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

केंद्रीय भूमि जल बोर्ड
Central Ground Water Board

NAQUIM 2.0

जलभृत प्रबंधन योजना
Aquifer Management Plan
भवानीगढ़, संगरूर जिला, पंजाब
Bhawanigarh, Sangrur District, Punjab

North Western Region (NWR)
Chandigarh
2024

भारतसरकार

Government of India

जलशक्तिमंत्रालय

Ministry of Jal Shakti

जलसंसाधनविभाग, नदीविकासऔरगंगासंरक्षण

Department of Water Resources

River Development andGanga Rejuvenation

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Aquifer Management Plan

भवानीगढ़, संगरूर जिला, पंजाब

Bhawanigarh, Sangrur District, Punjab

प्राथमिकता प्रकार: जल संकटग्रस्त क्षेत्र

Priority Type: Water Stressed Areas

North Western Region (NWR)

Chandigarh

2024

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Central Ground Water Board

Aquifer Management Plan

Bhawanigarh, Sangrur District, Punjab

CONTRIBUTORS

Team Lead	*Rakesh Rana*	*Hydrogeologist (Sc-D)*
Hydrogeology Expert	*Amandeep Kaur*	*Hydrogeologist (Sc-D)*
Hydro-chemistry Expert	*Rishi Raj*	*Chemist (Sc-B)*
Geophysics Expert	*S. Bhatnagar*	*Geophysicist (Sc-D)*
Data compilation & Report Preparation	*Amandeep Kaur*	*Hydrogeologist (Sc-D)*

CENTRAL GROUND WATER BOARD

NORTH-WESTERN REGION,

CHANDIGARH

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

भारत सरकार
जल शक्ति मंत्रालय
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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

अनुराग खन्ना

Anurag Khanna

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
केंद्रीय भूजल जल बोर्ड

सत्यमेव जयते

ITUWTSA

Government of India
Department of Water Resources, RD & GR
Central Ground Water Board

Message

A realistic evaluation of the availability and utilization of a natural resource is imperative for formulating strategies to ensure its sustainable development and management. This significance is heightened, especially in the context of groundwater in the Country, which faces escalating stress due to its extraction for diverse purposes. The consequence of this situation is a decline in groundwater levels, the desaturation of aquifers, and the deterioration of water quality, among other issues. Groundwater needs to be used and managed in a sustainable way to ensure its long-term sustainability.

The NAQUIM 2.0 study has involved meticulous fieldwork, advanced analysis, and detailed interpretation to ensure that our findings are both accurate and informative. The study covers various aspects, including availability, and potential for future development. The data and recommendations outlined after this study will be instrumental in guiding strategic decisions and supporting sustainable management of groundwater resources. The findings obtained after this study are of great importance not only to policymakers and stakeholders but also to the public. Understanding the status and potential of our groundwater resources is crucial for informed decision-making and fostering community engagement.

The report, titled "NAQUIM 2.0 Report of Bhawanigarh Block, Sangrur District" serves as a comprehensive outcome of the exploration results. The report embodies water level behavior, ground water exploration, geophysical exploration, geochemical analysis, hydro meteorological aspects, statistical analysis, land subsidence and resources in Bhawanigarh Block, Sangrur district of Punjab state. This is the first attempt to synthesize the entire set of related data, analyze and interpret them and to present the findings on micro level in a format that appeal to the academicians, administrators and all the stakeholders in ground water.

The commendable endeavors undertaken by the Central Ground Water Board, Northwestern Region, Chandigarh in the creation of the "NAQUIM 2.0 study of Bhawanigarh Block, Sangrur District" Report deserve praise. I have every confidence that this report will offer substantial benefits to a wide range of stakeholders, academicians, administrators and the public alike and will go a long way in the planning and management of the ground water resources for the state of Chandigarh.

अनुराग खन्ना

(Anurag Khanna)

Member (North-west)

अनुराग खन्ना

Anurag Khanna

भारत सरकार
जल शक्ति मंत्रालय
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केंद्रीय भूवम जल बोर्ड

Government of India
Ministry of Jal Shakti
Department of Water Resources, RD & GR

FOREWORD

Central Groundwater Board has taken the initiative of Aquifer mapping and management during 2012-2023 to address the issue of groundwater overexploitation and contamination etc. During Phase 1 of NAQUIM, there were some limitations on the implementation of specific recommendations. Building on the experience of NAQUIM 1.0 and considering the future requirements NAQUIM 2.0 was launched during 2023. It aims to provide information in higher granularity with a focus on increasing the density of dynamic data like groundwater level, groundwater quality, etc. providing issue-based scientific inputs for groundwater management up to the Panchayat leveland to ensure the implementation of the recommended strategies.

In the study area, available data from state government and local bodies was compiled, data gap analysis was carried out and data was generated to fill these gaps. Extensive hydrogeological surveys were carriedout including village-wise well inventory, water level, and water quality monitoring, etc. All the data collected using various techniques was studied and synthesized in the form of Aquifer maps incorporating the various attributes of the aquifer system. Based on these Aquifer maps and analysis of data, Aquifer Management Plans were prepared. The study also identifies the major groundwater issues in the study area that need redressal through appropriate management plans.

The report deals with each aspect of the study carried out in much detail. A new methodology for dynamic groundwater Resources has been developed. It is expected that this report will be of immense help and interest to planners, policymakers, professionals, academicians, and researchers dealing with water resources in general and groundwater r in particular.

The support received from different state government agencies, especially the Department of Water Resources, Punjab, and panchayats has helped a lot in the completion of this study. I place on record my deep appreciation for the commendable efforts put in by the authors Smt Amandeep Kaur (Scientist D), Sh Rakesh Rana (Scientist D), and Sh Rishi Raj (Scientist B) in bringing out this report.

(Anurag Khanna)
Regional Director
CGWB, NWR
Chandigarh

ACKNOWLEDGMENTS

The successful completion of the NAQUIM 2.0 Report for Aquifer Management Plan of Bhawanigarh Block, Sangrur District *Punjab has been made possible through the collective efforts and Guidance received from* ***Shri Anurag Khanna,*** *Member (North & West) and Regional Director Central Ground Water Board (CGWB), Northwestern Region (NWR), Chandigarh. We express our gratitude to* ***Shri Dinesh Tewari,*** *Scientist-E for his guidance and support in the completion of the Report.*

First and foremost, we express our sincere appreciation to ***Dr. Sunil Kumar Ambast****, Chairman,* ***Central Ground Water Board (CGWB),*** *for their visionary leadership and continued support in the implementation of the National Aquifer Mapping and Management (NAQUIM 2.0) program. Their commitment to sustainable groundwater management has been instrumental in guiding this project.*

We also acknowledge the contributions of the Punjab State Water Resources Department for their collaboration and assistance in facilitating field activities and data collection. Their localknowledge and logistical support were crucial in ensuring the smooth execution of this project.

We would like to thank the various stakeholders, including farmers, local communities, and NGOs, for their active participation and valuable input during the consultations and field surveys. Their involvement has enriched the study with practical insights and on-ground realities.

A special mention is dedicated to ***Shri Rakesh Rana,*** *Scientist D (Hg),* ***Shri Rishiraj,*** *Scientist B (Chemical) for their commitment, hard work, and professionalism being the backbone of thisreport. Furthermore, I thank* ***Smt. Naima Akhtar,*** *Scientist-C (Hg),* ***and Shri Manish Shrivastava (A.H.G****), and for all possible help and technical guidance to complete the preparation of this report.*

Finally, we express our gratitude to all those who, directly or indirectly, have contributed to the completion of the NAQUIM 2.0 Report for Bhawanigarh Block. Your support and collaboration have been instrumental in advancing our understanding of groundwater resources and promoting sustainable management practices.

Thank you all for your invaluable contributions.

(**Amandeep Kaur**)
Scientist – D
CGWB, NWR, Chandigarh

EXECUTIVE SUMMARY

NAQUIM 2.0 was implemented in 2023 as a result of the successful implementation of NAQUIM and keeping in mind its shortcomings. NAQUIM 2.0 focused on the limitations of NAQUIM and was formulated accordingly to work on its lacuna and provide site-specific groundwater interventions. Therefore NAQUIM 2.0 aims to provide information in higher granularity with a focus on increasing the density of dynamic data like groundwater level, groundwater quality, etc. providing issue-based scientific inputs for groundwater management up to the Panchayat level and to ensure the implementation of the recommended strategies. Under NAQUIM 2.0 Bhawanigarh block of Sangrur district was taken up for its water-stressed condition.

Bhawanigarh block falls in the central-eastern part of the Sangrur District and is bounded by latitudes 30^0 07’ (N) to 30^0 22’ (N) and longitude 75^0 55’ (E) to 76^0 12.5’ (E)”. The block has 67 nos. of villages. The Bhawanigarh Block falls under the **Water Stressed Area** because the Stage of Groundwater Extraction is 348% as per GWRE-2023 and therefore the area falls under the **Over-Exploited** category. The Bhawanigarh block forms part of the Indo-Gangetic plain and lies in the Ghaggar Sub-Basin. The area of the block in general is plain. The block is occupied by the Older Alluvium of the Quaternary age of the Indo Gangetic plain. The alluvium comprises coarse to medium-grained sand, which forms the potential aquifers admixed with clay. There is no well-defined drainage in the area except the Sirhind Choa drain.

To understand the lithological framework and aquifer disposition of Bhawanigarh Block, the lithology data of 41 number of boreholes have been collected from DWSS and 1 number from private agencies, and 5 number of exploration borewells have been conducted by CGWB to generate more sub-surface data. The aquifer disposition model of the Bhawanigarh block thus drawn revealed a broad picture of aquifer disposition, interrelationship of granular zones, nature, geometry, and extension of aquifers in the entire block. The aquifer grouping has been carried out using the sub-surface lithology and a three-dimensional aquifer model has been prepared. The aquifers have been grouped into two groups up to a depth of 150 meters in the Bhawanigarh block. A few clay layers intervening these aquifer groups pinch out against the sand zones at a few places.

The first aquifer is the water table aquifer (Unconfined Aquifer) extending all over the study area. This aquifer is mainly composed of medium to coarse-grained sand. The top of the first aquifer is unsaturated. The average thickness of the unsaturated zone is 37.6 m.

The thickness of the unsaturated zone has been estimated based on Geophysical data and water level monitoring. The average thickness of aquifer I is estimated to be 55 m. The first and second aquifer is separated by a clay layer having very fine sand with an average thickness of 11 m in the study area.

The Second aquifer is semi-confined in nature and extends up to a depth of 142m with an average thickness of 35m. After the Second aquifer, there comes the thick confining clay layers up to a depth of 165 m.

A network of 49 key wells was established to monitor the groundwater level in the study area. Out of 49 key wells 35 key wells represent the Unconfined Aquifer (Aquifer I) whereas the 14 key wells represent Aquifer II. The depth to water level in unconfined aquifers varies between 32.92 m bgl to 48.55 m bgl during pre-monsoon in Unconfined Aquifers and between 35.85 m bgl to 49.13 m bgl during post-monsoon. The seasonal Fluctuation of 1-2m was observed in the study area.

The stage of groundwater Development (SOD) of the Sangrur Block, Sangrur District has shown continuous deterioration from 219% in 2004 to 310% in 2023. The block has been categorized as Over-exploited and is notified by CGWA. The Resources have been refined by two methods: i) Resource calculation using High-Frequency Groundwater level data, and ii) Refinement of existing GEC methodology inputs. The stage of groundwater Development (SOD) by using High-Frequency Groundwater level data is 145% and the stage of groundwater Development (SOD) by Refinement of existing GEC methodology is 231%.

There are 47 groundwater samples collected during pre-monsoon and 74 groundwater samples collected during post-monsoon for analysis of basic parameters. In general, the quality of groundwater is fresh and potable in the study area. For Heavy metal analysis, a total of 47 and 118 groundwater samples were collected and analyzed during pre and post-monsoon for Uranium and other heavy metals. Uranium concentration more than the permissible limit of 0.03 mg/L was noticed in 42.5% of samples during pre-monsoon and 33 % of samples during post-monsoon. The groundwater is suitable for irrigation but care must be taken while using water as with time the quality is changing from good to medium in terms of salinity.

To identify regions exhibiting indications of land subsidence within the Bhawanigarh block, comprehensive field surveys were conducted throughout the area, during which discussions were held with farmers and local residents regarding the issues they faced. A comparative analysis of decadal satellite imagery revealed that there were no variations in the reference points designated for elevation comparison across the images.

The major challenges observed during the NAQUIM 2.0 studies in the Bhawanigarh block are the declining water levels and Groundwater quality.

To effectively tackle the challenges associated with declining water levels and groundwater quality, a comprehensive management plan is crucial. This plan should not only focus on reversing the declining trend of water levels but also prioritize the enhancement of groundwater quality. Furthermore, it is essential to identify aquifers that are free from uranium to ensure the provision of safe water to end users. The interventions should be implemented both on the demand and supply sides to arrest the declining water levels and to increase water use efficiency.

The interventions aimed at addressing the demand side of water management in agriculture involve switching from PUSA 440 to PR 126 paddy variant, implementing AI/Pump controllers and Flow meters in agricultural fields to optimize groundwater extraction from tube wells, and reducing the standing water column from 145 cm to 120 cm.

On the other hand, supply-side interventions focus on lining unlined channels in agricultural fields, laying underground pipelines to decrease groundwater overdraft by 20%, increasing the supply of canal water for irrigation to lessen farmers' reliance on groundwater, installing artificial recharge structures in government buildings, renovating ponds in paleochannels, widening their width, and utilizing treated wastewater from village ponds for irrigation purposes. These measures collectively aim to diminish the dependency on groundwater for irrigation in agricultural practices.

The wells drilled by CGWB tapping the tapping granular zones below the depth of 120 have remained uncontaminated by Uranium. Therefore, the Department of Water Supply & Sanitation should focus on tapping only the deeper aquifers when implementing drinking water supply schemes in rural areas. This will help ensure the provision of safe and uncontaminated drinking water to the communities.

कार्यकारी सारांश

NAQUIM 2.0 को 2023 में NAQUIM के सफल कार्यान्वयन और इसकी कमियों को ध्यान में रखते हुए लागू किया गया। NAQUIM 2.0 ने NAQUIM की सीमाओं पर ध्यान केंद्रित किया और इसे उसके दोषों को दूर करने और स्थल-विशिष्ट भूजल हस्तक्षेप प्रदान करने के लिए तैयार किया गया। इसलिए, NAQUIM 2.0 का उद्देश्य उच्च ग्रैन्युलैरिटी के साथ जानकारी प्रदान करना है, जिसमें भूजल स्तर, भूजल गुणवत्ता आदि जैसे गतिशील डेटा की घनत्व को बढ़ाना शामिल है। यह पंचायत स्तर तक भूजल प्रबंधन के लिए मुद्दा-आधारित वैज्ञानिक इनपुट प्रदान करने और अनुशंसित रणनीतियों के कार्यान्वयन को सुनिश्चित करने पर केंद्रित है। NAQUIM 2.0 के अंतर्गत, इसके जल संकट की स्थिति को देखते हुए संगरूर जिले के भवानीगढ़ ब्लॉक को चुना गया।

भवानीगढ़ ब्लॉक संगरूर जिले के मध्य-पूर्वी भाग में स्थित है और अक्षांश 30°07′ (उत्तर) से 30°22′ (उत्तर) तथा देशांतर 75°55′ (पूर्व) से 76°12.5′ (पूर्व) के बीच सीमाबद्ध है। इस ब्लॉक में कुल 67 गाँव हैं। भवानीगढ़ ब्लॉक जल संकटग्रस्त क्षेत्र की श्रेणी में आता है क्योंकि भूजल निष्कर्षण का स्तर GWRE-2023 के अनुसार 348% है, जिससे यह अति-शोषित (Over-Exploited) श्रेणी में आता है। यह ब्लॉक इंडो-गंगा मैदान का हिस्सा है और घग्गर उप-बेसिन में स्थित है। सामान्यतः, यह क्षेत्र समतल भू-भाग का है। इस ब्लॉक में इंडो-गंगा मैदान के चतुर्थकालीन काल के पुराने जलोढ़ निक्षेप (Older Alluvium) पाए जाते हैं। जलोढ़ निक्षेपों में मुख्य रूप से मोटे से मध्यम दानेदार बालू होती है, जो संभावित जलभृत का निर्माण करती है, जिसमें कुछ स्थानों पर मिट्टी मिश्रित होती है। इस क्षेत्र में कोई सुव्यवस्थित जल निकासी प्रणाली नहीं है, केवल सिरहिंद चोआ नाला यहाँ बहता है।

भवानीगढ़ ब्लॉक की शैलवैज्ञानिक संरचना और जलभृत विन्यास को समझने के लिए, जल आपूर्ति एवं स्वच्छता विभाग (DWSS) से 41 बोरहोलों का डेटा और निजी एजेंसियों से 1 बोरहोल का डेटा एकत्र किया गया, तथा केंद्रीय भूजल बोर्ड (CGWB) द्वारा 5 अन्वेषण बोरवेल किए गए ताकि अधिक उप-सतही डेटा प्राप्त किया जा सके। इस डेटा के आधार पर भवानीगढ़ ब्लॉक का जलभृत विन्यास मॉडल तैयार किया गया, जिससे जलभृतों का विस्तृत चित्रण, कणीय क्षेत्रों का पारस्परिक संबंध, प्रकृति, ज्यामिति और विस्तार की जानकारी प्राप्त हुई। जलभृतों को उप-सतही शैलरचना के आधार पर वर्गीकृत किया गया और तीन-आयामी जलभृत मॉडल तैयार किया गया। इस ब्लॉक में 150 मीटर की गहराई तक जलभृतों को दो समूहों में विभाजित किया गया। कुछ स्थानों पर इन जलभृत समूहों के बीच की चिकनी मिट्टी की परतें बालू के क्षेत्रों के साथ विलीन हो जाती हैं।

पहला जलभृत (Unconfined Aquifer) संपूर्ण अध्ययन क्षेत्र में फैला हुआ है। यह मुख्य रूप से मध्यम से मोटे दानेदार बालू से बना है। इस जलभृत का शीर्ष भाग अवसादित नहीं है। अवसादित क्षेत्र

की औसत मोटाई 37.6 मीटर है, जिसे भूभौतिकीय डेटा और जलस्तर निगरानी के आधार पर आंका गया है। पहले जलभृत की औसत मोटाई 55 मीटर आंकी गई है। पहले और दूसरे जलभृत को बहुत महीन बालू वाली चिकनी मिट्टी की 11 मीटर मोटी परत अलग करती है।

दूसरा जलभृत अर्ध-संवृत (Semi-Confined) प्रकृति का है और यह 142 मीटर की गहराई तक फैला हुआ है, जिसकी औसत मोटाई 35 मीटर है। इस जलभृत के बाद 165 मीटर की गहराई तक मोटी चिकनी मिट्टी की परतें पाई जाती हैं।

अध्ययन क्षेत्र में भूजल स्तर की निगरानी के लिए 49 कुओं का एक नेटवर्क स्थापित किया गया। इनमें से 35 कुएँ असंवृत जलभृत (Unconfined Aquifer-I) का प्रतिनिधित्व करते हैं, जबकि 14 कुएँ जलभृत-II को दर्शाते हैं। असंवृत जलभृत में प्री-मानसून के दौरान जलस्तर 32.92 मीटर से 48.55 मीटर के बीच और पोस्ट-मानसून के दौरान 35.85 मीटर से 49.13 मीटर के बीच पाया गया। अध्ययन क्षेत्र में 1-2 मीटर का मौसमी उतार-चढ़ाव देखा गया।

संगरूर ब्लॉक में भूजल विकास स्तर (SOD) में लगातार गिरावट देखी गई है, जो 2004 में 219% से बढ़कर 2023 में 310% हो गया। इसे अति-शोषित क्षेत्र के रूप में वर्गीकृत किया गया है और केंद्रीय भूजल प्राधिकरण (CGWA) द्वारा अधिसूचित किया गया है। भूजल संसाधनों को दो तरीकों से परिष्कृत किया गया:

1. उच्च-आवृत्ति भूजल स्तर डेटा का उपयोग करके संसाधन गणना।
2. मौजूदा GEC पद्धति के इनपुट्स को परिष्कृत करके।

उच्च-आवृत्ति भूजल स्तर डेटा के अनुसार भूजल विकास स्तर 145% पाया गया, जबकि परिष्कृत GEC पद्धति के अनुसार यह 231% था।

प्री-मानसून के दौरान 47 और पोस्ट-मानसून के दौरान 74 भूजल नमूने एकत्र किए गए और उनके बुनियादी मापदंडों का विश्लेषण किया गया। सामान्यतः, अध्ययन क्षेत्र का भूजल मीठा और पीने योग्य है। भारी धातु विश्लेषण के लिए प्री-मानसून में 47 और पोस्ट-मानसून में 118 नमूने एकत्र किए गए। प्री-मानसून में 42.5% और पोस्ट-मानसून में 33% नमूनों में यूरेनियम की सांद्रता 0.03 mg/L की अनुमेय सीमा से अधिक पाई गई।

भवानीगढ़ ब्लॉक में भूमि धंसाव के संकेतों की पहचान के लिए व्यापक क्षेत्रीय सर्वेक्षण किए गए, जिसमें किसानों और स्थानीय निवासियों के साथ चर्चा की गई। दशकीय उपग्रह चित्रों के तुलनात्मक विश्लेषण से पता चला कि ऊंचाई तुलना के लिए निर्धारित संदर्भ बिंदुओं में कोई बदलाव नहीं हुआ।

NAQUIM 2.0 के अध्ययन के दौरान भवानीगढ़ ब्लॉक में मुख्य रूप से जलस्तर में गिरावट और भूजल गुणवत्ता की समस्याएं देखी गईं। जलस्तर में गिरावट को रोकने और भूजल गुणवत्ता में सुधार के लिए एक व्यापक प्रबंधन योजना आवश्यक है।

कृषि में जल उपयोग दक्षता बढ़ाने के लिए मांग-पक्षीय हस्तक्षेपों में PUSA 440 की जगह PR 126 धान किस्म अपनाना, कृषि क्षेत्रों में एआई/पंप कंट्रोलर और फ्लो मीटर लगाना, और स्थायी जलस्तंभ की ऊंचाई 145 से 120 सेमी तक घटाना शामिल है।

आपूर्ति-पक्षीय उपायों में कृषि क्षेत्रों में बिना पक्के चैनलों को पक्का करना, भूमिगत पाइपलाइन बिछाना, नहर के पानी की आपूर्ति बढ़ाना, सरकारी भवनों में कृत्रिम पुनर्भरण संरचनाएं लगाना, पुराने चैनलों में तालाबों का पुनर्निर्माण करना, तथा गांवों के तालाबों से उपचारित अपशिष्ट जल का सिंचाई के लिए उपयोग करना शामिल है।

CGWB द्वारा 120 मीटर से अधिक गहराई पर खुदे कुएं यूरेनियम से अप्रभावित पाए गए हैं। इसलिए, ग्रामीण पेयजल योजनाओं के तहत केवल गहरे जलभृतों से जलापूर्ति सुनिश्चित की जानी चाहिए ताकि स्वच्छ और सुरक्षित पेयजल उपलब्ध कराया जा सके।

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Aquifer Management Plan of Bhawanigarh Block, Sangrur district, Punjab
Target Area: 351.7 sq km

CHAPTER 1. INTRODUCTION

1.1 General Introduction

NAQUIM: The Aquifer Mapping and Management programme (NAQUIM) was launched by CGWB in the year 2012 as per the recommendations of the Report of the Steering Committee on Water Resources and Sanitation for Twelfth Five Year Plan (2012-2017), Planning Commission. NAQUIM was taken up with the objectives of delineating aquifers, characterising aquifers and preparing aquifer management plans. National-level mapping of Aquifers on a 1:50,000 scale was considered sufficient for planning requirements up to the block level. Some of the important uses of Aquifer mapping at a 1:50,000 scale include:

i. Identification of suitable areas for groundwater based supply to large urban agglomerations,

ii. Determine the sustainability of groundwater development,

iii. Identification of aquifers capable of providing water supply during protracted drought periods,

iv. Prioritization of aquifers for managed aquifer recharge,

v. Identification of aquifers and determination of their suitability for various purposes in regions where new urban centres or industrial hubs are likely to come up in future,

vi. Planning of integrated groundwater recharge schemes,

vii. Issuing advisories to the state agencies on repercussions of continued development of groundwater in select areas,

viii. Recommendations to state agencies in respect of areas that have prospects for groundwater development etc.

NAQUIM 2.0: Though the NAQUIM outputs have been useful for sustainable groundwater management in numerous ways as enumerated above, large-scale implementation of its recommendations at ground level by the user agencies has been lacking. As per the feedback received from the agencies using the NAQUIM outputs, major limitations of the ongoing studies include i) non-availability of printed Hydro-geological, Chemical and Geo-Physical maps at usable scales and ii) lack of site-specific recommendations for Groundwater Management at village level.

Keeping the above limitations in mind and considering the future requirements, the broad objectives of NAQUIM 2.0 studies will be

i. Providing information in higher granularity with a focus on increasing the density of dynamic data like groundwater level, groundwater quality etc.
ii. providing issue-based scientific inputs for groundwater management up to the village level,
iii. Providing printed maps to the users on a scale of 1:10000.
iv. Putting in place a strategy to ensure implementation of the recommended strategies. Involving state agencies in the studies for a sense of ownership.

The studies under NAQUIM 2.0 are proposed as issue-specific and will be undertaken in prioritized focus areas. Broadly 11 Priority areas are identified based on groundwater-related issues as given below:

1: Water Stressed Areas; 2: Urban Agglomerate; 3: Coastal Areas; 4: Industrial Clusters and Mining Areas; 5: Areas with spring as the principal source; 6: Areas with Deeper Aquifers; 7: Ground Water Contamination; 8: Auto-flow zones; 9: Canal Command Areas, 10: Areas withpoor groundwater quality, 11: Other specific Issues.

The present study has been assigned w.r.t priority area ***Water Stressed Areas,*** taking Bhawanigarh block of Sangrur district City as the area of Interest.

1.2 Study Area:

The Bhawanigarh block forms the part of the Sangrur district of Punjab confined within North Latitudes 30^0 7′ and 30^0 22′ and East Longitudes 75^0 55′ and 76^0 12.5″. The area is falling mainly and partly in Survey of India Toposheets bearing nos. 44N/15, 44N/16, 53B/3 and 53B/4. The block shares its boundary with Dhuri in the North, Sangrur in the west, Sunam in the South and Patiala Districts in the east. The block has 67 nos. of villages. The base map of Bhwanigarh is shown in Figure 1. The study area covers an area of 351.7 km^2 and topographically area is plain.

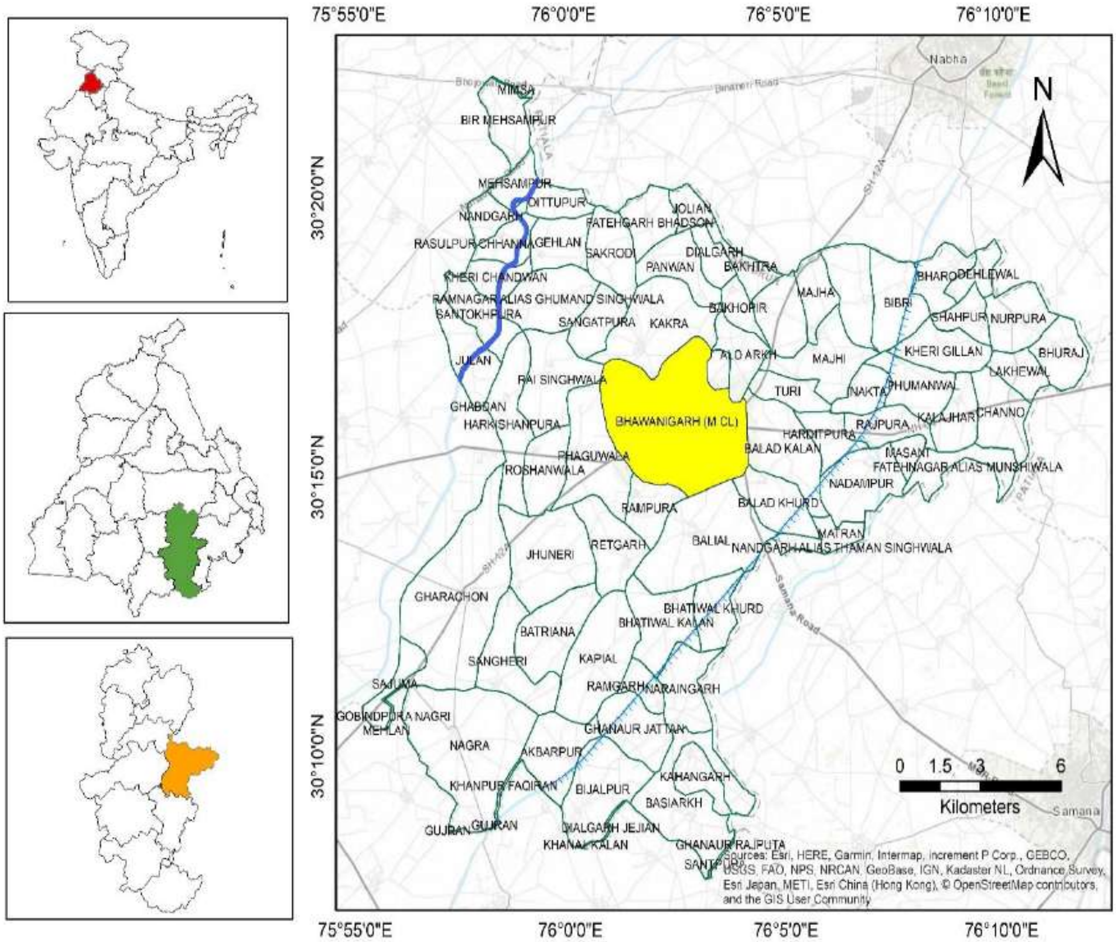


Figure 1 Base Map of Bhawanigarh block, Sangrur District

1.3 Demography

The population as per Census 2011 is 104507 out of which 55,524 are males whereas females are 48,983 and the population density is 312 people per km^2. The literacy rate of Bhawanigarh is 67.56% which is higher than the state average. In Bhawanigarh, Male literacy is around 82.60% while female literacy is 71.95%. The total number of households in the district as per the 2011 census is 19852. The majority of the population is involved in agricultural activities. With time, the Bhawanigarh city has shown rapid urbanization and it is also reflected in its population growth and area spread. The details are given in Table 1 and Figure 2.

Table 1 Urbanization pattern of Bhawanigarh Block, Sangrur District.

Year	Population	City Area (sq km)	Perimeter (sq km)
1991	13900	9.41	2.68
2011	17792	15.1	3.59
2022	22320	18.9	5.51

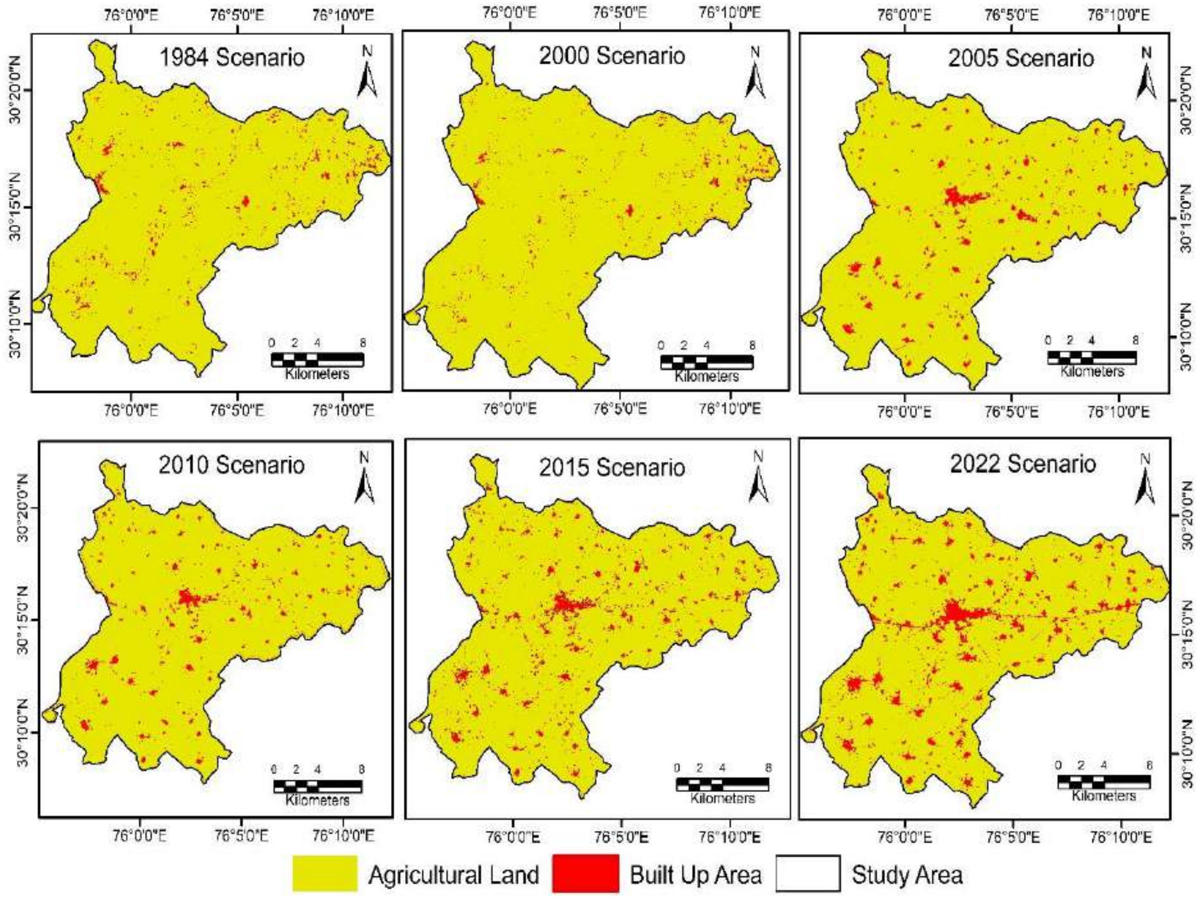


Figure 2 Urbanization pattern of Bhawanigarh Block, Sangrur District

1.4 Hydrometeorology

1.4.1 Climate:

According to the Köppen climate classification, the study area is classified as Cwa. The district experiences a predominantly dry climate, with a short monsoon season, hot summers, and cold winters. The year can be divided into four seasons. The cold season lasts from November to March, followed by the hot season until the end of June. July to mid-September is the rainy season, characterized by the southwest monsoon, while the second half of September and October can be considered as the post-monsoon or transition period. The average annual temperature in the district is 29.05ºC (84.29ºF), which is 3.08% higher than the national average in India. The meteorological data from the nearest observatory in Sangrur is utilized for this analysis.

1.4.2 Rainfall:

The normal annual precipitation is 553 mm over the span of 51 days, with an uneven distribution across the region. Monsoon rainfall makes up 75% of the total annual precipitation in the area from July to September, with July being the month with the highest amount of rainfall. The remaining 25% of the yearly precipitation falls during the non-monsoon period due to western disturbances. The annual Rainfall pattern is illustrated in Figure 3 and Long term Rainfall rainfall is illustrated in Figure 4.

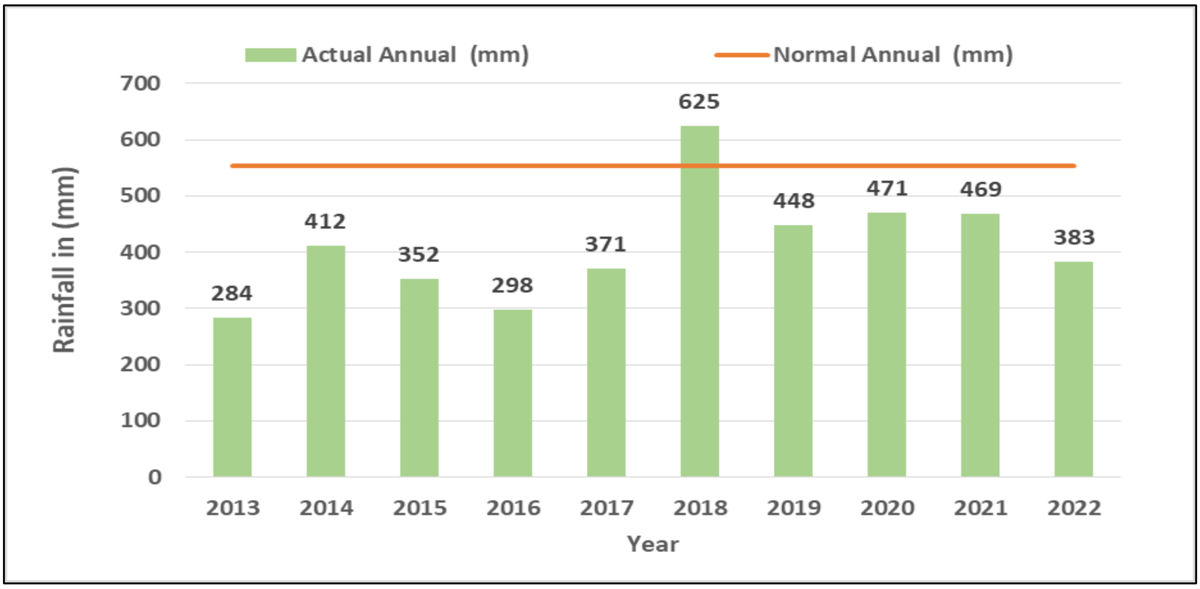


Figure 3 Long-term Rainfall Variation in Bhawanigarh Block, Sangrur District

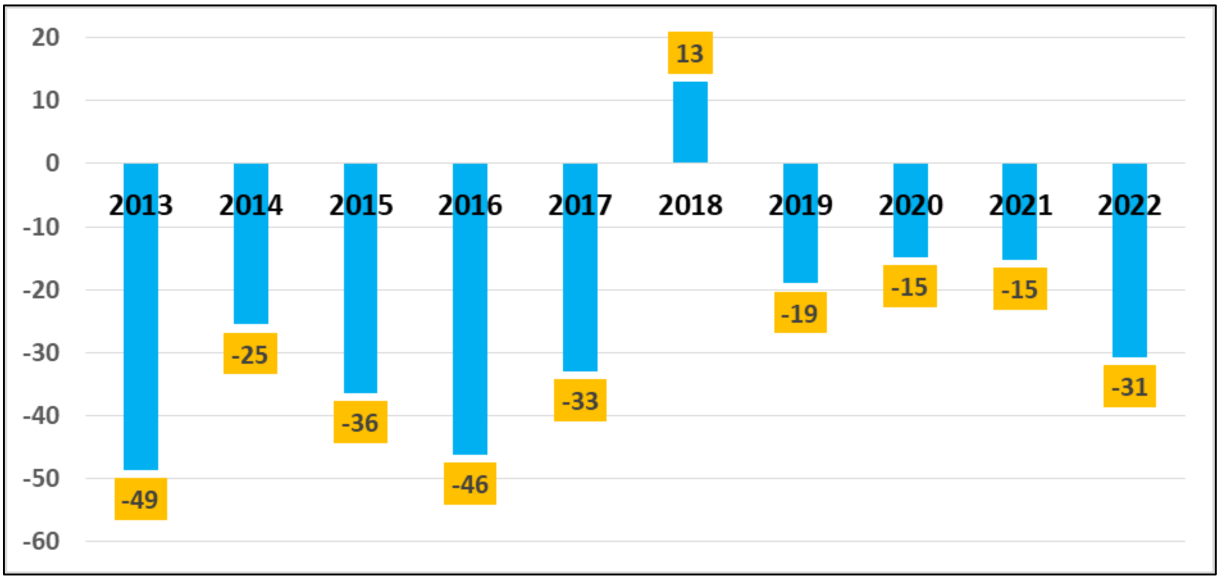


Figure 4 Percentage deviation in actual annual rainfall from normal Rainfall in Bhawanigarh Block, Sangrur District

1.4.3 Temperature

May and June typically experience the highest temperatures of the year, reaching between 30 °C to 41 °C. Conversely, January is known for being the coldest month, with temperatures ranging from 8 °C to 19 °C. Figure 5 illustrates the average temperatures during day and night for each month in 2023. In Bhawanigarh, the normal mean maximum temperature is 35.6ºC, while the minimum temperature is 8.3ºC.

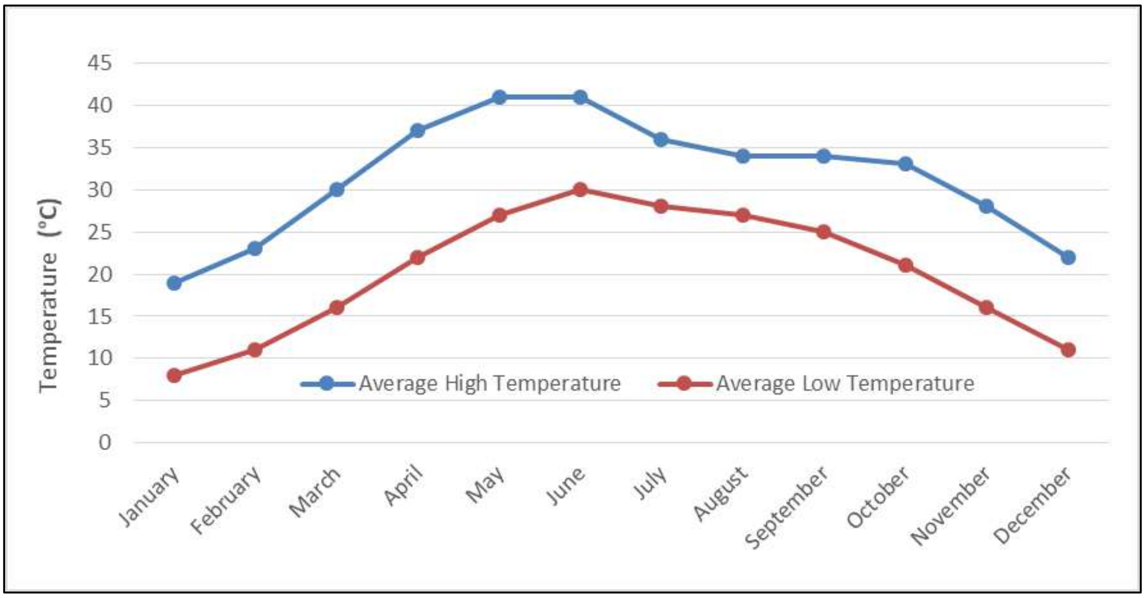


Figure 5 Annual Temperature Variation in Bhawanigarh Block, Sangrur District

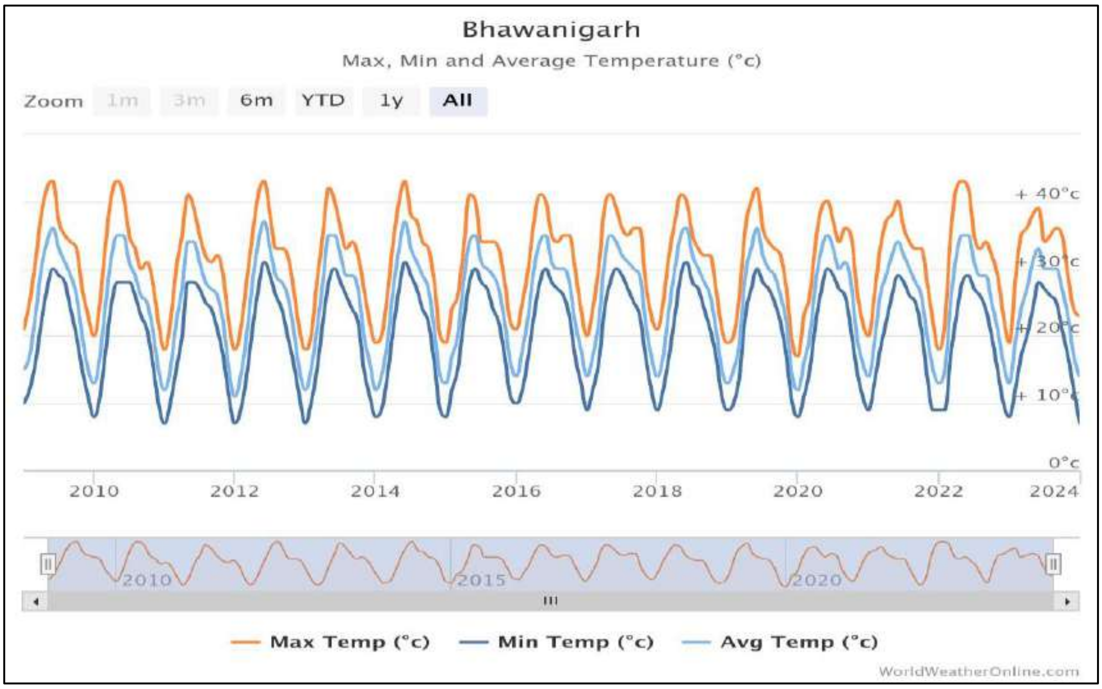


Figure 6 Decadal Temperature Variation in Bhawanigarh Block, Sangrur District

1.4.4 Humidity:

For most of the year, Bhawanigarh experiences low levels of humidity. However, during the monsoon season, humidity levels reach their peak at 67%, while in April and May, humidity levels drop to below 30%, marking the lowest levels. Figure 7 illustrates the average humidity % variations in Bhwanigarh block, Sangrur district, Punjab.

