000 | 0.005 | 0.037 | 0.000 | 0.001 | 0.007 | 0.000 | 0.000 | 0.531 | 0.004 | 0.015 | 0.000 | 0.090 | 0.000 | 0.001 | 0.002 |
| 13 | DIG Bunglow | DW | 0.114 | 0.026 | 0.000 | 0.092 | 0.063 | 0.001 | 0.001 | 0.007 | 0.001 | 0.000 | 0.518 | 0.002 | 0.005 | 0.000 | 0.094 | 0.000 | 0.002 | 0.002 |
| 14 | JP Nagar | BW | 0.096 | 0.015 | 0.000 | 0.069 | 0.245 | 0.002 | 0.001 | 0.023 | 0.000 | 0.000 | 1.417 | 0.001 | 0.006 | 0.000 | 0.078 | 0.000 | 0.001 | 0.006 |
| 15 | KenchiChhola | BW | 0.035 | 0.010 | 0.000 | 0.018 | 0.059 | 0.001 | 0.002 | 0.014 | 0.000 | 0.000 | 1.394 | 0.001 | 0.009 | 0.000 | 0.161 | 0.000 | 0.001 | 0.013 |
| 16 | Shankar Nagar | BW | 0.059 | 0.018 | 0.000 | 0.480 | 0.067 | 0.002 | 0.007 | 0.006 | 0.001 | 0.000 | 1.215 | 0.002 | 0.012 | 0.000 | 0.145 | 0.000 | 0.001 | 0.006 |
| 17 | Bhanpur | BW | 0.043 | 0.053 | 0.000 | 0.581 | 0.419 | 0.003 | 0.012 | 0.038 | 0.001 | 0.000 | 1.121 | 0.001 | 0.003 | 0.000 | 0.179 | 0.000 | 0.003 | 0.004 |
| 18 | Daamkheda | HP | 0.090 | 0.000 | 0.000 | 0.031 | 0.001 | 0.001 | 0.001 | 0.876 | 0.000 | 0.003 | 1.620 | 0.000 | 0.000 | 0.000 | 0.029 | 0.000 | 0.000 | 0.004 |
| 19 | Nabibagh | DW | 0.059 | 0.016 | 0.000 | 0.008 | 0.034 | 0.001 | 0.002 | 0.022 | 0.000 | 0.001 | 0.813 | 0.001 | 0.012 | 0.000 | 0.046 | 0.000 | 0.001 | 0.002 |

| S. No. | Parameters Analysed | | B | Al | Cr | Mn | Fe | Ni | Cu | Zn | As | Se | Sr | Mo | Ag | Cd | Ba | Hg | Pb | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acceptable and Permissible limits of BIS standards | | 0.5 to 1.0 | 0.03 to 0.2 | 0.05 to No relaxation | 0.1 to 0.3 | 1.0 to No relaxation | 0.02 to No relaxation | 0.05 to 1.50 | 5 to 15 | 0.01 to No relaxation | 0.01 to No relaxation | | 0.07 to No relaxation | 0.1 to No relaxation | 0.003 to No relaxation | 0.7 to No relaxation | 0.001 to No relaxation | 0.05 to No relaxation | 0.03 to No relaxation |
| | Locations | Sources | 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 | mg/L |
| 20 | Panna Nagar | HP | 0.147 | 0.026 | 0.000 | 0.034 | 1.879 | 0.001 | 0.001 | 0.064 | 0.000 | 0.000 | 0.754 | 0.001 | 0.010 | 0.000 | 0.068 | 0.000 | 0.001 | 0.004 |
| 21 | Badwai | HP | 0.228 | 0.027 | 0.000 | 0.052 | 0.434 | 0.001 | 0.003 | 0.156 | 0.001 | 0.003 | 1.976 | 0.003 | 0.013 | 0.000 | 0.054 | 0.000 | 0.001 | 0.008 |
| 22 | RGPV University | BW | 0.036 | 0.007 | 0.000 | 0.001 | 0.030 | 0.000 | 0.010 | 0.013 | 0.000 | 0.000 | 0.198 | 0.001 | 0.042 | 0.000 | 0.073 | 0.000 | 0.001 | 0.000 |
| 23 | Navri | BW | 0.013 | 0.023 | 0.000 | 0.166 | 4.398 | 0.001 | 0.001 | 0.090 | 0.000 | 0.000 | 1.152 | 0.002 | 0.021 | 0.000 | 0.080 | 0.000 | 0.001 | 0.001 |
| 24 | Golghar Museum | BW | 0.025 | 0.133 | 0.000 | 0.116 | 0.611 | 0.002 | 0.001 | 0.010 | 0.012 | 0.000 | 0.234 | 0.011 | 0.004 | 0.000 | 0.190 | 0.000 | 0.001 | 0.003 |
| 25 | Shahjahanabad | DW | 0.038 | 0.025 | 0.000 | 0.473 | 3.981 | 0.001 | 0.001 | 0.015 | 0.005 | 0.000 | 0.285 | 0.002 | 0.007 | 0.000 | 0.161 | 0.000 | 0.001 | 0.000 |
| 26 | Sundar Nagar | BW | 0.122 | 0.018 | 0.000 | 0.163 | 0.118 | 0.003 | 0.001 | 0.007 | 0.001 | 0.000 | 1.353 | 0.001 | 0.005 | 0.000 | 0.143 | 0.000 | 0.001 | 0.005 |
| 27 | Ashoka Garden | BW | 0.034 | 0.000 | 0.000 | 0.007 | 0.956 | 0.001 | 0.000 | 0.010 | 0.000 | 0.000 | 0.608 | 0.000 | 0.001 | 0.000 | 0.055 | 0.000 | 0.000 | 0.002 |
| 28 | Jhangirabad | HP | 0.024 | 0.013 | 0.000 | 0.079 | 11.664 | 0.001 | 0.002 | 0.083 | 0.000 | 0.000 | 0.207 | 0.003 | 0.012 | 0.000 | 0.086 | 0.000 | 0.004 | 0.001 |
| 29 | Bharat Talkies | BW | 0.040 | 0.009 | 0.000 | 0.006 | 0.028 | 0.001 | 0.001 | 0.017 | 0.001 | 0.000 | 0.308 | 0.002 | 0.001 | 0.000 | 0.116 | 0.000 | 0.001 | 0.002 |
| 30 | Murli Nagar | BW | 0.100 | 0.008 | 0.000 | 0.010 | 0.075 | 0.000 | 0.001 | 0.028 | 0.000 | 0.000 | 0.392 | 0.001 | 0.002 | 0.000 | 0.033 | 0.000 | 0.001 | 0.002 |
| 31 | Palasi Village | BW | 0.068 | 0.006 | 0.000 | 0.036 | 1.310 | 0.002 | 0.001 | 0.484 | 0.000 | 0.000 | 1.289 | 0.001 | 0.006 | 0.000 | 0.118 | 0.000 | 0.001 | 0.003 |
| 32 | Karond | BW | 0.073 | 0.020 | 0.000 | 0.003 | 0.048 | 0.000 | 0.002 | 0.013 | 0.000 | 0.000 | 0.566 | 0.001 | 0.006 | 0.000 | 0.041 | 0.000 | 0.001 | 0.002 |
| 33 | Bhopal Memorial Hospital | BW | 0.127 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.409 | 0.000 | 0.000 | 0.000 | 0.017 | 0.000 | 0.000 | 0.003 |
| 34 | Bhanpur | BW | 0.050 | 0.000 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | 0.021 | 0.003 | 0.000 | 0.986 | 0.000 | 0.000 | 0.000 | 0.055 | 0.000 | 0.000 | 0.005 |
| 35 | Khejda | BW | 0.044 | 0.008 | 0.000 | 0.003 | 0.097 | 0.001 | 0.001 | 0.031 | 0.000 | 0.000 | 1.374 | 0.001 | 0.010 | 0.000 | 0.080 | 0.000 | 0.001 | 0.003 |
| 36 | Barkhedi | BW | 0.029 | 0.000 | 0.000 | 0.024 | 0.000 | 0.001 | 0.001 | 0.018 | 0.001 | 0.000 | 0.230 | 0.001 | 0.000 | 0.000 | 0.124 | 0.000 | 0.000 | 0.002 |