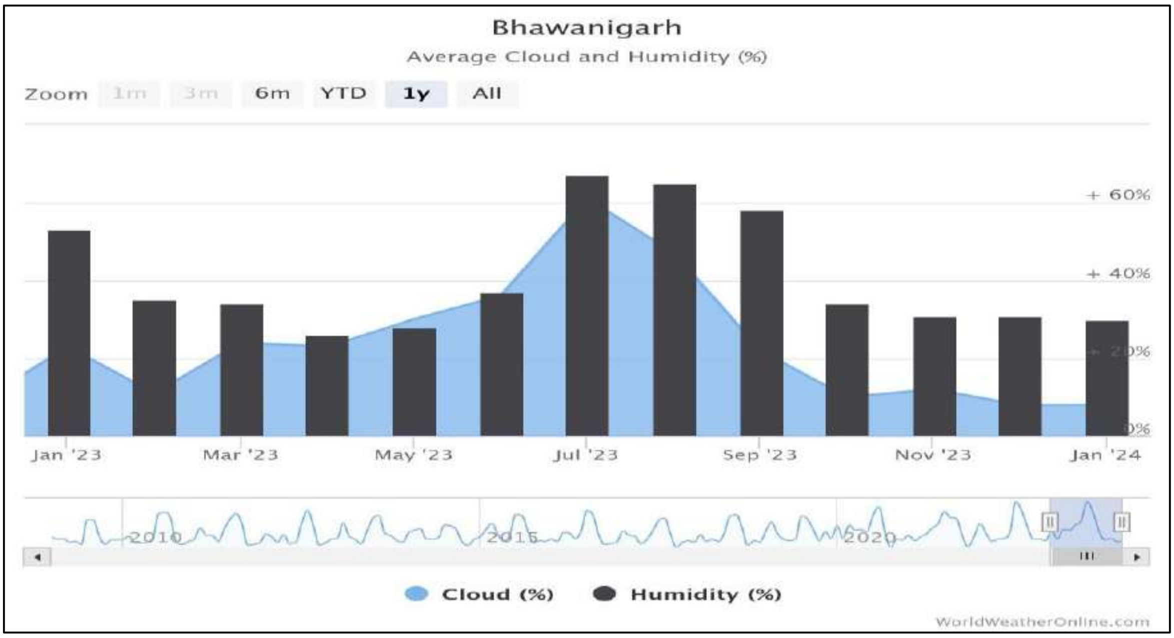


Figure 7 Average Humidity % Variation in Bhawanigarh Block, Sangrur District for 2023

1.4.5 Wind

Throughout the year, Bhawanigarh experiences varying wind velocities, with higher speeds typically seen in May and June before the monsoon season, and lower speeds in January. The maximum wind velocity recorded is 19.2 km/h in June, while the minimum is 12.8 km/h in January. On average, the annual wind velocity in Bhawanigarh is 10.4 km/h.

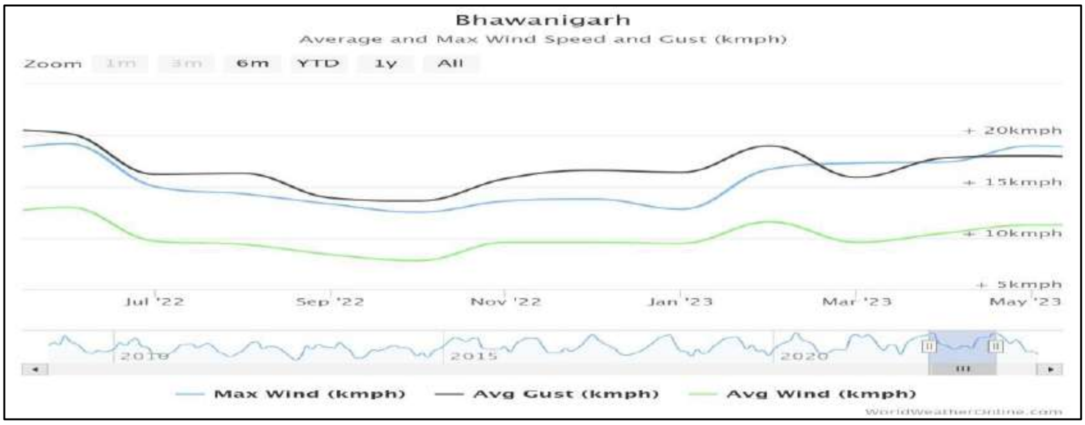


Figure 8 Average Wind Velocity in Bhawanigarh Block, Sangrur District for 2023

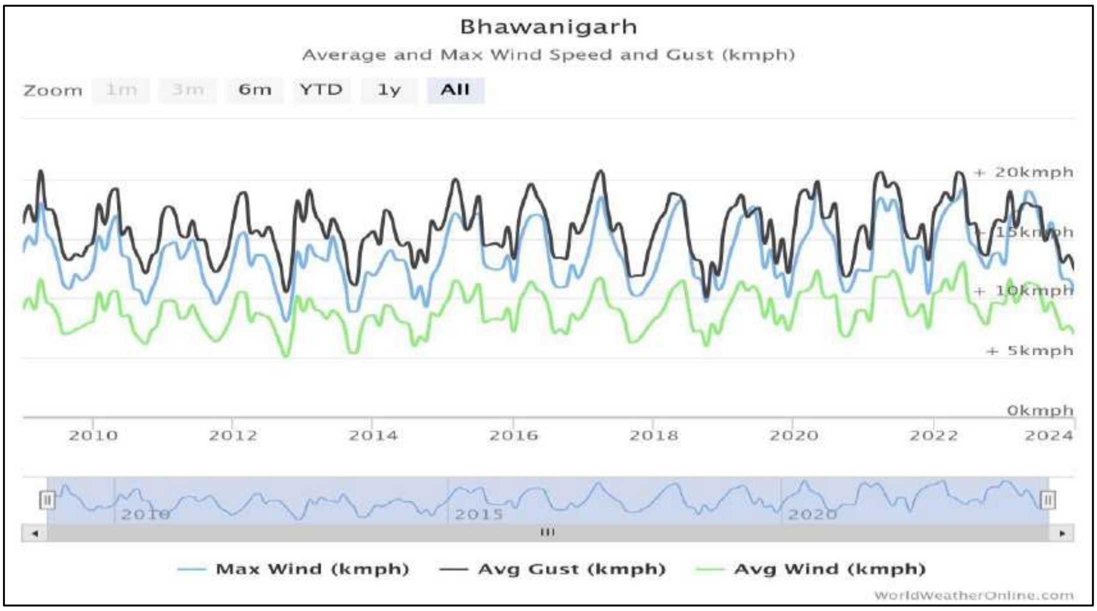


Figure 9 Long-term Variation of Wind in Bhawanigarh Block, Sangrur District

1.5 Geomorphology

The Bhawanigarh block is situated within the Indo-Gangetic plain, characterized by predominantly flat terrain, except the sand dunes that are abundant in the southwestern region. The elevation of the land in this area ranges from 152m in the southwest to 225m above mean sea level in the northeast, with a general slope towards the southwest.

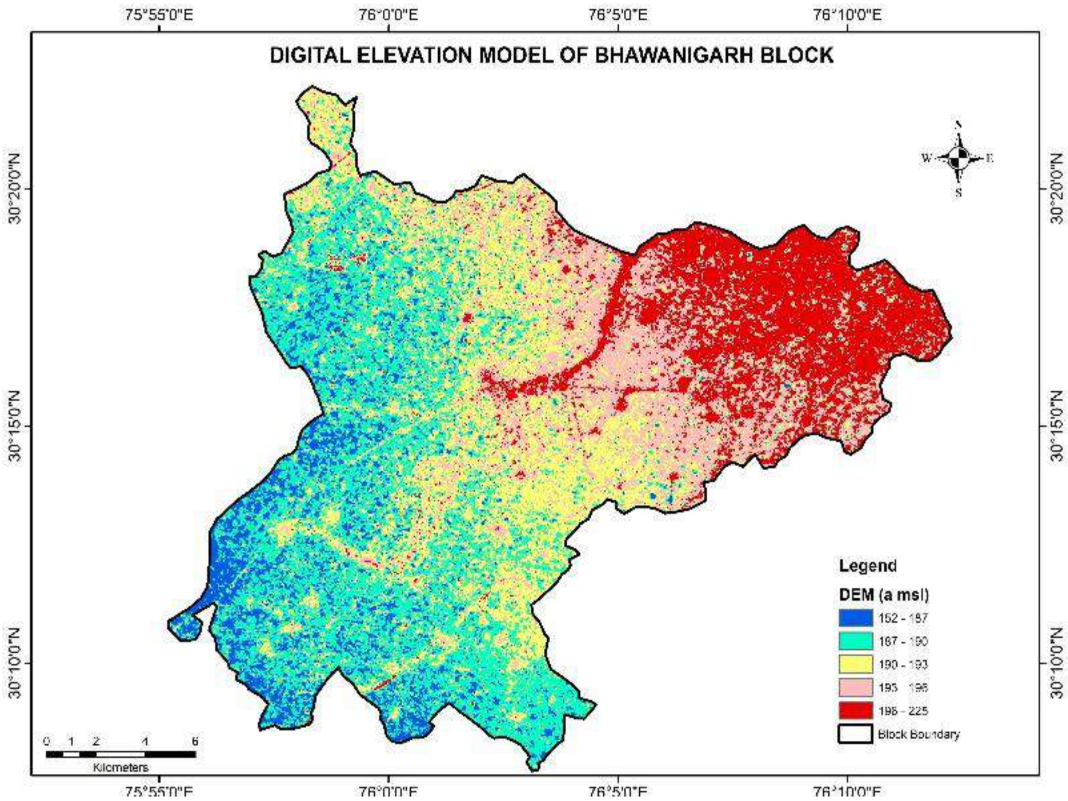


Figure 10 Digital Elevation Map of Bhawanigarh Block, Sangrur District

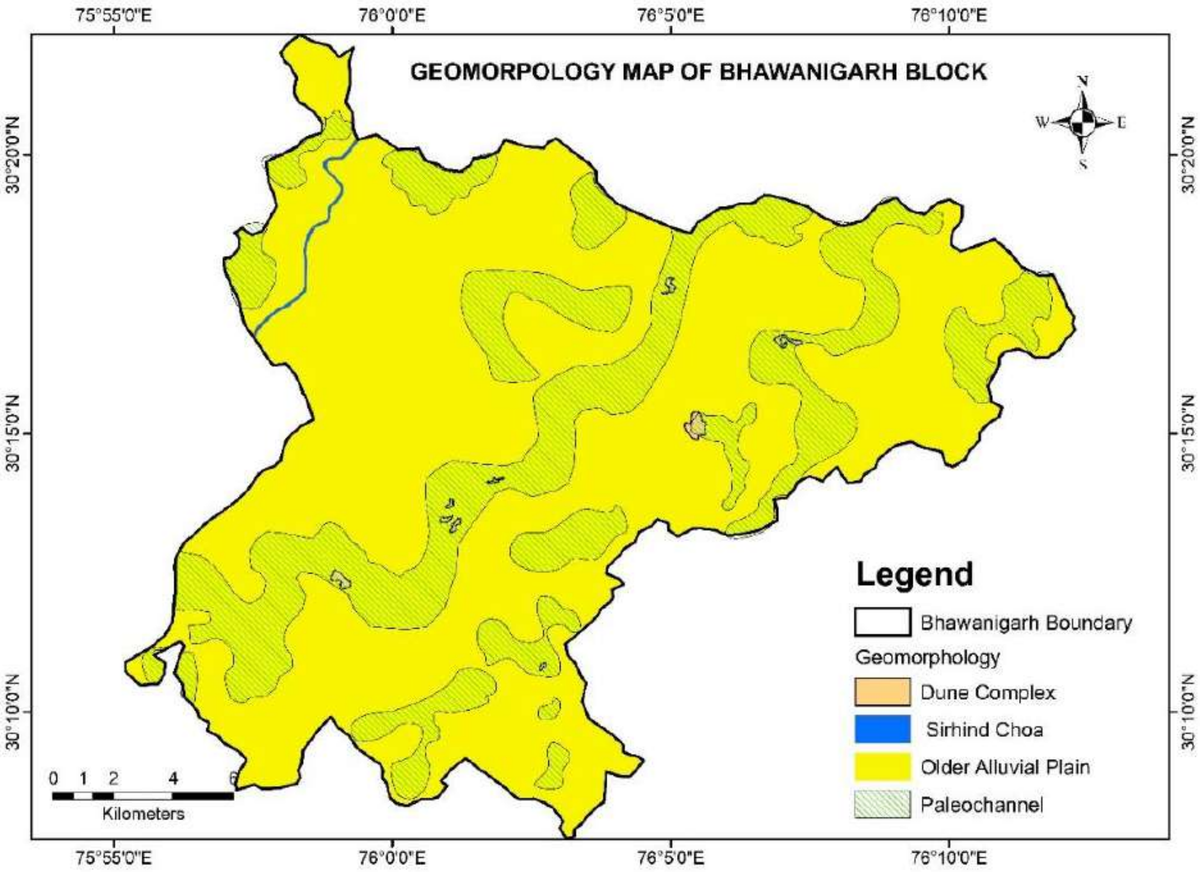


Figure 11 Geomorphollogy Map of Bhawanigarh Block, Sangrur District

The existence of paleochannels has been delineated during the NAQUIM studies using Geophysical, exploration and Remote sensing.

1.6 Soil

The soils found in Bhawanigarh display a sandy loam to loamy texture and are taxonomically categorized as Ustochrepts. These well-drained soils have a brownish hue, with kanker occurring at depths ranging from 15 to 42 meters below the ground surface. The soil composition varies from coarse to fine-grained, with clay lenses interspersed throughout. Moderate saline sodicity characteristics are evident in these soils. As per soil Taxonomy, the majority of the area is classified as Typic Ustochrepts, with some areas classified as Typic Natrustalfs, Natric ustochrepts, and only a small portion showing Udic Ustochrepts (Table 2). The soils in this region are minimally impacted by salinity and sodicity. Figure 12 illustrates the soil map of Bhawanigarh block, Sangrur district, Punjab.

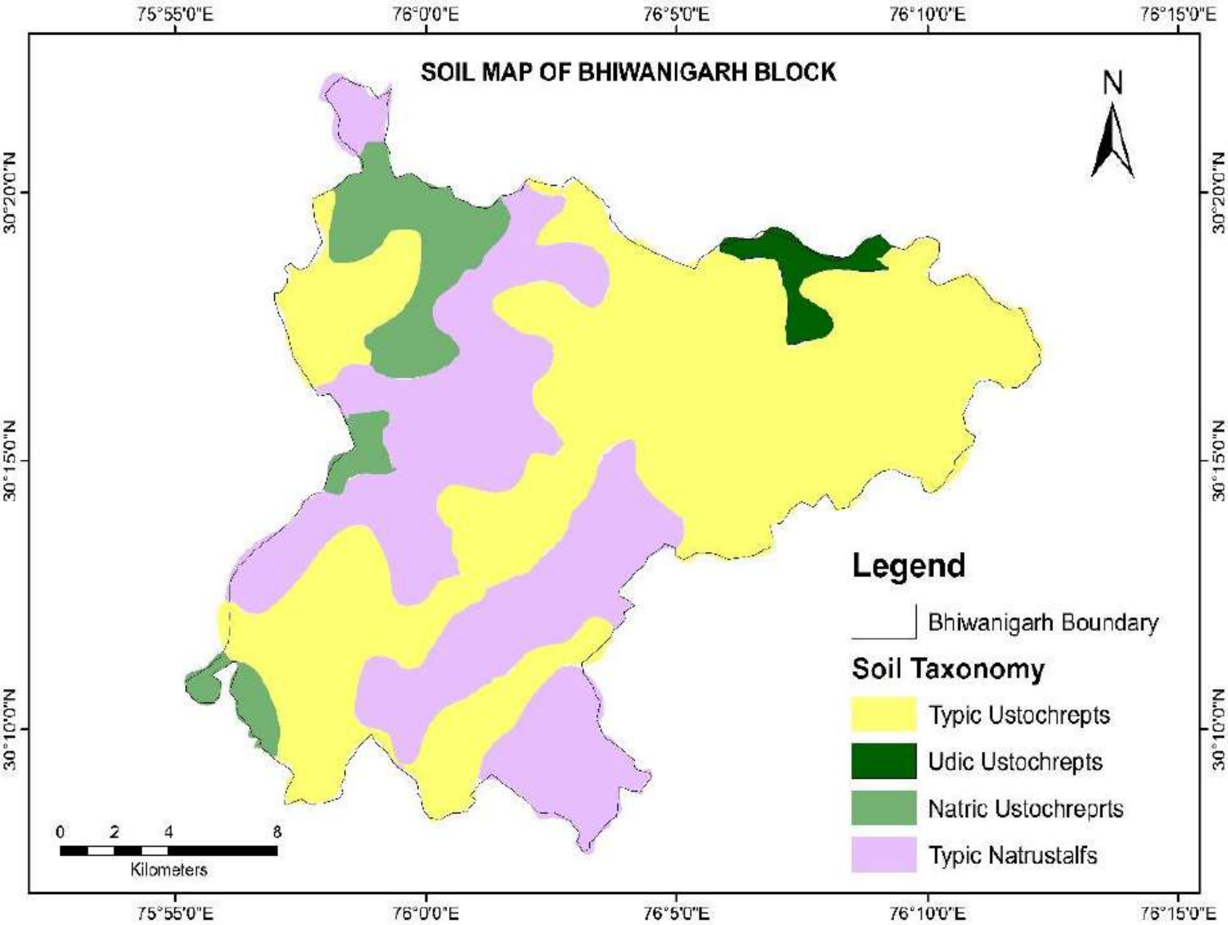


Figure 12 Soil map of Bhawanigarh Block, Sangrur District

Table 2 Soil Types in Bhawanigarh Block, Sangrur District

Soil Type	**Description**
Typic Ustochrepts (62)	Calcareous, coarse loamy soil on near-level slopes with loamy surface slight salinity and moderate sodicity
Typic Natrustalfs (81)	Fine loamy soil on near level slopes (less than 0.5% slope) with loamy surface, moderate salinity and strong sodicity
Natric Ustochrepts (80)	Calcareous, coarse loamy with the loamy surface, slight salinity and moderate sodicity
Udic Ustochrepts (54)	Coarse loamy soils on nearly level slopes with loamy surface and slight erosion.

1.6.1 Soil Infiltration studies

In Bhawanigarh District, a total of 10 soil infiltration tests were conducted using the double-ring infiltrometer. Among these tests, 4 were specifically carried out in the paleochannel. The findings of the study indicated that the infiltration rate within the paleochannel ranged from 66m/hr to 76 mm/hr, which can be classified as moderately rapid. The soil composition in this area primarily consists of sandy loam.

On the other hand, outside the paleochannel, the infiltration rate varied from 12mm/hr to 27mm/hr. The infiltration class in this region can be categorized as moderately slow to moderate, and the soil type is predominantly sandy clay loam to loamy sand. Due to the moderately high infiltration rate observed in the paleochannels, they possess a significant capacity to recharge the runoff during the monsoon season. Consequently, these paleochannels serve as potential sources for managed aquifer recharge.

1.7 Drainage and Canals

The region lacks a clearly defined drainage system, except for the Sirhind Choa drain. Agriculture serves as the primary economic driver in the area. Irrigation is predominantly carried out through tubewells and canals. The block benefits from an extensive network of canals, including the Ghaggar Branch, Bhawanigarh distributary, Namada distributary, and Ramgarh distributary. These canals are all part of the Sirhind canal system connected to the Bhakhra main canal. Figure 13 illustrates the Drainage and water bodies map of Bhawanigarh block, Sangrur district, Punjab.

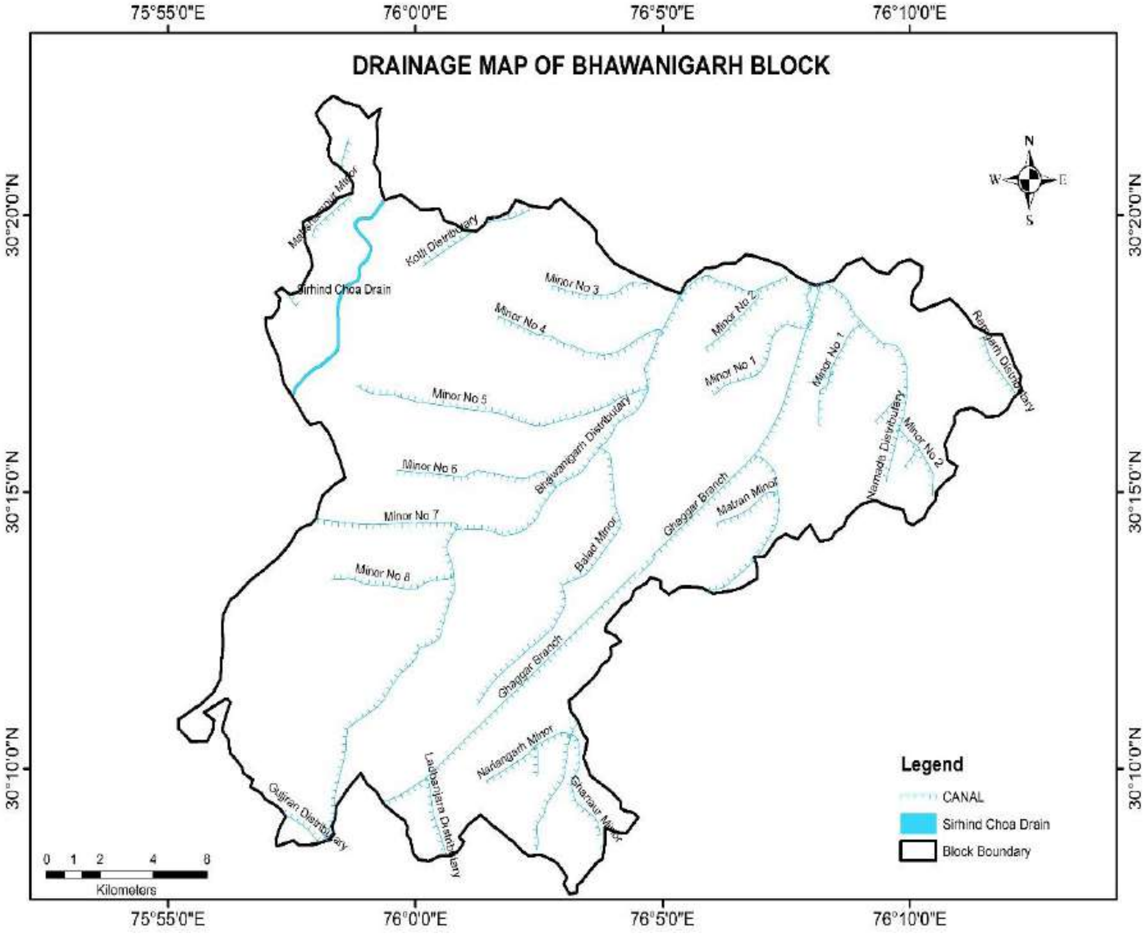


Figure 13 Drainage and water bodies map of Bhawanigarh Block, Sangrur District

1.8 Land use/ Land Cover

The block spans a total area of 351.70 square kilometres, (35170 hectares). Bhawanigarh primarily dedicates its land to agricultural activities, boasting a cropping intensity of 188%. The net sown area covers 30528 hectares, while the gross sown area extends to 57382 hectares. The land utilization pattern for the year 2022-23 is detailed in Table 3, showcasing the distribution across different categories. The breakdown of land utilization percentages across various classes can be found in Figure 14.

Table 3: Utilization of Land in Bhawanigarh Block, Sangrur District, Punjab

S. No	TYPE OF LAND USE	AREA (HECTARES)
1	Forest	120
2	Land under non-agricultural use	3756
3	Barren Land	198
4	Fallow land	568
5	Net area sown	30528
6	Gross area sown	57382
7	Cropping intensity	189
8	Net irrigated	30421
9	Gross irrigated	57381
10	Irrigation Intensity	189

(Source: Statistical Abstract, Punjab, 2022)

A thorough examination of the land use pattern spanning from 2016 to 2023 reveals that there has been no prominent shift in the way land is utilized. Figure 15 illustrates the Land Use and Land Cover Map of Bhawanigarh.

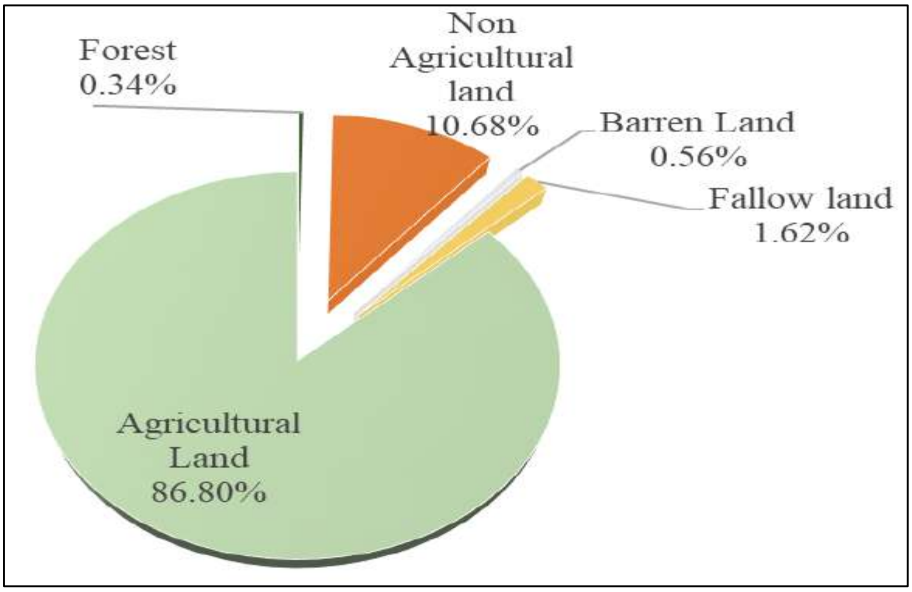


Figure 14 Percentage of Land utilization under various classes

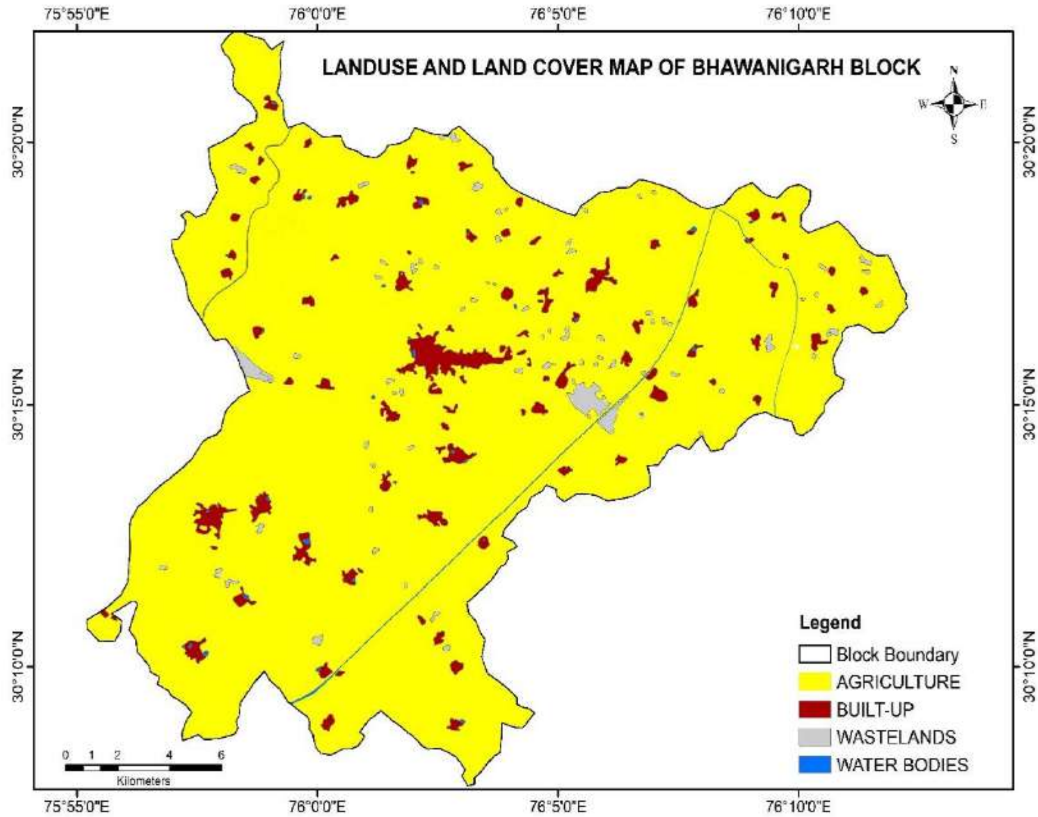


Figure 15 Land use and Land cover Map of Bhawanigarh Block, Sangrur District

1.9 Agriculture

Agriculture plays a vital role in sustaining the community in this region, with agriculture and its allied occupations being the primary sources of income for the inhabitants. The soil composition in the district supports the cultivation of a wide range of crops, including Paddy, Wheat, Cotton, Sugarcane, and other non-cereal crops. The distribution of principal crops grown in the Bhawanigarh block can be observed in Figure 16, while Table 4 displays the area dedicated to various crops from 2018 to 2022.

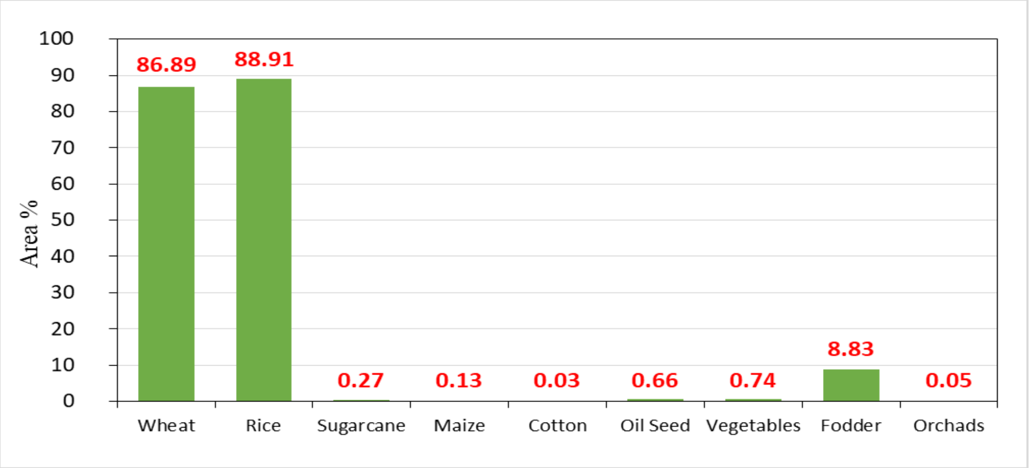


Figure 16 Crop distribution in Bhawanigarh Block, Sangrur District

Table 4 Area under Different crops in Bhawanigarh Block, Sangrur District, Punjab

S. N	CROP	AREA (HECTARES)			
		2018-19	2019-20	2020-21	2021-22
1	Wheat	26833	26826	26820	26526
2	High Yielding Wheat	26833	26826	26820	26576
3	Rice	26576	26686	26653	27141
4	High Yielding Rice	26576	26686	26653	27631
5	Cotton	29	29	55	8
6	Sugarcane	173	145	143	81
7	High Yielding Maize	15	7	21	34
8	Maize	13	7	21	41
9	Other cereals	692	626	616	446
10	Oil Seed	148	148	145	201
11	Other Crop Vegetable	102	104	106	225
12	Fodder	2792	2794	2805	2697
13	Orchards	22	16	16	14

1.10 Irrigation

The Sangrur district stands out as one of the districts in Punjab State that reap the rewards of abundant agricultural land. Effective irrigation is a key factor in driving intensive agriculture and boosting crop productivity. Therefore, it is imperative to focus on enhancing water resources and utilizing them efficiently to support agricultural activities. Furthermore, the role of irrigation in agriculture has become increasingly vital in light of advancements in farming technology.

Following Independence, there has been a notable enhancement in the irrigation infrastructure within this region. The introduction of tube wells and expansion of canal irrigation have resulted in a substantial rise in the irrigated land area of the district. The Bhawanigarh block currently boasts a net irrigated area of 30,420 hectares, with the gross irrigated area reaching 57,380 hectares (Table 5). The irrigation intensity percentage stands at 189%, showcasing the significant impact of these developments. Groundwater has emerged as a key player in the irrigation sector, with 95.2% of irrigation being sourced from groundwater, while only 4.8% is attributed to canal networks. This shift towards groundwater-based irrigation has played a crucial role in the overall improvement of irrigation facilities in the area.

Table 5: Area under Irrigation in Bhawanigarh Block, Sangrur District, Punjab

S. N	Type of Land use	Area (hectares) (2021-22)
1	Gross Irrigated Area	57380
2	Net Irrigated area	30420
3	Gross area irrigated to total cropped area	100.00%
4	Net area irrigated to Net area sown	100.00%
5	Irrigation intensity	189.00%

(Source: Statistical Abstract, Sangrur, 2022)

1.11 Industries

Bhawanigarh Block does not have a designated industrial area, however, there are a few clusters of industries located in Aloarkh and Channo village. The total count of industries in Bhawanigarh block amounts to 341, employing 2678 individuals. Notably, the prominent industry in Channo village is Pepsico, which consumes 9.8 million cubic meters of water on an annual basis. Further details can be found in Table 6.

Table 6 Details of Industry in Bhawanigarh Block, Sangrur District

Type of Industrial Unit	**Number**	**Employees**
Village & Khadi Industries	261	624
Small Scale Industry	74	1279
Large scale Industry	6	925

1.12 Drinking Water Supply

In a significant development, the Public Health Department has successfully provided drinking water to 54 out of 68 villages through the installation of tubewells. The remaining villages are scheduled to be covered under the jal jeevan mission by the end of 2024. It is worth mentioning that the water quality is excellent and meets the necessary standards for drinking.

CHAPTER 2. DATA AVAILABILITY, COLLECTION AND GENERATION

2.1. Data Availability, Collection and Generation

The data available with the CGWB was compiled and plotted on a 1:10000 scale map, and an analysis of data gaps was carried out. Table 7 below summarises the data required, its availability, the Data Gap, and the data generated after data analysis in the Bhawanigarh Block during NAQUIM 2.0.

Table 7 Data Requirement, Data Availability, and Data Gap Analysis

S. No	Items	Data Requirement	Data Availability	Data Gap	Data Generated
1	Meteorological data	Meteorological stations spread over the project area	No Meteorological Station	Meteorological Station	World weather website
2	Soil	Soil map	Scanned Soil Map	Soil Taxonomy map	Prepared in Arc GIS
3	Land Use	Latest Land Use Pattern	Land Use Data of 2012-13	Latest land Use Data map	Prepared in Arc GIS
4	Geomorphology	Geomorphological Map	Prepared in GIS	Nil	Nil
5	Geophysics	Geophysical data in each Quadrant	02 no of VES done till now	72	40 VES, 2 Logging
6	Exploration	1 EW in 5 X 5 km Quadrant	2	12	47 (5 CGWB + State 41 + 1 Private)
7	Monitoring Regime	1 Key well in each 5 X 5 km quadrant	4 (1 CGWB & 3 State)	18	49
8	Ground Water Quality	1 Quality station in each 5 X 5 km quadrant	1	20	47 (pre-monsoon) & 128 (Post monsoon)
8	Recharge Parameters	Recharge parameters for different soil and aquifer types based on field studies	Recharge parameters are given in Ground Water resource estimation	Available	Nil
9	Discharge Parameters / Draft Data	Discharge parameters for different GW abstraction structures	Discharge parameters are given in Ground Water Resource Estimation GEC 2023	Available	Nil
10	Geology	All the maps on a 1:10000 scale	All the maps on a 1:50000 scale	All the maps on a 1:50000 scale	Prepared in GIS

The available data of Exploration carried out by North western Region, Chandigarh, Geophysical Survey carried out in the area, Groundwater Regime monitoring, and Groundwater quality stations were compiled and analyzed for adequacy of the same for carrying out NAQUIM 2.0 in Bhawanigarh Block of Sangrur District. The Data Gap analysis map for Key wells for water level monitoring, Quality monitoring, Exploration, and VES was prepared and is shown in Figures 17, 18, 19, and 20 respectively. In these maps, the existing and the proposed data gap points are marked.

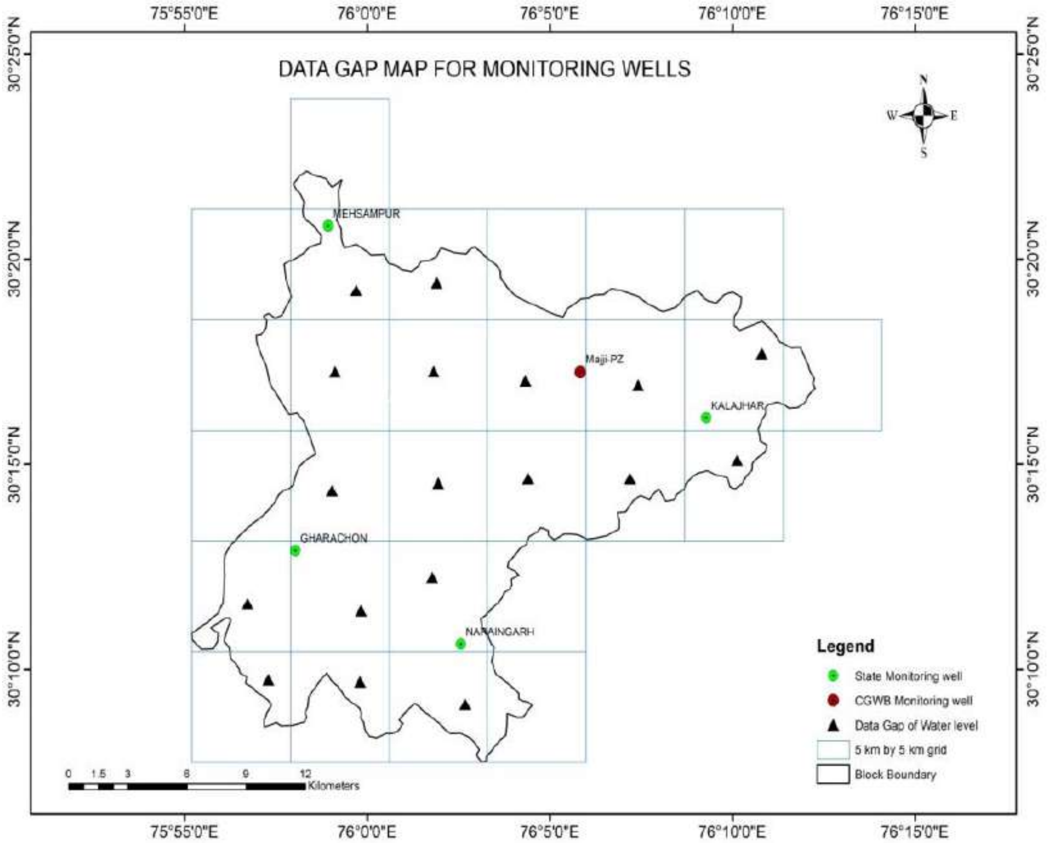


Figure 17 Map showing Existing and Proposed Water Level Monitoring Key Wells in Bhawanigarh Block, Sangrur District

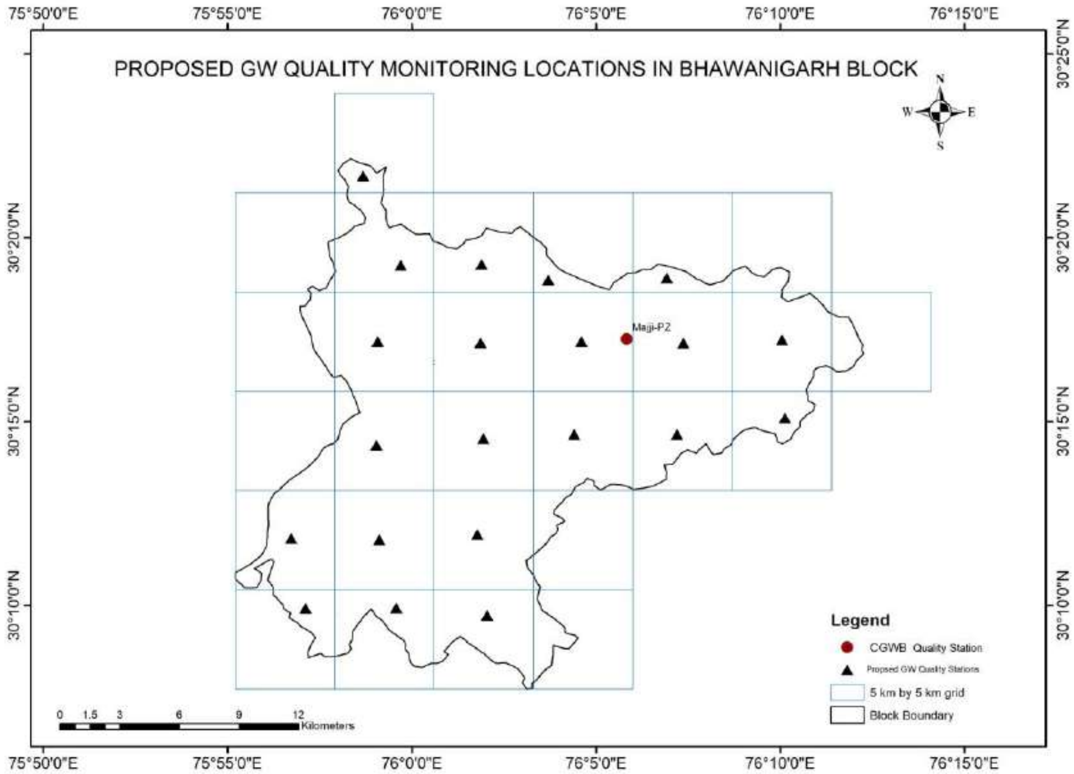


Figure 18 Map showing Existing and Proposed Quality Monitoring stations in Bhawanigarh Block, Sangrur District

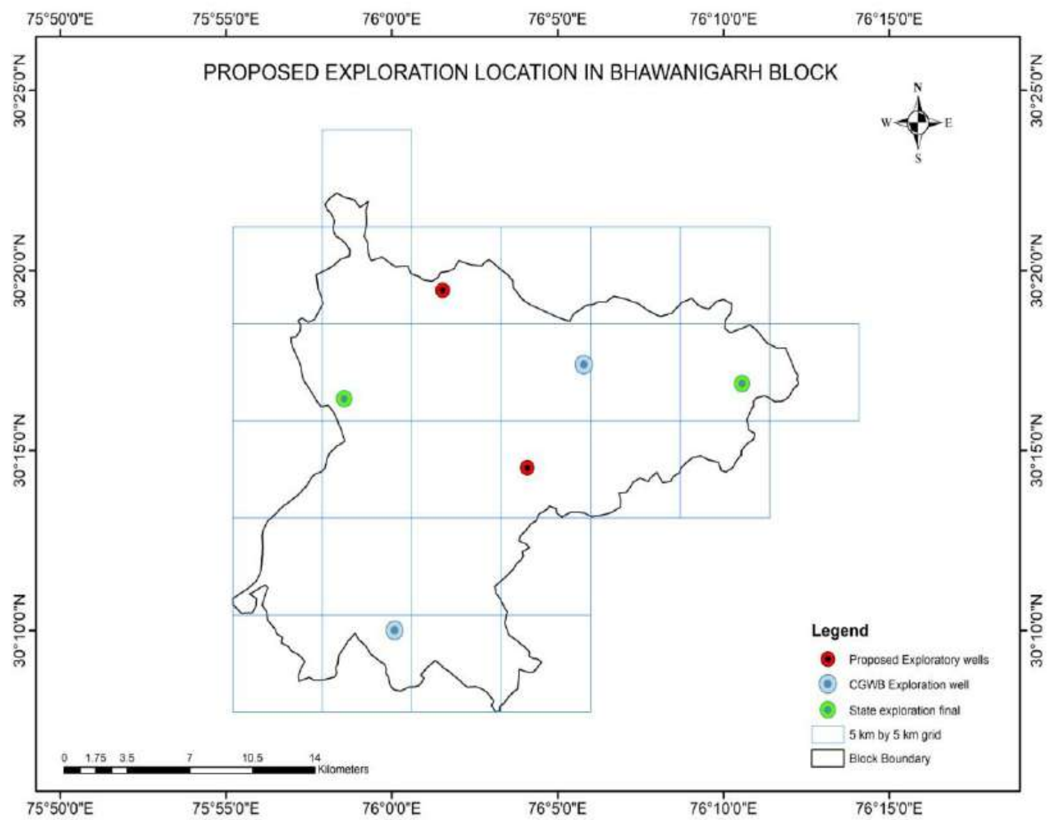


Figure 19 Map showing Existing and Proposed exploratory wells in Bhawanigarh Block, Sangrur District

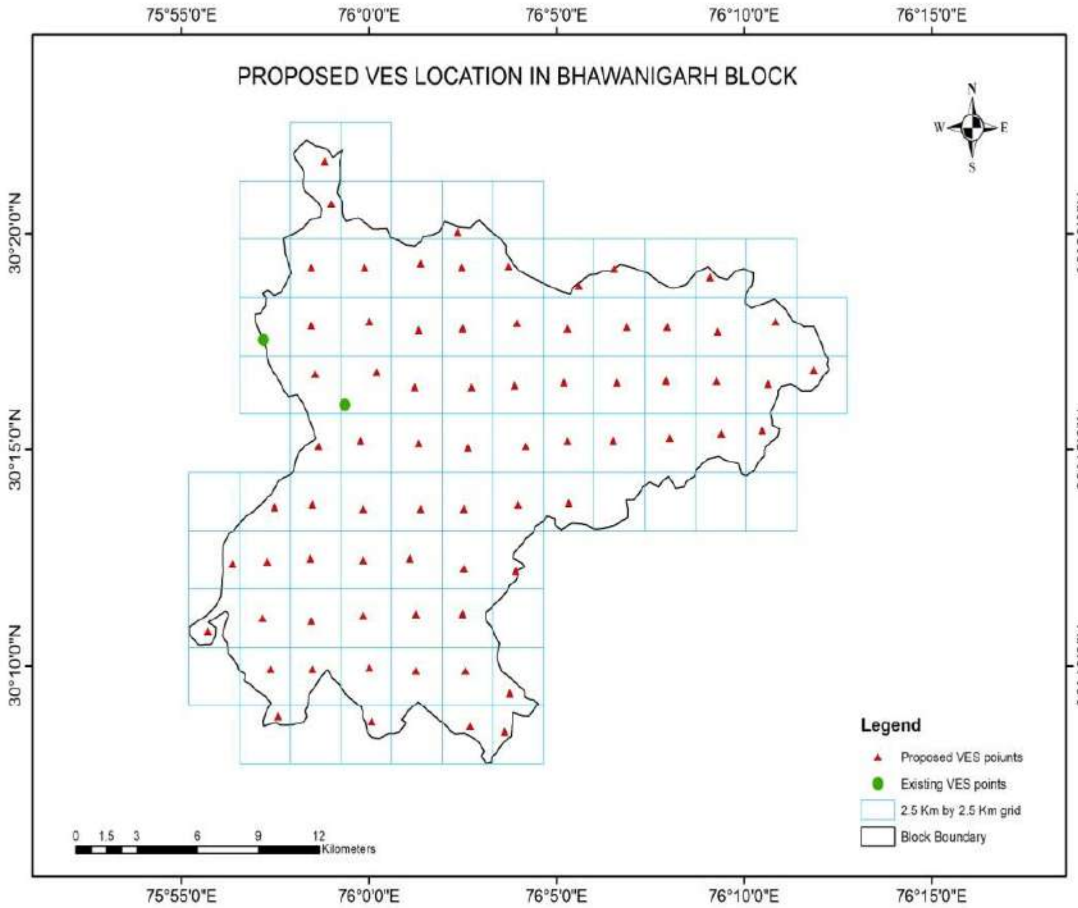


Figure 20 Map showing Existing and Proposed Vertical Electrical Resistivity Survey (VES) in Bhawanigarh Block, Sangrur District

CHAPTER 3. HYDROGEOLOGICAL CONDITIONS

3.1. Geology

The Bhawanigarh Block is situated within the Indo-Gangetic alluvial plains and is located in the Ghaggar Sub-Basin. The topography of the block is predominantly flat, characterized by the presence of Quaternary age alluvium from the Indo-Gangetic plain. This alluvium consists of a mixture of fine to coarse sand, kanker, and clay, forming potential aquifers within the region. The alluvium is further categorized into older and newer deposits, with the newer deposits resulting from the deposition of wind-eroded or water-eroded materials in the low-lying areas of the block.

The geological Map of Bhawanigarh, as depicted in Figure 21, provides a visual representation of the area's geological features. Additionally, a generalized stratigraphic sequence of the region can be found in Table 7, offering valuable insights into the geological composition of Bhawanigarh Block. Overall, the presence of diverse alluvial deposits within the block highlights the complex geological history of the region and underscores the significance of understanding these formations for various scientific and environmental studies.The Bhawanigarh Block forms part of the Indo-Gangetic alluvial plains and lies in the Ghaggar Sub-Basin. The area of the block in general is plain. The block is occupied by the Alluvium of Quaternary age of Indo Gangetic plain. The alluvium comprises of fine to coarse sand and kanker which forms the potential aquifers admixed with clay. The alluvium is further subdivided into older alluvium deposits and newer alluvium deposits. The newer alluvium is the deposits which are formed by deposition of either wind-eroded or water-eroded alluvium in the low-lying tracts of the block. The geological Map of Bhawanigarh is shown in Figure 21. The generalized stratigraphic sequence of the area is given in Table 8.

Table 8 Generalized Stratigraphy of Bhawanigarh Block, Sangrur District

Age	Super Group	Group/ Formation	Lithological Characteristics	Water Bearing Characteristics
Pleistocene to recent	Quaternary	Newer Alluvium	Streamlined Windblown sand with clay, and Kanker and channel alluvium deposited by local nalas	Good water-bearing horizons with good yield
		Older Alluvium	Poorely sorted, semi consolidated, Grey and brown sand, silt with clay and kanker.	

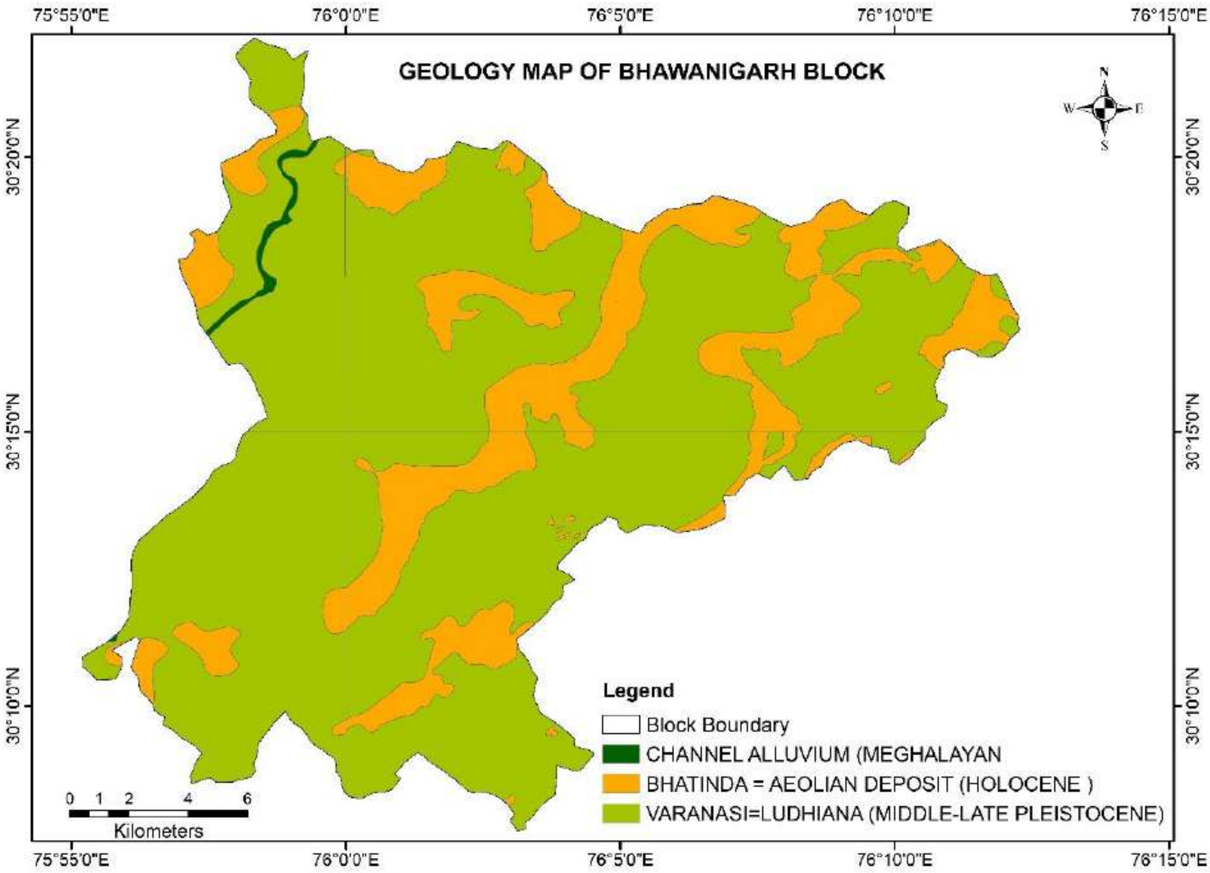


Figure 21 Geology Map of Bhawanigarh Block, Sangrur District

3.2. Sub-Surface Geology

In the surveyed region, the Central Ground Water Board conducted several exploration programs/projects, resulting in the drilling of a combined total of nine exploratory boreholes. These boreholes consisted of four EW (Exploration) boreholes, three OW (observation Well) boreholes, and seven Piezometer boreholes. For further information on the specific locations and characteristics of these boreholes, please refer to Table 9. Additionally, Figure 22 provides a visual representation of the exploration area through an Exploration Map.

Table 9 Exploration carried out in Bhawanigarh Block, Sangrur District

Location	Type	Depth Drilled	Constructed	Year	Project
Akbarpur	EW, OW	537	173	1977	Ghaggar Studies
Majji	EW, OW	200	200	2015	NAQUIM 1.0
Balial	EW, OW	150	148	2023	NAQUIM 2.0
Kakra	EW, OW	150	148	2023	NAQUIM 2.0
Kakra	Piezometer	105	78	2024	NAQUIM 2.0

In addition to the Central Ground Water Board's efforts, the Water Resource Department of Punjab State conducted drilling activities in the Bhawanigarh Block. They focused on installing 6 piezometers to monitor and analyze water level fluctuations in the area. Furthermore, the PHED (Public Health Engineering Department), Irrigation Department, and Agriculture Department also contributed to the drilling efforts by establishing multiple wells within the block. The lithology data for a total of 47 wells has been collected from various state Government agencies, providing valuable information for further analysis and understanding of the area's groundwater resources.

Analysis of different lithologies reveals the presence of two distinct clay layers up to a depth of 150 meters. The initial clay layer, which is mixed with fine sand, is identified at approximately 90 meters below the surface and measures around 12 meters in thickness. On the other hand, the second clay layer is situated between 140 to 160 meters. The strata up to 50 meters consist mainly of medium to coarse sand with the occurrence of numerous Kankers. Beyond the 50-meter mark, the strata exhibit varying grades of sand, ranging from fine to medium. Below the second clay layer, the strata are characterized by medium sand, occasionally transitioning to medium to coarse sand. Small clay lenses are a common feature in both the upper and lower strata.

The total thickness of the alluvium remains unknown as the borehole drilled at Akbarpur has not reached the basement even after descending to a depth of 537 meters.

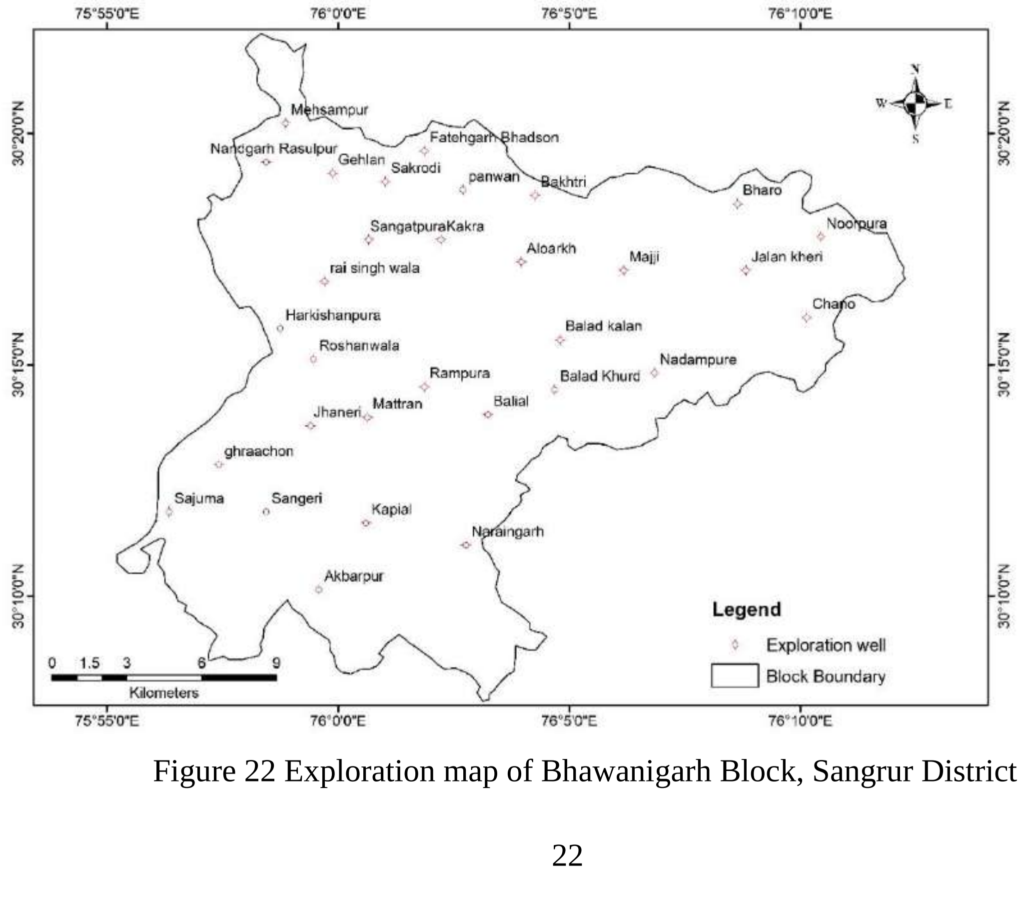


Figure 22 Exploration map of Bhawanigarh Block, Sangrur District

3.3. Hydrogeology

The Bhawanigarh block is mainly underlain by alluvium of Quaternary age which forms the principal groundwater reservoir. The groundwater occurs under both Confined and Unconfined Conditions. The groundwater up to the depth of 96 meters occurs under the unconfined conditions below which a thick clay layer along with fine sand of about 10m to 14m thickness separates Aquifer I from Aquifer II. The groundwater occurring below this clay bed is under confined conditions. Two Aquifers have been delineated to a depth of 150 meters. The sand of various grades along with kanker forms the potential aquifers.

3.4. Source of Groundwater

Groundwater in the area primarily originates from precipitation. When it rains, the water can take different paths: it can evaporate or be transpired by plants, flow over the land surface and enter surface drainage, or infiltrate into the ground. Once in the ground, the water can either remain as soil moisture, move laterally as interflow to streams, or percolate downwards to the zone of saturation, becoming part of the groundwater. In addition to rainfall, groundwater recharge is also influenced by agricultural irrigation and canal seepage. These factors contribute to the overall replenishment of groundwater resources in the area.

CHAPTER 4-AQUIFER DISPOSITION

4.1. Objective

The geometry and nature of aquifers provide the basic parameters for determining the occurrence and movement of groundwater. To understand the sub-surface distribution of aquifers and their disposition in the study area the 3-D stratigraphic model, Fence diagram and sub-surface profile section will be prepared.

4.2. Material Methodology

To understand the lithological framework and aquifer disposition of Bhawanigarh Block, the lithological data generated through exploration and lithological layers interpreted through Geophysical methods has been utilized. The lithology data of wells drilled by CGWB, DWSS and the Department of Rural Drinking Water Supply were integrated, optimized and modelled into a 3-dimensional synoptic picture by using the RockWorks15 software. The Lithology data of 41 numbers of boreholes drilled by State Government agencies up to the depth of 150 meters, 1 private borehole data up to 160 meters and 5 Bore wells of CGWB up to the depth of 160 meters have been used. Along with drilling data the geophysical data has also been integrated to provide the synoptic picture of the area. The details are given in Table no 10. The detailed Geophysical Report is attached as Annexure 8.

Table 10 Details of Exploration data and Geophysical Data used in the preparation of Aquifer Disposition of Bhawanigarh Block, Sangrur District Punjab

Exploration Data		**Geophysical Data**	
Agency	Number	Method	Number
CGWB	5	Surface (VES)	35
State	41	Sub-surface (Logging)	3
Private	1		

The topographic elevation values of exploration wells have been plotted to prepare the elevation contour map and are shown in Figure 23. The map showing the location of boreholes is shown in Figure 24. The data is calibrated for elevations with Shuttle Radar Topography Mission (SRTM) data. The 3-dimensional Aquifer Disposition model, Fence diagram and 2-dimensional cross-section of Aquifers have been prepared. The fence diagram provides a much clearer representation of sub-surface lithology in space.

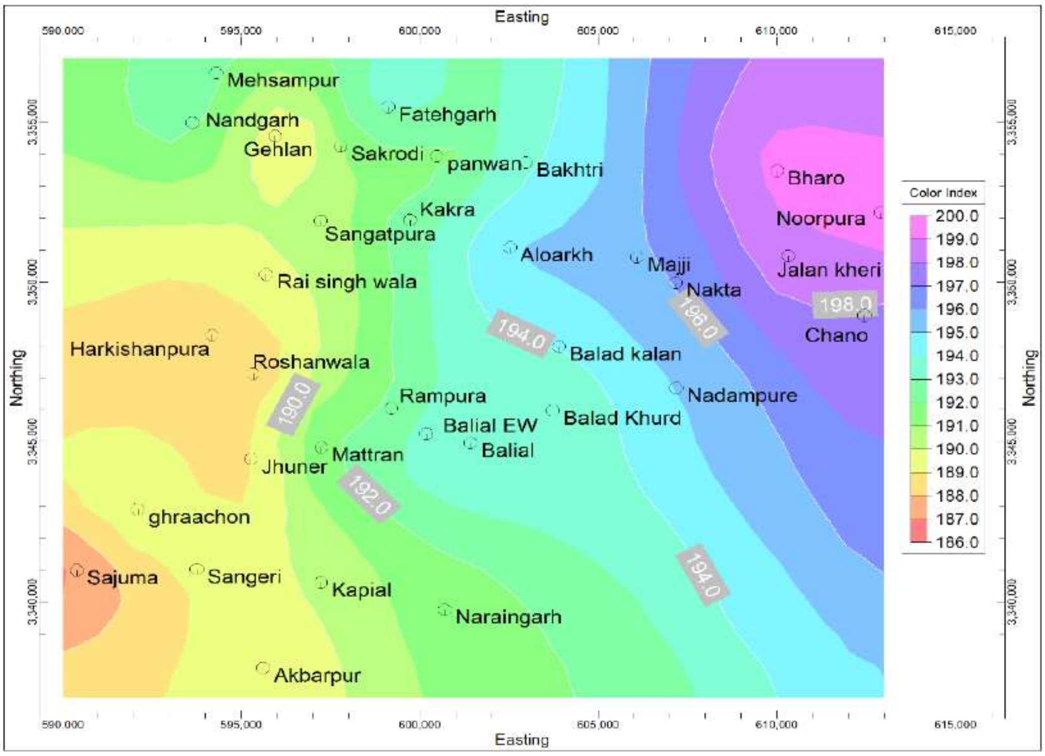


Figure 23 Elevation Map of Bhawanigarh Block, Sangrur District, Punjab

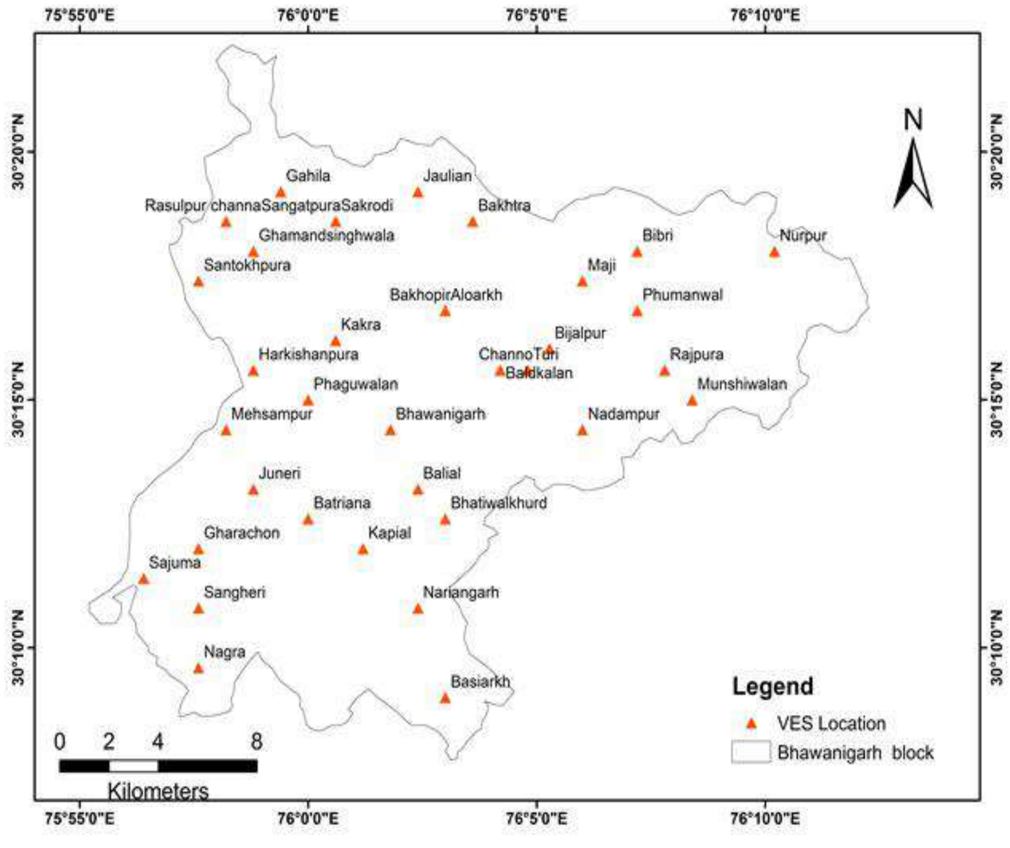


Figure 24 Geophysical Vertical Electrical sounding Survey location in Bhawanigarh Block, Sangrur Dist. Punjab

4.3 Aquifer Disposition:

The Aquifer disposition model of the Bhawanigarh block reveals the broad picture of aquifer disposition, interrelationship of granular zones, nature, geometry and extension of aquifers in the entire study area. The aquifer grouping has been carried out using the sub-surface lithology and a three-dimensional aquifer model has been prepared. The aquifer group embodies several granular layers alternating with thin clay lenses. The aquifers have been grouped into two groups up to a depth of 150 meters in the Bhawanigarh block.

The first aquifer is the water table aquifer (Unconfined Aquifer) extending all over the study area. This aquifer is mainly composed of medium to coarse-grained sand. The top of the first aquifer is unsaturated. The average thickness of the unsaturated zone is 37.6 m. The thickness of the unsaturated zone has been estimated based on Geophysical data and water level monitoring. The average thickness of aquifer I is estimated to be 55 m. The first and second aquifer is separated by a clay layer having very fine sand with an average thickness of 11 m in the study area.

The Second aquifer is semi-confined in nature and extends up to a depth of 142m with an average thickness of 35m. After the Second aquifer, there comes the thick confining clay layers up to a depth of 165 m. The 3-dimensional Aquifer Disposition model and fence diagram are shown in Figures 25 and 26 respectively. The generalized Aquifer grouping is shown in Table 11.

Table 11 Generalized Aquifer Group of Bhawanigarh Block, Sangrur District. Punjab

Type	Depth		Average Thickness (m)
	From	To	
Top Soil	0	3.4	3.4
Unsaturated Zone	3.4	41	37.6
Aquifer I	41	96	55
Aquiclude I	96	107	11
Aquifer II	107	142	35
Aquiclude II	142	165	23

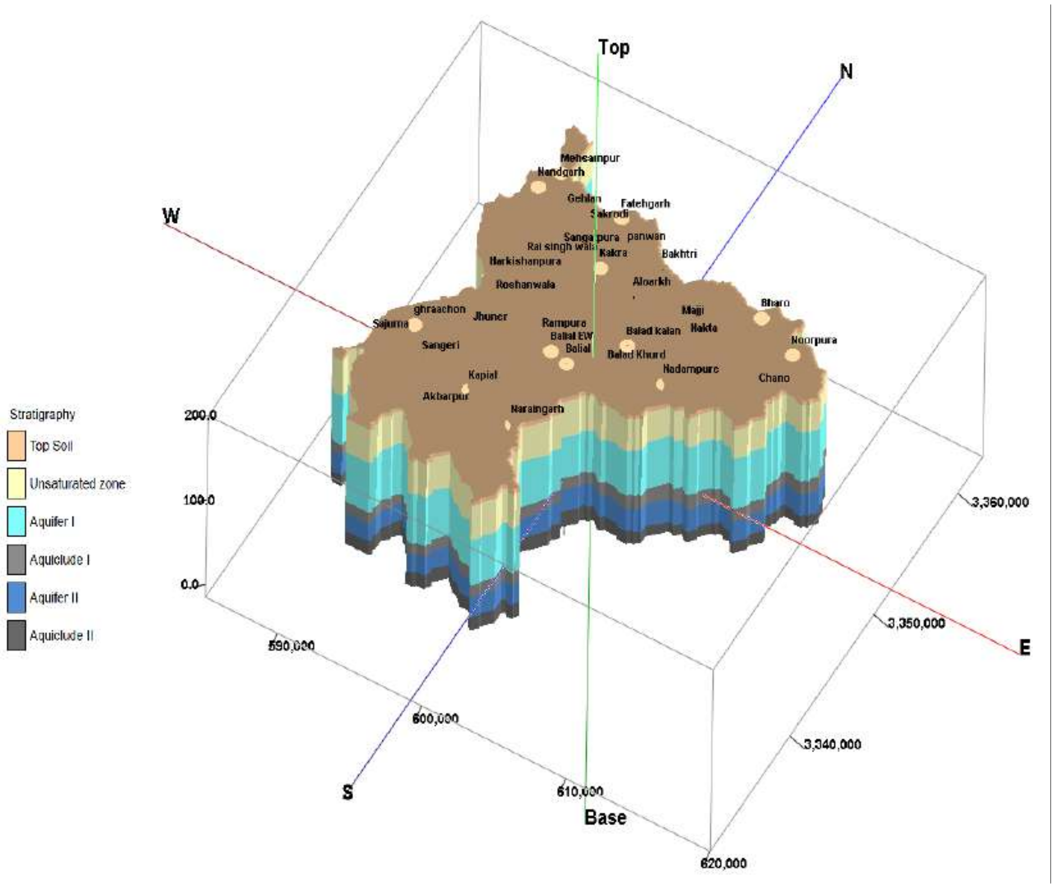


Figure 25 Aquifer Disposition Model of Bhawanigarh Block, Sangrur District. Punjab

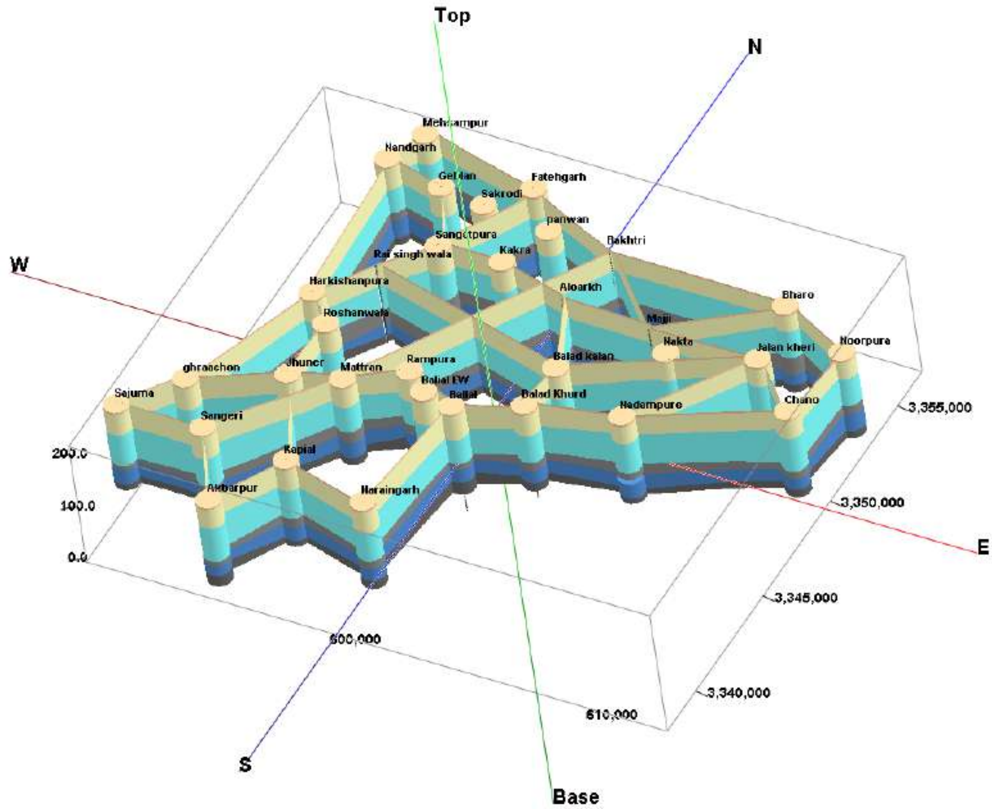


Figure 26 Aquifer Disposition Fence diagram of Bhawanigarh Block, Sangrur Dist. Punjab

In addition to the 3D Aquifer Disposition model, the Two-Dimensional cross-sections of the Bhawanigarh block were developed using the Lithology data gathered. Cross section A-A’ (fig. 27) extends in the N-S direction from Fatehgarh Bhadson to Akbarpur, spanning approximately 23.20 km. The thickness of the unsaturated zone remains uniform throughout the section, as does the thickness of Aquifer I. However, the thickness of Aquiclude I diminishes gradually towards the southern region of the study area.

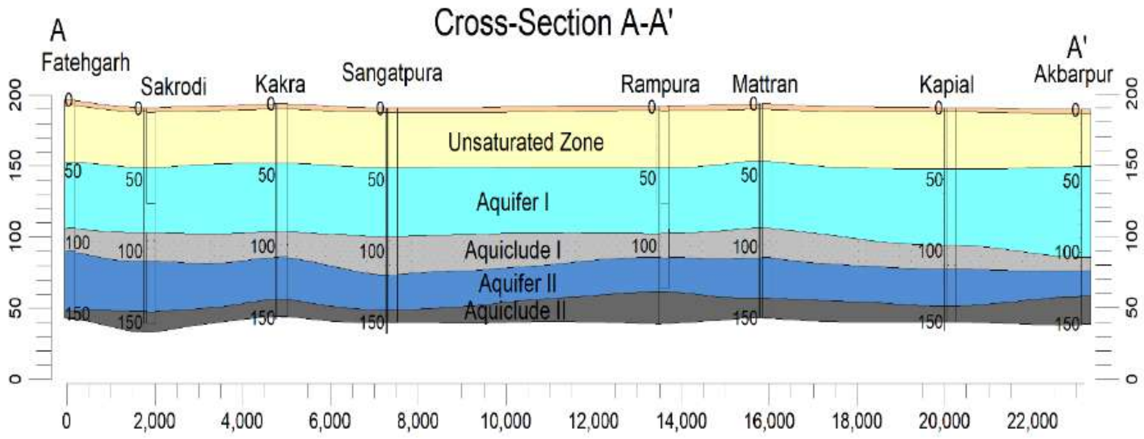


Figure 27 Cross Section A-A’ (N-S direction) of Bhawanigarh Block, Sangrur District

The B-B’ cross section (Fig. 28) extends from Bakhtri to Sajuma in a NE-SW direction, spanning approximately 23 km. The unsaturated zone maintains a consistent thickness along the entire section. Aquifer I thickness shows a gradual increase from Bakhtri towards Sajuma in the south western region of the study area. Conversely, the thickness of Aquiclude I decreases progressively towards the south western part of the study area.

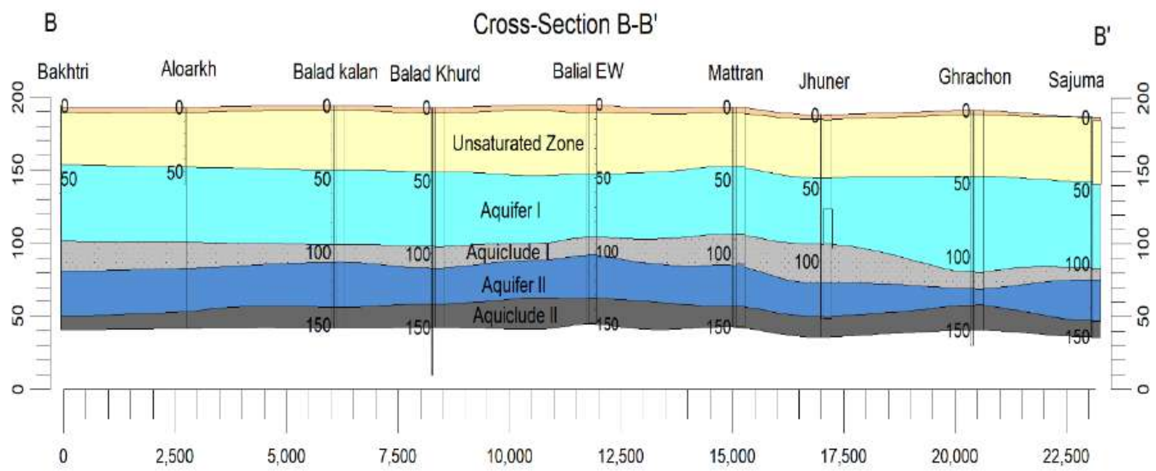


Figure 28 Cross Section B-B’ (NE-SW direction) of Bhawanigarh Block, Sangrur District

The cross section C-C’ (Figure 29) spans from Harkishanpura in the western direction to Chano in the eastern direction, covering a distance of approximately 21.24 km.

Throughout the entire section, the unsaturated zone maintains a consistent thickness. Aquifer I displays a trend of increasing thickness towards the eastern side of the study area, while Aquifer II remains relatively constant in thickness, with a slight thinning observed at Gharachon. The thickness of Aquiclude I gradually decreases towards the eastern region of the study area.

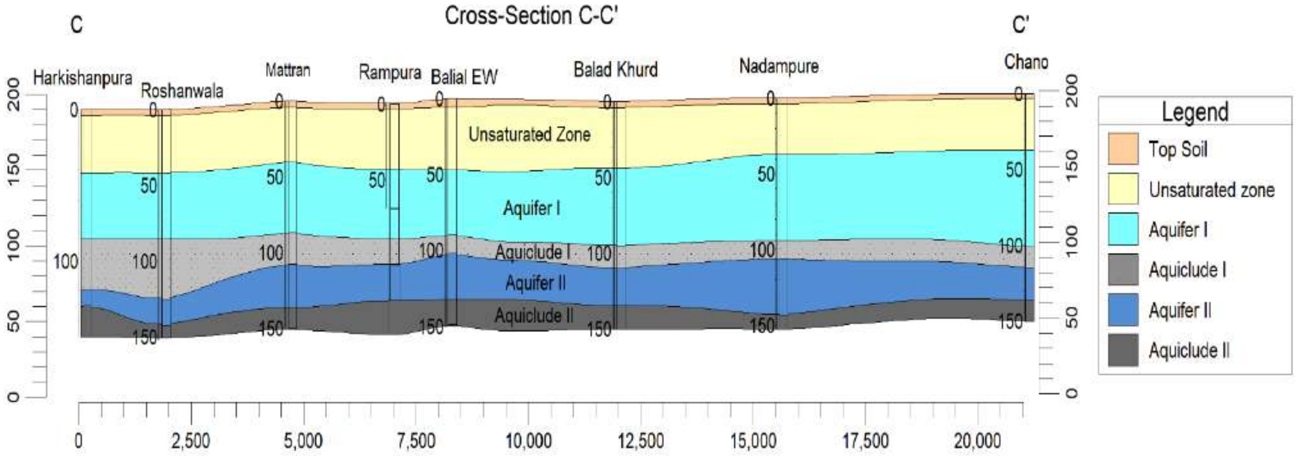


Figure 29 Cross Section C-C' (W-E direction) of Bhawanigarh Block, Sangrur District

The aquifer's arrangement and geometry were also analyzed through surface Geophysical studies, resulting in the creation of two geo-electrical sections displayed in Figures 30 and 31. These sections were oriented along the SW-NE and NW-SE directions for a comprehensive understanding of the aquifer's structure.

Geo-electric section AA'

The Geo-electrical cross-section AA' extends in a southwest-to-northeast (SW-NE) direction, spanning a length of 28 kilometres (Figure 30). The section commences at the Sujuma VES location and concludes at the Nurpur VES location, encompassing seven VES locations in total. Throughout this section, a substantial layer of unsaturated sand is consistently present, except in the Batriana location.

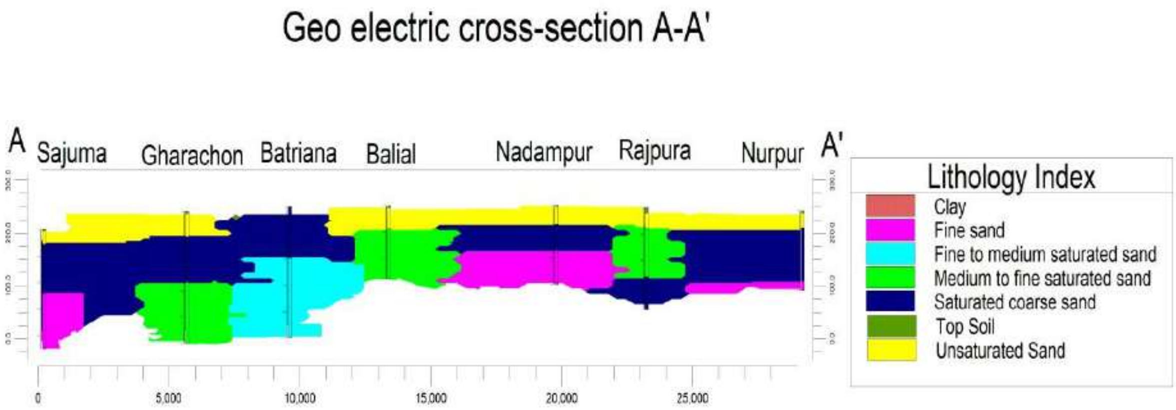


Figure 30 Geo-electric Section A-A’ of Bhawanigarh Block, Sangrur District, Punjab

Geo-electric section BB’

The Geo-electrical cross-section BB’ extends in a northwest-to-southeast (NW-SE) direction. The section commences at the Santokpura VES location and concludes at the Bhatiwal Khurd VES location, encompassing six VES locations in total (Figure 31). The total length of the section is 13 kilometres, this section includes six VES locations. Similar to the SW-NE section, a substantial layer of unsaturated sediments is consistently distributed across this section. The final layer is characterized by finer sediments. This section is shown below:

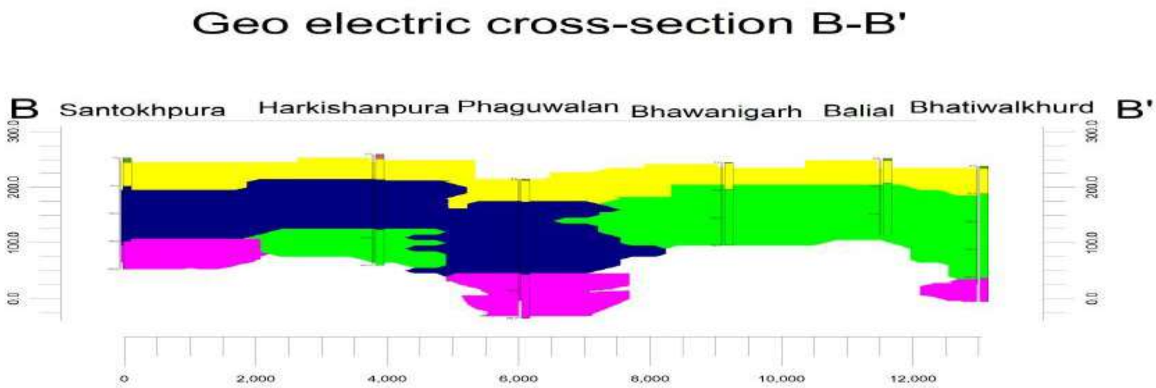


Figure 31 Geo-electric Section B-B’ of Bhawanigarh Block, Sangrur District, Punjab

A detailed maps showcasing the top and bottom of the first aquifer, along with the desaturated thickness, has been prepared for the Bhawanigarh block. This map is based on the aquifer layout identified through exploration and geophysical studies and can be found in Figures 32 to 35.

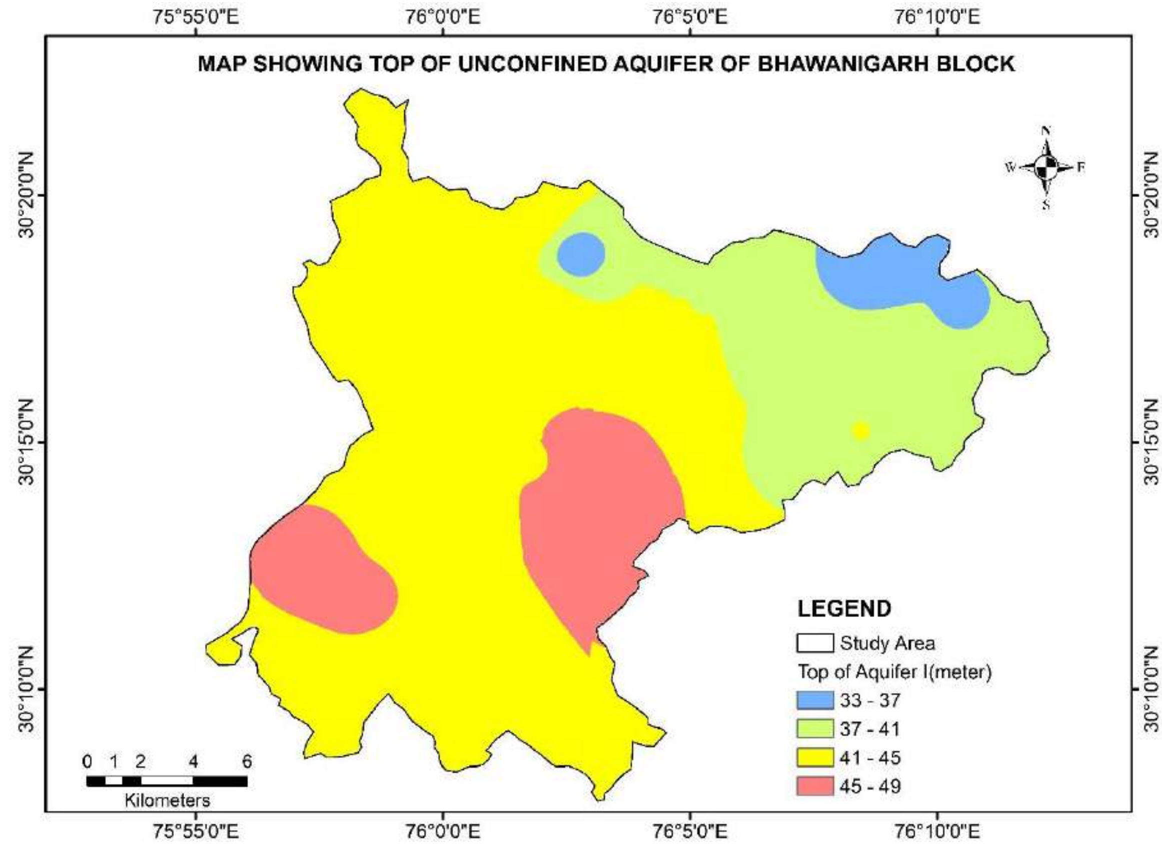


Figure 32 Map showing the Top of the First Aquifer (Unconfined) of Bhawanigarh Block Sangrur District, Punjab

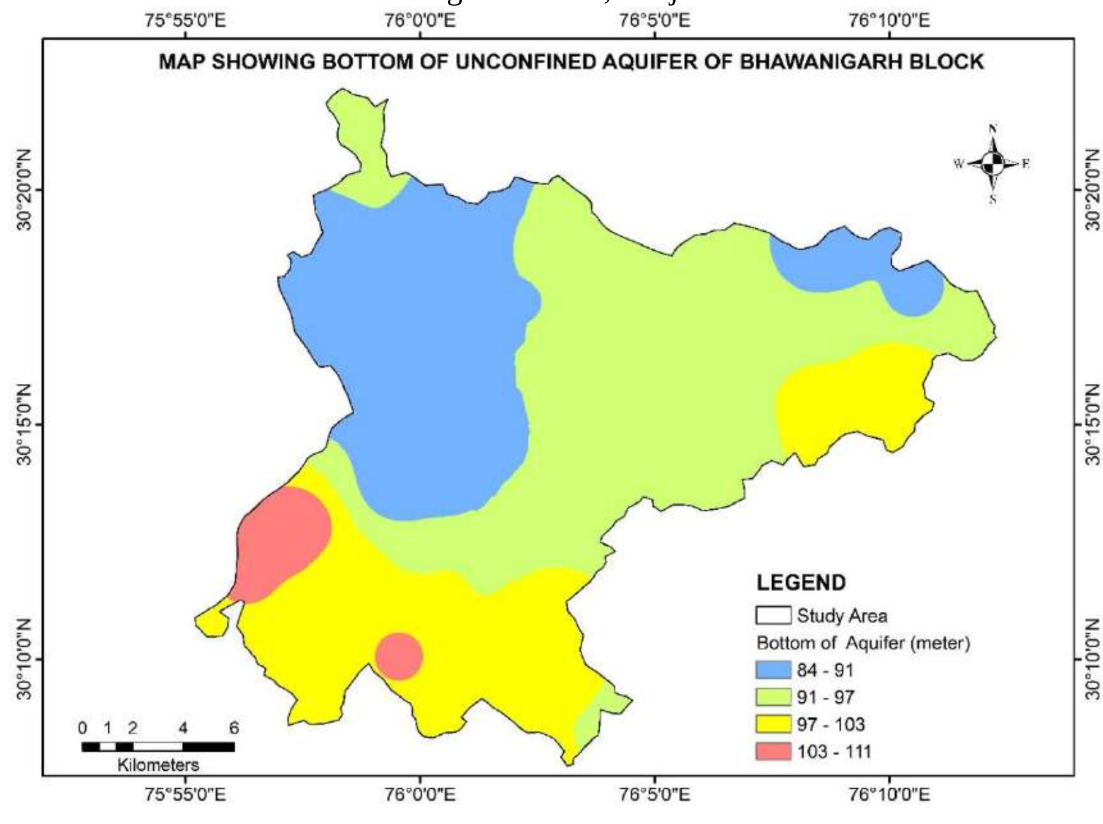


Figure 33 Map showing the Bottom of the First Aquifer (Unconfined) of Bhawanigarh Block Sangrur District, Punjab

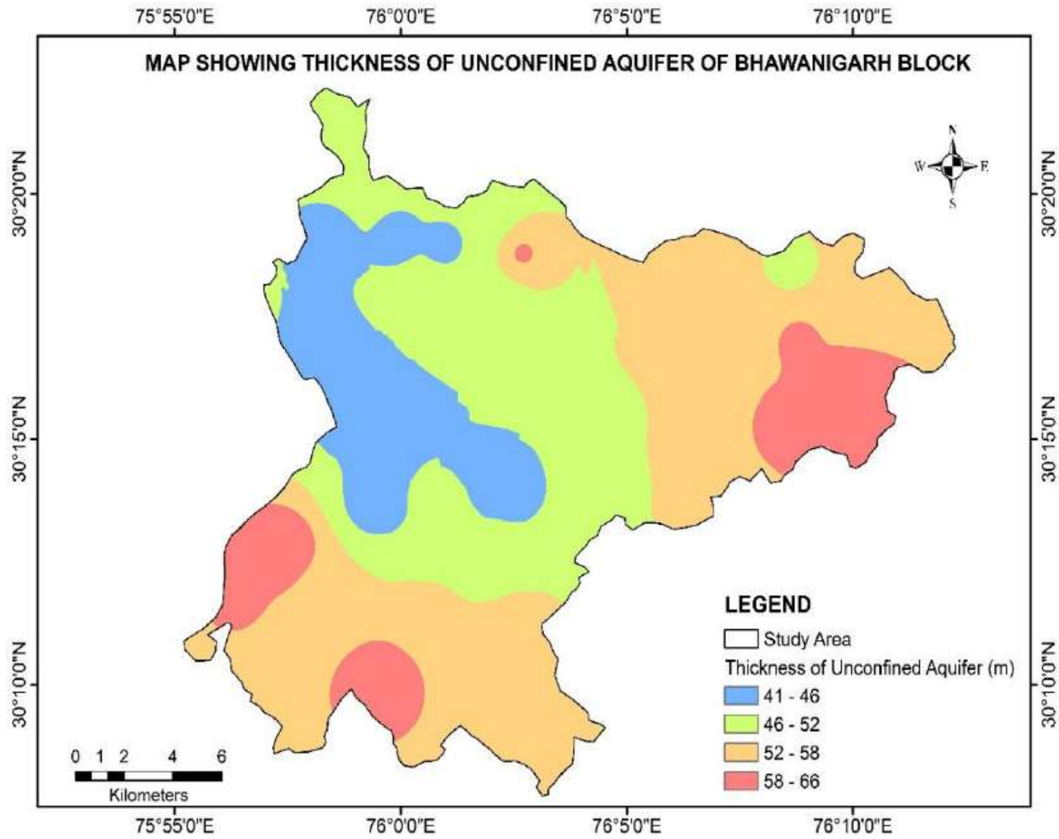


Figure 34 Map showing the Thickness of the First Aquifer (Unconfined) of Bhawanigarh Block Sangrur District, Punjab

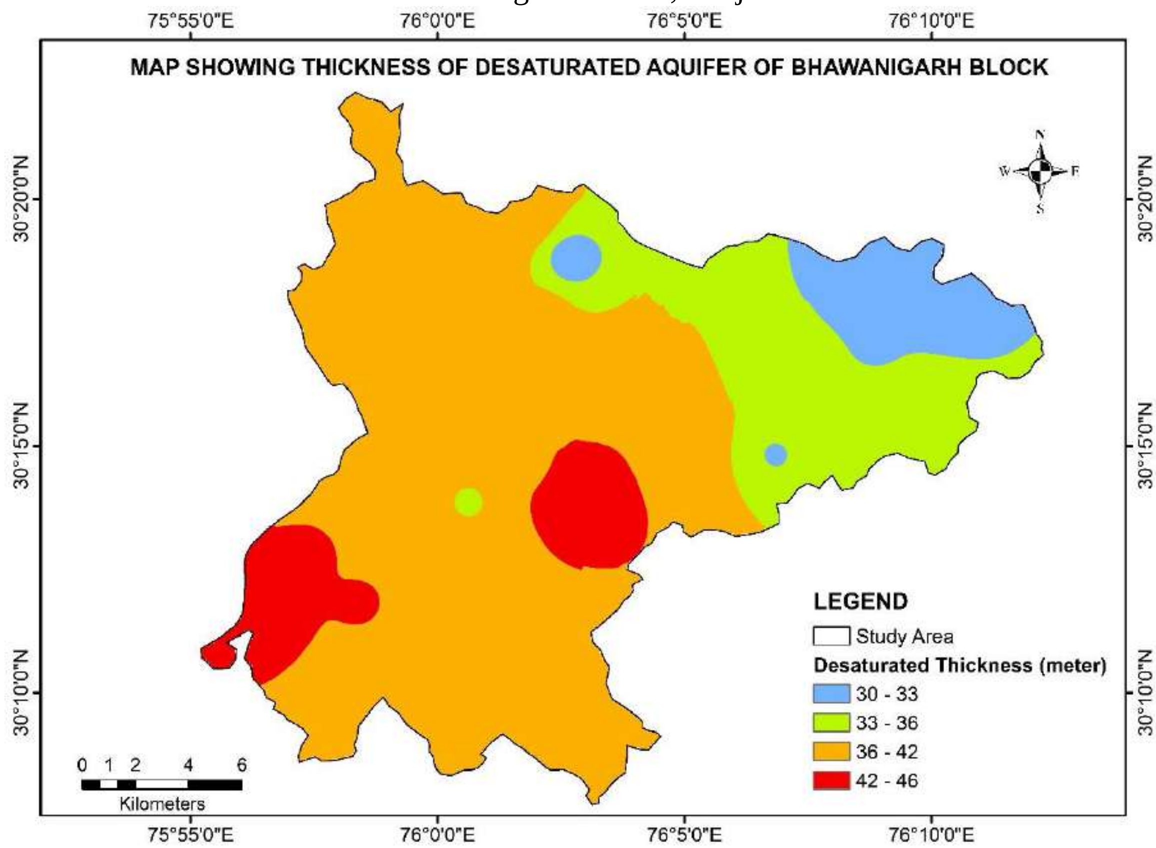


Figure 35 Map showing the Thickness of the De-saturated Aquifer (Unsaturated Zone) of Bhawanigarh Block Sangrur District, Punjab

CHAPTER 5 - GROUNDWATER LEVEL

5.1. Objective

To know the groundwater level behavior of shallow as well as deeper aquifers in the Bhawanigarh blocks the monitoring of groundwater levels from different aquifers is important. For the same, the water level monitoring key wells need to be established and monitored during pre-monsoon (June) & Post Monsoon (November).