**Annexure-XXIV: Correlation matrix of pre-monsoon water samples of Shallow aquifer**

| | *pH* | *EC* | *HCO3* | *Cl* | *SO4* | *NO3* | *F* | *PO4* | *SiO2* | *TH* | *Ca* | *Mg* | *Na* | *K* | *TDS* | *Fe* | *Mn* | *Zn* | *As* | *Pb* | *Cr)* | *U* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| EC | 0.07 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| HCO3 | 0.20 | 0.85 | 1.00 | | | | | | | | | | | | | | | | | | | |
| Cl | -0.05 | 0.87 | 0.56 | 1.00 | | | | | | | | | | | | | | | | | | |
| SO4 | -0.04 | 0.34 | 0.04 | 0.29 | 1.00 | | | | | | | | | | | | | | | | | |
| NO3 | -0.14 | 0.35 | 0.09 | 0.25 | 0.13 | 1.00 | | | | | | | | | | | | | | | | |
| F | 0.24 | 0.13 | 0.23 | -0.01 | -0.06 | 0.04 | 1.00 | | | | | | | | | | | | | | | |
| PO4 | 0.11 | 0.11 | 0.10 | 0.13 | -0.06 | -0.05 | -0.16 | 1.00 | | | | | | | | | | | | | | |
| SiO2 | 0.12 | 0.25 | 0.31 | 0.17 | 0.05 | -0.03 | -0.14 | 0.10 | 1.00 | | | | | | | | | | | | | |
| TH | 0.01 | 0.90 | 0.75 | 0.76 | 0.33 | 0.40 | 0.01 | 0.09 | 0.29 | 1.00 | | | | | | | | | | | | |
| Ca | -0.22 | 0.69 | 0.50 | 0.57 | 0.39 | 0.48 | -0.04 | 0.09 | 0.18 | 0.79 | 1.00 | | | | | | | | | | | |
| Mg | 0.26 | 0.69 | 0.66 | 0.59 | 0.09 | 0.11 | 0.07 | 0.04 | 0.26 | 0.73 | 0.16 | 1.00 | | | | | | | | | | |
| Na | 0.14 | 0.55 | 0.51 | 0.53 | 0.11 | 0.02 | 0.28 | 0.06 | 0.06 | 0.15 | 0.04 | 0.20 | 1.00 | | | | | | | | | |
| K | 0.03 | 0.14 | 0.09 | 0.15 | 0.03 | 0.00 | 0.06 | 0.26 | -0.12 | 0.02 | 0.18 | -0.17 | 0.16 | 1.00 | | | | | | | | |
| TDS | 0.07 | 1.00 | 0.85 | 0.87 | 0.34 | 0.35 | 0.13 | 0.11 | 0.25 | 0.90 | 0.69 | 0.69 | 0.55 | 0.14 | 1.00 | | | | | | | |
| Fe | -0.13 | 0.17 | 0.20 | 0.13 | -0.02 | -0.01 | 0.16 | 0.15 | 0.01 | 0.07 | 0.11 | -0.01 | 0.24 | 0.32 | 0.17 | 1.00 | | | | | | |
| Mn | -0.22 | 0.02 | 0.10 | 0.04 | -0.17 | -0.11 | 0.21 | 0.10 | -0.11 | -0.13 | -0.05 | -0.15 | 0.31 | 0.26 | 0.02 | 0.42 | 1.00 | | | | | |
| Zn | 0.09 | 0.09 | 0.06 | 0.12 | -0.06 | 0.04 | -0.14 | 0.55 | 0.07 | 0.12 | 0.19 | -0.02 | -0.03 | 0.20 | 0.09 | 0.05 | 0.00 | 1.00 | | | | |
| As | -0.19 | -0.11 | -0.03 | -0.07 | -0.20 | -0.08 | -0.01 | 0.13 | 0.00 | -0.19 | -0.11 | -0.18 | 0.14 | 0.18 | -0.11 | 0.24 | 0.69 | -0.04 | 1.00 | | | |
| Pb | -0.18 | -0.04 | 0.02 | -0.07 | -0.03 | -0.07 | 0.26 | -0.07 | -0.12 | -0.07 | 0.01 | -0.12 | 0.02 | 0.16 | -0.04 | 0.56 | 0.56 | 0.04 | 0.30 | 1.00 | | |
| Cr | 0.10 | 0.02 | 0.08 | -0.01 | -0.08 | -0.05 | 0.04 | 0.15 | 0.14 | 0.05 | -0.16 | 0.26 | -0.04 | -0.10 | 0.02 | -0.08 | -0.06 | -0.04 | 0.00 | -0.02 | 1.00 | |
| U | 0.13 | 0.46 | 0.42 | 0.41 | 0.09 | 0.04 | 0.06 | -0.04 | -0.10 | 0.38 | 0.15 | 0.45 | 0.31 | 0.08 | 0.46 | 0.12 | 0.01 | -0.07 | 0.02 | 0.05 | 0.11 | 1.00 |