5.2. Material and Methodology

The central groundwater Board regularly monitors the water level data from National Hydrograph stations (NHS) 4 times a year. At present there is only 1 NHS monitoring station and 2 State monitoring stations in the Bhawanigarh Block. So the data Gap was identified and 49 new Key wells were established uniformly throughout the Bhawanigarh Block to provide a holistic water level scenario. A total of 35 key wells represent the Unconfined Aquifer (Aquifer I) and 14 key wells represent Aquifer II. The water level measurements were carried out twice a year during Pre-monsoon (June) and Post-monsoon (November). The overall depth-to-water level scenario of the Bhawanigarh Block has been drawn based on the water level data monitored from the Key wells & NHS stations. Water level data was collected and plotted using ArcGIS software to prepare Depth to water level Map. Aquifer-wise depth to water level maps; the water table elevation and flow direction maps are generated.

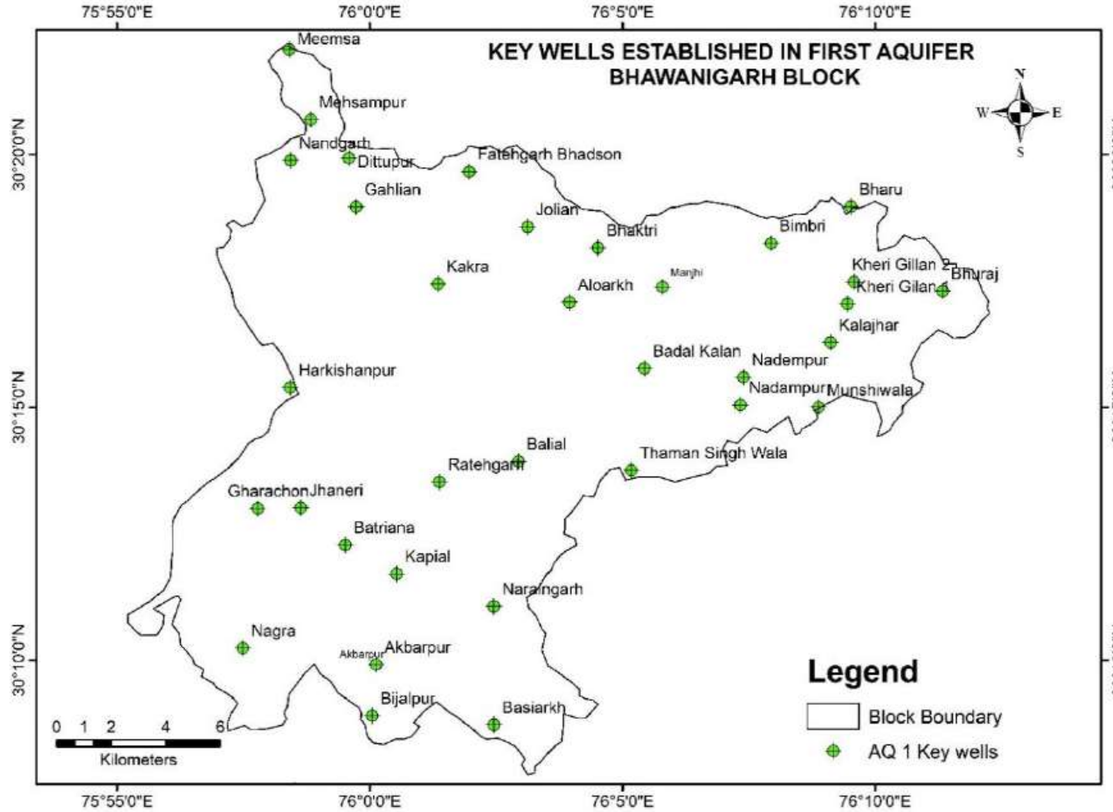


Figure 36 Map showing the location of Key wells established in the First Aquifer Aquifer

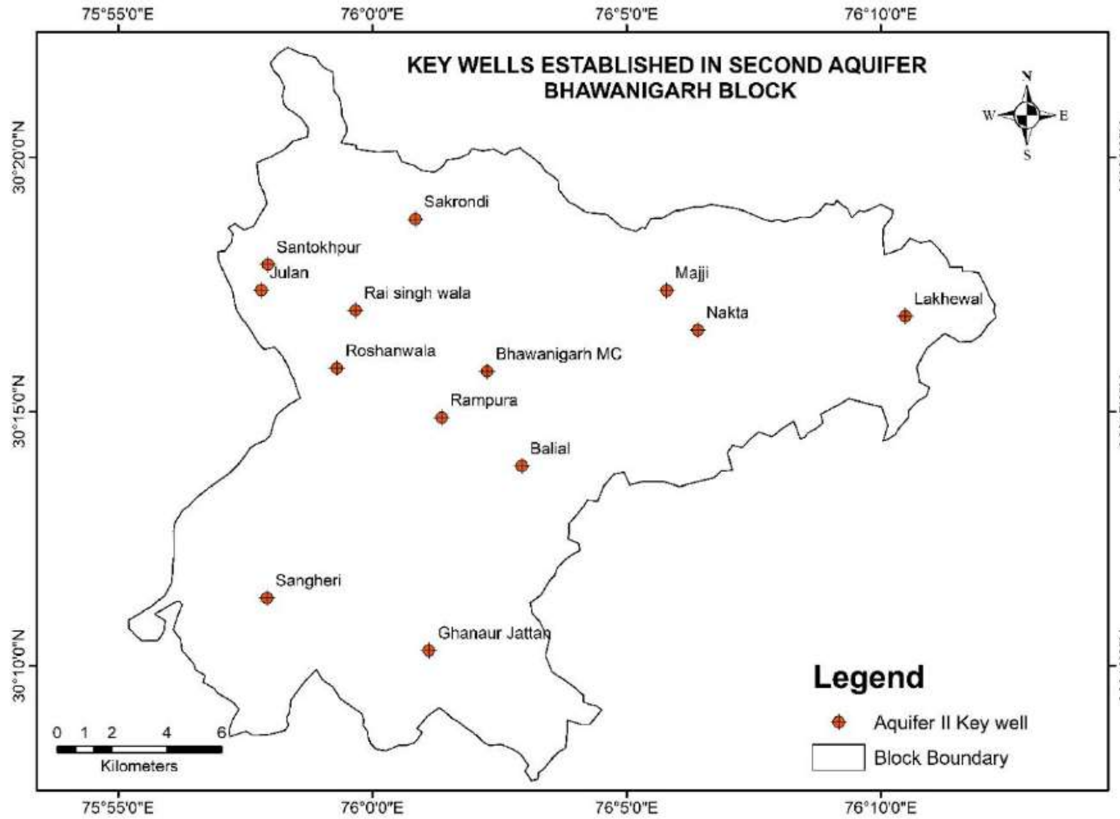


Figure 37 Map showing the location of Key wells established in the Second Aquifer

5.3. Results and Discussion

5.3.1 Unconfined Aquifer/ Aquifer I

Pre-monsoon Depth to Water Level

The depth to water level varies between 32.92 m bgl to 48.55 m bgl during pre-monsoon in Unconfined Aquifers (Figure 38) giving rise to a depth difference of 15m. The depth to water level differs greatly at many places while the topographic elevation of land remains almost the same, indicating that the variation in depth to the water level in the area is due to other than topographic differences. The shallowest water level is recorded at Bimbri and the deepest water level is recorded at Batriana. The water levels (<36mbgl) are observed as an isolated patch around Bimbri in the North-eastern part of the block. The eastern part dominantly shows the water level in the range between 37 to 40 mbgl. Whereas, the South-western part majorly shows water level deeper than 45 mbgl water level. The majority of the area is dominated by water levels in the range of 41-44 mbgl.

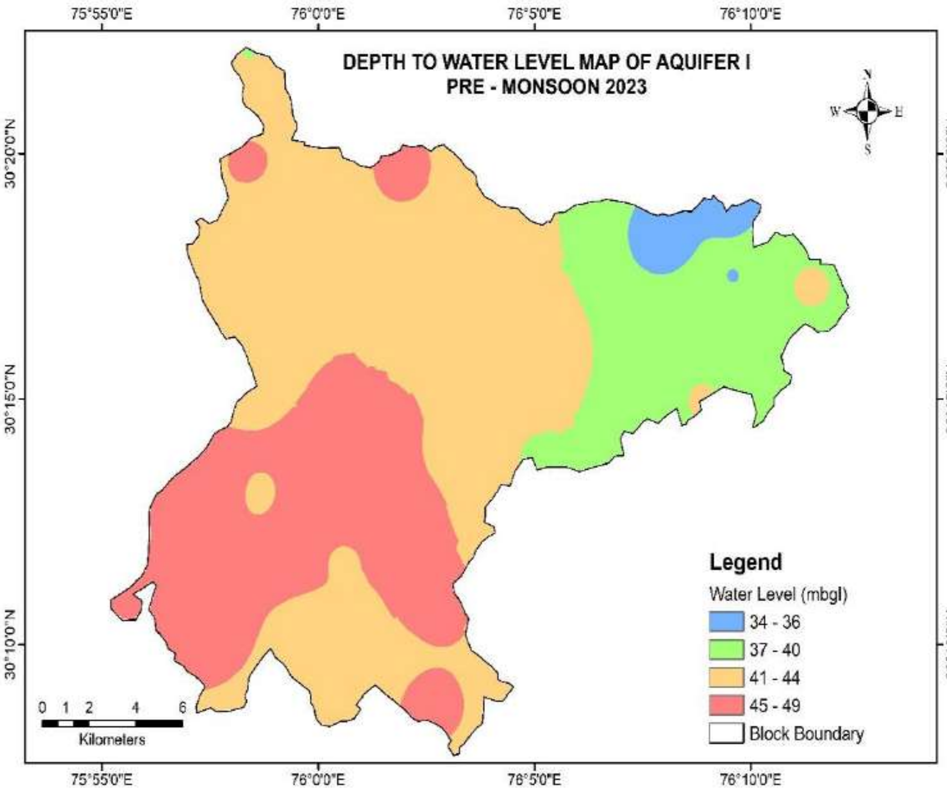


Figure 38 Pre-Monsoon Depth to Water Level Map of Bhawanigarh Block, Sangrur District

Post Monsoon Depth to Water Level

The depth to water level varies between 35.85 m bgl to 49.13 m bgl during post-monsoon (Figure 39). The shallowest water level is recorded at Bimbri and the deepest water level is recorded at Batriana. The water levels (<36mbgl) are observed as an isolated patch around Bimbri in the North-eastern part of the block. The eastern part which dominantly showed water levels in the range between 37 to 40 mbgl during pre-monsoon has now shrunk. During the Post-monsoon the majority of the area showed the water level deeper than 45 mbgl.

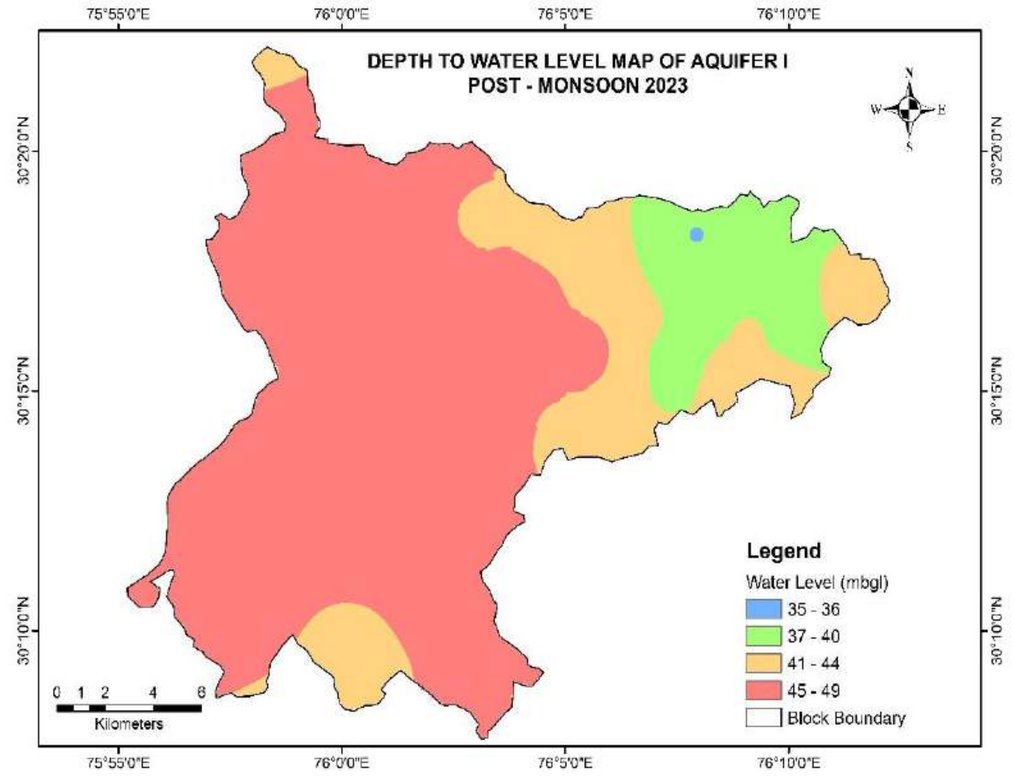


Figure 39 Post-Monsoon Depth to Water Level Map of Bhawanigarh Block, Sangrur District

Seasonal Fluctuation

The seasonal Fluctuation in Aquifer I is inferred by comparing the pre and post-monsoon water levels monitored during 2023. The minimum fluctuation is – 0.02 mbgl at Thaman Singh Wala and a maximum of -3.92 mbgl at Jolian Key well. Out of a total 30% of the key wells have shown a fall in the range of 0.02 to 1 mbgl, whereas a fall in the range of 1-2 mbgl is observed in 36 % of key wells and a fall greater than 2 m has been observed in 34 % of the key wells.

Decadal Fluctuation

The decadal fluctuation of (-)0.53 m to (-)1.103m bgl has been observed in the Bhawanigarh block. Water levels have declined in the past at an average rate of 0.72 m /year in the past decade. The rate of Decline during pre-monsoon and post-monsoon is given in Table 12 and the Long-term trend of Akbarpur, Kalajhar and Mehsampur is shown in figures 40,41 and 42 respectively.

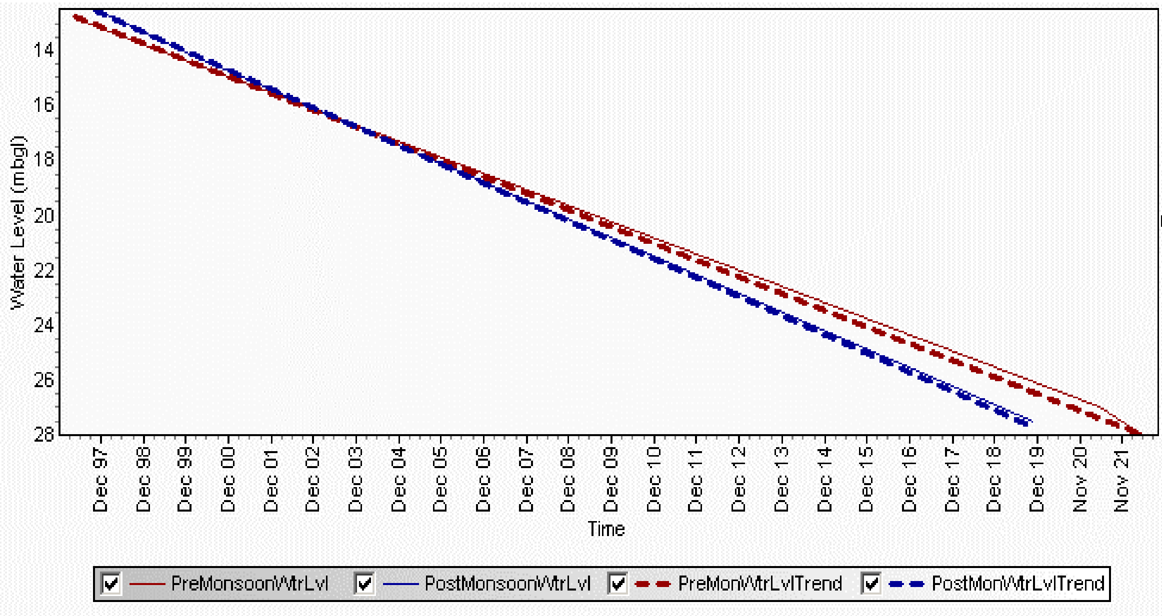


Figure 40 Hydrograph showing the long-term Groundwater level Trend of Akbarpur

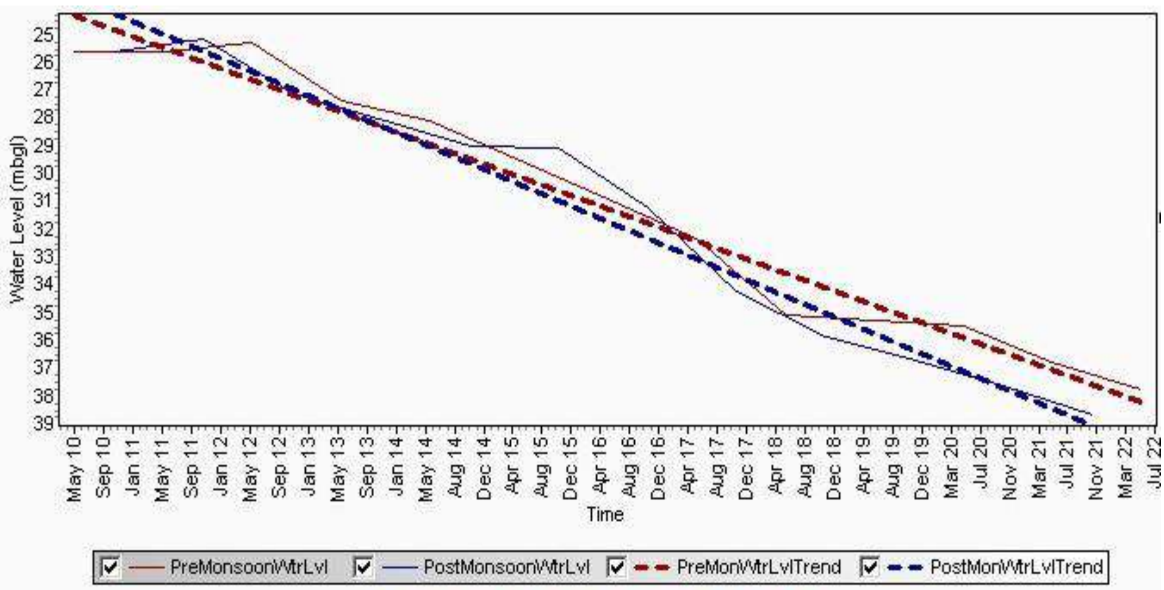


Figure 41 Hydrograph showing the long-term Groundwater level Trend of Kalajhar

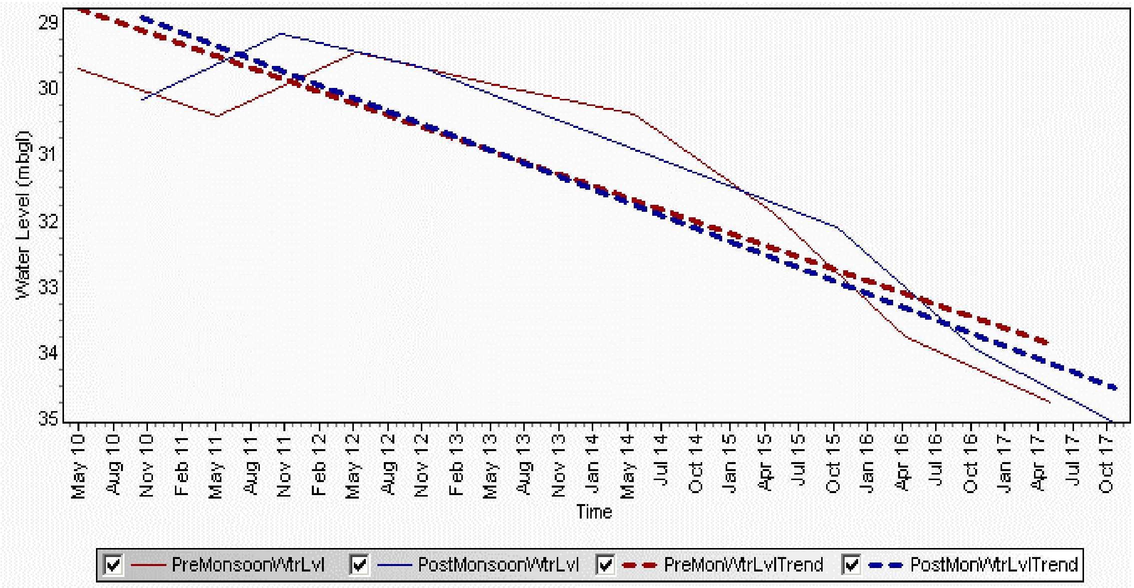


Figure 42 Hydrograph showing the long-term Groundwater level Trend of Mehsampur

Table 12 Decadal Station wise trend of Groundwater level, Bhawanigarh Block, District Sangrur

Station	Pre-monsoon trend	Post-monsoon trend	Annual trend
Akbarpur	- 0.49 m/yr	- 0.56 m/yr	- 0.53 m/yr
Kalajhar	- 0.95 m/yr	- 1.11 m/yr	- 1.03 m/yr
Mehsampur	- 0.59 m/yr	- 0.65 m/yr	- 0.62 m/yr

5.3.2 Aquifer-II

The Aquifer II starts from the average depth range of 107 m below the ground surface up to 142 m. The Aquifer I and II are separated by a Thick clay horizon which is intermixed with fine sand of average 11 m thickness. The Piezometric level map was prepared based on the piezometric data monitored from the 14 key wells during pre-monsoon (figure 43) and post-monsoon (figure 44).

The piezometric head varies between 36.97 m bgl at Lakhewal to 45.91 m bgl at Sangheri during pre-monsoon and 39.25 mbgl at Bhawanigarh MC to 47 mbgl at Nakta during post–monsoon. Most of the area shows a piezometric head in the range of 41-44 mbgl during pre-monsoon and 45-47 mbgl in post-monsoon. The piezometric heads are shallower in the north-eastern part and they go on deepening in the southwestern part of the block. Both the Aquifers show almost the same water level trend with slight variation indicating that both the aquifers are interconnected.

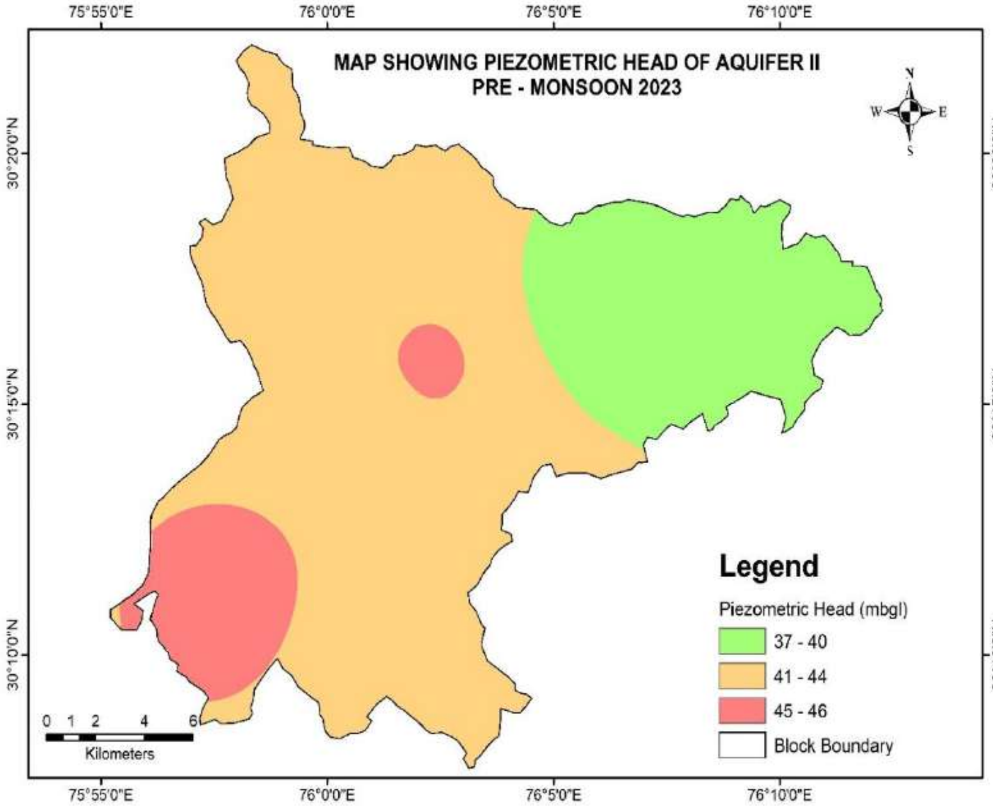


Figure 43 Map showing the Pre- monsoon Piezometric head of the Second Aquifer, Bhawanigarh Block, Sangrur District

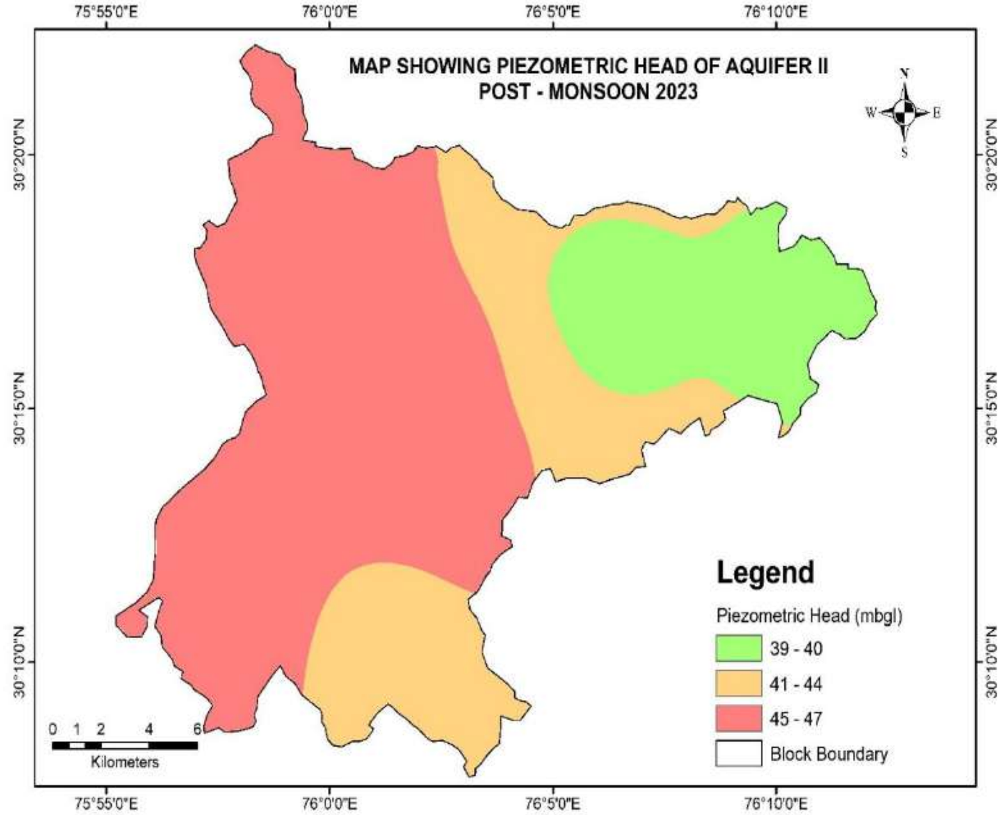


Figure 44 Map showing the Post- monsoon Piezometric head of the Second Aquifer, Bhawanigarh Block, Sangrur District

Seasonal fluctuation

The seasonal Fluctuation map of Aquifer II is inferred by comparing the pre and post-monsoon water levels monitored during 2023. The minimum fluctuation is – 0.091 mbgl at Sangheri and a maximum of -0.265 mbgl at Julan Key well. Out of a total 14% of the key wells have shown a fall in the range of 0 to 1 mbgl, whereas a fall in the range of 1-2 mbgl is observed in 29 % of key wells and a fall greater than 2 m has been observed in 57 % of the key wells.

5.3.3 Water Table Elevation

Water table elevations range from 143 to 168 m above mean sea level (amsl) and the general groundwater flow is from northeast to southwest. The water table elevation map of Bhawanigarh Block is shown in Figure 45.

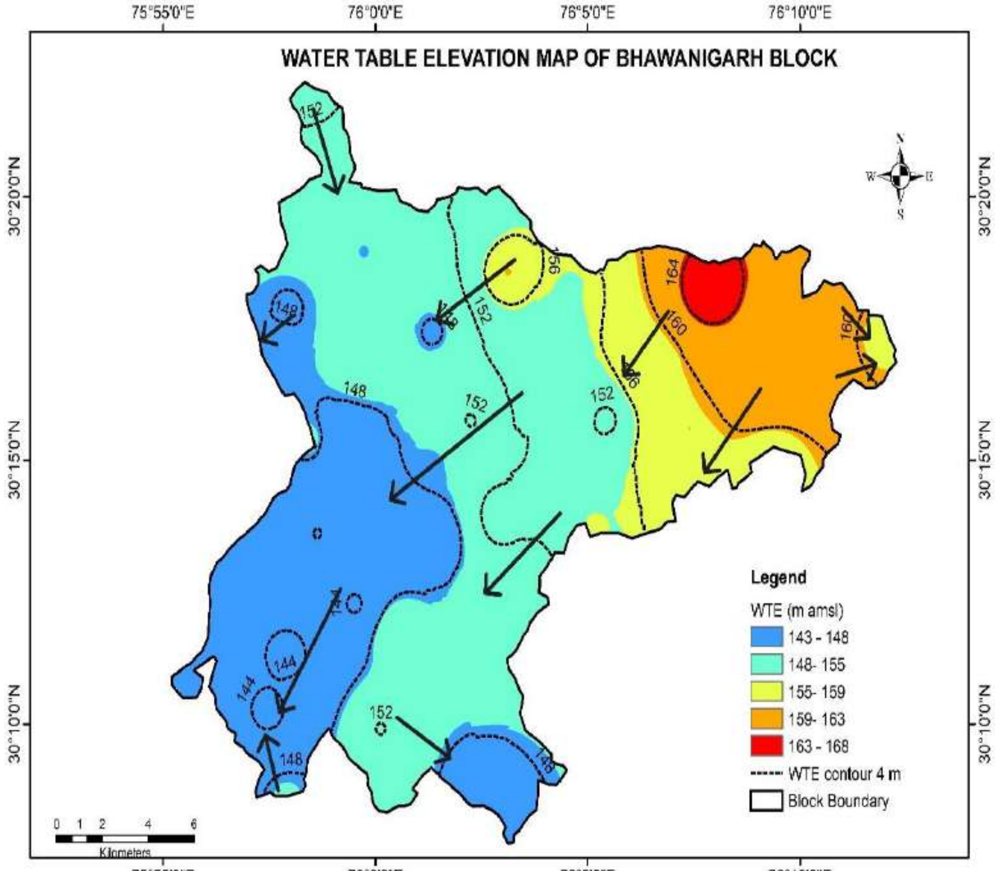


Figure 45 Water Table Elevation Map of Bhawanigarh Block, Sangrur District

CHAPTER 6- GROUNDWATER RESOURCE ESTIMATION/REFINEMENT

6.1. Objective

Groundwater resources in the Bhawanigarh Block, Sangrur District, will be assessed using dynamic and in-storage data from unconfined and confined aquifers. Based on field sample surveys, the dynamic groundwater resources computed using GEC 2015 will be modified by modifying inputs such as the rainfall infiltration factor and unit draft. A new approach for calculating groundwater resources is also being developed, which will make use of high-frequency groundwater level data collected every six hours.

6.2. Material and Methodology

Potential aquifers (productive granular zones) have been identified to a depth of 150 m using aquifer-specific subsurface mapping. The exploratory drilling data and geophysical data were used to calculate the overall saturated thickness of granular zones. The static resources of an unconfined aquifer are groundwater resources accessible below the fluctuating zone of water level up to the first restricting layer, whereas the dynamic resources are those of the water level fluctuation zone. The GEC 2015 was used to conduct an assessment of dynamic groundwater resources in unconfined aquifers. The in-storage groundwater resource is computed separately for unconfined and confined aquifers using the specific yield and storativity concepts. A combination of the confined and unconfined aquifers' groundwater resources down to 150 meters will be used to assess the block's overall groundwater resources in Bhawanigarh.

Total Availability of Ground water resources	=	**Dynamic Resources**	+	**In-storage Resources**

6.2.1 Ground Water Resources of Unconfined Aquifers

1) **Dynamic Groundwater Resources**

The dynamic groundwater resources were calculated using the water balance equation, which stipulates that groundwater extraction must be balanced against groundwater availability (recharge).

ΔS (Change in storage) = Inflows into the aquifer – Outflows from the aquifer

According to GWRE 2023, the Bhawanigarh block has a net groundwater availability of 8160 ham and a net groundwater extraction of 27787 ham.

2) **In storage Groundwater resources**

In the case of the alluvial area, the in-storage resources of the unconfined aquifer were calculated based on the aquifer's specific yield(given below). The alluvium has a specific yield of 12%, with 60% (0.072) being appropriately yielded by unconfined aquifers.

$$\Delta S = \Delta h * A * Sy$$

Where ΔS = In storage Groundwater Resources (Unconfined Aquifer)

Δh = Thickness of the Granular Zone below the zone of water level fluctuation down to the bottom of the unconfined aquifer

Sy = Specific Yield

A = Areal extent of the Unconfined Aquifer

Table 13 In-storage Groundwater Resource of Unconfined Aquifer

INSTORAGE GROUND WATER RESOURCES IN UNCONFINED AQUIFER –I						
Area (Sq km)	**Average Post-monsoon Water Level (m bgl)**	**Depth to bottom of Aquifer Group I (m bgl)**	**Total Thickness of formation below Post-monsoon Water Level (m)**	**Thickness of the Granular Zone below Post-monsoon WL**	**Average Specific Yield**	**In-Storage Ground Water Resources (mcm)**
351.7	41	96	55	24	0.12	1013

6.2.2 Groundwater Resources of Confined/Semi-confined Aquifers

Groundwater withdrawals from confined aquifers are known to have substantial environmental consequences, hence a preliminary assessment of groundwater resources in a confined aquifer is required. The Specific Yield and Storativity approach is used to calculate the groundwater resources of confined aquifers (Table 14).

Storativity Concept

$$\Delta S' = \Delta h * A * St$$

Where ΔS' = In storage Groundwater Resources (Confined Aquifer)

Δh = Thickness of the water column in the Piezometer of the confined aquifer up to the top layer of the same confined aquifer

St = Storativity of the confined aquifers

A = Areal extent of the confined Aquifer

Specific Yield Concept

ΔS = Δh * A * Sy

Where ΔS = In storage Groundwater Resources (Confined Aquifer)

Δh = Thickness of the Confined Aquifer (Granular Zone) below the bottom layer of the confined aquifer

Sy = Specific Yield of the Aquifer

A = Areal extent of the Confined Aquifer

Table 14 In-storage Groundwater Resource of confined/Semi confined Aquifer

INSTORAGE GROUND WATER RESOURCES – CONFINED/SEMI-CONFINED AQUIFERS UPTO 150 METERS											
Area (sq km)	Top of Aquifer II (m bgl)	Depth to bottom of Aquifer II (m bgl)	Piezo-metric Head (m bgl)	Thickness of piezo-metric level(m bgl)	Total Thickness of confined aquifer down to explored depth (m)	Thickness of the Granular Zone in confined aquifer down to explored depth (m)	Average Specific Yield	Average value of Storativity	In-Storage Ground Water Resources (Specific yield concept)	In-Storage Ground Water Resources (Storativity concept)	Total in-Storage Ground Water Resources (mcm)
351.7	102	142	42	100	40	20	0.12	0.00195	844	68.58	913

The Bhawanigarh block in Sangrur district has a total groundwater resource of 2007 mcm, of which 1094 mcm is comprised of the unconfined aquifer and 913 mcm is made up of the Confined aquifer. This calculation is done up to a depth of 150 m (Table 15).

Table 15 Total Groundwater Resource of Bhawanigarh block up to 150 m depth

Dynamic Groundwater Resources (2023) AQUIFER-I	In-storage Groundwater Resources AQUIFER-I	Groundwater Resources AQUIFER-I	In-storage Groundwater Resources AQUIFER-II	Total Availabilty of	
				mcm	ham
81.60	1012.90	1094	913	2007	200715.75

6.3. Results and Discussion

Based upon the dynamic Groundwater resources calculated till 2023 the stage of groundwater development (SOD) has continuously increased, from 217% to 348%, and the block has been considered overexploited. As a result, groundwater extraction outpaces replenishment each year. Table 16 shows the details of groundwater extraction, availability, and extraction stage from 2004 to 2023.

Table 16 Dynamic Groundwater Resource & Development Potential (31.03.2022) in ham

Year	Resource Available / Recharge (ham)	Groundwater Draft for irrigation	Groundwater Draft for Domestic & Industrial water supply	Total Draft	Stage of Development	Category
2004	17212	37559	204	37763	219	Over Exploited
2009	18004	39754	261	39014	217	Over Exploited
2011	13054	39010	269	39279	301	Over Exploited
2013	18285	38589	258	38847	212	Over Exploited
2017	15845	39288	431	39719	251	Over Exploited
2020	10596	31680	434	32114	303	Over Exploited
2022	8150	27788	603	27788	348	Over Exploited
2023	8160	27787	606	28393	348	Over Exploited

Figure 46 shows the total groundwater availability determined for each year from 2004 to 2023 plotted against the draft estimate and Figure 47 shows the stage of development estimate for that year.

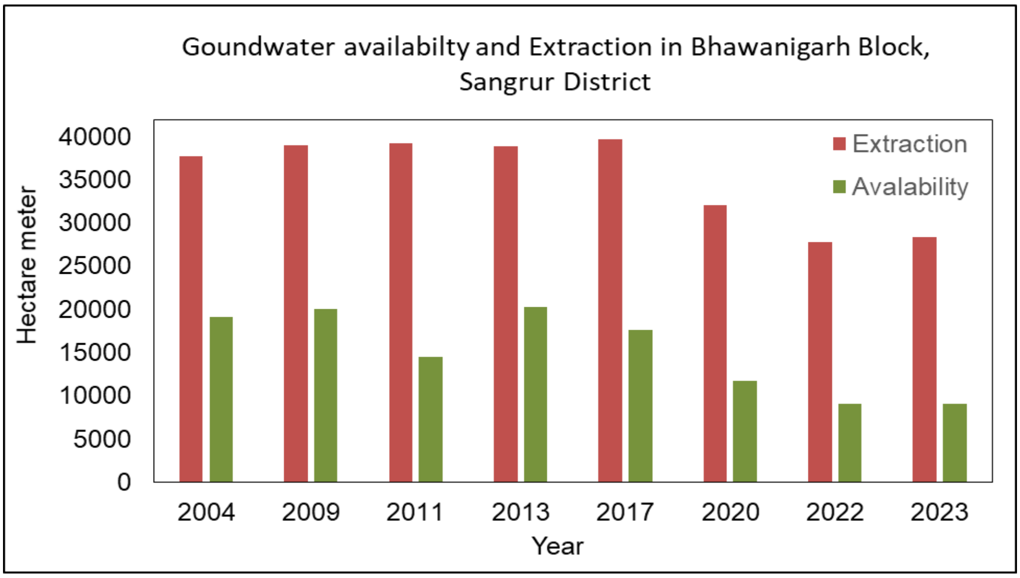


Figure 46 Comparison of Net Ground water availability vs Draft in Bhawanigarh Block

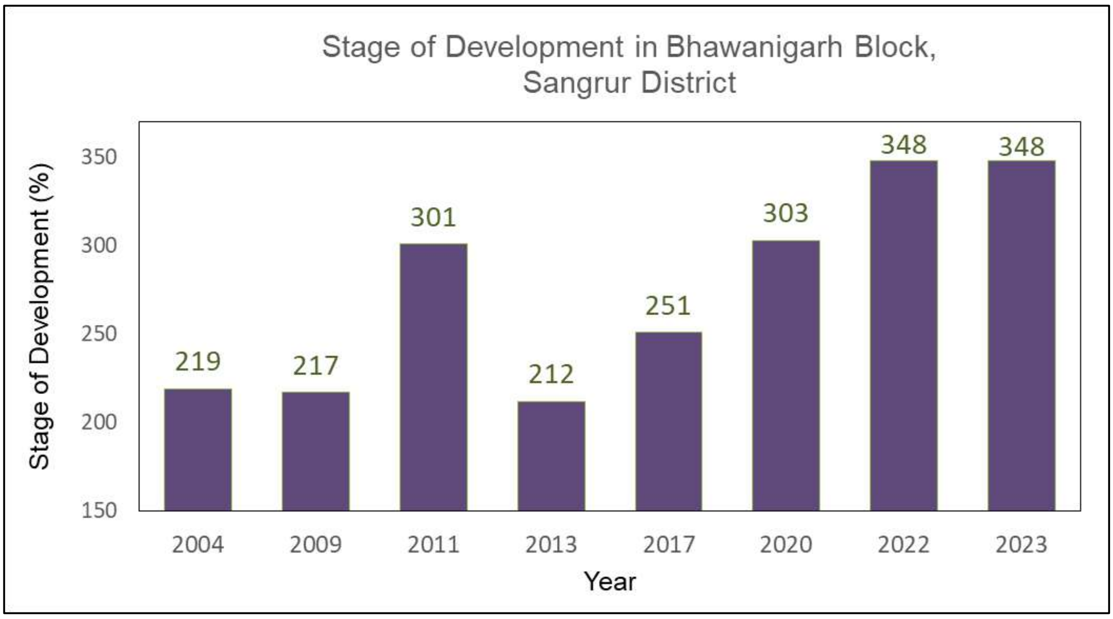


Figure 47 Comparison of Stage of Groundwater Development in Bhawanigarh Block

Upon examining Figures 46 and 47, it can be inferred that although the Stage of Development (SOD) has grown over time, groundwater extraction and availability (recharge) have decreased. Rainfall plays a crucial role in replenishing groundwater, and a closer look at the Long-Term Rainfall Data (Figure 48) shows that during the last 10 years, rainfall has not deviated much from the average.