## Annexure-XXV: Co-relation matrix of post-monsoon water samples of Shallow aquifer

| | pH | EC | HCO3 | Cl | SO4 | NO3 | F | PO4 | SiO2 | TH | Ca | Mg | Na | K | TDS | Fe | Mn | Cu | Zn | As | Pb | Cr) | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.00 | | | | | | | | | | | | | | | | | | | | | | |
| EC | -0.09 | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| HCO3 | 0.09 | 0.86 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| Cl | -0.19 | 0.85 | 0.52 | 1.00 | | | | | | | | | | | | | | | | | | | |
| SO4 | -0.20 | 0.41 | 0.15 | 0.38 | 1.00 | | | | | | | | | | | | | | | | | | |
| NO3 | -0.16 | 0.41 | 0.15 | 0.38 | 0.25 | 1.00 | | | | | | | | | | | | | | | | | |
| F | 0.36 | 0.14 | 0.25 | 0.00 | -0.10 | 0.08 | 1.00 | | | | | | | | | | | | | | | | |
| PO4 | 0.02 | 0.12 | 0.20 | 0.06 | -0.03 | -0.06 | 0.02 | 1.00 | | | | | | | | | | | | | | | |
| SiO2 | 0.01 | 0.35 | 0.41 | 0.25 | -0.02 | 0.00 | -0.03 | 0.19 | 1.00 | | | | | | | | | | | | | | |
| TH | -0.06 | 0.88 | 0.71 | 0.78 | 0.47 | 0.45 | 0.05 | 0.02 | 0.32 | 1.00 | | | | | | | | | | | | | |
| Ca | -0.23 | 0.72 | 0.50 | 0.70 | 0.50 | 0.46 | -0.03 | 0.02 | 0.20 | 0.85 | 1.00 | | | | | | | | | | | | |
| Mg | 0.13 | 0.76 | 0.70 | 0.61 | 0.28 | 0.30 | 0.12 | 0.01 | 0.34 | 0.83 | 0.42 | 1.00 | | | | | | | | | | | |
| Na | -0.06 | 0.61 | 0.62 | 0.48 | 0.08 | 0.11 | 0.22 | 0.24 | 0.23 | 0.18 | 0.09 | 0.22 | 1.00 | | | | | | | | | | |
| K | -0.13 | 0.16 | 0.11 | 0.18 | 0.00 | 0.02 | -0.04 | 0.14 | -0.17 | 0.00 | 0.09 | -0.09 | 0.23 | 1.00 | | | | | | | | | |
| TDS | -0.09 | 1.00 | 0.86 | 0.85 | 0.41 | 0.41 | 0.14 | 0.12 | 0.35 | 0.88 | 0.73 | 0.76 | 0.61 | 0.16 | 1.00 | | | | | | | | |
| Fe | -0.20 | 0.14 | 0.13 | 0.14 | -0.08 | 0.06 | 0.03 | 0.08 | -0.13 | 0.02 | 0.05 | -0.01 | 0.23 | 0.28 | 0.14 | 1.00 | | | | | | | |
| Mn | 0.01 | -0.05 | 0.00 | -0.08 | -0.07 | -0.03 | 0.23 | 0.07 | -0.10 | -0.11 | -0.14 | -0.05 | 0.08 | 0.11 | -0.05 | 0.49 | 1.00 | | | | | | |
| Cu | -0.08 | 0.06 | -0.06 | 0.20 | -0.05 | 0.13 | -0.06 | -0.04 | 0.10 | 0.04 | 0.06 | 0.01 | 0.04 | 0.21 | 0.06 | 0.16 | 0.09 | 1.00 | | | | | |
| Zn | -0.12 | 0.02 | -0.03 | 0.08 | -0.09 | 0.04 | -0.13 | 0.06 | 0.06 | -0.02 | 0.04 | -0.07 | 0.03 | 0.23 | 0.02 | 0.26 | 0.09 | -0.03 | 1.00 | | | | |
| As | -0.05 | -0.10 | -0.12 | -0.02 | -0.13 | -0.05 | -0.14 | -0.02 | 0.09 | -0.10 | -0.09 | -0.08 | -0.07 | 0.29 | -0.10 | 0.01 | 0.11 | 0.84 | -0.03 | 1.00 | | | |
| Pb | -0.16 | -0.11 | -0.10 | -0.08 | 0.01 | -0.03 | 0.00 | -0.06 | 0.03 | -0.08 | -0.05 | -0.09 | -0.07 | -0.04 | -0.11 | 0.04 | 0.16 | 0.01 | 0.01 | -0.04 | 1.00 | | |
| Cr) | -0.18 | 0.39 | 0.21 | 0.47 | 0.12 | 0.28 | 0.05 | -0.03 | -0.02 | 0.26 | 0.27 | 0.15 | 0.38 | 0.17 | 0.39 | 0.51 | 0.03 | 0.68 | -0.03 | 0.38 | -0.02 | 1.00 | |
| U | -0.11 | 0.30 | 0.05 | 0.43 | 0.20 | 0.42 | 0.13 | -0.03 | -0.01 | 0.33 | 0.34 | 0.21 | 0.09 | -0.05 | 0.30 | 0.25 | 0.01 | 0.57 | -0.02 | 0.08 | 0.06 | 0.70 | 1.00 |

**Annexure-XXVI: Strange Table to determine surface runoff coefficient**

| Total Monsoon rainfall (inches) | Total Monsoon rainfall (mm) | Percentage of Runoff to rainfall | | | Total Monsoon rainfall (inches) | Total Monsoon rainfall (mm) | Percentage of Runoff to rainfall | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Good catchment | Average catchment | Bad catchment | | | Good catchment | Average catchment | Bad catchment |
| 1.0 | 25.4 | 0.1 | 0.1 | 0.1 | 31.0 | 787.4 | 27.4 | 20.5 | 13.7 |
| 2.0 | 50.8 | 0.2 | 0.2 | 0.1 | 32.0 | 812.8 | 28.5 | 21.3 | 14.2 |
| 3.0 | 76.2 | 0.4 | 0.3 | 0.2 | 33.0 | 838.2 | 29.6 | 22.2 | 14.8 |
| 4.0 | 101.6 | 0.7 | 0.5 | 0.3 | 34.0 | 863.6 | 30.8 | 23.1 | 15.4 |
| 5.0 | 127.0 | 1.0 | 0.7 | 0.5 | 35.0 | 889.0 | 31.9 | 23.9 | 15.9 |
| 6.0 | 152.4 | 1.5 | 1.1 | 0.7 | 36.0 | 914.4 | 33.0 | 24.7 | 16.5 |
| 7.0 | 177.8 | 2.1 | 1.5 | 1.0 | 37.0 | 939.8 | 34.1 | 25.5 | 17.0 |
| 8.0 | 203.2 | 2.8 | 2.1 | 1.4 | 38.0 | 965.2 | 35.3 | 26.4 | 17.6 |
| 9.0 | 228.6 | 3.5 | 2.6 | 1.7 | 39.0 | 990.6 | 36.4 | 27.3 | 18.2 |
| 10.0 | 254.0 | 4.3 | 3.2 | 2.1 | 40.0 | 1016.0 | 37.5 | 28.1 | 18.7 |
| 11.0 | 279.4 | 5.2 | 3.9 | 2.6 | 41.0 | 1 041.4 | 38.6 | 28.9 | 19.3 |
| 12.0 | 304.8 | 6.2 | 4.6 | 3.1 | 42.0 | 1066.8 | 39.8 | 29.8 | 19.9 |
| 13.0 | 330.2 | 7.2 | 5.4 | 3.6 | 43.0 | 1092.2 | 40.9 | 30.6 | 20.4 |
| 14.0 | 355.6 | 8.3 | 6.2 | 4.1 | 44.0 | 1117.6 | 42.0 | 31.5 | 21.0 |
| 15.0 | 381.0 | 9.4 | 7.0 | 4.7 | 45.0 | 1143.0 | 43.1 | 32.3 | 21.5 |
| 16.0 | 406.4 | 10.5 | 7.8 | 5.2 | 46.0 | 1168.4 | 44.3 | 33.2 | 22.1 |
| 17.0 | 431.8 | 11.6 | 8.7 | 5.8 | 47.0 | 1193.8 | 45.4 | 34.0 | 22.7 |
| 18.0 | 457.2 | 12.8 | 9.6 | 6.4 | 48.0 | 1219.2 | 46.5 | 34.8 | 23.2 |
| 19.0 | 482.6 | 13.9 | 10.4 | 6.9 | 49.0 | 1244.6 | 47.6 | 35.7 | 23.8 |
| 20.0 | 508.0 | 15.0 | 11.3 | 7.5 | 50.0 | 1270.0 | 48.8 | 36.6 | 24.4 |
| 21.0 | 533.4 | 16.1 | 12.0 | 8.0 | 51.0 | 1295.4 | 49.9 | 37.4 | 24.9 |
| 22.0 | 558.8 | 17.3 | 12.9 | 8.6 | 52.0 | 1320.8 | 51.0 | 38.2 | 25.5 |
| 23.0 | 584.2 | 18.4 | 13.8 | 9.2 | 53.0 | 1346.2 | 52.1 | 39.0 | 26.0 |
| 24.0 | 609.6 | 19.5 | 14.6 | 9.7 | 54.0 | 1371.6 | 53.3 | 39.9 | 26.6 |
| 25.0 | 635.0 | 20.6 | 15.4 | 10.3 | 55.0 | 1397.0 | 54.4 | 40.8 | 27.2 |
| 26.0 | 660.4 | 21.8 | 16.3 | 10.9 | 56.0 | 1422.4 | 55.5 | 41.6 | 27.7 |
| 27.0 | 685.8 | 22.9 | 17.1 | 11.4 | 57.0 | 1447.8 | 56.6 | 42.4 | 28.3 |
| 28.0 | 711.2 | 24.0 | 18.0 | 12.0 | 58.0 | 1473.2 | 57.8 | 43.3 | 28.9 |
| 29.0 | 736.6 | 25.1 | 18.8 | 12.5 | 59.0 | 1498.6 | 58.9 | 44.4 | 29.4 |
| 30.0 | 762.0 | 26.3 | 19.7 | 13.1 | 60.0 | 1524.0 | 60.0 | 45.0 | 30.0 |

## Annexure-XXVII: Norms Recommended for specific yield (Source: GEC-2015)

| NORMS RECOMMENDED FOR THE SPECIFIC YIELD | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Principal Aquifer | Major Aquifers | | Age | Recommended (%) | Minimum (%) | Maximum (%) |
| | | Code | Name | | | | |
| 1 | Alluvium | AL01 | Younger Alluvium (Clay/Silt/Sand/ Calcareous concretions) | Quaternary | 10 | 8 | 12 |
| 2 | Alluvium | AL02 | Pebble / Gravel/ Bazada/ Kandi | Quaternary | 16 | 12 | 20 |
| 3 | Alluvium | AL03 | Older Alluvium (Silt/Sand/Gravel/Lithomargic clay) | Quaternary | 6 | 4 | 8 |
| 4 | Alluvium | AL04 | Aeolian Alluvium (Silt/ Sand) | Quaternary | 16 | 12 | 20 |
| 5 | Alluvium | AL05 | Coastal Alluvium (Sand/Silt/Clay) | Quaternary | 10 | 8 | 12 |
| 6 | Alluvium | AL06 | Valley Fills | Quaternary | 16 | 12 | 20 |
| 7 | Alluvium | AL07 | Glacial Deposits | Quaternary | 16 | 12 | 20 |
| 8 | Laterite | LT01 | Laterite / Ferruginous concretions | Quaternary | 2.5 | 2 | 3 |
| 9 | Basalt | BS01 | Basic Rocks (Basalt) - Weathered, Vesicular or Jointed | Mesozoic to Cenozoic | 2 | 1 | 3 |
| 10 | Basalt | BS01 | Basic Rocks (Basalt) - Massive Poorly Jointed | Mesozoic to Cenozoic | 0.35 | 0.2 | 0.5 |
| 11 | Basalt | BS02 | Ultra Basic - Weathered, Vesicular or Jointed | Mesozoic to Cenozoic | 2 | 1 | 3 |
| 12 | Basalt | BS02 | Ultra Basic - Massive Poorly Jointed | Mesozoic to Cenozoic | 0.35 | 0.2 | 0.5 |
| 13 | Sandstone | ST01 | Sandstone/Conglomerate | Upper Palaeozoic to Cenozoic | 3 | 1 | 5 |
| 14 | Sandstone | ST02 | Sandstone with Shale | Upper Palaeozoic to Cenozoic | 3 | 1 | 5 |
| 15 | Sandstone | ST03 | Sandstone with shale/ coal beds | Upper Palaeozoic to Cenozoic | 3 | 1 | 5 |

| NORMS RECOMMENDED FOR THE SPECIFIC YIELD | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Principal Aquifer | Major Aquifers | | Age | Recommended (%) | Minimum (%) | Maximum (%) |
| | | Code | Name | | | | |
| 16 | Sandstone | ST04 | Sandstone with Clay | Upper Palaeozoic to Cenozoic | 3 | 1 | 5 |
| 17 | Sandstone | ST05 | Sandstone/Conglomerate | Proterozoic to Cenozoic | 3 | 1 | 5 |
| 18 | Sandstone | ST06 | Sandstone with Shale | Proterozoic to Cenozoic | 3 | 1 | 5 |
| 19 | Shale | SH01 | Shale with limestone | Upper Palaeozoic to Cenozoic | 1.5 | 1 | 2 |
| 20 | Shale | SH02 | Shale with Sandstone | Upper Palaeozoic to Cenozoic | 1.5 | 1 | 2 |
| 21 | Shale | SH03 | Shale, limestone and sandstone | Upper Palaeozoic to Cenozoic | 1.5 | 1 | 2 |
| 22 | Shale | SH04 | Shale | Upper Palaeozoic to Cenozoic | 1.5 | 1 | 2 |
| 23 | Shale | SH05 | Shale/Shale with Sandstone | Proterozoic to Cenozoic | 1.5 | 1 | 2 |
| 24 | Shale | SH06 | Shale with Limestone | Proterozoic to Cenozoic | 1.5 | 1 | 2 |
| 25 | Limestone | LS01 | Miliolitic Limestone | Quarternary | 2 | 1 | 3 |
| 26 | Limestone | LS01 | KarstifiedMiliolitic Limestone | Quarternary | 10 | 5 | 15 |
| 27 | Limestone | LS02 | Limestone / Dolomite | Upper Palaeozoic to Cenozoic | 2 | 1 | 3 |
| 28 | Limestone | LS02 | KarstifiedLimestone / Dolomite | Upper Palaeozoic to Cenozoic | 10 | 5 | 15 |
| 29 | Limestone | LS03 | Limestone/Dolomite | Proterozoic | 2 | 1 | 3 |
| 30 | Limestone | LS03 | KarstifiedLimestone/Dolomite | Proterozoic | 10 | 5 | 15 |
| 31 | Limestone | LS04 | Limestone with Shale | Proterozoic | 2 | 1 | 3 |
| 32 | Limestone | LS04 | KarstifiedLimestone with Shale | Proterozoic | 10 | 5 | 15 |
| 33 | Limestone | LS05 | Marble | Azoic to Proterozoic | 2 | 1 | 3 |
| 34 | Limestone | LS05 | KarstifiedMarble | Azoic to Proterozoic | 10 | 5 | 15 |