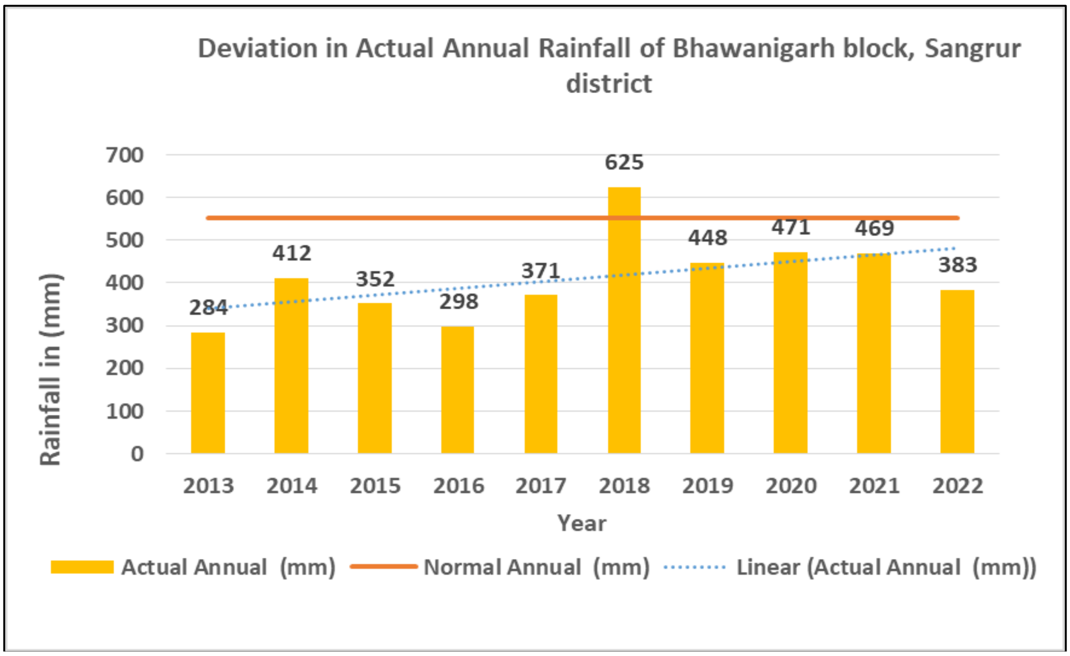


Figure 48 Decadal Rainfall Trend in Bhawanigarh Block

Recharge from non-rainfall sources, including seepage from the canal, is thought to be the primary cause of the decline in groundwater availability each year, based on the graphing of recharge from rainfall and non-rainfall sources (Figure 49). The Punjab government began lining the canals in the Bhawanigarh block to supply water to users at the tail end; thus, seepage was stopped and recharge dropped. Therefore, either the recharging should be raised or the extraction should be decreased to lower the SOD.

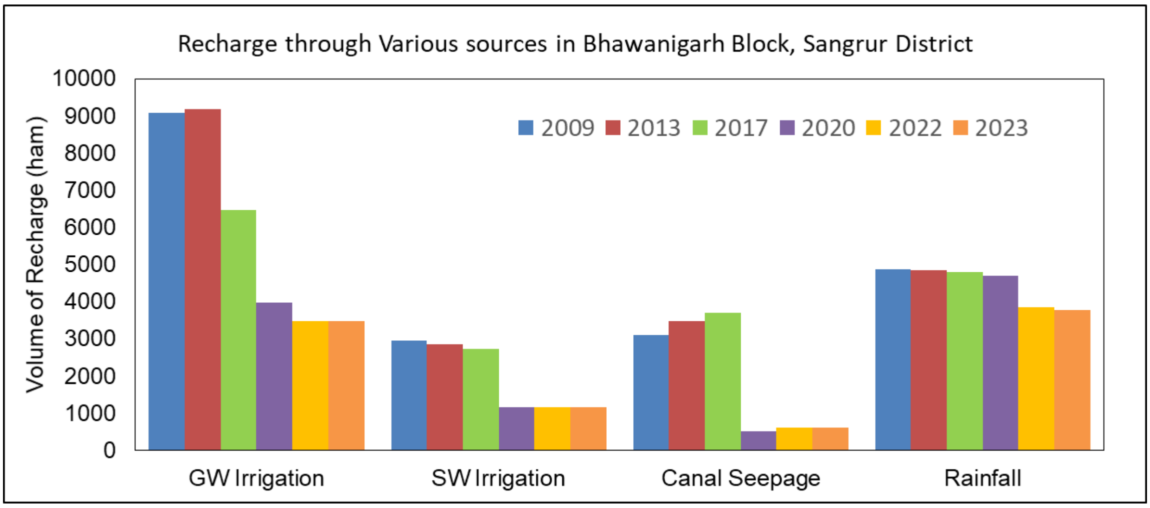


Figure 49 Comparison of Recharge from various sources in Bhawanigarh Block

6.4. Refinement of Resources

The refinement of resources is carried out using 2 methods:

a) Resources calculation using High-Frequency Groundwater level data
b) Refinement of existing GEC methodology inputs

6.4.1. Resources calculation using High-Frequency Groundwater level data

The water balance equation or change in storage was used to compute the dynamic groundwater resources based on the GEC 2015 approach (as stated above). According to GEC 2015, numerous computations utilizing empirical formulas, field research, and the participation of numerous departments are necessary to determine groundwater resources. Thus, the groundwater level fluctuation approach using long-term high-frequency data (HFD) can be used to estimate the change in storage.

The HFD of four observation wells, which correspond to the four distinct sections of the block, is taken into consideration for this method between January 2022 and December 2022 (Figure 50 to 54). Every well is thought to be emblematic of that specific region. Based on data on transmissivity, soil taxonomy, soil infiltration rate, rainfall infiltration factor and groundwater level, the study region is separated into four sections (Figure 55).

The change in groundwater storage (ΔS) during a specified period can be estimated based on Equation

$$\Delta S = \Delta h * A * Sy$$

where, Δh = change in groundwater level (rise or fall) during the given period;

A = area influenced by the well;

Sy = specific yield of the aquifer.

The study area experiences a consistent pattern of groundwater levels throughout the year. From January to June 10, there is a noticeable increase in water levels, followed by a decline until September 30. However, after this period, there is a subsequent rise in the water level as depicted in figures 50, 51, 52 and 53. It is widely acknowledged that the monsoon season plays a significant role in influencing groundwater levels. The precipitation during this season acts as an input to the aquifer system, leading to an increase in water levels. However, in the Bhawanigarh block, the excessive use of groundwater for paddy cultivation negatively impacts groundwater storage during the monsoon season leading to a fall in groundwater levels.

Interestingly, the water requirements for paddy cultivation decreased in the last 20 days before cultivation. As a result, by the end of September, the water levels begin to rise once again, indicating a replenishment of groundwater resources. Subsequently, during the last week of October, the water levels experienced a slight decrease due to the cultivation of wheat crops, which require less water compared to paddy. This temporary decline is followed by a rise in groundwater levels once more. Additionally, non-monsoon rainfalls also play a role in replenishing groundwater levels, further influencing the overall change in storage as indicated in Table 17, which provides individual calculations for each well.

Table 17Resource refinement based on High Frequency data in Bhawanigarh Block, Sangrur District

Period	**Bhawanigarh**	**Kalajhar**	**Naraingarh**	**Gharacho**	**Total**
Water levels Rise during Pre-monsoon (meter)	0.6	0.8	1.0	0.5	2.9
Water levels Fall during Monsoon (meter)	-1.6	-2.2	-2.6	-2.2	-8.5
Water levels Rise during Post monsoon (meter)	0.6	0.5	1.0	0.8	2.9
Area (Hectare)	15890	5471	6654	7155	35170
The volume of water added (ham)	2192.8	860.0	1636.9	1081.8	5771.6
The volume of water Extracted (ham)	-3012.7	-1418.1	-2068.1	-1863.2	-8362.1
ΔS (Change in storage)	-819.9	-558.0	-431.2	-781.3	-2590.5
SOD %	137.4	164.9	126.3	172.2	144.9

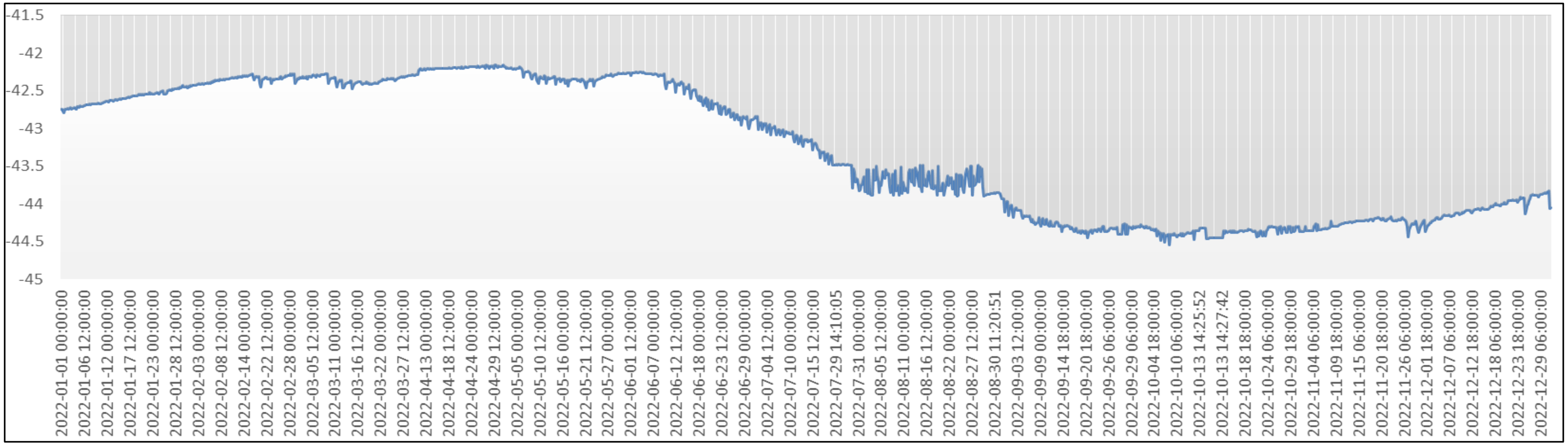


Figure 50 High-Frequency Data of Gharacho Piezometer, Bhawanigarh Block, Sangrur District

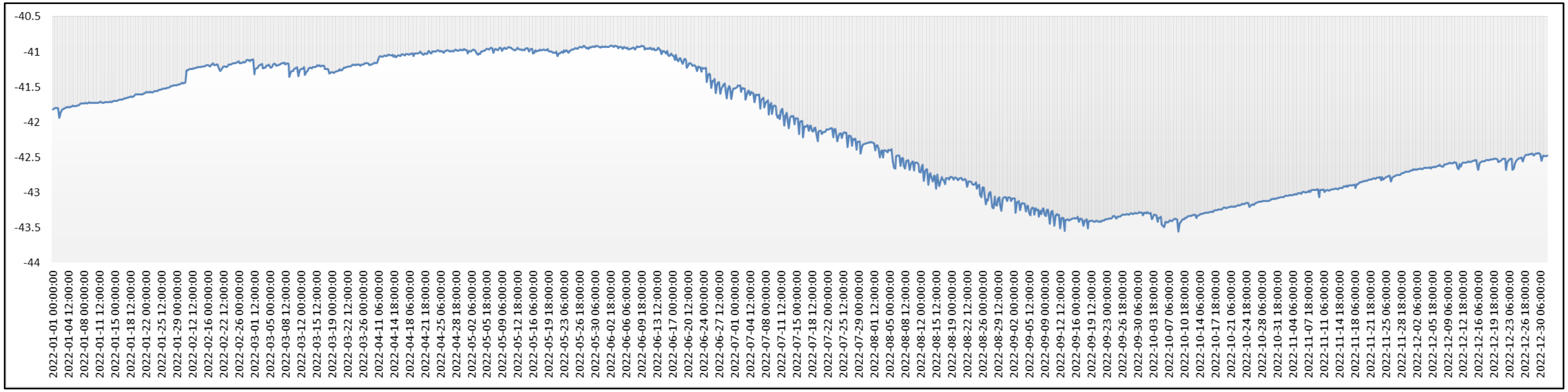


Figure 51 High-Frequency Data of Naraingarh Piezometer, Bhawanigarh Block, Sangrur District

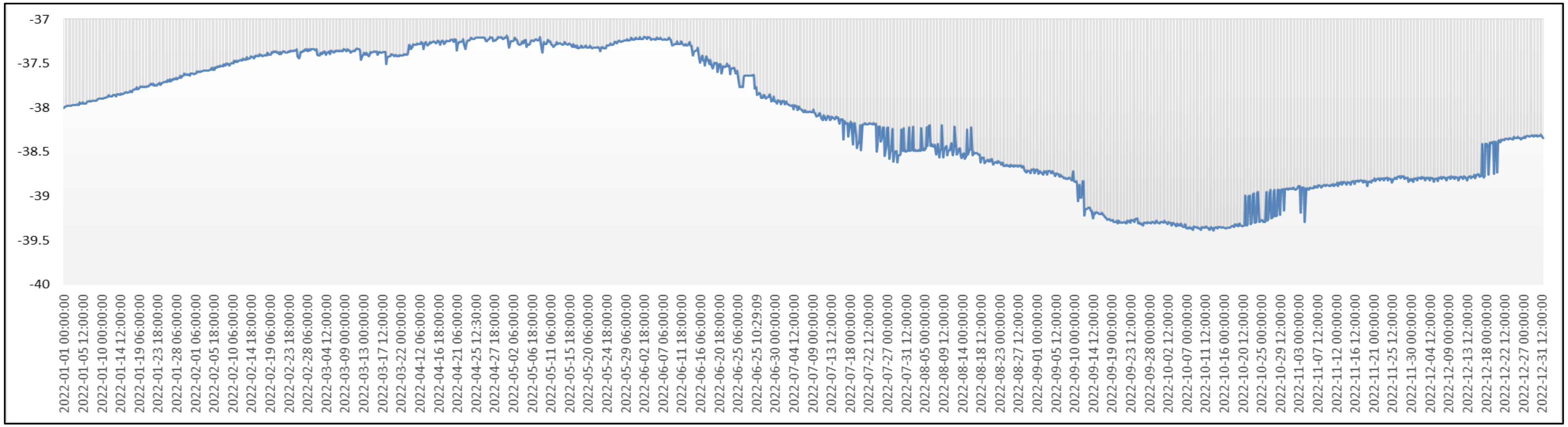


Figure 52 High-Frequency Data of Kalajhar Piezometer, Bhawanigarh Block, Sangrur District

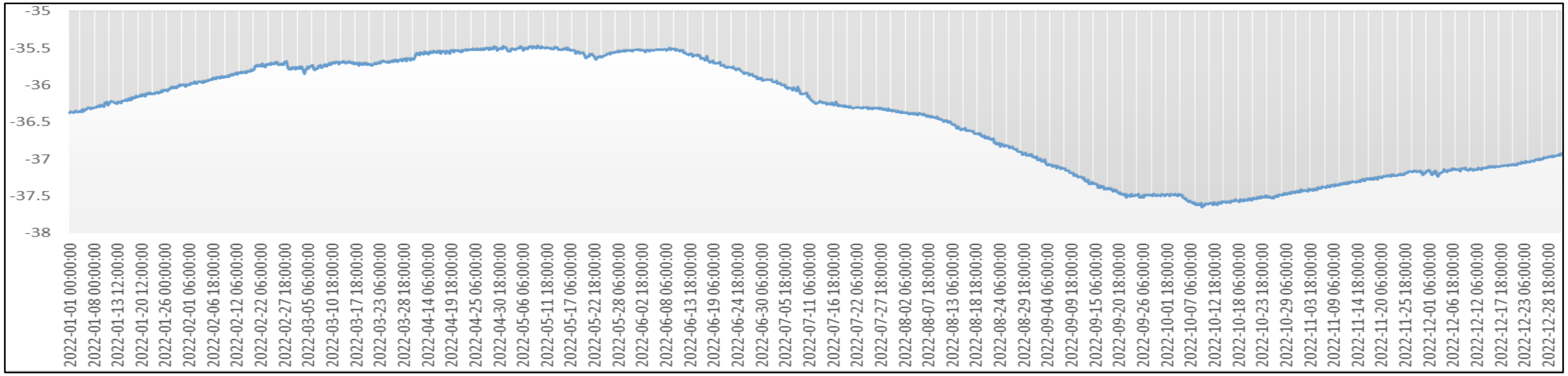


Figure 53 High-Frequency Data of Bhawanigarh Piezometer, Bhawanigarh Block, Sangrur District

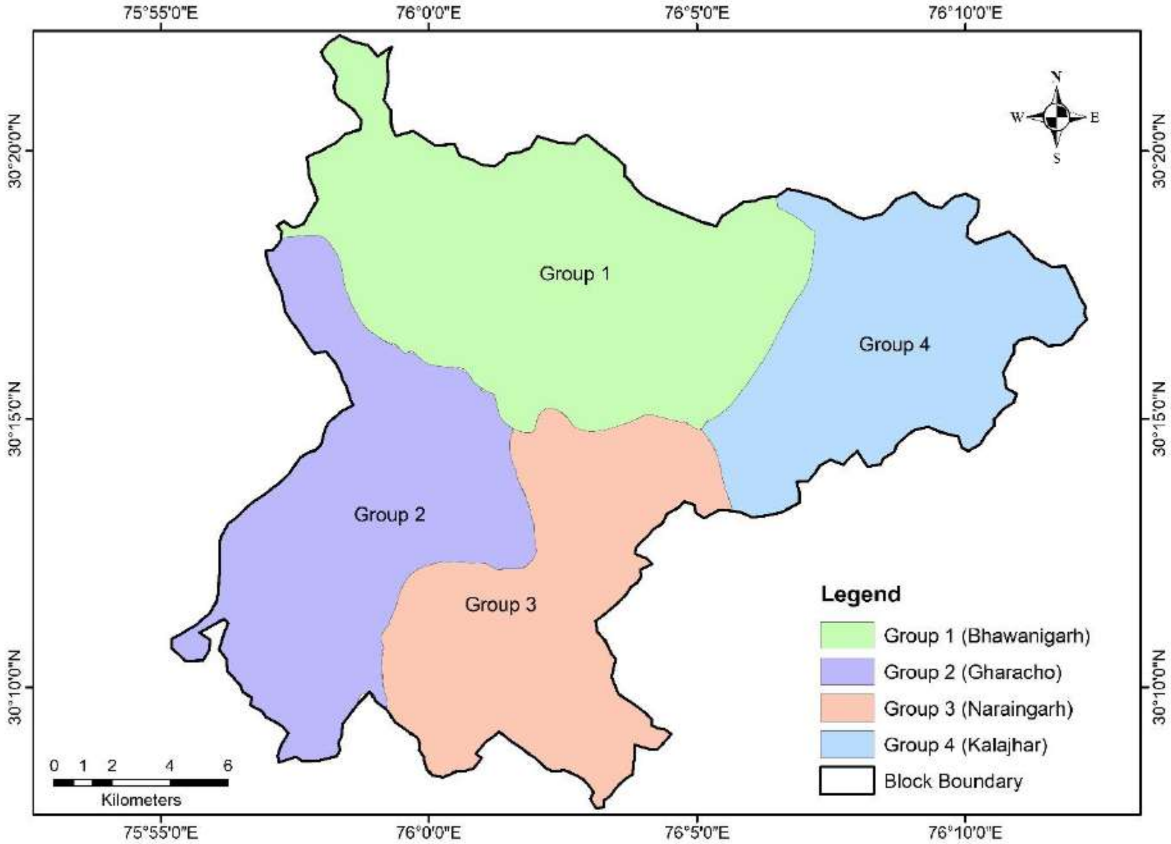


Figure 54 Map showing Bhawanigarh Area grouping based upon HFD data

The previous chapters have reported that the Bhawanigarh block experienced an average decline of 0.72 m/year over the past decade. However, after conducting the HFD calculation for the Year 2022, it has been discovered that the actual annual decline is 0.62 m/year, which aligns closely with the current situation on the ground. This finding contradicts the estimation presented by GEC 2015, which indicated a decline of 4.65 meters/year, as shown in Table 18.

Table 18 Comparison of GEC 2015 and HFD methodology

Item	GEC 2015	WLF Method
Extraction	283.93 mcm	83.619 mcm
Availability	81.60 mcm	57.705 mcm
SOD	348 %	145 %
Av WL decline	4.79 m/year	0.62 m/year

6.4.2. Refinement of existing GEC methodology inputs

The groundwater resource estimation methodology outlined in the GEC 2015 is predominantly based on the water balance principle, which stipulates that the inflow into the aquifer system should be equivalent to the outflow (extraction) from the aquifer system. Inputs into the system include precipitation and seepage from various water bodies, while outputs consist of water extracted for irrigation, industrial, domestic, and drinking water purposes. The Irrigation draft alone accounts for 80% of the total draft and refinement in its draft can help in refining the SOD of the Bhawanigarh block. The computation of the irrigation draft involves the multiplication of the unit draft by the number of tube wells in the Bhawanigarh block.

The unit draft values for GWRE 2023, provided by the Agricultural Department of Punjab, were initially set at 1.67 ham for Kharif and 0.71 ham for Rabi. However, the field survey revealed that the actual unit draft values were 1.3 ham for Kharif and 0.22 ham for Rabi. The revised draft implementation has yielded a significant reduction in groundwater extraction for irrigation purposes, with the total extraction decreasing from 28569.52 ham to 18246.08 ham, resulting in an overall extraction of 18852.08 ham. This commendable accomplishment has brought about a remarkable enhancement in the SOD of the Bhawanigarh block, witnessing a reduction from 348% to 231% (Table 19).

Table 19 Comparision of Resources calculated as per sample survey and GWRE,2023

	Revision in GEC		**AS per GEC**	
Season	**Monsoon**	**Non-Monsoon**	**Monsoon**	**Non-Monsoon**
Number of wells	12004	12004	12004	12004
Estimated Draft per well	1.3	0.22	1.61	0.705
Draft season wise	15605.2	2640.88	19326.44	8462.82
Irrigation Draft	18246.08		27789.26	
Domestic & Industrial Draft	606		606	
Draft	18852.08		28395.26	
Availability (GEC)	8,159.61		8,161.61	
SOD	231 %		348 %	

6.5. Conclusion

In conclusion, we may argue that revising the irrigation unit draft will improve SOD and better reflect the genuine ground situation. A more straightforward approach that is faithful to the ground scenario is the HFD methodology, which may be used to calculate groundwater resources.

CHAPTER 7 - GROUNDWATER CHEMICAL QUALITY

7.1 Objective

Naquim 2.0 Study has been taken to confirm the Aquifer Quality such as the concentration of Basic elements and heavy metals which were found to be more than the permissible limits (set by BIS). Accordingly, groundwater samples have been collected pre and Post Monsoon and analyzed for constituting Detailed, Heavy Metals from contaminated pockets identified based on the water-stressed block Bhawanigarh of Sangrur district of Punjab State. During the study, details were collected on the sampling point source. It has been gathered that mostly tube wells have indicated that tube wells have tapped aquifer in the depth range up to 70m bgl. Tube wells of government water supplying agency i.e. Municipal Corporation have tapped the aquifer II in the depth up to 150-160 m.

7.2 Sample Collection and Preservation

The water samples were collected in two Set polyethylene bottles of 1-litre capacity for major elements and 60mL capacity for heavy metals/trace elements analysis. Before sampling, the tube wells were continuously pumped for about 5-10 minutes to ensure that the groundwater sampled was representative of the aquifer tapped by the well. At the site water samples were filtered using What Man Filter Paper (0.45 mm) and treated with Supra pure Nitric acid 65% (1:1) at the time of collection. Heavy metals present were stabilized by lowering pH to less than 2.0. The analysis was carried out by standard methods as per APHA, 22nd edition. The total No. of Samples collected for basic analysis during pre-monsoon was 47 number whereas for the post-monsoon it was 74. Whereas for the heavy metal analysis, 47 and 118 number of samples were collected during pre and post-monsoon respectively.

7.3 Methodology

The water samples were analyzed by the Regional Chemical Laboratory at CGWB, Chandigarh, following the procedures outlined in the American Public Health Agency (APHA) 23rd Edition 2017 and Bureau Indian Standards (BIS). The analysis included measuring major cations (Ca, Mg, Na, K) and anions (CO3, HCO3, Cl, NO3, SO4), as well as pH, EC, F, SiO2, PO4, and TH as CaCO3. The Regional Laboratory is accredited by

NABL and also tested the samples for common heavy metals such as Manganese (Mn), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Copper (Cu), Lead (Pb), Nickel (Ni), Iron (Fe), Arsenic (As), Selenium (Se), and Uranium (U). The table 20 and 21 provides information on the methods and equipment used for the chemical analysis.

Table 20 Methods used in Chemical analysis

Parameter	Methodologies
pH	APHA 22nd Edition; 4500 H^+ B
EC	APHA 22nd Edition; 2510 BB
Cl	APHA 22nd Edition; 4500 Cl^- B
NO_3	APHA 22nd Edition; 4500 NO_3^- B
F	APHA 22nd Edition; 4500- F^- D
TH	APHA 22nd Edition; 2340C
Ca	APHA 22nd Edition; 3500 CaB
Mg	APHA 22nd Edition; 3500 Mg^+ B
Na	IS 3025 (Pt45) 1993
K	IS 3025 (Pt45) 1993

Table 21 Types of equipment used in chemical analysis

Parameters	**Analytical Methods**
Physio-chemical analysis	
pH	Electrometric method
Conductivity (EC)	Electrical conductivity method
Carbonate & bicarbonate (CO_3, HCO_3)	Titrimetric method
Chloride (Cl)	Argentometric method
Sulphate (SO_4)	Nephlo-turbidity method
Nitrate (NO_3)	Spectro-photometric method
Fluoride (F)	Ion metric method
Total hardness (T.H)	EDTA-Titrimetric method
Calcium (Ca)	EDTA-Titrimetric method
Magnesium (Mg)	By difference
Sodium (Na)	Flame photometric method
Potassium (K)	Flame photometric method
Trace elements/Heavy metals analysis	
Copper (Cu) Cadmium (Cd) Chromium (Cr) Lead (Pb) Manganese (Mn) Zinc(Zn) Nickel (Ni) Iron (Fe) Arsenic (As), Selenium (Se) Uranium (U).	Inductively coupled plasma mass spectrometry (ICP-MS)

7.4 Results and Discussion

The chemistry of major ions is controlled by the interaction between solute and aquifer solids and overlying land use. Determination of major ions and heavy metals gives an idea of the general hydrochemistry of the groundwater concerning the groundwater development which is being taken place by various stakeholders for drinking/domestic, agricultural, and industrial usages.

7.4.1 Groundwater Quality for Drinking Purposes

The water quality samples were collected under the NAQUIM 2.0 Programme from 47 locations during pre-monsoon and 74 locations during post-monsoon in various parts of the Bhawanigarh Block, as previously mentioned. The sampling points are illustrated in Figures 55 and 56 for pre and post-monsoon respectively. Furthermore, data on groundwater quality from the Central Ground Water Board was also incorporated in this study. Table 22 displays the range of chemical constituents in groundwater samples collected during both pre and post-monsoon periods in the Bhawanigarh Block. Analysis of the data reveals significant variations in groundwater quality across different sites.

Table 22 Range of Chemical Constituents in Ground Water of Pre and Post-Monsoon

Parameters	**Pre Monsoon**		**Post Monsoon**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
pH	7.10	8.32	7.15	8.60
EC (micro mhos /cm at 25^{o}C)	413	1416	492	2580
CO_3	nil	48	nil	60
HCO_3 (mg/l)	130	749	146	1086
Cl (mg/l)	6.45	131	7.0	211
SO_4 (mg/l)	15	250	nd	24
NO_3 (mg/l)	nd	85	nd	54
F (mg/l)	0.13	0.83	0.30	1.60
Ca (mg/l)	8.0	102	8.0	107
Mg (mg/l)	2.0	81	9.0	81
Na (mg/l)	9.22	280	12	385
K (mg/l)	2.2	27	2.22	23
Sio2(mg/l)	13	27	15	25
Total Hardness As $CaCO_3$ (mg/l)	59	451	95	513

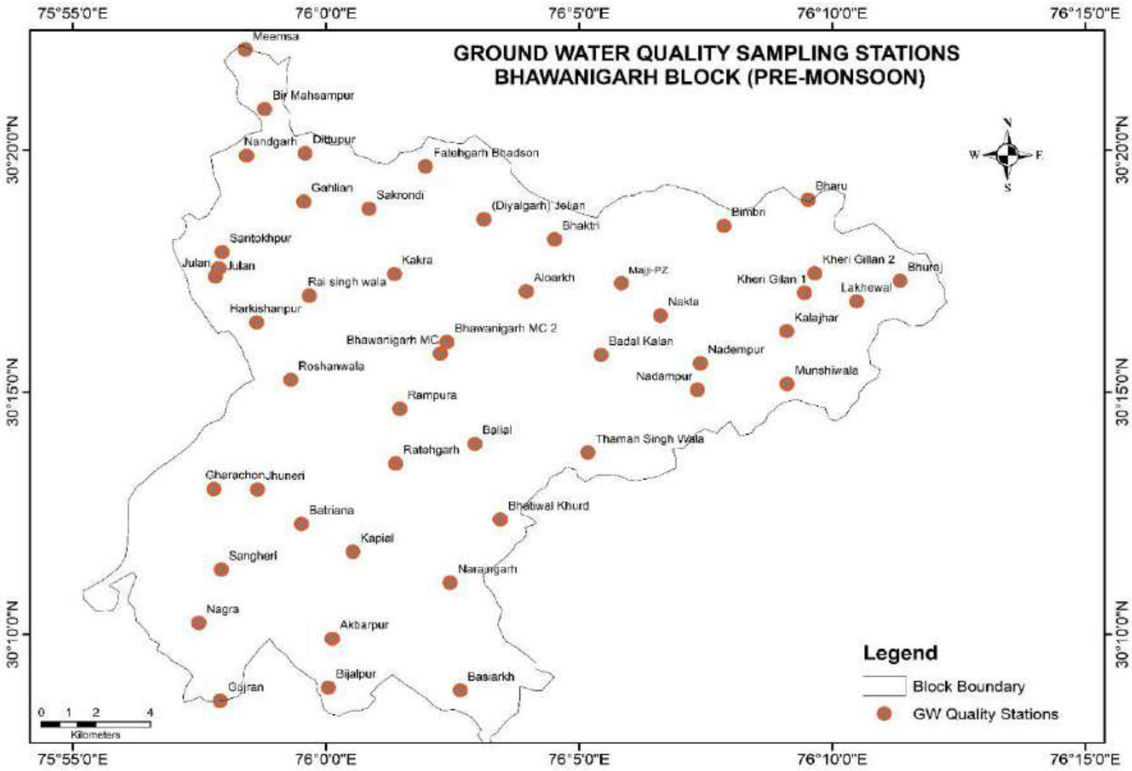


Figure 55 Location of Sampling Points pre-monsoon of Bhawanigarh Block of Sangrur district.

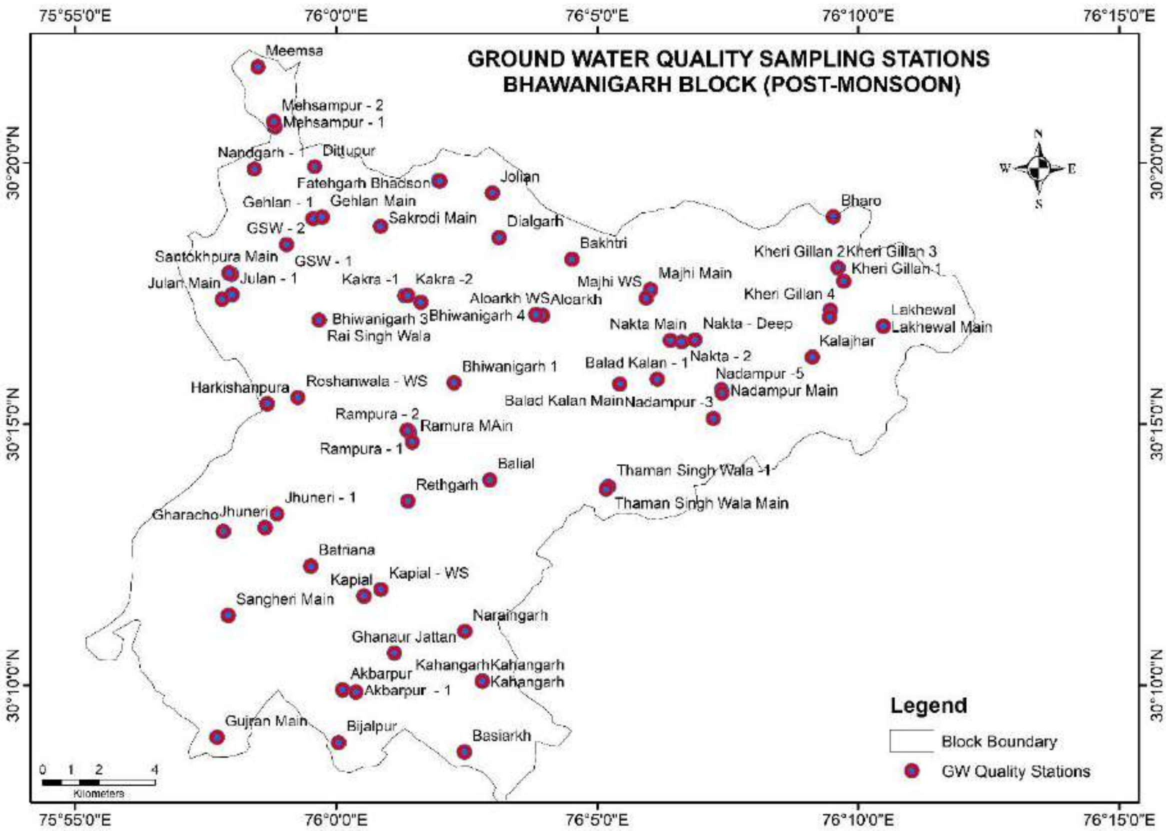


Figure 56 Location of Sampling Points post-monsoon of Bhawanigarh Block of Sangrur district

7.4.1.1. pH (Potential of Hydrogen)

The pH levels of the groundwater in the Bhawanigarh block are alkaline, ranging from 7.10 to 8.32 during the pre-monsoon period and 7.15 to 8.60 during the post-monsoon period.

7.4.1.2 Electrical Conductivity(EC)

Electrical conductivity is a measure of the total mineral contents of dissolved solids in water. It depends upon the ionic strength of the solution. An increase in dissolved solids causes a proportional increase in electrical conductivity. The electrical conductivity value of groundwater in Bawanigarh Block has been found to vary from 413 to 1416 µS/cm at 25ºC. A maximum concentration of 1416 µS/ cm has been reported from Harkishanpur village in pre-monsoon (Figure 57). In post-monsoon, the electrical conductivity value of groundwater in Bawanigarh Block has been found to vary from 492 to 2580 µS/cm at 25ºC (Figure 58). The post-monsoon samples indicate an elevated EC value, as a greater number of samples were collected during this period. Table 23 shows the summarized results of EC.

The spatial variation of EC shows a relatively higher value in the major part of the block. EC above 1000 µS/cm value has been observed in isolated patches in Bhawanigarh Block. Because of finer sediments in the aquifer, flushing of groundwater is not proper, and longer residence time of water in the aquifer results in the dissolution of salts from the aquifer material, which leads to higher TDS content and in turn higher EC.

Table 23 Summarized results of EC in Bhawanigarh block Sangrur District, Punjab

Category	Range	No. of Samples		Percentage of Samples	
		Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
Fresh	< 750	21	40	45	54
Moderate	750- 2250	26	33	55	45
Slightly mineralized	2251- 3000	0	01	0	1
Highly mineralized	> 3000	0	0	0	0

EC in µS/cm at 25 ^{0}C

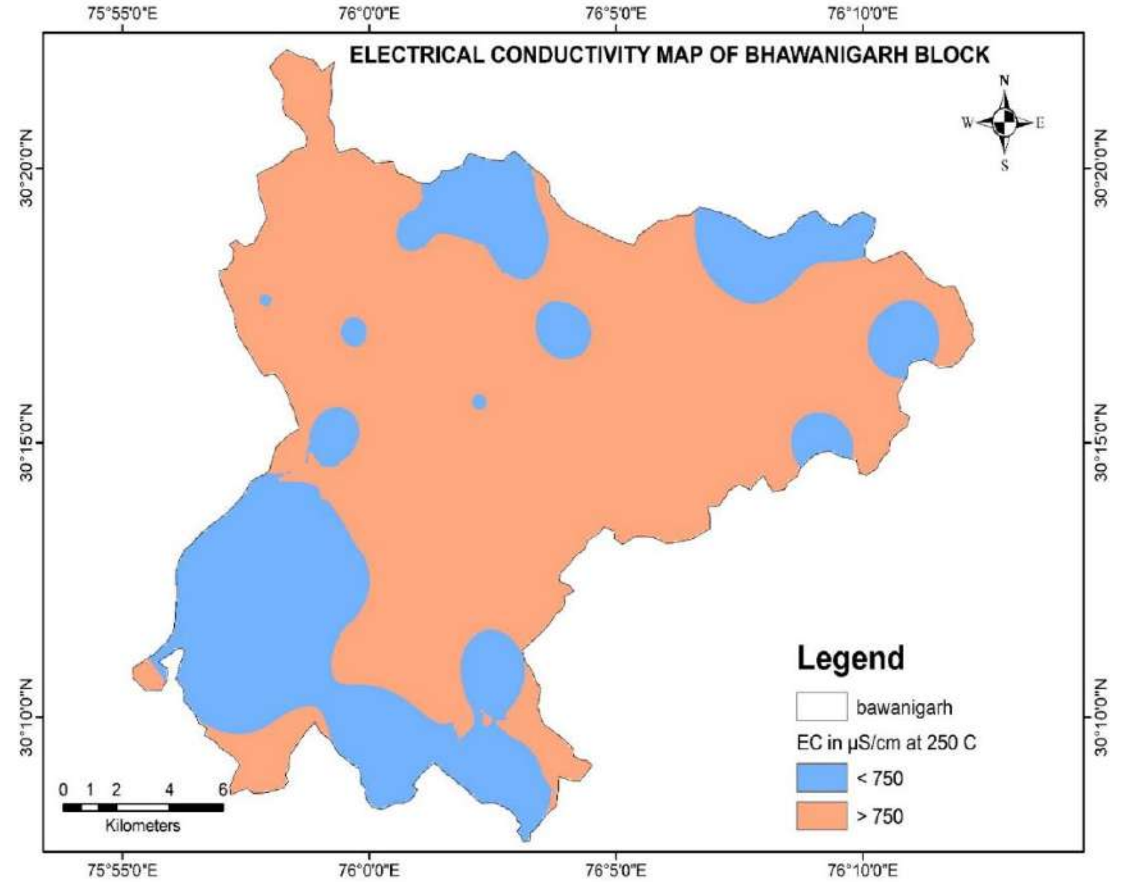


Figure 57 Distribution of EC in groundwater in Pre Monsoon of Bhawanigarh Block

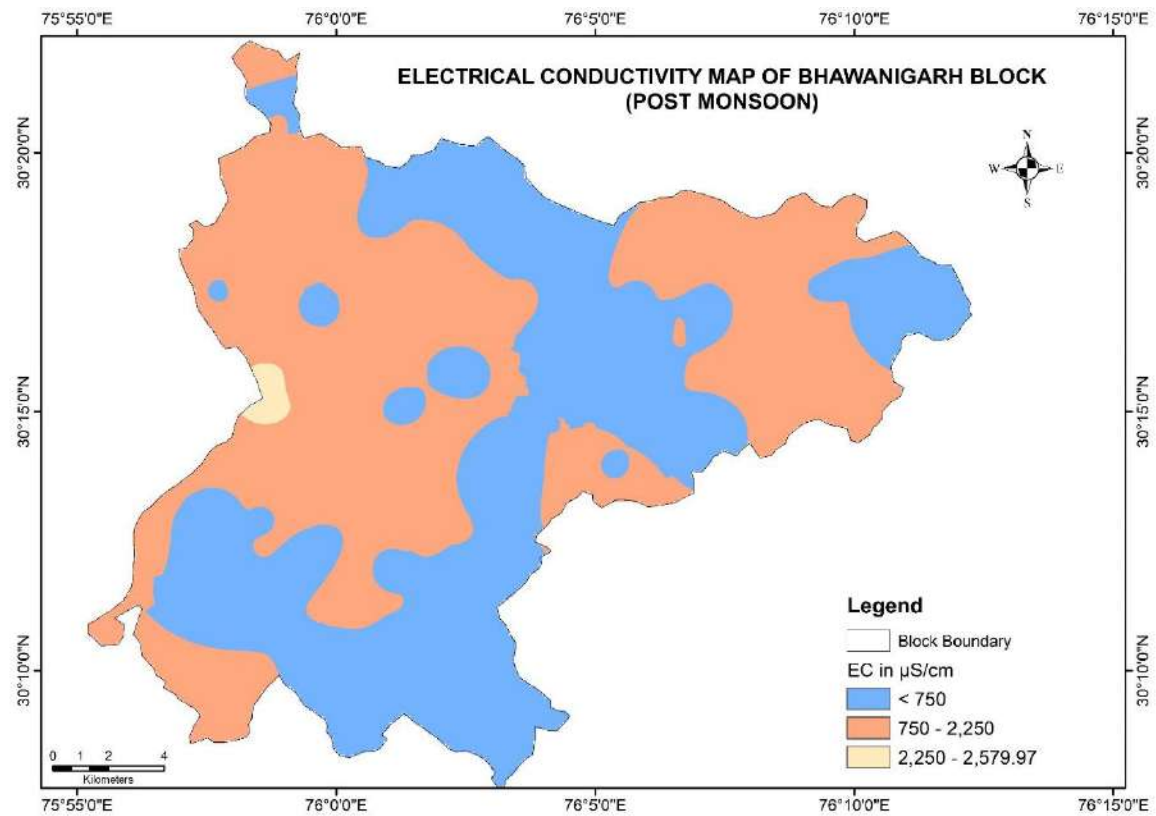


Figure 58 Distribution of EC in groundwater in Post Monsoon of Bhawanigarh Block

7.4.1.3. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) in water include all dissolved materials in the solution, whether ionized or not. It is the numerical sum of all mineral constituents dissolved in water and is expressed in mg/l. The TDS contents of groundwater are controlled by the mineral dissolution rate, the chemical character of groundwater, and the ionic saturation status of the solution. The concentration of total dissolved solids in the groundwater has been found to vary generally between 268 mg/l to 920 mg/l. TDS of 100 % of analyzed water samples falls in the category of fresh water, in Pre Monsoon (Table 24). In post-monsoon, the concentration of total dissolved solids in the groundwater has been found to vary between 320 mg/l to 1677 mg/l. TDS of 100 % of analyzed water samples falls in the category of fresh water. No TDS has been found over the maximum permissible limit of 2000 mg/l.

Table 24 Classification of water based on Total Dissolved Solids

TDS(mg/l)	Water Quality	% Samples	
		Pre Monsoon	Post Monsoon
0-1000	Freshwater	100	100
1000-10,000	Brackish water	Nil	Nil
10,000-100,000	Saline water	Nil	Nil
>100,000	Brine	Nil	Nil

7.4.1.4. Total Hardness (TH)

TH has been found to vary between 59 mg/l and 451 mg/l, in Pre-monsoon and 95 mg/l to 513 mg/l in post-monsoon indicating hard to very hard type of ground water (Table 25). High hardness may cause precipitation of calcium carbonate and encrustation on water supply distribution systems. Long-term consumption of extremely hard water might lead to an increased incidence of urolithiasis, encephaly, and cardiovascular disorders. The Total Hardness has not exceeded the recommended maximum permissible limit of 600 mg/l (IS-10500: 2012) in total analyzed groundwater samples in pre & Post Monsoon.