| NORMS RECOMMENDED FOR THE SPECIFIC YIELD | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Principal Aquifer | Major Aquifers | | Age | Recommended (%) | Minimum (%) | Maximum (%) |
| | | Code | Name | | | | |
| 35 | Granite | GR01 | Acidic Rocks (Granite,Syenite, Rhyolite etc.) - Weathered , Jointed | Mesozoic to Cenozoic | 1.5 | 1 | 2 |
| 36 | Granite | GR01 | Acidic Rocks (Granite,Syenite, Rhyolite etc.)-Massive or Poorly Fractured | Mesozoic to Cenozoic | 0.35 | 0.2 | 0.5 |
| 37 | Granite | GR02 | Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Weathered, Jointed | Proterozoic to Cenozoic | 3 | 2 | 4 |
| 38 | Granite | GR02 | Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Massive, Poorly Fractured | Proterozoic to Cenozoic | 0.35 | 0.2 | 0.5 |
| 39 | Schist | SC01 | Schist - Weathered, Jointed | Azoic to Proterozoic | 1.5 | 1 | 2 |
| 40 | Schist | SC01 | Schist - Massive, Poorly Fractured | Azoic to Proterozoic | 0.35 | 0.2 | 0.5 |
| 41 | Schist | SC02 | Phyllite | Azoic to Proterozoic | 1.5 | 1 | 2 |
| 42 | Schist | SC03 | Slate | Azoic to Proterozoic | 1.5 | 1 | 2 |
| 43 | Quartzite | QZ01 | Quartzite - Weathered, Jointed | Proterozoic to Cenozoic | 1.5 | 1 | 2 |
| 44 | Quartzite | QZ01 | Quartzite - Massive, Poorly Fractured | Proterozoic to Cenozoic | 0.3 | 0.2 | 0.4 |
| 45 | Quartzite | QZ02 | Quartzite - Weathered, Jointed | Azoic to Proterozoic | 1.5 | 1 | 2 |
| 46 | Quartzite | QZ02 | Quartzite- Massive, Poorly Fractured | Azoic to Proterozoic | 0.3 | 0.2 | 0.4 |
| 47 | Charnockite | CK01 | Charnockite - Weathered, Jointed | Azoic | 3 | 2 | 4 |

| NORMS RECOMMENDED FOR THE SPECIFIC YIELD | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Principal Aquifer | Major Aquifers | | Age | Recommended (%) | Minimum (%) | Maximum (%) |
| | | Code | Name | | | | |
| 48 | Charnockite | CK01 | Charnockite - Massive, Poorly Fractured | Azoic | 0.3 | 0.2 | 0.4 |
| 49 | Khondalite | KH01 | Khondalites, Granulites - Weathered, Jointed | Azoic | 1.5 | 1 | 2 |
| 50 | Khondalite | KH01 | Khondalites, Granulites - Mssive, Poorly Fractured | Azoic | 0.3 | 0.2 | 0.4 |
| 51 | Banded Gneissic Complex | BG01 | Banded Gneissic Complex - Weathered, Jointed | Azoic | 1.5 | 1 | 2 |
| 52 | Banded Gneissic Complex | BG01 | Banded Gneissic Complex - Massive, Poorly Fractured | Azoic | 0.3 | 0.2 | 0.4 |
| 53 | Gneiss | GN01 | Undifferentiated metasedimentaries/ Undifferentiated metamorphic - Weathered, Jointed | Azoic to Proterozoic | 1.5 | 1 | 2 |
| 54 | Gneiss | GN01 | Undifferentiated metasedimentaries/ Undifferentiated metamorphic - Massive, Poorly Fractured | Azoic to Proterozoic | 0.3 | 0.2 | 0.4 |
| 55 | Gneiss | GN02 | Gneiss -Weathered, Jointed | Azoic to Proterozoic | 3 | 2 | 4 |
| 56 | Gneiss | GN02 | Gneiss-Massive, Poorly Fractured | Azoic to Proterozoic | 0.3 | 0.2 | 0.4 |
| 57 | Gneiss | GN03 | Migmatitic Gneiss - Weathered, Jointed | Azoic | 1.5 | 1 | 2 |
| 58 | Gneiss | GN03 | Migmatitic Gneiss - Massive, Poorly Fractured | Azoic | 0.3 | 0.2 | 0.4 |

| NORMS RECOMMENDED FOR THE SPECIFIC YIELD | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Principal Aquifer | Major Aquifers | | Age | Recommended (%) | Minimum (%) | Maximum (%) |
| | | Code | Name | | | | |
| 59 | Intrusive | IN01 | Basic Rocks (Dolerite, Anorthosite etc.) - Weathered, Jointed | Proterozoic to Cenozoic | 2 | 1 | 3 |
| 60 | Intrusive | IN01 | Basic Rocks (Dolerite, Anorthosite etc.) - Massive, Poorly Fractured | Proterozoic to Cenozoic | 0.35 | 0.2 | 0.5 |
| 61 | Intrusive | IN02 | Ultrabasics (Epidiorite, Granophyre etc.) - Weathered, Jointed | Proterozoic to Cenozoic | 2 | 1 | 3 |
| 62 | Intrusive | IN02 | Ultrabasics (Epidiorite, Granophyre etc.) - Massive, Poorly Fractured | Proterozoic to Cenozoic | 0.35 | 0.2 | 0.5 |

## Annexure-XXVIII Proposed Artificial Recharge structures of Kolans Watershed

| Number | Proposed Structure | Latitude | Longitude |
|---|---|---|---|
| 1 | Check dam | 23.1005189 | 77.1374142 |
| 2 | Check dam | 23.0990241 | 77.14105 |
| 3 | Check dam | 23.0980981 | 77.1454884 |
| 4 | Check dam | 23.0983594 | 77.1505218 |
| 5 | Check dam | 23.0968143 | 77.1536923 |
| 6 | Check dam | 23.0976485 | 77.1581171 |
| 7 | Check dam | 23.0985959 | 77.1651366 |
| 8 | Check dam | 23.1022133 | 77.1689422 |
| 9 | Check dam | 23.1028124 | 77.1727931 |
| 10 | Check dam | 23.1047814 | 77.1762498 |
| 11 | Check dam | 23.1103274 | 77.1831756 |
| 12 | Check dam | 23.1152118 | 77.1889519 |
| 13 | Check dam | 23.1180188 | 77.191953 |
| 14 | Check dam | 23.1233401 | 77.193473 |
| 15 | Check dam | 23.097745 | 77.203063 |
| 16 | Check dam | 23.1027732 | 77.2011679 |
| 17 | Check dam | 23.1093421 | 77.1994382 |
| 18 | Check dam | 23.1129394 | 77.1975655 |
| 19 | Check dam | 23.1184296 | 77.1969427 |
| 20 | Check dam | 23.1239526 | 77.1967217 |
| 21 | Check dam | 23.1334164 | 77.1714623 |
| 22 | Check dam | 23.131156 | 77.1765985 |
| 23 | Check dam | 23.1289016 | 77.1853249 |
| 24 | Check dam | 23.1277039 | 77.1931838 |
| 25 | Check dam | 23.1210715 | 77.2146986 |
| 26 | Check dam | 23.1260992 | 77.2095417 |
| 27 | Check dam | 23.1362925 | 77.2050063 |
| 28 | Check dam | 23.1425714 | 77.2053316 |
| 29 | Check dam | 23.1376962 | 77.2258052 |
| 30 | Check dam | 23.1404428 | 77.2205349 |
| 31 | Check dam | 23.1448178 | 77.2122234 |
| 32 | Check dam | 23.146111 | 77.208056 |
| 33 | Check dam | 23.1493515 | 77.213784 |
| 34 | Check dam | 23.1548615 | 77.2150975 |
| 35 | Check dam | 23.1608598 | 77.2177338 |
| 36 | Check dam | 23.1566873 | 77.1938897 |
| 37 | Check dam | 23.1517057 | 77.1822437 |
| 38 | Check dam | 23.1568105 | 77.2019749 |
| 39 | Check dam | 23.1583488 | 77.2059956 |
| 40 | Check dam | 23.1617504 | 77.2089105 |
| 41 | Check dam | 23.1620521 | 77.2148252 |
| 42 | Check dam | 23.1762019 | 77.2231309 |
| 43 | Check dam | 23.1799057 | 77.2262474 |
| 44 | Check dam | 23.1849666 | 77.228184 |

| Number | Proposed Structure | Latitude | Longitude |
|---|---|---|---|
| 45 | Check dam | 23.1896086 | 77.2298808 |
| 46 | Check dam | 23.2115459 | 77.1816455 |
| 47 | Check dam | 23.2125872 | 77.1881441 |
| 48 | Check dam | 23.2131789 | 77.1939743 |
| 49 | Check dam | 23.2160482 | 77.1982808 |
| 50 | Check dam | 23.2200362 | 77.2093992 |
| 51 | Check dam | 23.2253889 | 77.2172436 |
| 52 | Check dam | 23.2269225 | 77.2229204 |
| 53 | Check dam | 23.2269576 | 77.230078 |
| 54 | Check dam | 23.228034 | 77.2362394 |
| 55 | Check dam | 23.229163 | 77.2413545 |
| 56 | Check dam | 23.2303267 | 77.248611 |
| 57 | Check dam | 23.1334017 | 77.2699183 |
| 58 | Check dam | 23.1376396 | 77.2669785 |
| 59 | Check dam | 23.1406627 | 77.2641753 |
| 60 | Check dam | 23.1440409 | 77.26173 |
| 61 | Check dam | 23.15145 | 77.2609958 |
| 62 | Check dam | 23.1587155 | 77.2580105 |
| 63 | Check dam | 23.1624154 | 77.2544733 |
| 64 | Check dam | 23.1652809 | 77.2497848 |
| 65 | Check dam | 23.1683418 | 77.2480579 |
| 66 | Check dam | 23.1730097 | 77.2437507 |
| 67 | Check dam | 23.1775373 | 77.2407471 |
| 68 | Check dam | 23.1847072 | 77.2381585 |
| 69 | Check dam | 23.1860177 | 77.232597 |
| 70 | Check dam | 23.1840474 | 77.268298 |
| 71 | Check dam | 23.1873999 | 77.2652589 |
| 72 | Check dam | 23.1916081 | 77.2638912 |
| 73 | Check dam | 23.195733 | 77.2653378 |
| 74 | Check dam | 23.2050274 | 77.2602434 |
| 75 | Check dam | 23.20767 | 77.2583658 |
| 76 | Check dam | 23.2133321 | 77.2583388 |
| 77 | Check dam | 23.2186726 | 77.2567004 |
| 78 | Check dam | 23.230685 | 77.2599907 |
| 1 | Percolation Tank | 23.1931201 | 77.2305556 |
| 2 | Percolation Tank | 23.208947 | 77.2357423 |
| 3 | Percolation Tank | 23.2212367 | 77.2443854 |
| 4 | Percolation Tank | 23.2297685 | 77.2599059 |
| 1 | Gully Plug | 23.1075709 | 77.109598 |
| 2 | Gully Plug | 23.1064906 | 77.1112979 |
| 3 | Gully Plug | 23.1058361 | 77.1131735 |
| 4 | Gully Plug | 23.1053396 | 77.1155022 |
| 5 | Gully Plug | 23.1045286 | 77.1200774 |
| 6 | Gully Plug | 23.1044037 | 77.1219157 |
| 7 | Gully Plug | 23.1099473 | 77.1190102 |
| 8 | Gully Plug | 23.1083357 | 77.1208905 |