Table 25 Total Hardness Classification of water

Hardness(mg/l)	Water Class	% Sample	
		Pre Monsoon	Post Monsoon
0-75	Soft	4.3%	0%
75-150	Moderately Hard	21.3%	19%
150-350	Hard	51 %	62%
>350	Very Hard	23.4%	19%

7.4.1.5. Major Anions (HCO_3^{-}, SO_4^{-}, Cl^{-}, NO_3^{-}, F^{-})

The predominant anions found in the analyzed samples are HCo3¯ and SO4 2¯, with HCO3¯ being the most abundant, followed by SO4 2¯, Cl¯, NO3 ¯, and F¯ in the majority of the groundwater samples before and after the monsoon season. The Figure 59 and 56 illustrates the contribution of these anions to the overall anionic charge balance for pre and post monsoon respectively.

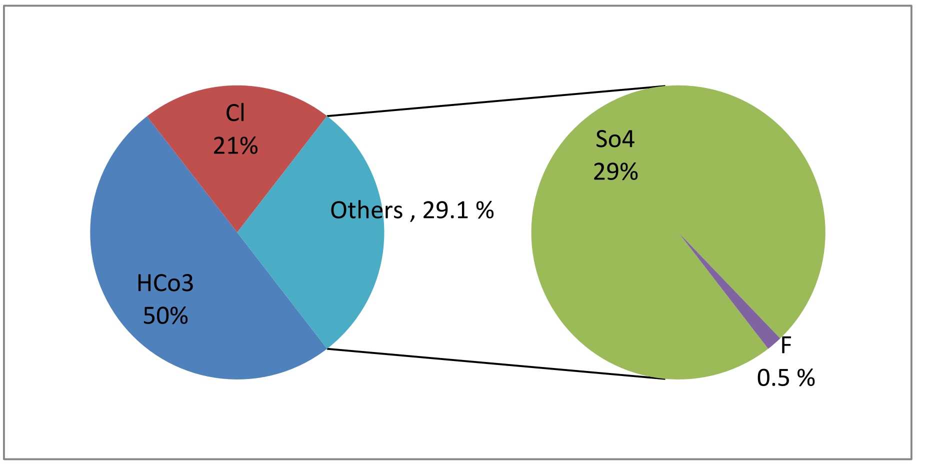


Figure 59 Contribution of anions towards the total anionic charge balance in Pre Monsoon

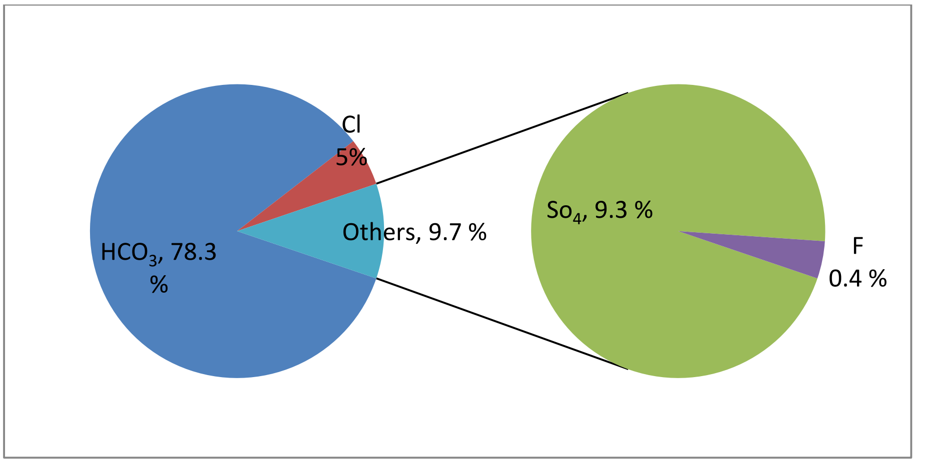


Figure 60 Contribution of anions towards the total anionic charge balance in Post Monsoon

Bi-carbonate is the most dominant anion, contributing 50% in pre-monsoon and 78% in post-monsoon in terms of the total anionic (TZ^{-}) mass balance in equivalent units. The concentration of Bicarbonates (HCO_3^{-}) has been found to vary from 84 mg/l to 429 mg/l. Bicarbonates are derived mainly from the soil zone CO_2 and at the time of weathering of parent minerals or from the dissolution of carbonates and/or silicate minerals by the carbonic acid.

The concentration of Sulphate (SO_4^{--}) ranges from 15 mg/l to 250 mg/l during the pre-monsoon and it is not detectable to 242 mg/l in post-monsoon. It contributes to 29.1% of the total anionic charge balance in pre-monsoon and 9.7% in post-monsoon. Only a few samples showed the Sulphate concentration exceeding the desirable, while overall, the concentrations remain well within the permissible drinking water. The desirable and permissible limits as per IS-10500:2012, are 200 mg/l and 400 mg/l values respectively.

The Concentration of chloride varies from 6.45mg/l to 131mg/l in pre-monsoon and 6.81mg/l to 211mg/l in post-monsoon. The highest chloride concentration was reported from Village Kapial during the pre-monsoon and Village Roshanwala – Water Supply Tube Well in the post-monsoon. It contributes to 21% of the total anionic charge balance in pre-monsoon and 4.9% in post-monsoon. Elevated levels of Cl^- in drinking water result in a salty taste and laxative effect for individuals unaccustomed to it. The concentration of Cl^- does not exceed the desirable limit of 250 mg/l (IS-10500: 2012) in any sample in pre and post-monsoon. Table 26 shows the summarized results of Chloride.

Table 26 Summarized results of Chloride in Bhawanigarh block Sangrur District, Punjab

Category	Range	No. of Samples		Percentage of Samples	
		Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
Desirable limit	< 250	47	74	100	100
Permissible limit	251-1000	0	0	0	0
Beyond permissible limit	> 1000	0	0	0	0

Fluoride (F^-) is a crucial element in ensuring the proper growth of healthy teeth and bones. However, excessive levels of fluoride can lead to dental and skeletal fluorosis, resulting in issues like tooth discoloration, ligament deformities, and spinal cord bending. The fluoride concentration in groundwater samples ranges from 0.13 to 0.83mg/l during pre-monsoon and 0.30 to 1.60mg/l during post-monsoon. It contributes less than 1.0% to the total anionic charge balance. The fluoride levels in all analyzed samples, except for one location called Jhuner, are well below the maximum permissible limit of 1.50 mg/l (IS-10500: 2012). At Jhuner, the fluoride concentration was found to be 1.60 mg/l, exceeding the permissible limit. Table 27 shows the summarized results of Fluoride.

Table 27 Summarized results of Fluoride in Bhawanigarh block Sangrur District, Punjab

Category	Range	No. of Samples		Percentage of Samples	
		Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
Desirable limit	< 1.0	47	100	72	97.30
Permissible limit	1.0 - 1.5	0	0	01	1.35
Beyond permissible limit	>1.5	0	0	01	1.35

The concentration of Nitrate (NO_3^-) has been found to vary from 0 mg/l to 85 mg/l in the pre-monsoon period and 0 to 54 mg/l in the post-monsoon period. The Nitrate concentration marginally exceeds the maximum permissible limit of 45 mg/l in drinking water as prescribed by BIS (IS-10500:2012) in approximately 6% of the total groundwater samples (Figure 21) in pre- and 4% in post-monsoon. The highest Nitrate concentration is recorded at village Nakta (85mg/l) in pre-monsoon and Bhawanigarh (54mg/l) in post-monsoon. Excess nitrate in drinking water can cause Methemoglobinemia in infants, gastric cancer, goiter, birth malformations, and hypertension. Table 28 shows the summarized results of Nitrate

Table 28 Summarized results of Nitrate in Bhawanigarh block Sangrur District, Punjab

Category	Range	No. of Samples		Percentage of Samples	
		Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
Permissible limit	< 45	44	94	71	96
Beyond permissible limit	> 45	03	6	3	4

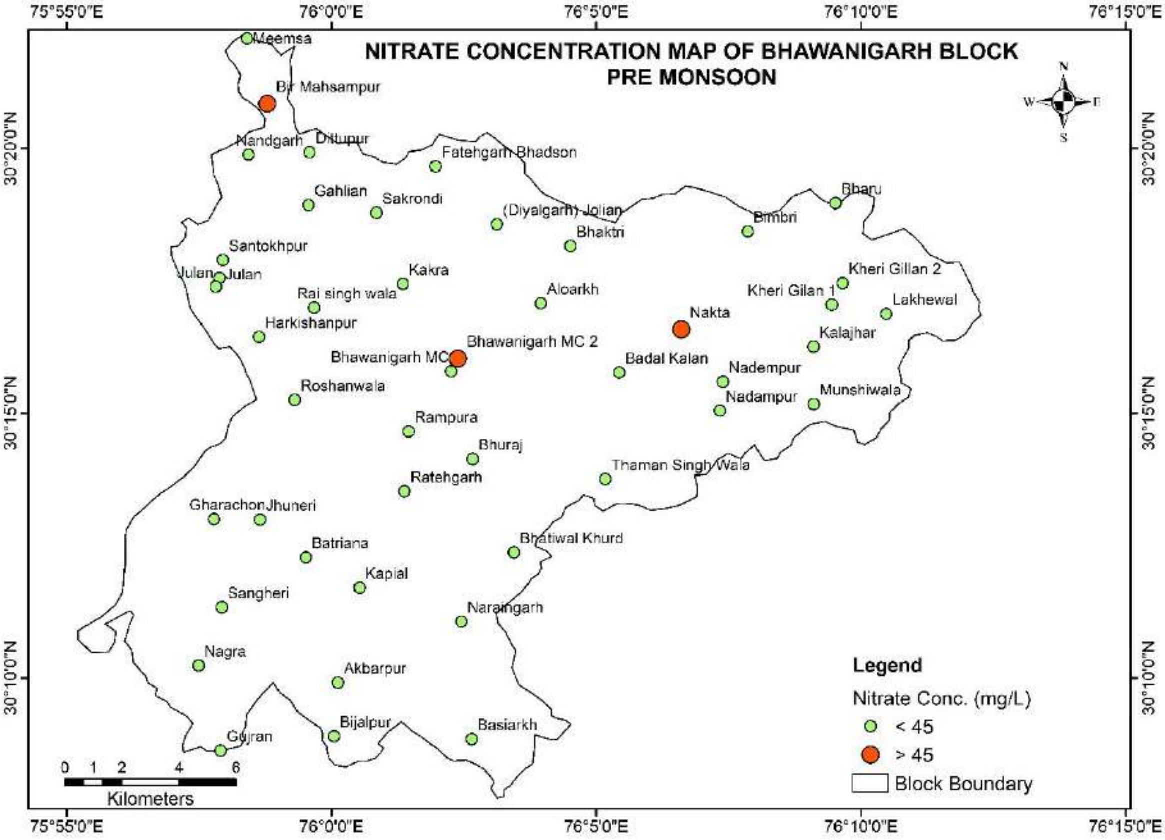


Figure 61 Distribution of Nitrate in Groundwater in Pre-Monsoon of Bhawanigarh Block

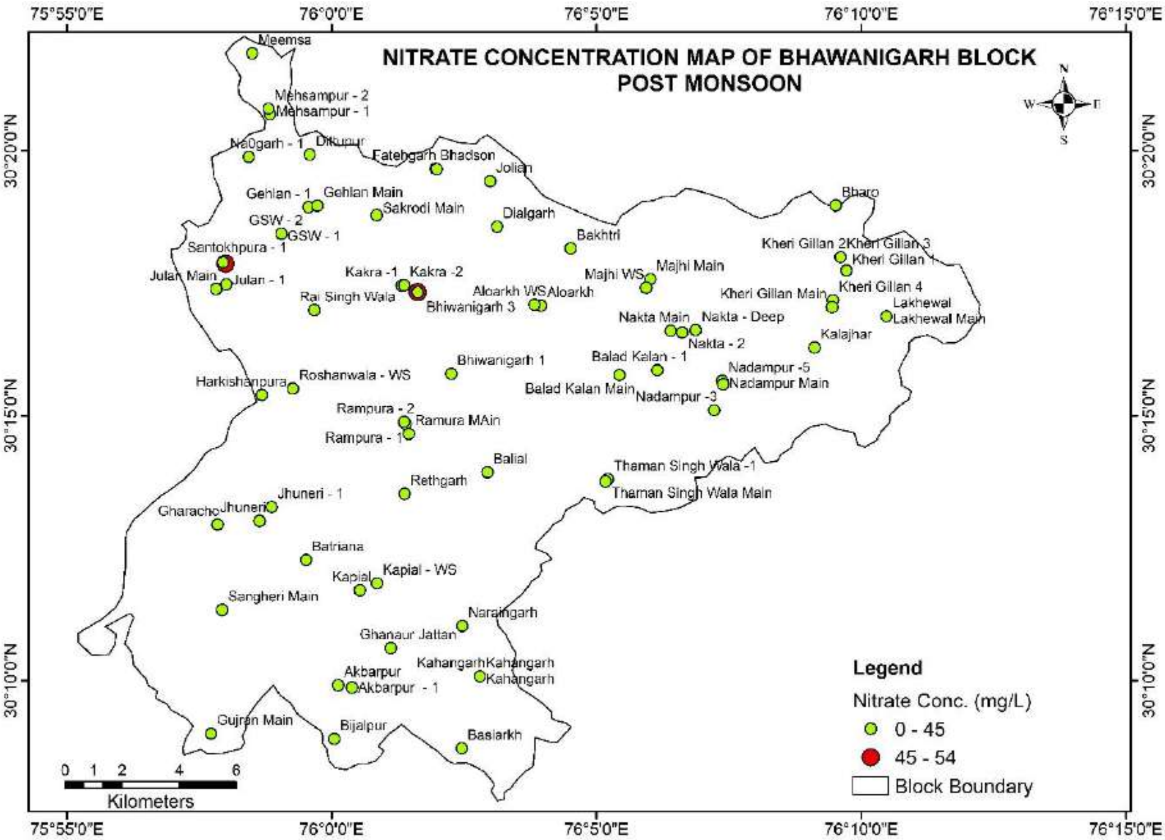


Figure 62 Distribution of Nitrate in Groundwater in Post Monsoon of Bhawanigarh Block

7.4.1.6. Major Cations (Ca, Mg, Na, K)

The primary cations in the water chemistry of the Bhawanigarh block in the Sangrur district are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). The dominance of alkaline earth metals (Ca + Mg) is slightly higher than alkali metals (Na + K) in this area. The combined presence of Ca^{2+} and Mg^{2+} accounts for 50% of the total cations (TZ+). In terms of abundance, the cationic order in groundwater is Na > Mg > Ca > K. The levels of these cations in groundwater are typically regulated by weathering and cation exchange processes. Figures 63 and 64 illustrate the contribution of different cations to the overall cationic charge balance during pre and post-monsoon respectively.

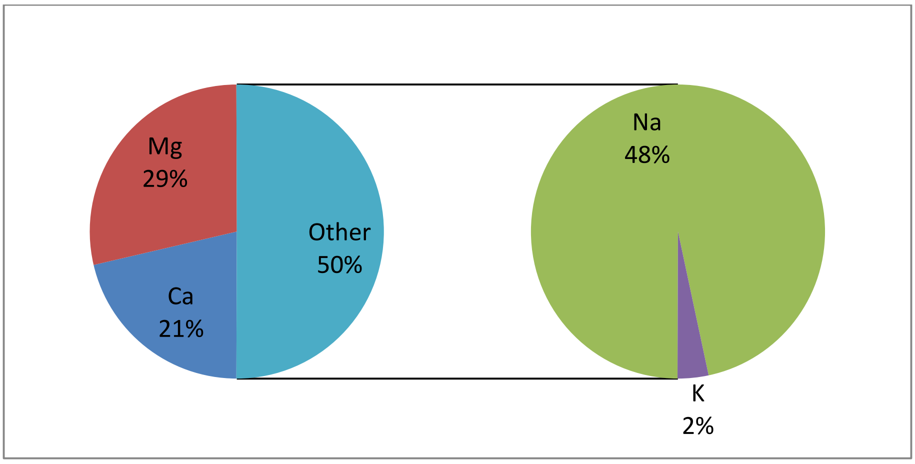


Figure 63 Contribution of cations towards the total cationic charge balance in pre monsoon

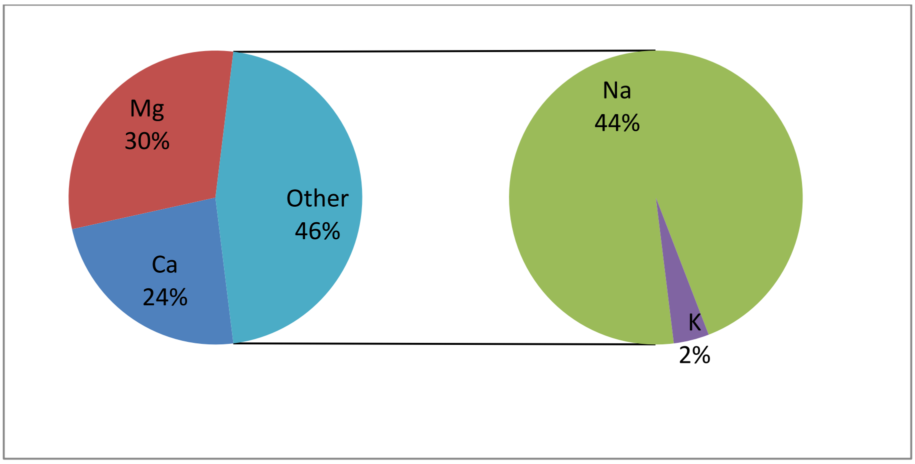


Figure 64 Contribution of cations towards the total cationic charge balance in post monsoon

Sodium (Na^+) stands out as the predominant cation in the groundwater of Bhawanigarh block during both pre and post-monsoon seasons, accounting for 48.4% and 44.3% respectively in the cationic charge balance (Refer to Fig. 22). The concentration of sodium ranges from 9.22 to 280 mg/l in the pre-monsoon period and 12 to 385 mg/l in the post-monsoon period. The highest concentrations of sodium are recorded in Rampura Village during the pre-monsoon season and Juneri Village during the post-monsoon season. Sodium is a crucial ion for human health, but excessive intake can lead to health issues such as hypertension, congenital heart diseases, nervous disorders, and kidney problems. Groundwater contamination by sodium and chloride is a common occurrence in rapidly developing areas. The sources of these ions can be attributed to human activities like the use of rock salt, leachate from landfills, and certain agricultural chemicals. Additionally, natural sources include interactions with rock formations, saline seeps, and minor contributions from the atmosphere.

Potassium levels range from 2.2mg/l to 27mg/l in pre-monsoon and 2.2mg/l to 23mg/l in post-monsoon. Potassium accounts for 1.7% and 1.8% of the total cationic mass balance in pre and post-monsoon, respectively.

Calcium, on the other hand, makes up 21.3% and 23.5% of the total cationic mass balance in pre and post-monsoon. Calcium is crucial for bone, nervous system, and cell development. Both Ca^{2+} and Mg^{2+} contribute significantly to water hardness. Prolonged ingestion of high levels of calcium may lead to an increased risk of kidney stones. The concentrations of Ca^{2+} and Mg^{2+} exceed the desirable levels for drinking water (75mg/l and 30mg/l, respectively) in approximately 13% and 55% of pre-monsoon samples, and 15% and 62% of post-monsoon samples. However, the concentrations of both ions do not surpass the maximum permissible levels of 200mg/l and 100mg/l, respectively.

7.4.2 Heavy Metals in Ground Water

Rocks undergo weathering, resulting in the release of various heavy metals. However, nature possesses effective mechanisms to manage this phenomenon. Generally, human exposure to heavy metals from natural sources is considered insignificant. Nevertheless, the presence of air pollutants, such as particles settling on water, acid rain dissolving metallic dust, and runoff from polluted soil, can contribute to the accumulation of heavy metals in water. Additionally, the application of phosphate fertilizers on land has been observed to enhance the leaching of cadmium from soil, which subsequently reaches the groundwater. Domestic sludge and solid waste exhibit high concentrations of metals such as copper (Cu), lead (Pb), nickel (Ni), zinc (Zn), chromium (Cr), cadmium (Cd), and manganese (Mn). Some fertilizers have been found to contain medium to high levels of copper (Cu), iron (Fe), manganese, zinc, chromium, and cadmium. Leaching from these fertilizers can contribute to an increased concentration of these metals in groundwater. The primary sources of heavy metals in groundwater include geological weathering, industrial processing of mines and minerals, industrial effluents from steel, petroleum refining, pulp and paper, fertilizers, as well as animal and human excreta, sludge, solid waste, and agricultural activities. It is a widely acknowledged fact that while certain heavy metals are necessary for normal bodily functions, they can also pose serious health risks, as some metals are toxic even at low levels. Heavy metal exposure can lead to enzyme inhibition, genetic damage, hypertension, and even carcinogenic effects.

The representative water quality samples were collected from various locations in the Bhawanigarh Block before and after the monsoon season. The examination of trace elements in the groundwater samples obtained through NAQUIM 2.0 indicated a wide range of concentrations, varying from values below the detection limit (BDL) to 0.101mg/L1. It is important to highlight that all the samples examined adhered to the highest allowable threshold established by the Bureau of Indian Standards (BIS) for potable water (IS-10500:2012). However, there were anomalies observed regarding Uranium Concentration during both the pre-monsoon and post-monsoon seasons, as well as higher levels of Lead and Selenium at a specific location. In these instances, the levels of Uranium exceeded the acceptable limits set by BIS. A summarized version of the heavy metal chemical analysis results can be found in Table 29.

Table 29 Summary of Heavy Metals analysis data for pre and post-monsoon

(Units in mg/l)	Pre-monsoon		Post-monsoon		Maximum Permissible Limit as prescribed by BIS(IS-10500:2012) mg/L (ppm)
	Minimum Range	Maximum Range	Minimum Range	Maximum Range	
Copper (Cu)	0.001	0.033	0.004	0.0324	1.5
Cadmium (Cd)	0.0003	0.0024	0.00002	0.0005	0.003
Chromium (Cr)	0.001	0.002	BDL	BDL	0.05
Lead (Pb)	0.00001	0.0023	0.00006	0.0120	0.01
Manganese (Mn)	0.001	0.336	0.0005	0.1763	0.3
Zinc(Zn)	0.033	0.298	0.004	0.675	15
Nickel (Ni)	BDL	0.004	0.005	0.022	0.2
Iron (Fe)	0.010	0.477	0.0021	0.373	1.0
Arsenic (As),	0.0005	0.0054	0.00038	0.00232	0.01
Selenium (Se)	0.000004	0.002	0.00008	0.01335	0.01
Uranium(U)	0.0097	0.726	9.394	0.1014	0.03

7.4.2.1. Uranium

Uranium is a radiotoxic and chemo toxic element, generally occurs in minerals such as carnotite, uraninite, and autunite in granitic & phosphatic rocks and ores. Uranium exists in various natural oxidation states such as +3, +4, +5, and +6. In an aquatic environment, the predominate states of U are tetravalent [U (IV)] and hexavalent [U (VI)] with the chemical forms UO_2 (uranous oxide) and UO_2^{2+} (uranyl ion), respectively. U (IV) is sparsely soluble and immobile, whereas U (VI) is soluble in water, mobile, and toxic to the environment. U (IV) is found in reducing environments, whereas U (VI) is found in oxidizing environments. U in groundwater occurs due to natural deposition from minerals, geochemical reactions, and anthropogenic activities such as mining and processing uranium ore, spent fuel disposal from nuclear power plants, and processing phosphate rocks.

Furthermore, carbonates in the groundwater react with U to form U-carbonate complexes. These complexes are highly soluble in water, which helps them mobilize quickly in the sub-surface water. Apart from this, other factors such as over-exploitation of groundwater, water-rock interactions, pH, Eh, organic matter, bicarbonates, and other ions influence U release into the groundwater. Exposure to uranium may also lead to other adverse health impacts, including bone toxicity and problems such as neurological effects, reproductive and developmental effects, and immune system effects. Ingestion of large amounts of uranium can lead to immediate health effects such as nausea, vomiting, and diarrhea. Inhalation of uranium dust or fumes can cause lung irritation and damage, including lung cancer.

During the pre-monsoon period, out of the 47 samples collected, it was observed that the concentration of Uranium exceeded 0.03 mg/L in 20 samples, accounting for 42.5% of the groundwater samples in the study area. The highest recorded value of Uranium concentration during this period was 0.072 mg/L, which was found in the village of Badal Kalan.

During the post-monsoon season, the frequency of collecting samples for Uranium analysis was increased in the vicinity of the hotspot where a significant concentration of uranium was detected in the pre-monsoon period. A total of 118 samples were collected throughout the post-monsoon period. In the post-monsoon phase, 33% of the groundwater samples (39 out of 118 samples) exhibited Uranium concentrations exceeding 0.03 mg/L, as per the standards set by BIS (2012). Notably, the village of Jhuneri – 1 registered the highest Uranium concentration at 0.101 mg/L during this time frame. The comparison of Uranium distribution between the pre and post-monsoon periods is illustrated in Figures 65 and 66, respectively.

Probable sources of Uranium in the groundwater of Bhawanigarh block, Sangrur District are Geogenic. There is a positive correlation between Uranium and bi-carbonate which form soluble uranyl carbonate complexes indicating geogenic contamination of Uranium in Bhawanigarh block which is exacerbated by over-exploitation of groundwater. The x-ray diffraction of soil particles showed the dominance of Illite followed by Kaolinite in the study area. The illite is considered the pathfinder mineral for the geological environment for Uranium occurrence. The negative correlation of Uranium with chloride & sulfate indicates no anthropogenic source of Uranium.

Table 30 Summarized results of Uranium in Bhawanigarh block Sangrur District, Punjab

Category	**Range**	**No. of Samples**		**Percentage of Samples**	
		Pre Monsoon	**Post Monsoon**	**Pre Monsoon**	**Post Monsoon**
Permissible limit	< 30	27	79	57.5	67
Beyond permissible limit	30-60	16	34	34	29
	>60	4	5	8.5	4

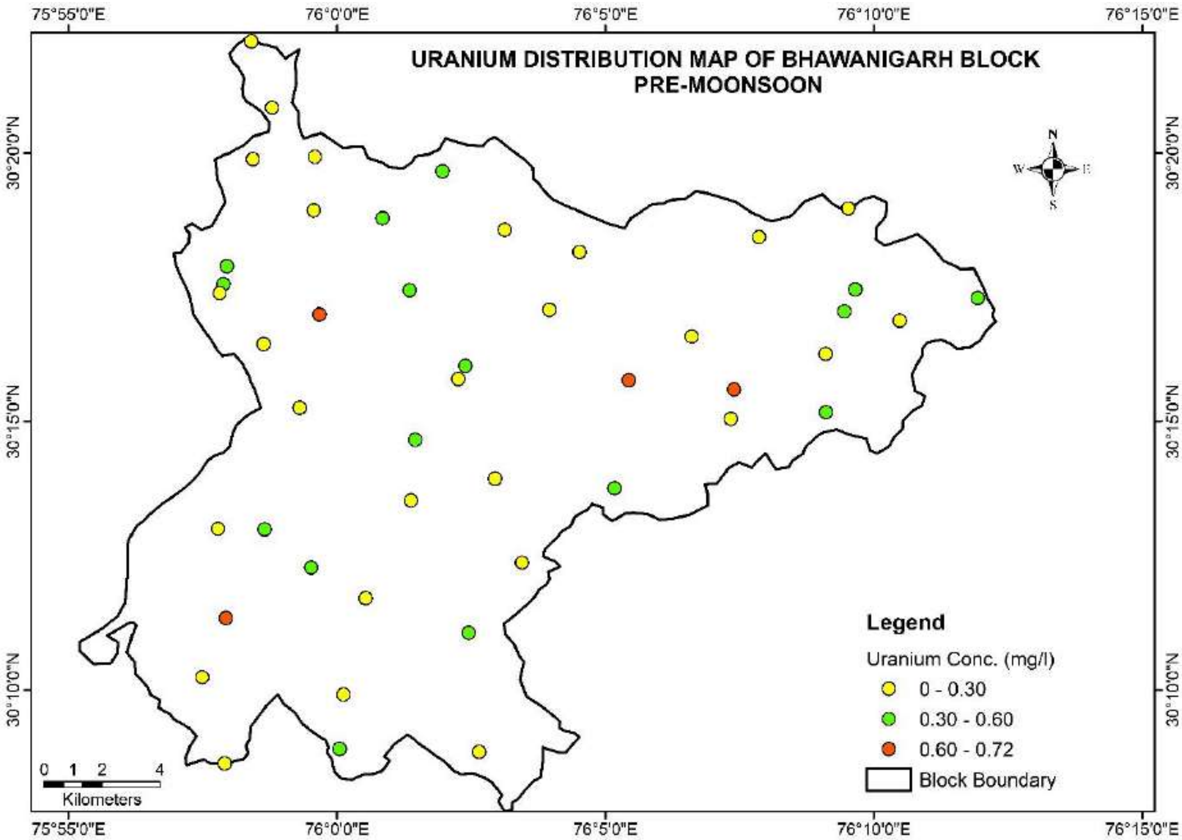


Figure 65 Distribution of Uranium in groundwater in Pre Monsoon of Bhawanigarh Block

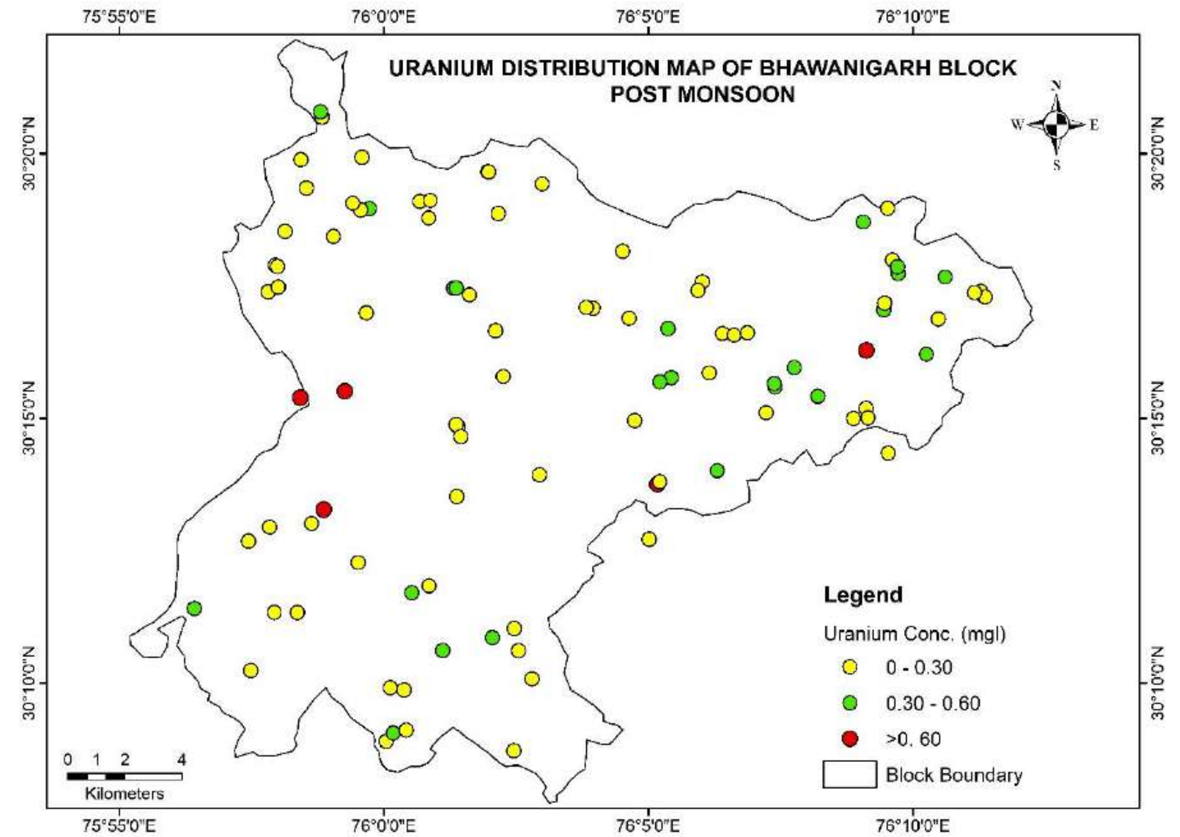


Figure 66 Distribution of Uranium in groundwater in Pre Monsoon of Bhawanigarh Block

7.5 Hydro geochemical Facies of Groundwater

The Hill and Piper diagram is a valuable tool for analyzing the relationships between various dissolved constituents and the categorization of water based on its chemical properties. The cationic triangle of the Piper diagram indicates that the groundwater samples do not predominantly fall dominantly into any specific class, while in the anionic triangle, most samples are situated within the bicarbonate fields (Figure 67 and 68). By plotting the chemical data on the central diamond-shaped field, which connects the cationic and anionic triangles, it is evident that the primary water types in the Bhawanigarh block are Magnesium Bicarbonate (45% of samples) and Mixed Type (Ca-Mg-Cl-SO4, Na-K-HCO3-Cl) (40% of samples), with the remaining samples falling under the sodium bicarbonate type. The majority of groundwater samples exhibit higher concentrations of alkali metal cations (Na++K+) compared to alkaline earth metals (Ca2++Mg2+). Overall, the groundwater is characterized by a prevalence of weak acids (HCO3-) over strong acids (Cl- +SO42).

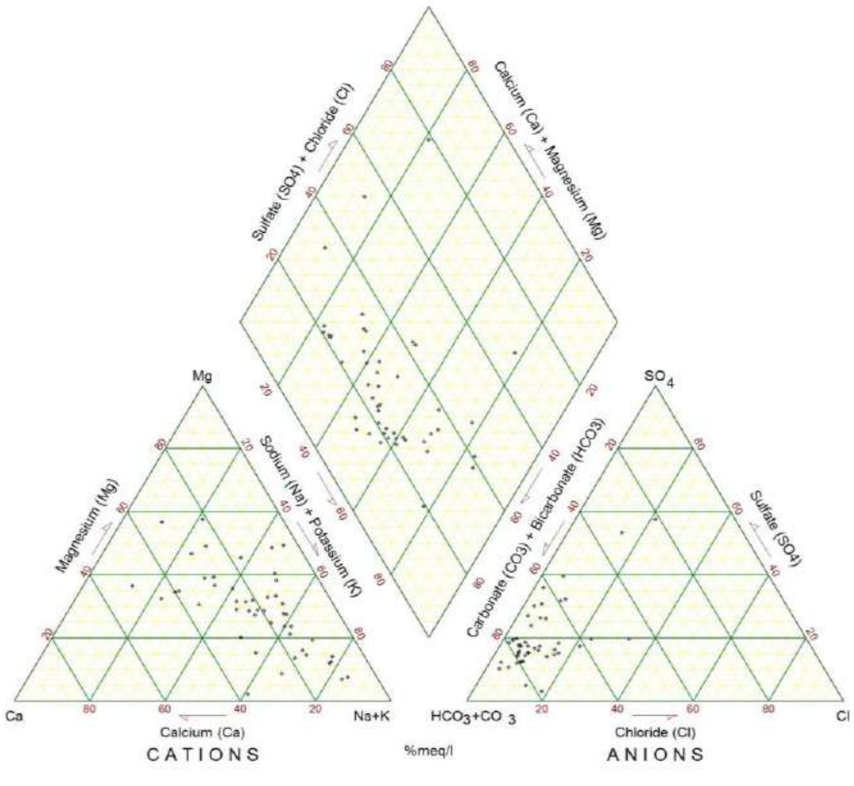


Figure 67 Hill and Piper plot showing water type and hydro chemical facies in pre-monsoon

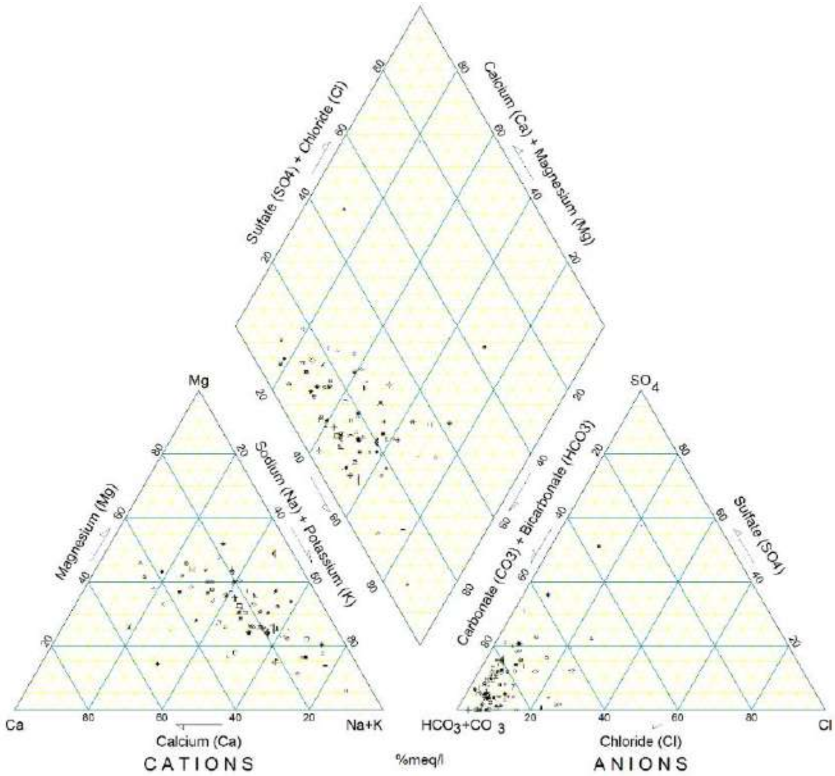


Figure 68 Hill and Piper plot showing water type and hydro chemical facies in post monsoon

7.6. Suitability for Irrigation purpose

Several different parameters are used to classify the suitability of water for irrigation. The most important characteristics of irrigation water in determining its quality are given below-

1) Electrical Conductivity (EC)
2) Sodium Adsorption Ratio (SAR)
3) Percent Sodium (% Na)
4) Residual Sodium Carbonate(RSC)

7.6.1 Sodium percentage and Electrical conductivity

The classification of groundwater for irrigation purposes in the Wilcox method is determined by the percentage of sodium and electrical conductivity (EC).

$$Na\% = Na+K/ (Ca+Mg+Na+K) \times 100$$

In the Bhawanigarh block, the sodium percentage in the groundwater ranges from 8.31% to 83.83%.

Analyzing the data using Wilcox's diagram, it is found that 4.26% and 1.35% of the samples exceed the recommended values for EC and Na%, respectively, indicating unsuitability for irrigation, particularly in the pre-monsoon and post-monsoon periods. In both pre and post-monsoon, 68% and 59% of the samples fall under the Permissible to doubtful category respectively. While the EC value exceeds the recommended limit of 2000µS/cm in only 1% of the samples, the %Na remains within the guideline value of 60% for all samples. This indicates the need for a special soil management plan due to the unsuitability of the groundwater for irrigation. It is important to note that high salt concentration (EC) in water leads to the formation of saline soil, while high sodium concentration leads to the development of alkaline soil. The classification of groundwater samples based on Na% can be found in Table 31, and the Wilcox Diagram is attached for reference.

Table 31 Water Classification based on Sodium Percent (Na%)

Na%	**Water Class**	***%Sample***		***EC*µS cm^{-1}**	***Water Category***	***%Sample***	
		Pre-monsoon	**Post monsoon**			**Pre-monsoon**	**Post monsoon**
<20 %	Excellent	4.26	6.76	<250	Low (C-1)	Nil	Nil
20 –40%	Good	23.40	32.43	250-750	Medium(C-2)	45	55
40–60%	Permissible	48.94	43.24	750-2250	High(C-3)	55	44
60-80%	Doubtful	19.15	16.22	>2250	Very High (C-4)	Nil	1
>80%	Unsuitable	4.26	1.35				

7.6.2 Sodium Adsorption ratio (SAR) and Electrical conductivity

The US Salinity Laboratory of the Department of Agriculture has categorized groundwater based on Salinity Hazard (EC) and Sodium hazard, which is determined by the sodium adsorption ratio (SAR). The sodium or alkali hazard in water used for irrigation is assessed by the concentration of cations, calculated using the formula SAR=Na/[(Ca+Mg)/2]0.5.

The SAR values in the study area varied between 0.27 and 9.17 during the pre-monsoon period, and between 0.33 and 15.1 during the post-monsoon period. The USSL Diagram plot for the pre-monsoon period revealed that the majority of the samples fell into the C2S1 and C2S2 categories, with only 4 samples falling into the C2S2 and C3S2 category. However, in the post-monsoon period, there was an improvement as all the samples fell into the C2S1 and C3S1 categories, making the area suitable for irrigation purposes for plants with good salt tolerance. The USSL salinity diagram for both the pre and post-monsoon periods is depicted in Figure 69 and 70 respectively. In the pre-monsoon period, 45% of the samples showed a medium salinity hazard, while 55% showed a high salinity hazard, with the alkali hazard falling into the excellent category. On the other hand, in the post-monsoon period, 55% of the samples showed a medium salinity hazard, while 44% showed a high salinity hazard, with the alkali hazard still falling into the excellent category. Irrigation water is classified into four categories based on sodium adsorption ratio (SAR) and EC (Table 32).

Table 32 Water classification based upon SAR and EC

SAR	***Water Category***	***% Sample***		***ECµS cm^{-1}***	***Water Category***	***%Sample***	
		Pre-monsoon	**Post monsoon**			**Pre monsoon**	**Post monsoon**
0 – 10	Excellent (S-1)	100	99	<250	Low (C-)	Nil	Nil
10 –18	Good(S-2)	Nil	1	250-750	Medium (C-2)	45	55
18 –26	Fair(S-3)	Nil	Nil	750-2250	High(C-3)	55	44
>26	Poor(S-4)	Nil	Nil	>2250	Very High(C-4)	Nil	1

High saline water cannot be used on soils with restricted drainage and requires special management for salinity control. Plants with good salt tolerance should be selected for such areas.

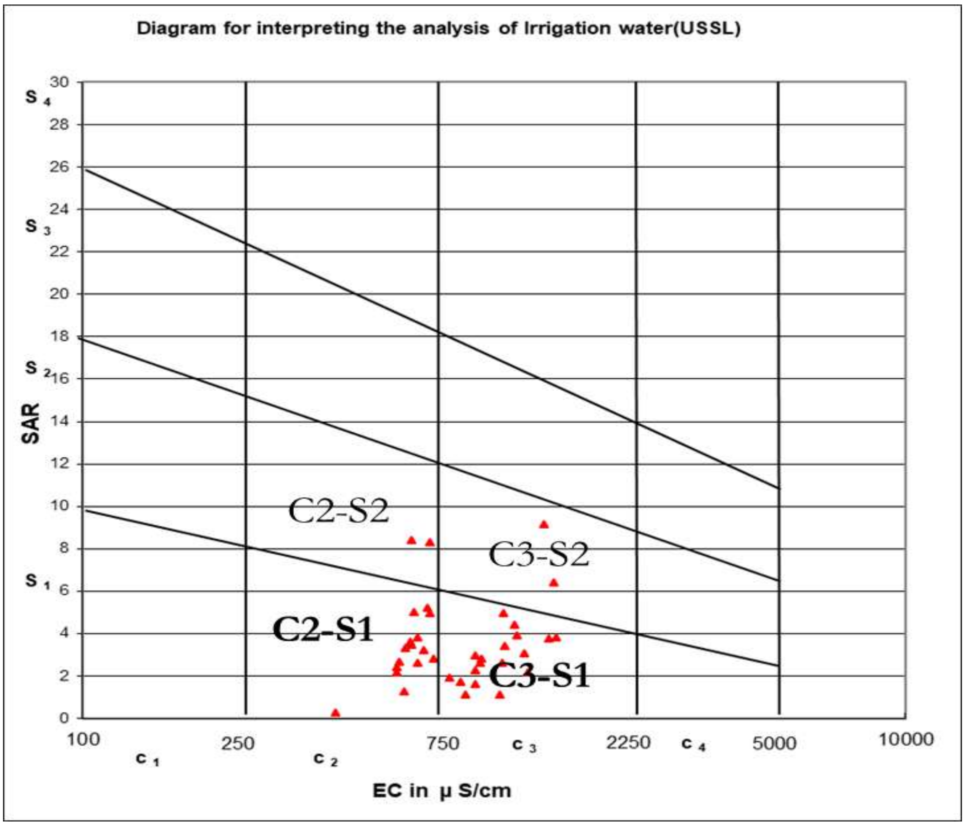


Figure 69 USSL Diagramme for classifying the Groundwater for irrigation purposes in Pre-monsoon

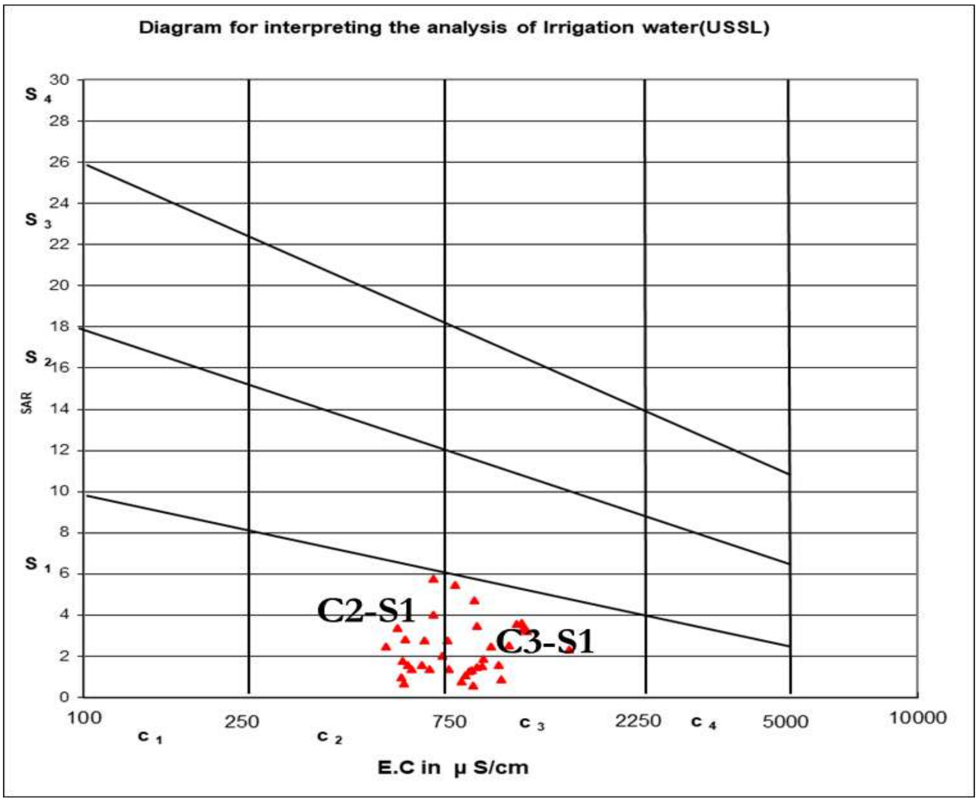


Figure 70 USSL Diagramme for classifying the Ground water for irrigation purpose in Pre monsoon

7.6.3 Residual Sodium Carbonate (RSC)

Eaton suggested assessing the residual sodium carbonate concentration as a means to evaluate the appropriateness of water for irrigation. The presence of the HCO3- anion holds significance in irrigation water. The analysis of samples from the Bhawanigarh block, both before and after the monsoon season, revealed RSC values falling into three categories: Safe, Marginal, and unsuitable, based on their respective percentages. These categories serve as indicators for determining the suitability of the water for irrigation purposes. 38% of samples fall under the safe RSC category during pre-monsoon and 27 % during post-monsoon (Table 33).

Table 33 Water classification based upon RSC

Description		**Pre-monsoon**		**Post monsoon**	
RSC Value in epm	**Category**	**No. of Samples**	***%Sample***	**No. of Samples**	***%Sample***
<1.25	Safe	18	38	20	27
1.25-2.50	Marginal	10	21	21	28
>2.50	Unsafe	19	41	33	45

7.7. Conclusion

1. The quality of groundwater is generally fresh in approximately 45% of samples during pre-monsoon and about 54% during post-monsoon, with an electrical conductivity (EC) value less than 750 µS/cm at 25°C. In around 55% of samples, the EC ranges between 751 - 2250 µS/cm at 25°C during pre-monsoon, while 45% fall within this range during post-monsoon. Only 1% of samples show slight mineralization in post-monsoon, indicating an improvement in groundwater quality in terms of EC due to dilution.
2. The chloride concentration in all samples analyzed is within permissible limits. Additionally, fluoride content is less than 1.5 mg/L in nearly all samples during pre-monsoon and in 99% of samples during post-monsoon, with about 1% exceeding the permissible limit in post-monsoon.
3. Nitrate content is less than 45 mg/L in approximately 94% and 96% of samples analyzed during pre and post-monsoon, with 6% and 4% respectively showing levels above 45 mg/L. This suggests an improvement in groundwater quality concerning nitrate post-monsoon due to dilution.
4. Uranium concentrations exceeding the permissible limit of 0.3 mg/L were observed in 42.5% of wells during pre-monsoon and 33% during post-monsoon in the Bhawanigarh block. Lead and Selenium were detected in only one location.
5. Evaluation of groundwater suitability for irrigation based on salinity, sodium absorption ratio (SAR), and residual sodium carbonate (RSC) reveals that 38% and 27% of collected samples have RSC values less than 1.25 during pre and post-monsoon respectively, making them safe for irrigation. Samples with RSC values ranging from 1.25 to 2.50 are marginally suitable for irrigation, accounting for 21% and 28% in pre and post-monsoon, while 41% and 45% respectively have RSC values exceeding 2.50, rendering them unsuitable for irrigation purposes.

CHAPTER 8 - AREAS SHOWING SIGNS OF LAND SUBSIDENCE

8.1 Objectives:

To produce this deliverable, it is essential to take into account the existing literature in the field, as well as the indications of subsidence noted during field investigations. The data analysis will involve combining satellite data with pertinent published research and field findings.

8.2 Material and Methods:

Land subsidence refers to the gradual settling or abrupt sinking of the Earth's surface, which can occur due to a variety of factors, including seismic activity and rapid declines in the water table. This phenomenon is particularly prevalent in regions characterized by loose soils, tectonic disturbances, and the presence of multiple faults and folds. Additionally, areas with significant clayey or sandy soil layers are also more susceptible to this process, highlighting the complex interplay between geological conditions and subsidence events.

To identify regions exhibiting indications of land subsidence within the Bhawanigarh block, comprehensive field surveys were conducted throughout the area, during which discussions were held with farmers and local residents regarding the issues they faced. A comparative analysis of decadal satellite imagery revealed that there were no variations in the reference points designated for elevation comparison across the images.

8.3 Results and Discussion:

Comprehensive investigations have revealed that there is no evidence of land subsidence occurring in the region.

CHAPTER 9 – GROUNDWATER ISSUES AND THEIR MANAGEMENT

9.1 Management Strategies and Aquifer Management Plan

The NAQUIM 2.0 initiative aims to conduct comprehensive studies that aim to provide more detailed information on various aspects of groundwater management. The focus is on increasing the density of dynamic data, such as groundwater level and groundwater quality, to offer issue-based scientific inputs for effective groundwater management at the village level.

The Aquifer Management Plan, which forms an integral part of this study, provides an outline of the strategies and measures to be implemented in the study area. It encompasses a wide range of factors, including population demographics, rainfall patterns, average annual rainfall, agricultural practices, irrigation methods, water bodies, groundwater availability, and groundwater extraction.

Furthermore, the plan also includes a detailed analysis of the behaviour of water levels in the study area, along with the disposition of aquifers and various cross-sections. This information is crucial for understanding the distribution and characteristics of groundwater resources in the area.

In addition to these aspects, the study also addresses other pertinent issues related to groundwater management. This includes the exploration of groundwater resources, the assessment of extraction practices, and the identification of potential areas for groundwater resource enhancement. Moreover, the study also explores demand-side interventions to ensure sustainable and efficient use of groundwater resources.

Overall, the NAQUIM 2.0 initiative strives to provide a comprehensive and detailed understanding of groundwater dynamics in the study area. By focusing on higher granularity and incorporating various scientific inputs, it aims to support effective groundwater management at the village level, ultimately contributing to sustainable water resource utilization.

9.2 Major Issues

The major challenges observed during the NAQUIM 2.0 studies in the Bhawanigarh block are the declining water levels and Groundwater quality.

9.2.1 Declining water groundwater level

The Bhawanigarh block has been the focal point of concern due to the significant decrease in water levels, with a decline of over 1 meter each year. This decline in water levels can be attributed to the excessive extraction of groundwater, surpassing the natural recharge rate. As a result, there is a clear imbalance between the extraction of groundwater and its replenishment, leading to the overexploitation of groundwater resources in the region.

The overexploitation of groundwater resources in the Bhawanigarh block poses a serious threat to the sustainability of the water supply in the area. With the continuous decline in water levels, there is a growing risk of depleting the groundwater reserves beyond their capacity for natural replenishment. This unsustainable practice not only jeopardizes the availability of water for current needs but also compromises the ability of future generations to access this vital resource. It is imperative for stakeholders to implement effective management strategies to address the overexploitation of groundwater resources and ensure the long-term sustainability of the water supply in the Bhawanigarh block.

9.2.2. Groundwater Quality

In the previous section discussing water quality, it was stated that the groundwater samples collected during the study period adhered to the acceptable limits for most of the basic and heavy metal parameters. However, it is worth noting that the concentration of uranium in these samples exceeded the permissible limits set by BIS.

Nevertheless, the presence of elevated levels of uranium in the collected groundwater samples raises concerns. Excessive levels of uranium can pose health risks, such as potential kidney damage and increased cancer risks. It is of utmost importance to address this issue and implement appropriate measures to reduce the concentration of fluoride and uranium in the groundwater.

9.3. Groundwater Management Strategies

To effectively tackle the challenges associated with declining water levels and groundwater quality, a comprehensive management plan is crucial. This plan should not only focus on reversing the declining trend of water levels but also prioritize the enhancement of groundwater quality. Furthermore, it is essential to identify aquifers that are free from uranium to ensure the provision of safe water to end users. The interventions should be implemented both on the demand and supply sides to arrest the declining water levels and to increase the water use efficiency.

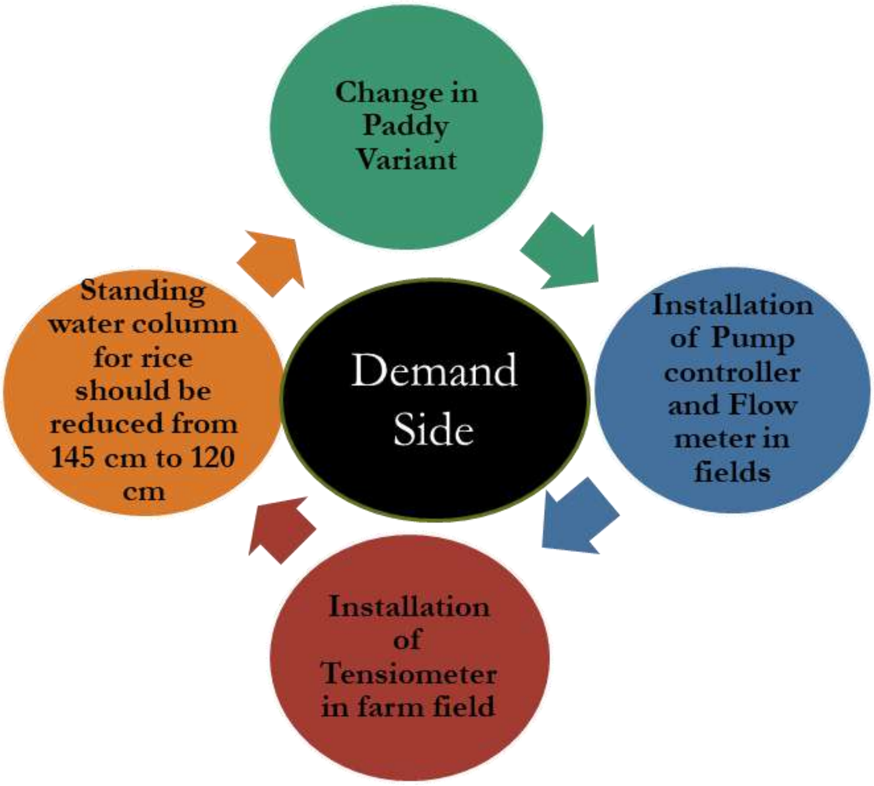


Figure 71 Demand side interventions needed in the Bhawanigarh block, Sangrur District

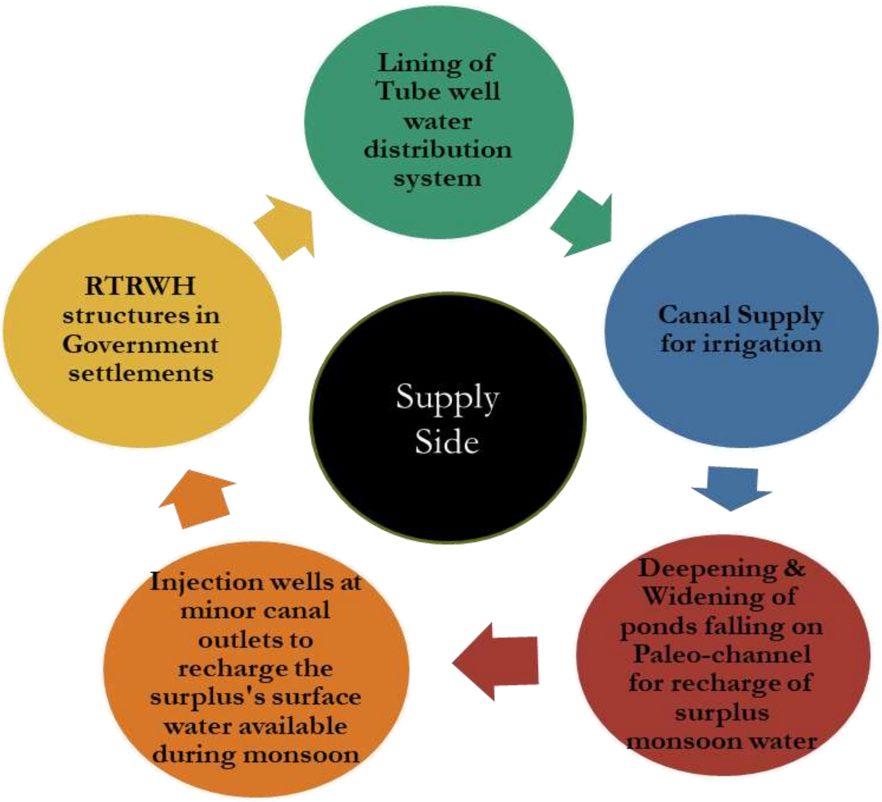


Figure 72 Supply side interventions needed in the Bhawanigarh block, Sangrur District

9.3.1. Management of declining water Level

The subject matter will be discussed in two distinct sections, namely the demand side interventions and the supply side interventions. Detailed information regarding each section is outlined below, with visual aids available in Figure 72 and 73 for better understanding.

9.3.1.1 Demand Side Interventions

I. **Change in paddy variant** - The transition away from paddy cultivation presents challenges due to its significance as the primary source of livelihood for farmers residing in the research area. However, an alternative approach could involve replacing the existing paddy variety, PUSA-44, which has a maturity period of 150 days, with the paddy variant PR-126, which matures in 117 days. This change has the potential to conserve an estimated 25% of groundwater levels, as indicated by a study carried out by PWRDA and PAU Ludhiana in Dhuri and sunam blocks of Sangrur.

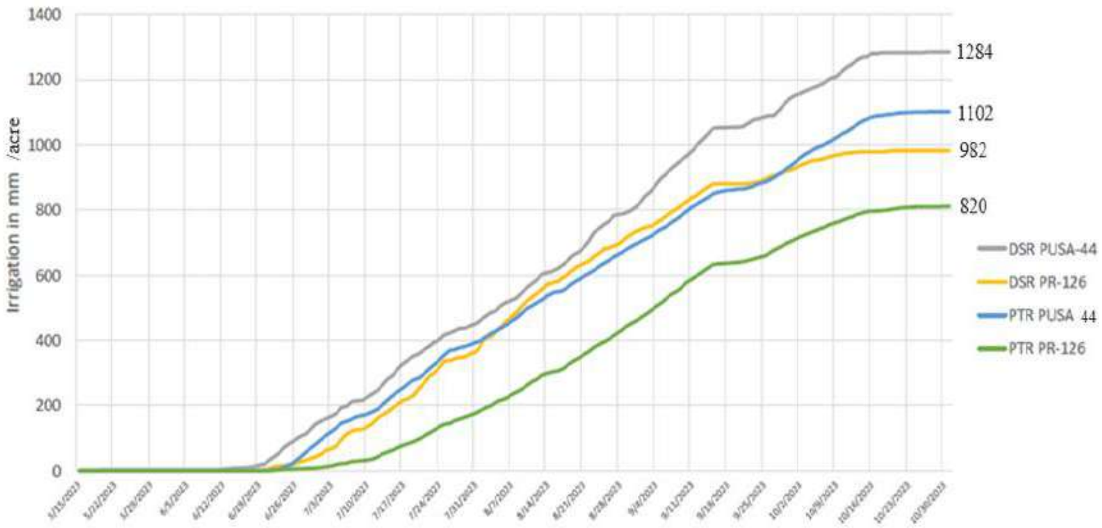


Figure 73 Comparison in irrigation among the paddy cultivars and sowing methods

II. **Use of AI and Tensiometers** - The utilization of artificial intelligence (AI) within the agricultural sector has the potential to significantly decrease the amount of water needed for irrigation. By incorporating technology such as tensiometers, which can accurately determine the optimal timing for turning off irrigation motors once the desired level of soil moisture is reached, farmers can effectively manage water usage. This precise control has resulted in a notable reduction in water requirements, as evidenced by a decrease from 1102 mm/acre to 820 mm/acre, as reported in a study conducted by PWRDA and PAU Ludhiana.

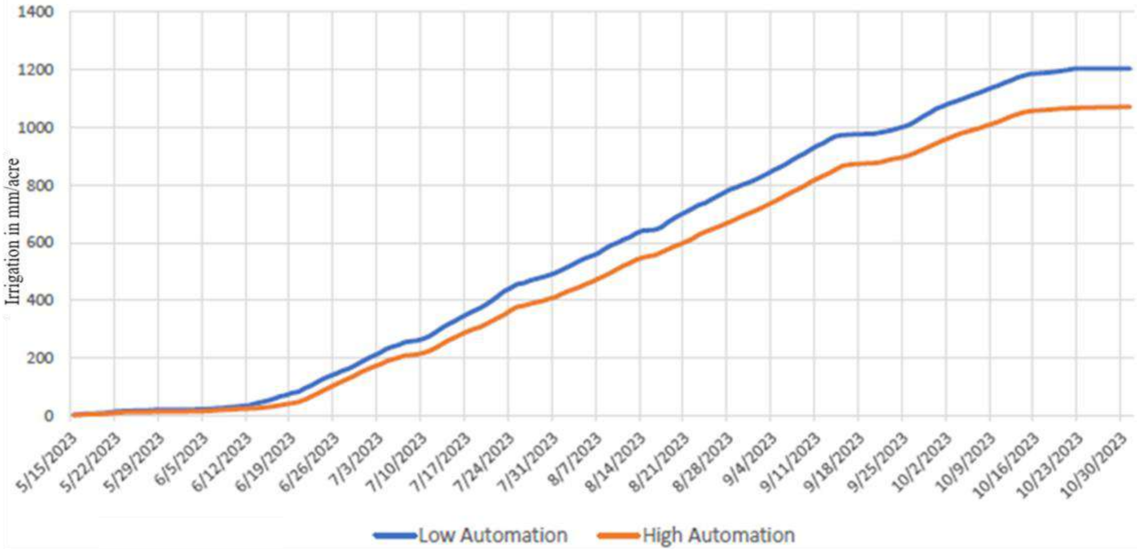


Figure 74 Effect of Automation in irrigation

III. **Reduction of standing water column** - PAU and PWRDA have also conducted a comprehensive study that re-evaluates the ideal standing water column for rice cultivation. Their research suggests a departure from the previously accepted norm of 145 cm, indicating that a water column of 120 cm is more appropriate for successful rice growth.

9.3.1.2 Supply-side interventions

I. **Lining of Unlined channels** - There are approximately 12,623 tube wells that farmers use for irrigation in the Sangrur block. These tube wells are connected to an unlined/Kutcha open channel system, through which water is discharged to the agricultural fields. Unfortunately, this process leads to a significant wastage of groundwater, with around 20% being lost due to soil moisture and evaporation. According to the GWRE 2023 report, the total groundwater draft for irrigation in the block is estimated to be 30,580 ham. However, it is expected that by transitioning to an lined water supply distribution system instead of the current unlined open channels, around 15-20% of the irrigation overdrafts can be reduced.

II. **Underground Pipelines** - In Bhawanigarh block about 2382 hectares of agricultural land has been covered in an underground pipeline system which is about 7% of the total area of 33158 hectares. Currently, the stage of groundwater development stands at 348%, but this can be decreased to 307% by implementing an underground pipeline system that covers 60% of the entire agricultural land.

III. **Canal water for Irrigation** - In the study area, there is a well-established network of canal systems that can be utilized for irrigation purposes. It is essential to ensure the maximum supply of canal water for irrigation, as this will play a crucial role in recharging the groundwater levels in the region. By prioritizing the distribution of canal water for agricultural use, the overall sustainability of the groundwater resources can be significantly enhanced.

IV. **Artificial Recharge in Paleochannels** - The identification of paleochannels in the Bhawanigarh block signifies a significant opportunity for enhancing groundwater recharge through artificial means. Through comprehensive soil infiltration assessments, it has been determined that the paleochannel region exhibits a notably high rate of recharge, making it an ideal location for such initiatives. To maximize the utilization of surplus monsoon precipitation, it is proposed to excavate and widen the ponds within the paleochannels to a depth of 2.5 meters. Furthermore, the construction of recharge trenches within these ponds will serve to augment the artificial recharge endeavours.

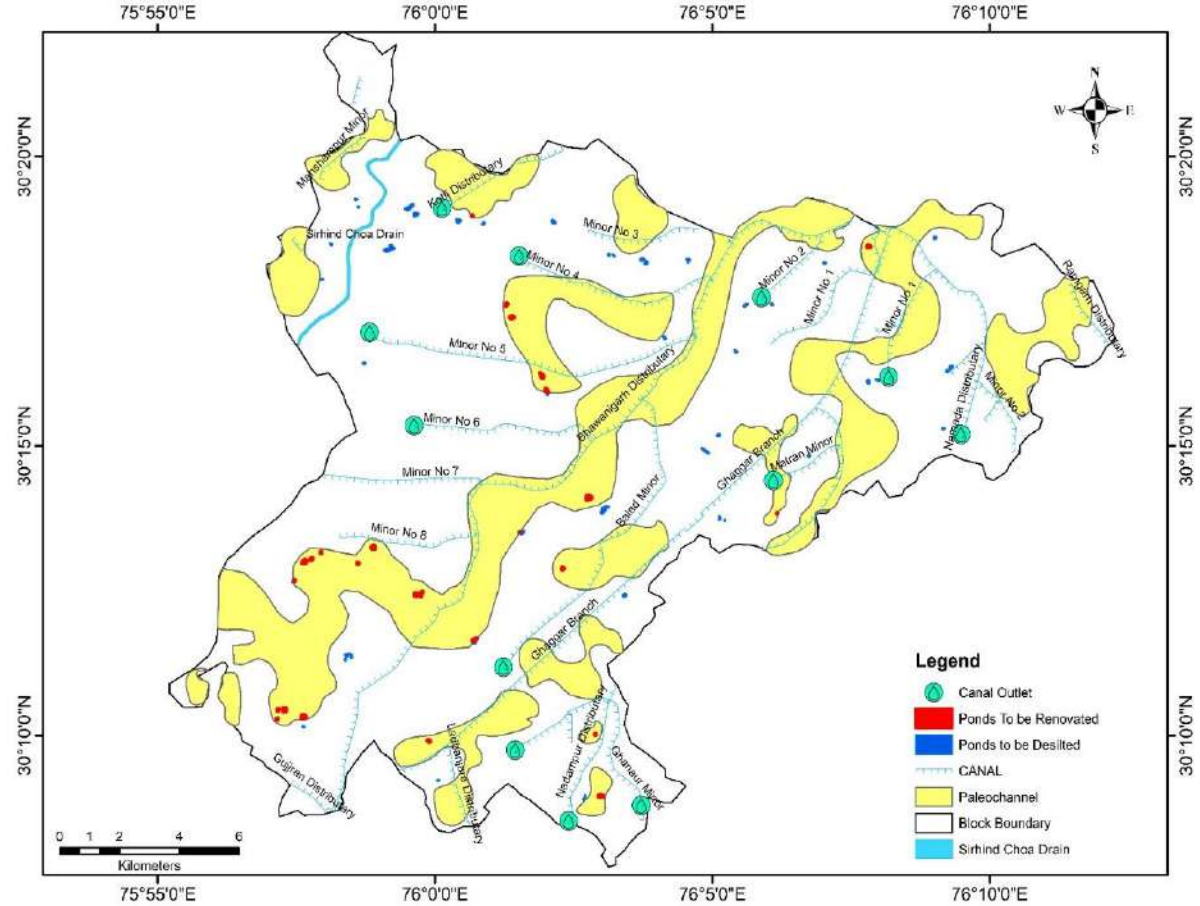


Figure 75 Artificial Recharge plan of Bhawanigarh Block, Sangrur District

V. **Reuse of waste water -** Bhawanigarh block boasts a total of 119 ponds, which are sustained by both rainfall and grey water from households. To repurpose this water for agricultural irrigation, there are two main methods of treatment available: the 3-pond system or the Thapar model. To further enhance the efficiency of water usage, the installation of a Solar panel system on these ponds can facilitate the lifting of treated water using solar energy to the fields, thereby contributing to the conservation of groundwater resources.

VI. **Construction of Injection well** – Through the construction of Injection wells at the outlet of the minor canal, a feasible solution emerges to effectively utilize the surplus canal water, which would otherwise be discharged into the rivers, for the purpose of recharging the groundwater. As a testament to the government's commitment towards enhancing water management and ensuring a sustainable water supply for the region, the construction of an Injection well has already commenced at Lehal Canal in the respective block. This initiative highlights the proactive measures taken to address water scarcity and signifies a step towards achieving long-term water resource sustainability.

VII. **Rain water Harvesting** - It is imperative to install rooftop rainwater harvesting and artificial recharge structures in all government buildings within the Bhawanigarh block. The collected rainwater can be utilized for either recharging groundwater or for sanitation purposes, thereby ensuring efficient water management and conservation.

9.3.2 Groundwater Quality Issue

Groundwater quality is primarily affected by the presence of Uranium in the shallow aquifer system. The analysis of samples collected from shallower aquifers has consistently revealed high levels of uranium, while samples from deeper aquifers have shown uranium levels that fall within the permissible limit. As mentioned in previous chapters, the wells drilled by CGWB tapping granular zones below the depth of 120 meters have remained uncontaminated by Uranium. Therefore, the Department of Water Supply & Sanitation should focus on tapping only the deeper aquifers when implementing drinking water supply schemes in rural areas. This will help ensure the provision of safe and uncontaminated drinking water to the communities.

9.4 Recommendations

1. Installation of AI/ Pump controller and Flow meter should be installed in the agricultural fields so that optimized groundwater can be withdrawn from the tube wells.
2. Agricultural seminars and workshops are to be organized regularly so that the farmers can be aware of the new varieties that can give the yield as well as conserve the groundwater.
3. To aware the public regarding the quality issue of groundwater, a mass awareness program has to be initiated on a large scale.
4. New Drinking water supply schemes should be done by tapping only the deeper Aquifers below 120 meters of depth.
5. Instead of the groundwater, the canal water should be supplied to the farmers for irrigation purposes thus decreasing groundwater withdrawal.
6. A good network of canal systems exists in the study area. Maximum canal water should be supplied for irrigation purposes which will ultimately recharge the ground water.
7. The defluoridation techniques either Nalgonda (or) Ion exchange technique should be undertaken in the case of fluoride-affected areas if the alternate water supply is not provided.
8. Before recharging the water into the aquifers, it is essential to conduct a thorough examination of the pond's water quality. This examination ensures that the water meets the standards set by the Central Pollution Control Board (CPCB) for the construction of recharge wells in village ponds, guaranteeing the proper quality of water.

Annexures

Annexure 1

Ground Water Quality monitoring stations established during pre-monsoon period (2023) in Bhawanigarh Block, Sangrur District

S. No	Unique ID	District	Block	Location	Source	Latitude	Longitude
1	1./23	Sangrur	Bhawanigarh	Badal Kalan	TW	30.2628	76.0906
2	2./23	Sangrur	Bhawanigarh	Bhawanigarh MC	TW	30.2632	76.0376
3	3./23	Sangrur	Bhawanigarh	Rampura	SB	30.2443	76.0243
4	197./23	Sangrur	Bhawanigarh	Harkishanpur	SB	30.274	75.9772
5	4./23	Sangrur	Bhawanigarh	Roshanwala	TW	30.2542	75.9884
6	5./23	Sangrur	Bhawanigarh	Rai singh wala	TW	30.2832	75.9945
7	6./23	Sangrur	Bhawanigarh	Kakra	SB	30.2907	76.0225
8	7./23	Sangrur	Bhawanigarh	Bhawanigarh MC 2	TW	30.2672	76.0398
9	8./23	Sangrur	Bhawanigarh	Nakta	SB	30.2764	76.1101
10	9./23	Sangrur	Bhawanigarh	Julan	SBB	30.2926	75.9647
11	10./23	Sangrur	Bhawanigarh	Julan	TW	30.2898	75.9636
12	11./23	Sangrur	Bhawanigarh	Santokhpur	TW	30.2982	75.9658
13	12./23	Sangrur	Bhawanigarh	Gahlian	SB	30.3155	75.9927
14	13./23	Sangrur	Bhawanigarh	Lakhewal	TW	30.2813	76.1747
15	14./23	Sangrur	Bhawanigarh	Bharu	SB	30.3161	76.1587
16	15./23	Sangrur	Bhawanigarh	Bimbri	SB	30.3072	76.131
17	16./23	Sangrur	Bhawanigarh	Aloarkh	SB	30.2846	76.0659
18	17./23	Sangrur	Bhawanigarh	Bhaktri	SB	30.3026	76.0753
19	18./23	Sangrur	Bhawanigarh	(Diyalgarh) Jolian	SB	30.3095	76.052
20	19./23	Sangrur	Bhawanigarh	Sakrondi	TW	30.3131	76.0142
21	196./23	Sangrur	Bhawanigarh	Bir Mahsampur	SB	30.3474	75.9798
22	20./23	Sangrur	Bhawanigarh	Meemsa	TW	30.368	75.9734
23	21./23	Sangrur	Bhawanigarh	Gharachon	SB	30.2167	75.963
24	22./23	Sangrur	Bhawanigarh	Sangheri	TW	30.1889	75.9655
25	23./23	Sangrur	Bhawanigarh	Nagra	SB	30.1706	75.9581
26	24./23	Sangrur	Bhawanigarh	Gujran	SB	30.1438	75.9651
27	25./23	Sangrur	Bhawanigarh	Bijalpur	SB	30.1483	76.0008
28	159./23	Sangrur	Bhawanigarh	Basiarkh	SB	30.1474	76.0441
29	26./23	Sangrur	Bhawanigarh	Naraingarh	SB	30.1844	76.0409
30	27./23	Sangrur	Bhawanigarh	Nadempur	SB	30.2599	76.1232
31	28./23	Sangrur	Bhawanigarh	Munshiwala	SB	30.2528	76.1518
32	29./23	Sangrur	Bhawanigarh	Nadampur	TW	30.2508	76.1223
33	30./23	Sangrur	Bhawanigarh	Thaman Singh Wala	SB	30.2293	76.0862
34	31./23	Sangrur	Bhawanigarh	Bhatiwal Khurd	SB	30.2062	76.0574
35	188./23	Sangrur	Bhawanigarh	Balial	SB	30.2322	76.049
36	32./23	Sangrur	Bhawanigarh	Ratehgarh	SB	30.2254	76.0229
37	33./23	Sangrur	Bhawanigarh	Kapial	SB	30.1951	76.0089
38	34./23	Sangrur	Bhawanigarh	Akbarpur	SB	30.1652	76.002
39	35./23	Sangrur	Bhawanigarh	Batriana	SB	30.2046	75.9919
40	187./23	Sangrur	Bhawanigarh	Jhuneri	SB	30.2165	75.9775
41	36./23	Sangrur	Bhawanigarh	Fatehgarh Bhadson	SB	30.3277	76.0328
42	37./23	Sangrur	Bhawanigarh	Dittupur	SB	30.3321	75.9931
43	38./23	Sangrur	Bhawanigarh	Nandgarh	SB	30.3314	75.9739
44	39./23	Sangrur	Bhawanigarh	Kalajhar	SB	30.2709	76.1517
45	40./23	Sangrur	Bhawanigarh	Kheri Gilan 1	SB	30.2841	76.1575
46	41./23	Sangrur	Bhawanigarh	Kheri Gillan 2	TW	30.2909	76.1609
47	190./23	Sangrur	Bhawanigarh	Bhuraj	SB	30.2883	76.189

Annexure 2

Ground Water Level monitoring stations established in Bhawanigarh Block, Sangrur District

S. No	Unique Code	Location	Lattitude	Longitude
1	KW -1	Akbarpur	30.1652044	76.0020407
2	KW -2	Aloarkh	30.2846361	76.0659138
3	KW -3	Badal Kalan	30.2628	76.090559
4	KW -4	Balial	30.2321956	76.049039
5	KW -5	Basiarkh	30.1453501	76.0409444
6	KW -6	Batriana	30.2046418	75.9919298
7	KW -7	Bhaktri	30.3026043	76.0752566
8	KW -8	Bhuraj	30.2883289	76.1889682
9	KW -9	Bharu	30.316145	76.15869
10	KW -10	Bhatiwal Khurd	30.2061972	76.6574132
11	KW -11	Bhawanigarh MC	30.26318	76.03763
12	KW -12	Bhawanigarh MC 2	30.2672	7.0398
13	KW -13	Bijalpur	30.1483374	76.0007884
14	KW -14	Bimbri	30.3040864	76.1323787
15	KW -15	Dittupur	30.3321435	75.9931367
16	KW -16	Fatehgarh Bhadson	30.3276892	76.0327576
17	KW -17	Gahlian	30.3160456	75.9954859
18	KW -18	Gharachon	30.2166696	75.9630359
19	KW -19	Gujran	30.12382	75.9751009
20	KW -20	Harkishanpur	30.2565	75.9737
21	KW -21	Jhaneri	30.2169094	75.9772597
22	KW -22	Jolian	30.3094924	76.0520374
23	KW -23	Julan	30.28982	75.9636
24	KW -24	Kakra	30.2907	76.0225
25	KW -25	Kalajhar	30.2713792	76.1520165
26	KW -26	Kapial	30.1950991	76.00886405
27	KW -27	Kheri Gilan 1	30.2841344	76.1575273
28	KW -28	Kheri Gillan 2	30.2913537	76.1597267
29	KW -29	Lakhewal	30.281263	76.174673
30	KW -30	Majji	30.2897	76.0965
31	KW -31	Meemsa	30.3679775	75.9734162
32	KW -32	Mehsampur	30.3448269	75.9805462
33	KW -33	Munshiwala	30.2500576	76.1479712
34	KW -34	Nadampur	30.2507832	76.1222616
35	KW -35	Nadempur	30.2599033	76.1232299
36	KW -36	Nagra	30.170626	75.9581346
37	KW -37	Nakta	30.2767	76.1067
38	KW -38	Nandgarh	30.3313934	75.9738775
39	KW -39	Naraingarh	30.1843985	76.0408904
40	KW -40	Rai singh wala	30.2832	75.9945
41	KW -41	Rampura	30.24804	76.02276
42	KW -42	Ratehgarh	30.2254303	76.0229481
43	KW -43	Roshanwala	30.2642	75.9884
44	KW -44	Sakrondi	30.3130983	76.0141538
45	KW -45	Sangheri	30.1889366	75.9655009
46	KW -46	Santokhpur	30.2982	75.9658
47	KW -47	Thaman Singh Wala	30.2292679	76.086187
48	KW -48	Ghanaur Jattan	30.17169158	76.0185766

Annexure 3

Ground Water Quality monitoring stations established during post-monsoon period (2023) in Bhawanigarh Block, Sangrur District

S.no	Unique Id	Site name	Latitude	Longitude
1	PM/1	Akbarpur	30.1652044	76.0020407
2	PM/2	Akbarpur - 1	30.1644826	76.006365
3	PM/3	Aloarkh	30.2846361	76.0659138
4	PM/4	Aloarkh WS	30.28493	76.06377
5	PM/5	Bakhtri	30.3026043	76.0752566
6	PM/6	Balad Kalan - 1	30.26432	76.10252
7	PM/7	Balad Kalan Main	30.2628	76.090559
8	PM/8	Balial	30.2321956	76.049039
9	PM/9	Basiarkh	30.1453501	76.0409444
10	PM/10	Batriana	30.2046418	75.9919298
11	PM/11	Bharo	30.316145	76.15869
12	PM/12	Bhatiwal Khurd	30.2061972	76.6574132
13	PM/13	Bhiwanigarh 1	30.26318	76.03763
14	PM/14	Bhiwanigarh 2	30.2672	7.0398
15	PM/15	Bhiwanigarh 3	30.2888393	76.0270489
16	PM/16	Bhiwanigarh 4	30.2888393	76.0270489
17	PM/17	Bijalpur	30.1483374	76.0007884
18	PM/18	Dialgarh	30.3094924	76.0520374
19	PM/19	Dittupur	30.332143	75.993137
20	PM/20	F. Bhadson	30.3276892	76.0327576
21	PM/21	F. Bhadson - 1	30.32758	76.03306
22	PM/22	Gehlan - 1	30.31559	75.99267
23	PM/23	Gehlan Main	30.3160456	75.9954859
24	PM/24	Ghanaur Jattan	30.1769158	76.0185766
25	PM/25	Gharacho	30.2157803	75.9640344
26	PM/26	GSW - 1	30.3072515	75.9841654
27	PM/27	GSW - 2	30.3072515	75.9841654
28	PM/28	Gujran Main	30.15	75.962
29	PM/29	Harkishanpura	30.2565	75.978
30	PM/30	Jhuneri	30.2169094	75.9772597
31	PM/31	Jhuneri - 1	30.22129	75.9811
32	PM/32	Jolian	30.32378	76.0498816
33	PM/33	Julan - 1	30.2913	75.96677
34	PM/34	Julan Main	30.28982	75.9636
35	PM/35	Kahangarh	30.16799	76.04666
36	PM/36	Kahangarh	30.16799	76.04666
37	PM/37	Kahangarh	30.16799	76.04666
38	PM/38	Kakra -1	30.29094	76.02197
39	PM/39	Kakra -2	30.29101	76.02283
40	PM/40	Kalajhar	30.2713792	76.1520165
41	PM/41	Kapial	30.1950991	76.00886405
42	PM/42	Kapial - WS	30.1972617	76.0142558
43	PM/43	Kheri Gillan 1	30.29562	76.16204
44	PM/44	Kheri Gillan 2	30.29987	76.16019
45	PM/45	Kheri Gillan 3	30.29987	76.16019
46	PM/46	Kheri Gillan 4	30.2863061	76.1577633
47	PM/47	Kheri Gillan Main	30.2841344	76.1575273
48	PM/48	Lakhewal	30.281263	76.174673
49	PM/49	Lakhewal Main	30.281263	76.174673
50	PM/50	Majhi Main	30.29294	76.10032
51	PM/51	Majhi WS	30.29025	76.09896
52	PM/52	Meemsa	30.364	75.975
53	PM/53	Mehsampur - 1	30.3448269	75.9805462
54	PM/54	Mehsampur - 2	30.3465405	75.9800714
55	PM/55	Nadampur -3	30.2517726	76.1204209
56	PM/56	Nadampur -5	30.2609616	76.1229706
57	PM/57	Nadampur Main	30.2599033	76.1232299
58	PM/58	Nakta - 2	30.2762003	76.1103321
59	PM/59	Nakta - Deep	30.2769128	76.1145536
60	PM/60	Nakta Main	30.2767	76.1067
61	PM/61	Na0garh - 1	30.3313934	75.9738775
62	PM/62	Naraingarh	30.18386	76.0411
63	PM/63	Rai Singh Wala	30.2832	75.9945
64	PM/64	Rampura - 1	30.24738	76.02337
65	PM/65	Rampura - 2	30.24804	76.02276
66	PM/66	Ramura MAin	30.244282	76.024279
67	PM/67	Rethgarh	30.2254303	76.0229481
68	PM/68	Roshanwala - WS	30.2585	75.98777
69	PM/69	Sakrodi Main	30.3130983	76.0141538
70	PM/70	Sangheri Main	30.1889366	75.9655009
71	PM/71	Santokhpura - 1	30.29782	75.96655
72	PM/72	Santokhpura Main	30.2982	75.9658
73	PM/73	T. Singh Wala -1	30.23002	76.08691
74	PM/74	T. Singh Wala Main	30.2292679	76.086187

Annexure 4

Analytical Results of water samples collected during the Pre-monsoon period (2023) in

Bhawanigarh Block, Sangrur District

S. No	Unique ID	pH	EC in µS/cm at 25^0 C	CO_3	HCO_3	Cl	SO_4	NO_3	F	PO_4	Ca	Mg	Na	K	SiO_2	TH as $CaCO_3$
				(mg/l)												
1	1./23	7.41	902	0	554	13	52	15	0.32	0	51	38	116	7.41	22	284
2	2./23	8.07	651	0	326	19	60	4.07	0.50	0	24	19	103	4.22	18	137
3	3./23	7.40	1325	0	749	39	88	35	0.50	0	31	24	280	6.74	23	177
4	197./23	7.75	1416	0	565	58	250	16	0.22	0	35	81	180	8.23	23	422
5	4./23	8.18	630	0	282	6.45	130	0.28	0.60	0	12	7	148	2.56	16	59
6	5./23	7.75	700	0	348	19	108	3.54	0.40	0	27	17	134	3.98	18	137
7	6./23	7.14	1135	0	663	39	83	18	0.36	0	39	57	165	9.03	26	333
8	7./23	7.21	1187	0	565	65	88	70	0.25	0	75	50	139	9.2	25	392
9	8./23	7.10	1035	0	478	65	15	85	0.27	0	102	45	55	8.15	25	441
10	9./23	8.17	697	0	293	26	124	0.2	0.70	0	16	7	158	2.18	15	69
11	10./23	7.28	903	0	445	39	77	22	0.37	0	51	45	92	6.49	25	314
12	11./23	7.65	782	0	369	32	70	31	0.22	0	31	50	74	5.63	21	284
13	12./23	7.24	927	0	489	32	78	10	0.29	0	16	64	105	7.09	26	304
14	13./23	7.83	582	0	337	13	62	8.55	0.60	0	31	29	78	4.89	21	196
15	14./23	7.18	603	0	424	19	68	37	0.28	0	75	41	54	7.42	25	353
16	15./23	7.62	413	0	185	13	58	7.21	0.15	0	31	33	9.22	4.33	17	216
17	16./23	7.78	580	0	348	6.88	40	0.87	0.38	0	31	26	68	5.29	21	186
18	17./23	7.38	1120	0	619	28	90	27	0.35	0	39	45	172	7.45	25	284
19	18./23	7.85	650	0	315	21	50	30	0.38	0	31	26	82	5.49	20	186
20	19./23	7.76	713	0	380	14	68	10	0.22	0	27	33	93	5.04	21	206
21	196./23	7.57	1205	0	532	76	94	55	0.13	0	79	62	106	8.49	27	451
22	20./23	7.89	1055	0	587	28	115	20	0.45	0	39	38	182	8.56	23	255
23	21./23	7.87	627	0	348	6.88	68	0	0.50	0	55	2	101	4.53	19	147
24	22./23	7.89	610	0	326	14	58	3.69	0.70	0	20	24	93	4.68	19	147
25	23./23	7.82	632	0	337	21	50	2.91	0.75	0	24	21	97	5.28	23	147
26	24./23	7.39	1395	0	576	117	128	25	0.64	0	79	17	240	7.7	18	265
27	25./23	7.79	676	0	369	6.88	72	4.39	0.62	0	31	24	99	4.32	18	177
28	159./23	8.15	690	0	348	14	130	0	0.69	0	20	21	140	3.88	18	137
29	26./23	7.94	640	0	337	14	90	0	0.38	0	24	14	125	3.32	17	118
30	27./23	7.20	830	0	478	6.88	88	0.29	0.69	0	55	48	72	8.0	19	333
31	28./23	7.78	588	0	348	14	35	0	0.37	0	27	24	79	5.88	20	167
32	29./23	7.30	853	0	434	28	55	23	0.71	0	47	57	49	15	24	353
33	30./23	7.38	1059	0	565	14	115	23	0.80	0	75	31	140	7.07	23	314
34	31./23	7.36	898	0	413	55	90	14	0.61	0	63	50	71	7.17	24	363
35	188./23	7.66	1044	0	467	62	78	35	0.46	0	59	45	111	8.22	24	333
36	32./23	7.30	931	0	445	34	80	37	0.66	0	8	64	110	7.46	24	284
37	33./23	7.40	1355	0	554	131	150	30	0.54	0	75	55	175	27	26	412
38	34./23	7.77	615	0	152	62	50	31	0.30	0	59	26	15	4.46	17	255
39	35./23	7.83	555	0	282	6.88	100	0	0.80	0	16	33	79	4.88	18	177
40	187./23	8.32	575	48	130	14	130	0	0.83	0	12	12	122	3.00	17	78
41	36./23	7.91	558	0	304	6.88	92	0	0.64	0	27	12	110	4.01	18	118
42	37./23	8.20	818	0	185	48	241.591	0	0.70	0	20	14	170	2.96	13	108
43	38./23	7.10	872	0	456	21	64	31	0.44	0	59	57	50	7.41	24	383
44	39./23	7.22	1228	0	684	41	82	23	0.57	0	39	55	182	9.07	26	324
45	40./23	7.18	1035	0	478	62	90	32	0.42	0	86	45	89	7.98	22	402
46	41./23	7.22	878	0	467	21	72	26	0.45	0	82	43	56	7.32	23	383
47	190./23	7.52	1213	0	665	62	32	30	0.55	0	79	26	176	7.69	23	304

Annexure 5

Water Level Monitoring Data of Key Well in Bhawanigarh Block, Sangrur District

S. No	Unique Code	Pre monsoon (mbgl)	November (mbgl)
1	KW -1	40.32	42.51
2	KW -2	42.6	45.35
3	KW -3	43.7	45.87
4	KW -4	43.29	45.37
5	KW -5	44.46	44.29
6	KW -6	48.53	49.13
7	KW -7	40.36	43.52
8	KW -8	40.59	41.31
9	KW -9	34.73	36.41
10	KW -10	43.27	43.11
11	KW -11	45.23	46.98
12	KW -12	44.45	46.32
13	KW -13	40.89	41.44
14	KW -14	33.92	35.85
15	KW -15	43.76	45.17
16	KW -16	44.78	44.86
17	KW -17	42.57	44.85
18	KW -18	45.98	46.29
19	KW -19	38.32	40.1
20	KW -20	42.48	43.94
21	KW -21	43.06	44.74
22	KW -22	43.5	43.52
23	KW -23	42.75	45.4
24	KW -24	42.99	45
25	KW -25	37.96	40.23
26	KW -26	43.6	45.79
27	KW -27	37.49	39.23
28	KW -28	36.82	38.86
29	KW -29	36.97	39.38
30	KW -30	36.64	39.76
31	KW -31	39.9	41.75
32	KW -32	43.69	45.35
33	KW -33	40.56	41.46
34	KW -34	37.67	39.57
35	KW -35	37.71	39.19
36	KW -36	46.56	47.23
37	KW -37	37.21	39.25
38	KW -38	44.42	45.27
39	KW -39	44.75	45.98
40	KW -40	42.85	44.42
41	KW -41	43	45.31
42	KW -42	47.96	48.26
43	KW -43	42.29	44.86
44	KW -44	42.63	44.69
45	KW -45	45.91	46.1
46	KW -46	42.83	44.74
47	KW -47	39.19	43.11
48	KW -48	41.78	42.66