| Number | Proposed Structure | Latitude | Longitude |
|---|---|---|---|
| 9 | Gully Plug | 23.1129504 | 77.1290496 |
| 10 | Gully Plug | 23.1097698 | 77.130711 |
| 11 | Gully Plug | 23.1130566 | 77.149881 |
| 12 | Gully Plug | 23.11 | 77.151389 |
| 13 | Gully Plug | 23.1064873 | 77.1633605 |
| 14 | Gully Plug | 23.105278 | 77.1647534 |
| 15 | Gully Plug | 23.1320191 | 77.1735634 |
| 16 | Gully Plug | 23.1139683 | 77.1866696 |
| 17 | Gully Plug | 23.0989472 | 77.1922221 |
| 18 | Gully Plug | 23.1003088 | 77.1928074 |
| 19 | Gully Plug | 23.1025548 | 77.1941663 |
| 20 | Gully Plug | 23.0939484 | 77.2063956 |
| 21 | Gully Plug | 23.0950339 | 77.20483 |
| 22 | Gully Plug | 23.0941101 | 77.2041277 |
| 23 | Gully Plug | 23.1059542 | 77.221322 |
| 24 | Gully Plug | 23.1060804 | 77.2178537 |
| 25 | Gully Plug | 23.1104169 | 77.2048574 |
| 26 | Gully Plug | 23.119444 | 77.225278 |
| 27 | Gully Plug | 23.133056 | 77.196944 |
| 28 | Gully Plug | 23.132962 | 77.2029915 |
| 29 | Gully Plug | 23.139617 | 77.2313997 |
| 30 | Gully Plug | 23.1342639 | 77.2301086 |
| 31 | Gully Plug | 23.1352869 | 77.1607247 |
| 32 | Gully Plug | 23.1341938 | 77.164698 |
| 33 | Gully Plug | 23.1334993 | 77.1691005 |
| 34 | Gully Plug | 23.1499133 | 77.1734922 |
| 35 | Gully Plug | 23.155556 | 77.180556 |
| 36 | Gully Plug | 23.1546384 | 77.1853548 |
| 37 | Gully Plug | 23.1626229 | 77.1782802 |
| 38 | Gully Plug | 23.1616825 | 77.1811362 |
| 39 | Gully Plug | 23.1612072 | 77.1839923 |
| 40 | Gully Plug | 23.1582856 | 77.1840658 |
| 41 | Gully Plug | 23.1573404 | 77.1868771 |
| 42 | Gully Plug | 23.1657723 | 77.193083 |
| 43 | Gully Plug | 23.1663147 | 77.1944456 |
| 44 | Gully Plug | 23.1649338 | 77.198088 |
| 45 | Gully Plug | 23.1644012 | 77.203034 |
| 46 | Gully Plug | 23.1745535 | 77.2053696 |
| 47 | Gully Plug | 23.1739507 | 77.2112578 |
| 48 | Gully Plug | 23.17425 | 77.2156959 |
| 49 | Gully Plug | 23.1889151 | 77.1886663 |
| 50 | Gully Plug | 23.1860936 | 77.184567 |
| 51 | Gully Plug | 23.1979706 | 77.1968577 |
| 52 | Gully Plug | 23.2225276 | 77.2013675 |
| 53 | Gully Plug | 23.2040042 | 77.1792809 |
| 54 | Gully Plug | 23.1784057 | 77.2794752 |

| Number | Proposed Structure | Latitude | Longitude |
|---|---|---|---|
| 55 | Gully Plug | 23.2013317 | 77.2671889 |

## Annexure-XXIX: Proposed Artificial Recharge structures of Kerwa watershed

| Number | Proposed structure | Latitude | Longitude |
|---|---|---|---|
| 1 | Check Dam | 23.1199785 | 77.3098686 |
| 2 | Check Dam | 23.122238 | 77.3137525 |
| 3 | Check Dam | 23.1238662 | 77.318418 |
| 4 | Check Dam | 23.1265381 | 77.3217092 |
| 5 | Check Dam | 23.1310773 | 77.3250223 |
| 6 | Check Dam | 23.1377919 | 77.3279352 |
| 7 | Check Dam | 23.1445444 | 77.3349527 |
| 8 | Check Dam | 23.1229263 | 77.342104 |
| 9 | Check Dam | 23.1301 | 77.3429067 |
| 10 | Check Dam | 23.1371413 | 77.3428286 |
| 11 | Check Dam | 23.144444 | 77.342778 |
| 12 | Check Dam | 23.1325793 | 77.3904512 |
| 13 | Check Dam | 23.132034 | 77.3929909 |
| 14 | Check Dam | 23.1312147 | 77.3950996 |
| 15 | Check Dam | 23.1294388 | 77.4012794 |
| 16 | Check Dam | 23.1223879 | 77.4116953 |
| 1 | Percolation Tank | 23.1655493 | 77.3731659 |
| 2 | Percolation Tank | 23.1468956 | 77.3854888 |
| 3 | Percolation Tank | 23.121776 | 77.4156702 |
| 1 | Gully Plug | 23.124376 | 77.3027276 |
| 2 | Gully Plug | 23.1212373 | 77.3057941 |
| 3 | Gully Plug | 23.1182752 | 77.3075797 |
| 4 | Gully Plug | 23.1179218 | 77.3047502 |
| 5 | Gully Plug | 23.118719 | 77.3180532 |
| 6 | Gully Plug | 23.1210197 | 77.3180396 |
| 7 | Gully Plug | 23.122699 | 77.3182157 |
| 8 | Gully Plug | 23.1323246 | 77.3055466 |
| 9 | Gully Plug | 23.1319585 | 77.3066722 |
| 10 | Gully Plug | 23.1316689 | 77.3081093 |
| 11 | Gully Plug | 23.1308349 | 77.3090616 |
| 12 | Gully Plug | 23.1308598 | 77.3108091 |
| 13 | Gully Plug | 23.131389 | 77.313056 |
| 14 | Gully Plug | 23.1319988 | 77.3155979 |
| 15 | Gully Plug | 23.130946 | 77.3165931 |
| 16 | Gully Plug | 23.129722 | 77.32 |
| 17 | Gully Plug | 23.1477619 | 77.3063437 |
| 18 | Gully Plug | 23.1464874 | 77.3088441 |
| 19 | Gully Plug | 23.1463529 | 77.311554 |
| 20 | Gully Plug | 23.1447472 | 77.313237 |

| Number | Proposed structure | Latitude | Longitude |
|---|---|---|---|
| 21 | Gully Plug | 23.1440947 | 77.3186589 |
| 22 | Gully Plug | 23.143562 | 77.3228485 |
| 23 | Gully Plug | 23.1425553 | 77.3255575 |
| 24 | Gully Plug | 23.1417191 | 77.3286215 |
| 25 | Gully Plug | 23.1511927 | 77.3260508 |
| 26 | Gully Plug | 23.1492636 | 77.3293364 |
| 27 | Gully Plug | 23.1479064 | 77.3319171 |
| 28 | Gully Plug | 23.1467079 | 77.3364929 |
| 29 | Gully Plug | 23.1545431 | 77.3337796 |
| 30 | Gully Plug | 23.1539917 | 77.3358653 |
| 31 | Gully Plug | 23.1522139 | 77.3371708 |
| 32 | Gully Plug | 23.1498309 | 77.3377265 |
| 33 | Gully Plug | 23.1382952 | 77.3580012 |
| 34 | Gully Plug | 23.1408405 | 77.3583016 |
| 35 | Gully Plug | 23.144444 | 77.356111 |
| 36 | Gully Plug | 23.1753581 | 77.3396429 |
| 37 | Gully Plug | 23.1767463 | 77.3426551 |
| 38 | Gully Plug | 23.1758173 | 77.3414652 |
| 39 | Gully Plug | 23.17832 | 77.3431452 |
| 40 | Gully Plug | 23.1789004 | 77.3409787 |
| 41 | Gully Plug | 23.1460226 | 77.3772226 |
| 42 | Gully Plug | 23.1470732 | 77.3795025 |
| 43 | Gully Plug | 23.1502502 | 77.3806613 |
| 44 | Gully Plug | 23.1487016 | 77.3823343 |
| 45 | Gully Plug | 23.1154018 | 77.3885755 |
| 46 | Gully Plug | 23.1156055 | 77.3920433 |
| 47 | Gully Plug | 23.1177609 | 77.3950652 |
| 48 | Gully Plug | 23.1174294 | 77.3978397 |
| 49 | Gully Plug | 23.1319842 | 77.3855801 |
| 50 | Gully Plug | 23.1307955 | 77.3930155 |
| 51 | Gully Plug | 23.1285213 | 77.3909233 |
| 52 | Gully Plug | 23.1332079 | 77.3876832 |
| 53 | Gully Plug | 23.130317 | 77.384883 |
| 54 | Gully Plug | 23.1239598 | 77.4156699 |
| 55 | Gully Plug | 23.1325999 | 77.4115369 |

**Annexure-XXX: Categories Exempted from seeking No Objection Certificate for Groundwater extraction**

- Individual domestic consumers in both rural and urban areas for drinking water and domesticuses.
- Rural drinking water supply schemes.
- Armed Forces Establishments and Central Armed Police Forces establishments in bothruraland urban areas.
- Agricultural activities.
- Micro and small Enterprises drawing groundwater less than 10 cum/day.
- All industries/ mining projects/ infrastructure projects drawing groundwater only for drinking/domestic purposes up to 5 Cum /day in all assessment units.
- Residential Apartments and Group Housing Societies:
    (a) For drinking water and domestic uses, drawing groundwater upto 20 $m^3$/day subject to theconditions mentioned in Para 2.0 of the guidelines.
    (b) Dwelling units for Economically Weaker Sections (EWS) under Government schemes.

**Annexure- XXXI: Farmers Feedback Proforma**

## Farmer Feedback Form


Photograph

| | | |
|---|---|---|
| Name | Dev narayan Meena | |
| Village | Chhichli | |
| Block | Phanda | |
| District | Bhopal | |
| Address | H No. 217, Chhichi, Phanda, Kolar road. | |
| Mobile Number (optional) | 9826457466 | |
| **Type and number of structures** | | |
| Type | Bore well | |
| Number | 1 | |
| (coordinates of the structures are to be obtained by the field officer) | 1 | 2005 drill |
| Drill time discharge (lps) | 1.5" | |
| Depth of installation of pump | 3HP - 100 feet | |
| Casing depth (Bore wells) HR | 40 feet | |
| Fracture encountered depth-HR | 50 feet | |
| Slotted pipe depths (TW) SR | 20-40 feet | |
| Average water levels – pre-monsoon | 40 feet | |
| Average water levels – post-monsoon | - 20 feet. | |
| The well is used for | Irrigation. – alternate with canal | |
| Is water available throughout the year | Yes | |
| If not for how many months water is available | Na | |

**Pumping Duration**

| | Number of days pump is operated (days) of each well | What is the average pumping duration (in hours) of each well | Instantaneous Discharge Measurement (to be carried out by the field officer) in lps |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Rabi (no of months to be specified) | 2 month | 8-10 hrs. | 2" |
| Kharif (no of months to be specified) | NO | Soyabean, dhan. | |
| Others (no of months to be specified) | | | |
| **Area Irrigated** | | | |
| | Area Irrigated | Type of crop taken | Remarks |
| Rabi (no of months to be specified) | ~~Wheat~~ - 2 Acre | Wheat | |
| Khariff (no of months to be specified) | 2 Acre | Soyabean | |
| Others (no of months to be specified) | - | - | - |
| **Cropping patterns (past and present) in the village** | | | |
| Traditional Cropping pattern in the village | Kharif | Rabi | Other |
| Type of Crop | Soyabean | Wheat | - |
| Area under crop | 2 Acre | 2 Acre | |
| Prevailing Cropping pattern in the village | Kharif | Rabi | Other |
| Type of Crop | same as above | | |
| Area under crop | | | |
| Reasons for change in cropping pattern in last 20 years. | No change | since 20years. | |
| If the cropping pattern is to be changed, which are the suitable crops that can be grown | moong in | summer | |
| Available Market for the crop | Mandideep | | |
| Average unit cost of production | W-2100 / quintal | , S - 3500 - 4500/- | |
| Average unit cost of selling | | | |
| Existing MSP and other related information | Crop wise details are to be collected<br>Wheat - 2275/- , Soyabean - no | | |
| Other subsidies, facilities, restrictions. | 6000/-per year from central govt. | | |

**Source of Energy**

| | |
|---|---|
| Solar | ○ Is it connected to grid<br>○ If yes how much incentive do you get per month on an average for feeding electricity to the grid (Rs per month) |
| Electric ✓ | ○ Do you get free electricity for irrigation?<br>✓ Do you pay a fixed charge - 3 month - 16500/-<br>○ If a fixed charge is paid, what is the per month charge<br>4000/month. |

| | |
|---|---|
| | ○ If unit-based charges are paid what is the average monthly charges in rupees<br><br>○ During kharif---- Na<br>○ During Rabi----- 4025 ₹ |
| Diesel | ○ Average consumption of diesel (liters) per month NA<br>○ During Kharif<br>○ During Rabi |
| Water Market* | ○ Do you share the pumped water with other farmers<br>✓ If yes<br>○ For how many days do you share pumped water in Kharif No<br>○ For how many days do you share pumped water in Rabi Period - 4 days - 8 hrs.<br>○ On an average how much do you charge per annum (in Rs) No charges. |
| | ○ Do you receive additional water from boreholes of nearby farmers<br><br>✓ If yes<br>○ For how many days do you receive pumped water in Kharif No.<br>○ For how many days do you receive pumped water in Rabi Period 8-10 days - 8 hrs.<br>○ On an average how much do you pay per annum (in Rs) No charges. |
| Other issues/Remarks | e.g. common problems in drilling of wells, common health issues in the area etc<br>Boulders during drilling about 80 feet, problem in drilling. |


594R+PXQ, Kerwa Dm Rd, Bhopal, Chichli, Madhya Pradesh 462042, India
Type Degree DMS
Latitude 23.1559134 23°9'21" N
Longitude 77.3923564 77°23'32" E
Google
04 Dec 2023, 11:56 am

# Annexure-XXXII: Field Photographs



7FG6+WHP, Ayodhya Bypass Rd, Sharda Nagar, Housing Board Colony, Govindpura, Bhopal, Madhya Pradesh 462023, India
Ayodhya Bypass Rd
Google
Type Degree DMS
Latitude 23.277417 23°16'39" N
Longitude 77.4613715 77°27'41" E
30 Jun 2023, 16:07 pm


Latitude: 23.242922
Longitude: 77.390658
Elevation: 553.78±12.59 m
Accuracy: 10.56 m
Time: 18-08-2023 15:37:30
Note: EW Location
NoteCam @ iOS

Central Ground Water Board
North Central Region
Block-1, 4th Floor, Parayawas Bhawan,
Arera Hills, Jail Road, Bhopal (M.P.) - 462011
Email: rdncr-cgwb@nic.in