Annexure 6

Analytical Results of water samples collected during the Post-monsoon period (2023) in Bhawanigarh Block, Sangrur District

S.no	Unique Id	pH	EC in µS/cm at 25^0 C	TDS	TH as $CaCO_3$	Ca	Mg	Fe	F	NO_3	Cl	SO_4
				(mg/l)								
1	PM/1	7.98	492	314.88	257	49	32	0.006503	0.30	20	48	58
2	PM/2	8.13	748	478.72	162	27	23	0.011	0.82	3.5	20	70
3	PM/3	8.28	538	344.32	200	30	30	0.022498	0.75	0	7	18
4	PM/4	7.83	898	574.72	266	49	35	0.059806	0.77	19	34	42
5	PM/5	8.02	546	349.44	219	27	37	0.016809	0.47	0.27	7	15
6	PM/6	8.3	598	382.72	247	42	35	0.005056	0.67	6.6	20	28
7	PM/7	8.22	746	477.44	266	49	35	0.003332	0.71	9.6	27	55
8	PM/8	7.83	671	429.44	257	42	37	0.024	0.56	23	20	8
9	PM/9	8.11	657	420.48	143	23	21	0.050158	0.70	0	14	40
10	PM/10	8.07	523	334.72	181	8	39	0.005	0.75	0	14	12
11	PM/11	7.57	820	524.8	352	80	37	0.012216	0.50	42	14	30
12	PM/12	7.83	767	490.88	285	46	42	0.012	0.74	5	34	12
13	PM/13	8.28	688	440.32	143	34	14	0.008937	0.85	3.2	27	82
14	PM/14	8.4	1044	668.16	361	46	60	0.009897	0.61	50	61	65
15	PM/15	7.46	1461	935.04	456	84	60	0.033874	0.49	54	129	10
16	PM/16	7.72	987	631.68	380	57	58	0.012048	0.52	38	48	20
17	PM/17	8.08	642	410.88	200	30	30	0.372978	0.61	0	14	30
18	PM/18	8.26	617	394.88	200	27	32		0.62	28	27	42
19	PM/19	8.48	778	497.92	133	23	18	0.041434	0.67	0	41	220
20	PM/20	8.1	520	332.8	143	23	21	0.033288	0.60	0	7	42
21	PM/21	8.22	556	355.84	114	27	12	0.011319	0.59	0	7	45
22	PM/22	7.44	865	553.6	124	15	21	0.031391	0.70	0	68	45
23	PM/23	7.59	950	608	323	69	37	0.02162	0.62	1	14	75
24	PM/24	8.11	694	444.16	285	46	42	0.017	0.66	14	14	0
25	PM/25	8.08	590	377.6	143	23	21	0.012062	0.72	0	7	20
26	PM/26	7.92	900	576	238	42	32	0.028526	0.58	13	34	72
27	PM/27	7.86	892	570.88	209	38	28	0.004013	0.68	14	34	0
28	PM/28	7.77	1331	851.84	285	46	42	0.115444	0.75	24	109	0
29	PM/29	7.48	2580	1651.2	513	72	81	0.006041	0.45	30	197	242
30	PM/30	8.22	589	376.96	171	19	30	0.004	0.82	1.3	13.61	72
31	PM/31	7.88	1794	1148.16	124	27	14	0.008	1.60	22	41	0
32	PM/32	8.15	592	378.88	171	30	23	0.007306	0.52	0	13.61	58
33	PM/33	7.74	911	583.04	333	76	35	0.010687	0.51	24	41	20
34	PM/34	8.4	688	440.32	114	11	21	0.016258	0.90	0.18	20	145
35	PM/35	7.89	646	413.44	219	34	32	0.009	0.74	2	14	20
36	PM/36	8.35	570	364.8	190	30	28		0.77	0	7	0
37	PM/37	8.11	636	407.04	171	15	32		0.80	4.2	20	0
38	PM/38	7.71	1150	736	361	61	51	0.005705	0.58	19	54	48
39	PM/39	7.58	1126	720.64	323	61	42	0.008874	0.58	20	48	30
40	PM/40	7.66	1158	741.12	380	65	53	0.010339	0.53	18	41	52
41	PM/41	7.15	1234	789.76	390	84	44	0.018	0.54	28	109	25
42	PM/42	8.10	602	385.28	181	23	30	0.002	0.70	1.4	13.61	15
43	PM/43	7.94	674	431.36	266	27	49	0.017582	0.52	1.89	14	18
44	PM/44	7.76	856	547.84	390	80	46	0.00873	0.44	32	20	15
45	PM/45	8.13	580	371.2	200	27	32	0.013502	0.69	3.2	14	12
46	PM/46	8.02	648	414.72	257	46	35	0.018347	0.69	15	14	42
47	PM/47	7.65	878	561.92	371	69	49	0.011382	0.45	20	34	58
48	PM/48	7.97	610	390.4	247	30	42	0.017537	0.75	8.32	7	80
49	PM/49	7.67	750	480	295	76	25		0.65	10	34	25
50	PM/50	7.66	1132	724.48	314	84	25	0.023112	0.51	20	68	0
51	PM/51	8.37	567	362.88	133	27	16	0.018204	0.70	0.95	13.61	42
52	PM/52	8.12	876	560.64	247	34	39	0.004602	0.68	14	14	50
53	PM/53	7.7	840	537.6	361	72	44	0.008792	0.47	23	27	17
54	PM/54	8.28	532	340.48	152	30	18	0.006401	0.60	0	14	60
55	PM/55	7.87	586	375.04	266	57	30	0.009184	0.65	7.3	14	35
56	PM/56	7.60	1005	643.2	485	91	62	0.030188	0.53	27	6.81	35
57	PM/57	7.58	850	544	399	65	58	0.007897	0.61	2.3	14	60
58	PM/58	7.64	902	577.28	314	99	16	0.009808	0.43	38	34	5
59	PM/59	7.8	576	368.64	257	46	35	0.013	0.55	16	7	30
60	PM/60	8.6	590	377.6	143	11	28	0.02389	0.88	0.34	14	40
61	PM/61	8.37	803	513.92	390	107	30	0.006927	0.46	31	20	0
62	PM/62	8.09	643	411.52	95	23	9	0.006	0.90	0	14	0
63	PM/63	7.97	685	438.4	143	23	21	0.003	0.64	3.8	20	65
64	PM/64	8.12	542	346.88	181	30	25	0.003091	0.71	0	13.61	12
65	PM/65	8.28	550	352	152	23	23	0.008228	0.72	1.5	14	0
66	PM/66	7.7	1532	980.48	190	30	28	0.012078	0.72	30	54	32
67	PM/67	7.95	780	499.2	276	34	46	0.003	0.60	21	27	0
68	PM/68	7.48	2150	1376	333	61	44	0.005327	0.40	32	211	15
69	PM/69	7.93	658	421.12	181	27	28	0.042284	0.65	0	14	36
70	PM/70	8.11	589	376.96	152	27	21	0.010147	0.75	6.5	14	5
71	PM/71	7.64	1088	696.32	314	80	28	0.014212	0.50	52	68	92
72	PM/72	7.94	723	462.72	257	42	37	0.011003	0.55	19	27	60
73	PM/73	8.48	592	378.88	95	11	16	0.015751	1.10	0	7	108
74	PM/74	7.92	978	625.92	323	57	44	0.003495	0.78	24	14	45

Annexure 7

Suggestion made by the National Level Expert Committee (NLEC) for the NWR Chandigarh

Study: Water stressed Area of Bhiwanigarh Block , Sangrur District, Punjab

Comments of NLEC:

- Aquifer parameters like specific yield values may be taken from NAQUIM studies.
- It was suggested that proper quality of water as per CPCB standards may be ensured for construction of recharge wells and pits in village ponds.
- Ground water quality of paleo-channels may also be studied.
- It was suggested that drilling of abstraction structures being used for drinking water, may be recommended on the concave part of meandering river/paleochannels.
- Uranium is also reported in fly ash from the thermal plants. It was suggested that the aspect of presence of uranium because of thermal plants may be explored.
- It was suggested that the resources estimation may be revised using parameters refined from NAQUIM studies.

Annexure 8

Geophysical survey report of Bhawanigarh Block, Sangrur District, Punjab

The Electrical Resistivity Survey was undertaken in Bhawanigarh block of Distt. Sangrur Punjab under NAQUIM 2 during the AAP 2022-23. The objective of the study was to understand the characteristics of sub-surface layers. 40 numbers of VES were conducted with a maximum current electrode separation of 700 meters. CRM 500 Resistivity Meter was used for data acquisition**.**

Electrical Resistivity Survey Results:

The study area is Bhawanigarh block of Distt.Sangrur Punjab shown in Figure 1. 40 numbers of VES were conducted in the study covering an area of 314 Sq.km. The locations of VES are shown in Figure 2.

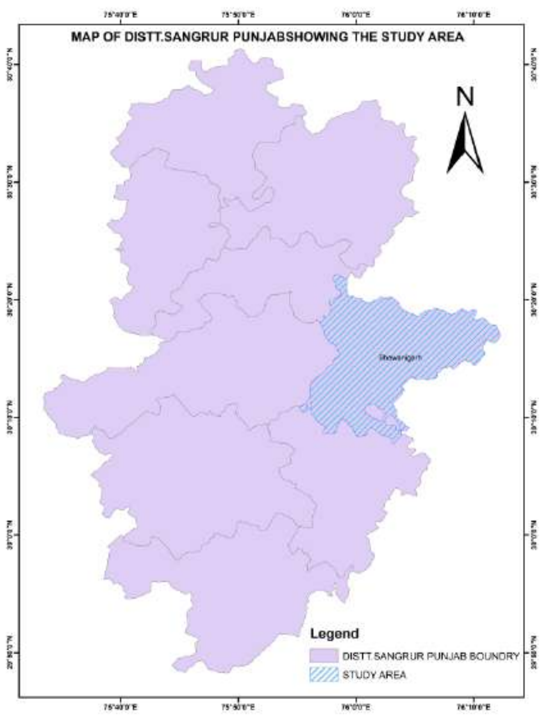


Figure 1:Map of Sangrur showing the study area

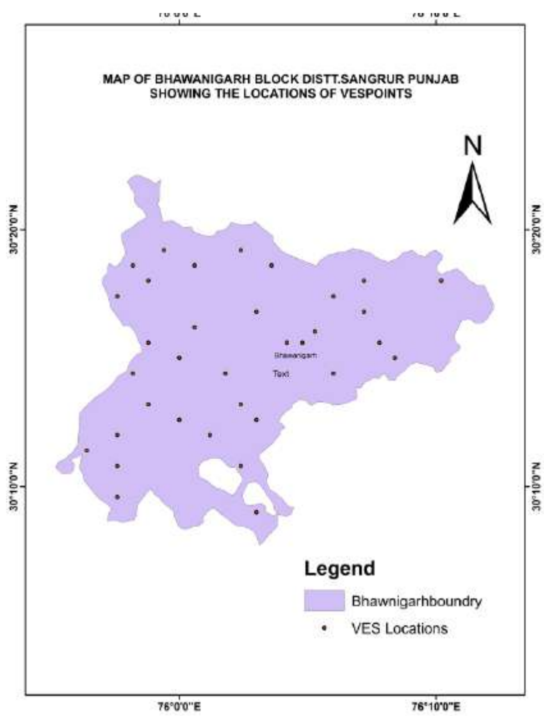


Figure 2:Map of Bhawanigarh block,Distt. Sangrur

Showing the location of VES points.

On the basis of results of geophysical electrical Resistivity well logs, the resistivity values were calibrated for best possible results of Electrical Resistivity Survey.The calibrated resistivity values are given below**:**

Resistivity Values	**Probable Lithology**
< 15 Ohm m	Clay
15 to 25 Ohm m	Fine Sand
25 to 35 Ohm m	Fine to Medium sand
35 to 50 Ohm m	Medium to Coarse sand
50 to 100 Ohm m	Coarse sand with gravels
>100 Ohm m	Unsaturated sand(Coarse)

Electrical resistivity is a geophysical method commonly used for identifying and characterizing aquifers, which are subsurface formations that contain water and can supply water wells. The electrical resistivity of different geological materials varies, and this variation can be exploited to delineate and understand the characteristics of aquifers. electrical resistivity is a valuable tool for aquifer identification, it is often used in conjunction with other geophysical methods and hydrogeological techniques for a comprehensive understanding of subsurface conditions.

In the study area(Bhawanigarh Block),”K” type of VES curves were obtained.The K curve is characterized by a nearly horizontal segment at the beginning, followed by a smooth, continuous increase in apparent resistivity with increasing electrode spacing. This type of curve is often associated with a homogeneous subsurface with a gradual increase in resistivity with depth. The different types of VES curves, including K, are useful for interpreting subsurface geology and identifying potential targets such as aquifers, bedrock, or geological structures.

In the study area,second identified geo electric layer is having high resistivity value in the ranges of 200 to 400 Ohm m with thickness of 3 to 45 meters in general. The high resistivity value indicates the unsaturated zone occupied with coarser sediments and they are best suited for Artificial Recharge. At Channo VES location, second layer is 40 meters thick with resistivity value of 200 Ohm m .Similarly at Nurpur,Turi,Majri,Musnshiwala,Rampur,Baldklana,Batial,Naraingarh and Sangheri VES locations, second layer is having high resistivity values with thickness in between 3 to 45 meters indicating the presence of unsaturated layer.In some of the VES locations like Bibri,Phumanwal,Rajpura,Bakhopir,Nadampur, Basiarkh,Nagra and Sujuma, the second identified sub surface layer is having very high resistivity value of the order of 400 and above Ohm m .This indicates the presence of river deposits in the form of coarse sand with gravels and in turn indicates the traces of paleo channels. The map showing the top and bottom of unsaturated aquifer are shown in figure 3 and 4.

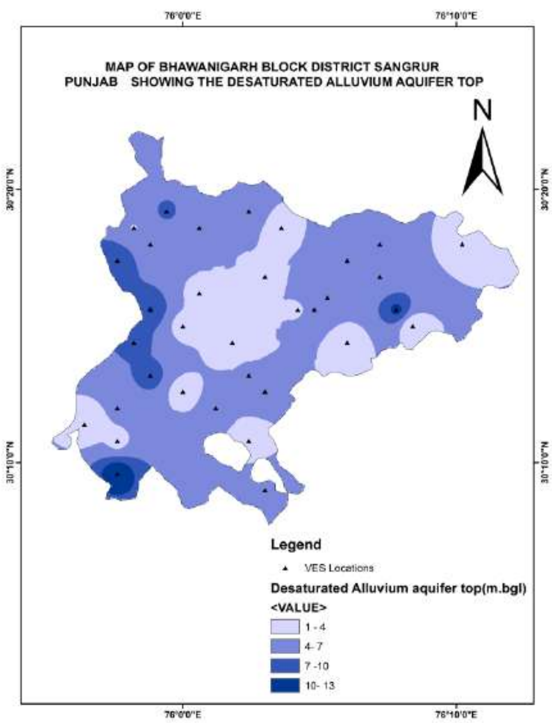


Figure 3: Map of Bhawanigarh block showing the desaturated aquifer top

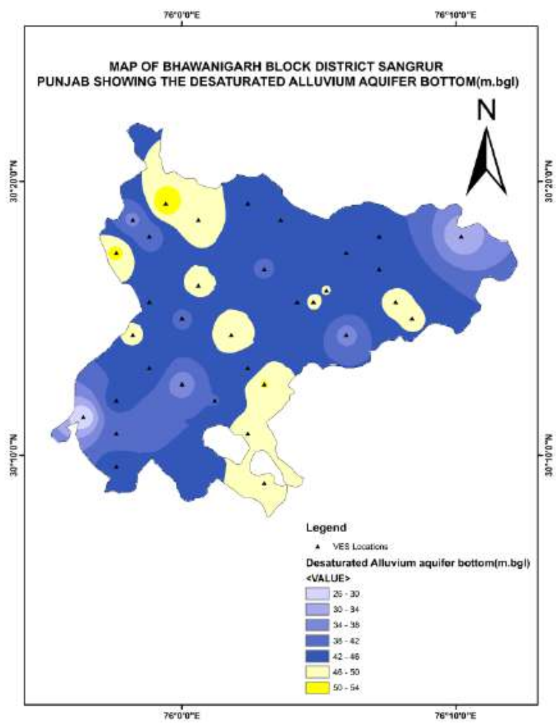


Figure 4: Map of Bhawanigarh block showing the desaturated aquifer bottom

In the study area, third identified sub surface layer is having moderate resistivity value lying in between 50 to 100 Ohm m with thickness in between 100 to 150 meters indicative of saturated coarse sand which indicates the first aquifer group. At Bibri, the third sub surface layer is having a moderate resistivity value of 55.3 Ohm m with thickness of 119 meters.

Similarly at Channa VES location, third layer is 110 meters thick with resistivity of 61.70 Ohm m. Similarly at Nurpur ,thickness of third layer is 102 meters with resistivity value of 90 Ohm m. Similar type of values are obtained for other VES location of the study area except at Phumanwal where fourth layer represents first aquifer group. At this location, fourth layer is 121 meters thick with resistivity value of 75 Ohm m. These values are indicative of presence of coarser sediments and form the first aquifer group. The moderate resistivity value indicates the presence of saturated coarse sand and this is the first aquifer group present in the study area. The third layer is followed by fourth geo electric layer having comparatively low resistivity values which are in general around 20 to 30 Ohm m indicating the presence of finer sediments (Fine sand) at deeper depth ranges(>100 meters)At Channa, it is 21 Ohm m ,at Nurpur 25 Ohm m ,at Bibri 22 Ohm m and similarly at other VES locations of the study area. This indicates that the first aquifer group are separated from second aquifer group by thick layer consisting of finer sediments. The map showing the top and bottom of the first aquifer group are shown in Figure 5 and 6.

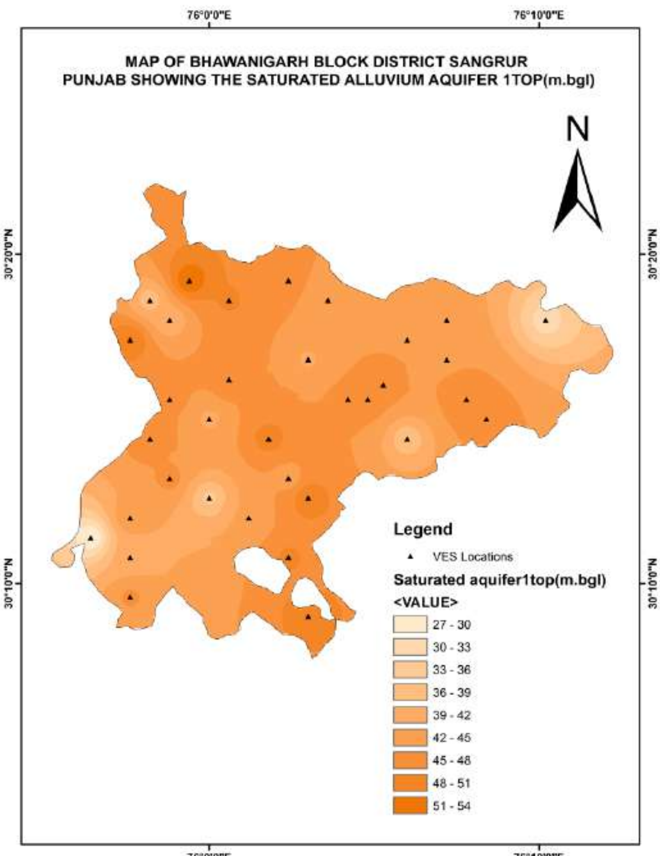


Figure 5:Map of Bhawanigarh block,Distt. Sangrur showing the saturated Aquifer top

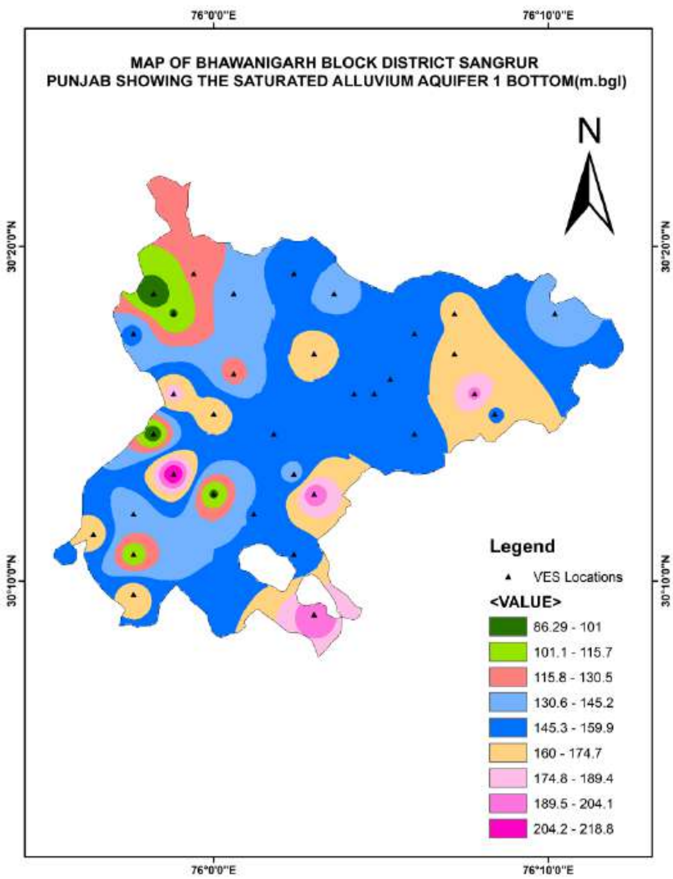


Figure 6:Map of Bhawanigarh block,Distt. Sangrur showing the saturated Aquifer bottom

To understand the aquifer disposition and aquifer geometry two geo electrical sections were prepared shown in Figures 7 and 8.

<u>Geoelectric section AA’</u>

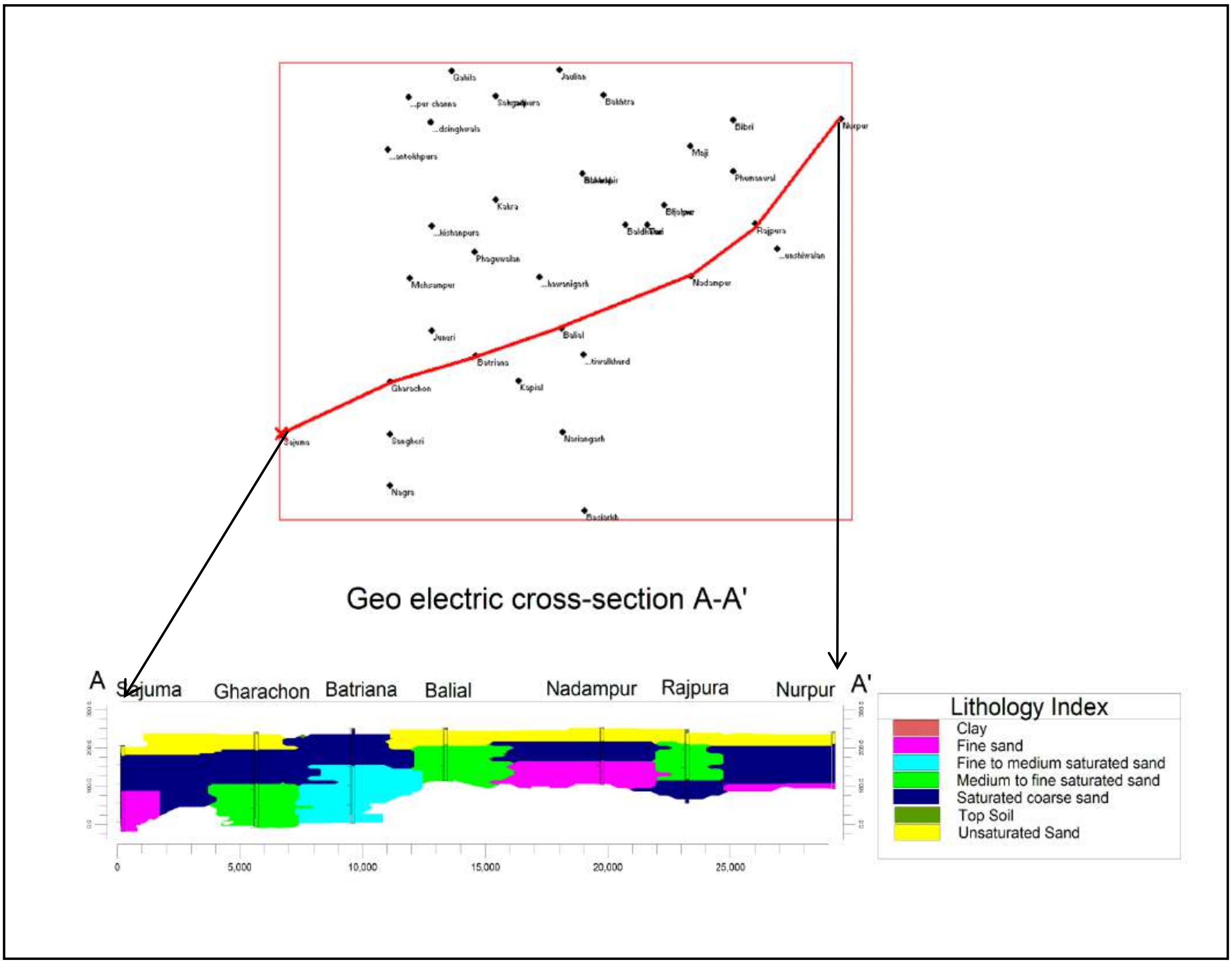


Figure 7: Geo electric section AA’

The Geo electrical cross-section A-A’ runs in the SW-NE direction. This section starts from the Sajuma VES location and finally terminates at the Nurpur VES location. This section is 28 Km long. Seven numbers of VES locations fall over this section. A thick layer of unsaturated sand is almost uniformly distributed over the entire section except at Batriana.

Geo electric section BB’

Another section BB’ was also prepared running in NW-SE direction. This section is 13 km long and six numbers of VES locations falls over this section. In this section also thick layer of unsaturated sediments is uniformly distributed. Last layer is occupied with finer sediments. This section is shown below:

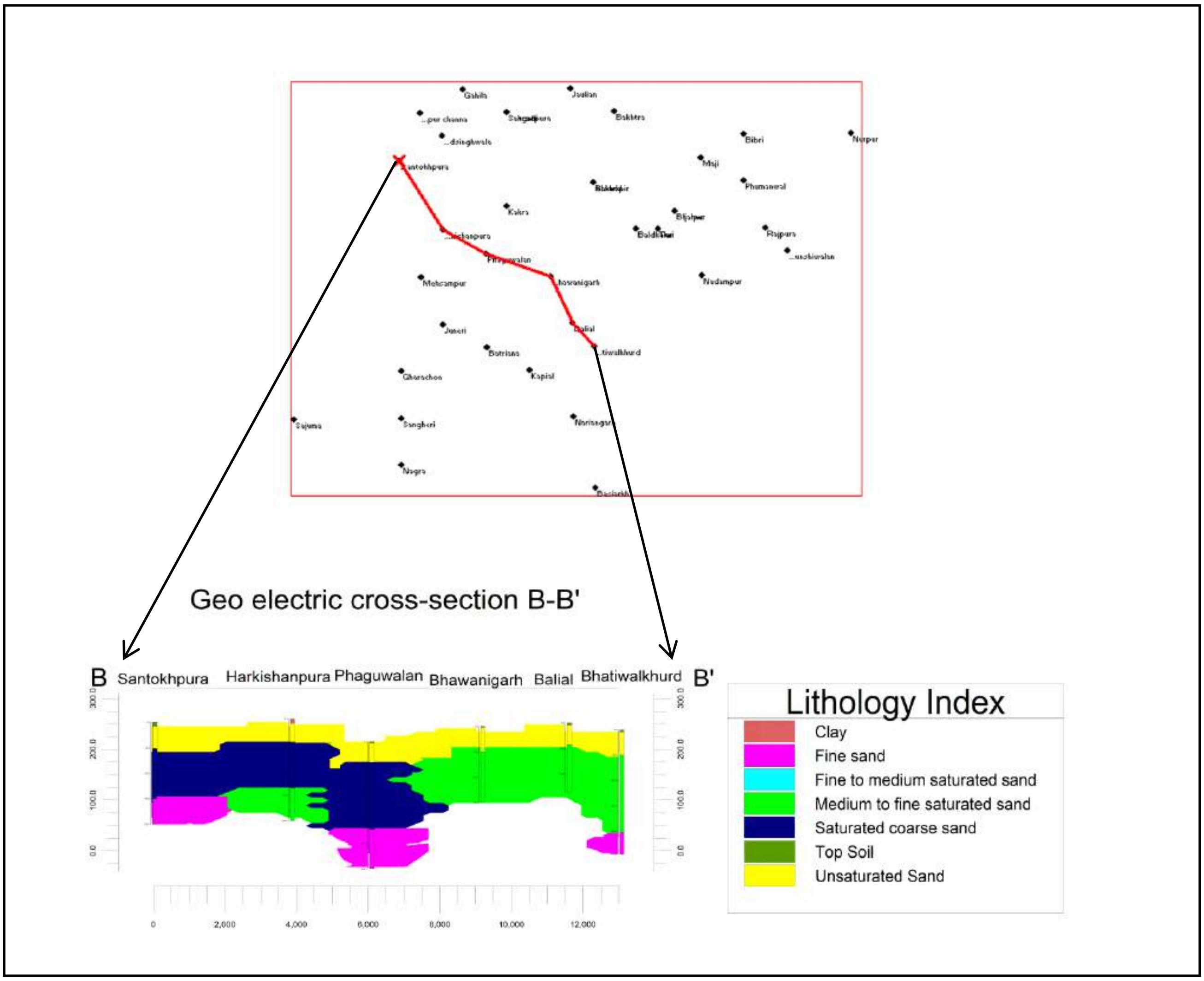


Figure 8: Geo electric section BB’

The aquifer geometry is shown as a fence diagram in Figure 9.

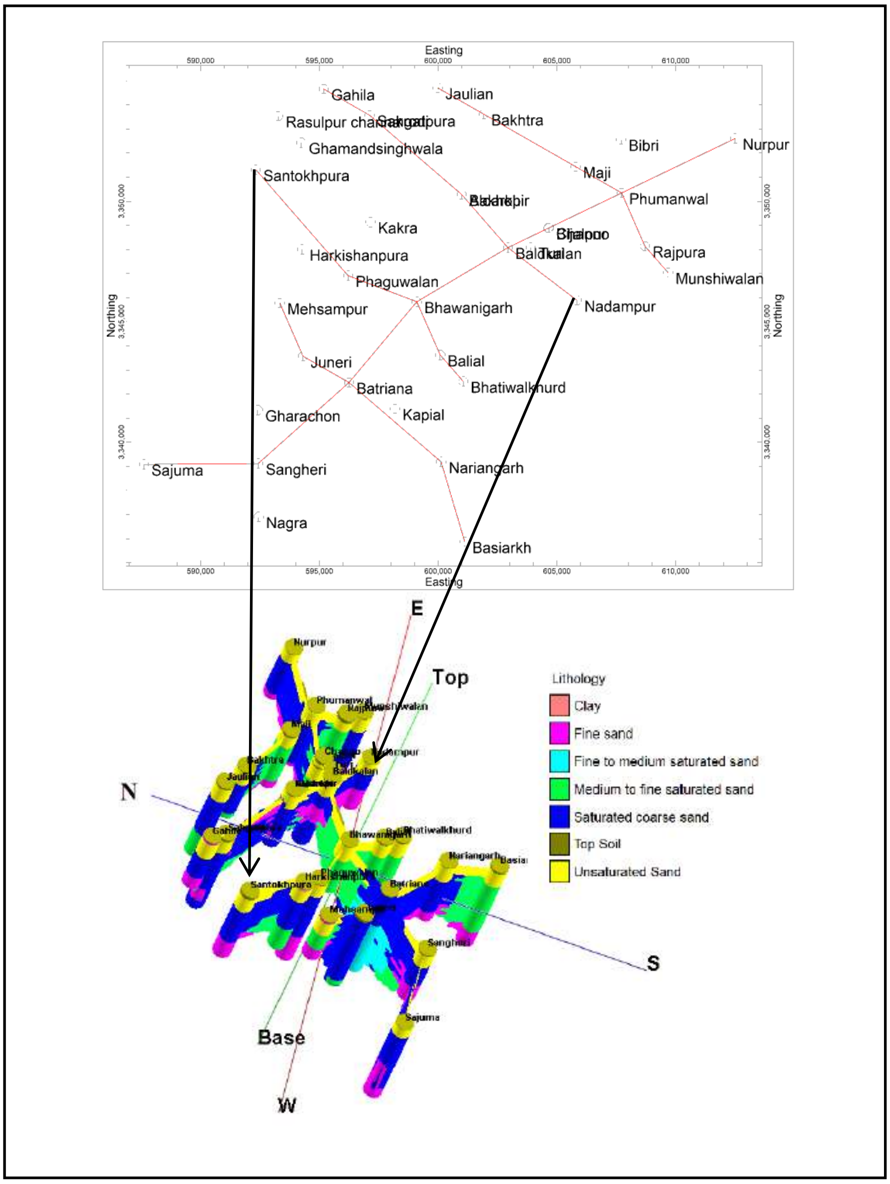


Figure 9:Fence Diagram of the study area

Conclusions:

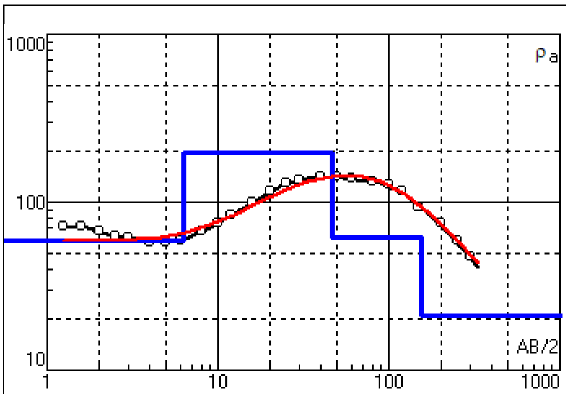
On the basis of geophysical studies taken up in Bhawanigarh block of Sangrur district Punjab, following conclusions are drawn:

1.The thickness of unsaturated aquifer in Sangrur block varies in between 10 to 45 meters and it is occupied with coarser sediments as high resistivity values are obtained for this zone. Therefore suitable artificial methods should be adopted to recharge this zone.

2.At some of the VES locations, high to very high resistivity values are obtained for second sub surface layer(>400 Ohm m).High resistivity values are indicative of presence of the paleo channels.

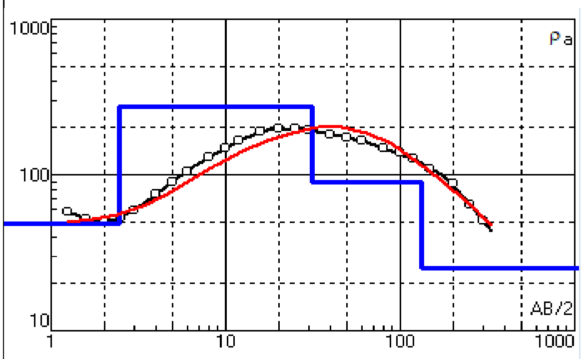
3.Saturated Aquifer is in between 45 to 150 meters. The average true resistivyt of this aquifer system is 60 Ohm m which indicates that the quality of ground water is freshand the aquifer system is occupied with coarser sediments.

The VES curves of the study area along with results are shown below:



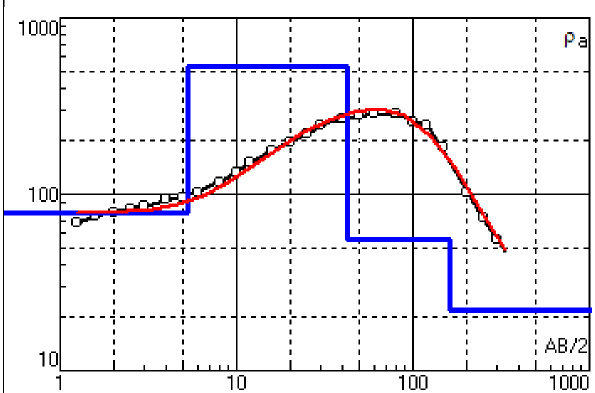
Chano

N	ρ	h	d	Alt
1	59.1	6.31	6.31	-6.31
2	197	40.1	46.4	-46.42
3	61.7	110	156	-156
4	21.1			



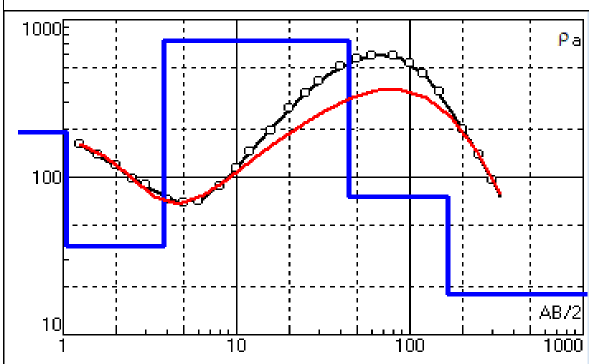
Nurpur

N	ρ	h	d	Alt
1	48.5	2.46	2.46	-2.457
2	274	28.8	31.3	-31.28
3	89.6	102	133	-133
4	25.1			



Bibri

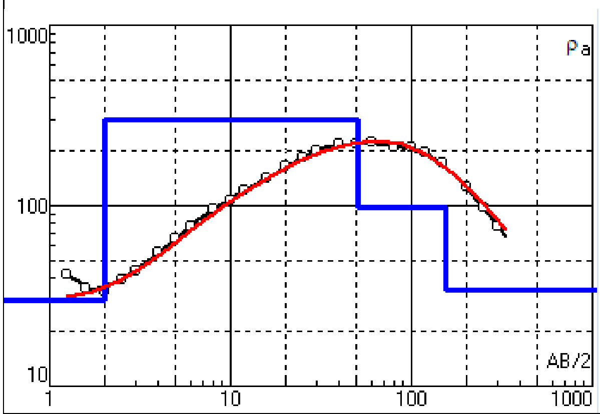
N	ρ	h	d	Alt
1	78.6	5.29	5.29	-5.294
2	529	37.2	42.5	-42.52
3	55.3	119	162	-162
4	22			



Phumanwal

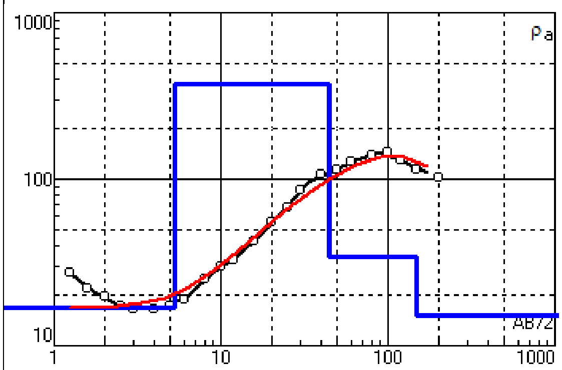
N	ρ	h	d	Alt
1	195	1.05	1.05	-1.054
2	36.5	2.76	3.81	-3.81
3	736	40.6	44.4	-44.43
4	75.2	121	166	-165.6
5	18.1			

Turi



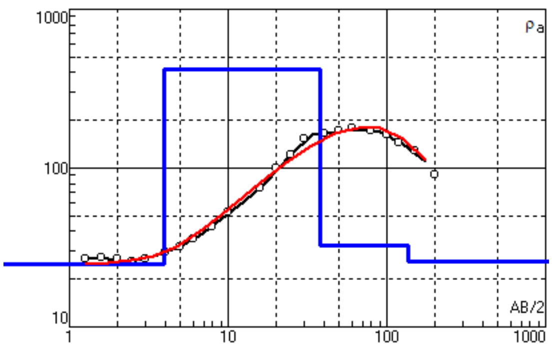
N	ρ	h	d	Alt
1	30	2	2	-2
2	300	48.7	50.7	-50.67
3	97.8	104	155	-155.1
4	34.1			

Majhi



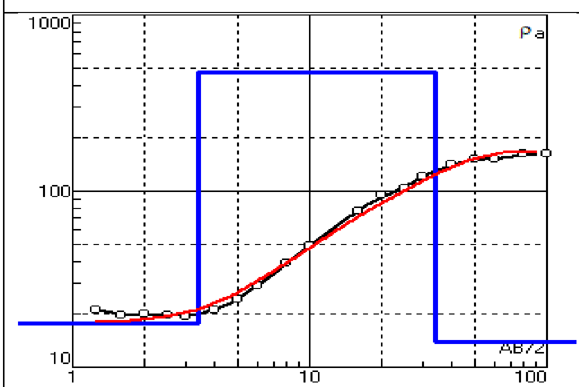
N	ρ	h	d	Alt
1	16.9	5.29	5.29	-5.294
2	373	39.1	44.4	-44.43
3	34.1	104	148	-148.4
4	15.2			

Balial

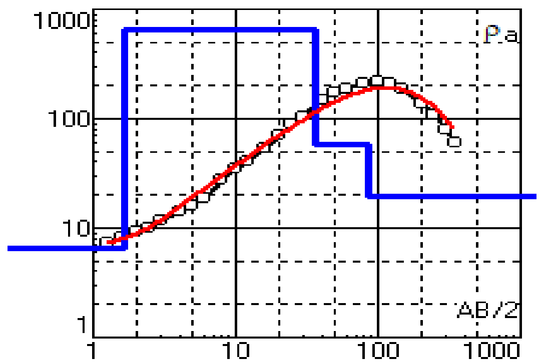


N	ρ	h	d	Alt
1	24.8	3.95	3.95	-3.95
2	419	34.1	38	-38.01
3	32.6	98.3	136	-136.3
4	25.8			

Bald Kalan

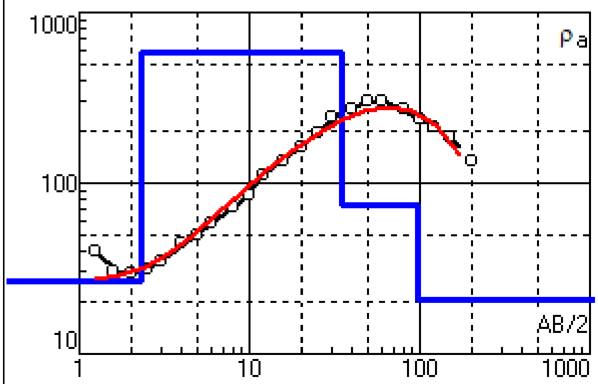


N	ρ	h	d	Alt
1	17.8	3.39	3.39	-3.391
2	472	30.5	33.9	-33.91
3	13.9			



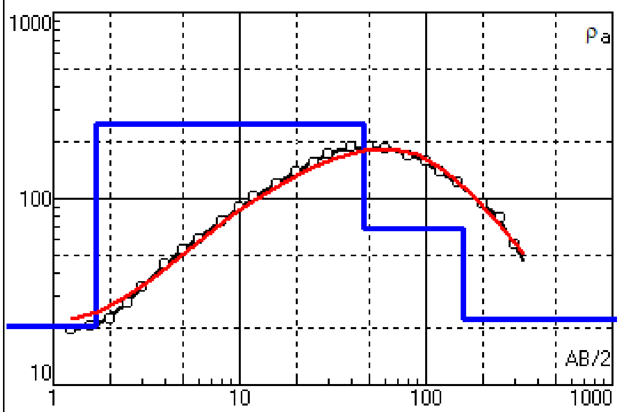
Nadampur

N	ρ	h	d	Alt
1	6.51	1.66	1.66	-1.661
2	651	34.6	36.3	-36.25
3	57.9	49.3	85.5	-85.55
4	19.4			



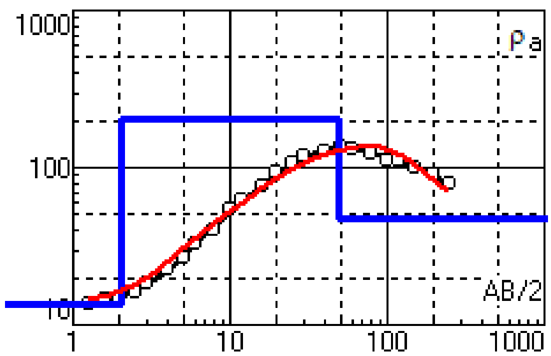
Batriana

N	ρ	h	d	Alt
1	26.3	2.31	2.31	-2.31
2	582	32.5	34.8	-34.77
3	74.2	63.5	98.3	-98.31
4	21			



Munshiwala

N	ρ	h	d	Alt
1	20.6	1.69	1.69	-1.693
2	251	44.7	46.4	-46.42
3	68.9	112	158	-158.5
4	22.5			



Rampura

N	ρ	h	d	Alt
1	13.8	2.04	2.04	-2.036
2	204	47.1	49.1	-49.11
3	47.5			

Annexure 9

Farmer Feedback Form

Farmer Feedback Form

		Photograph
Name	Parminder Singh	
Village	Kokkar	
Block	Bhawanigarh	
District	Sangrur	
Address		
Mobile Number (optional)	7890548002	
Type and number of structures		
Type	TW	
Number	01	
(coordinates of the structures are to be obtained by the field officer)		
Drill time discharge (lps)		
Depth of installation of pump	42 meters	
Casing depth (Bore wells) HR	— NA —	
Fracture encountered depth-HR	— NA —	
Slotted pipe depths (TW) SR	52 meters	
Average water levels – pre-monsoon	44 mbgl to 47mbgl	
Average water levels – post-monsoon	47mbgl to 48.7mbgl	
The well is used for	Domestic Purpose	
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~~) for drinking	Twice a day	2 hours to fill the tank	

Kharif (no of months to be specified)			
Others (no of months to be specified)			
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)			
Khariff (no of months to be specified)			
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			
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	vegetables
Area under crop			
Reasons for change in cropping pattern in last 20 years.	MSP of Rice & wheat & free electricity		
If the cropping pattern is to be changed, which are the suitable crops that can be grown	will depend upon MSP of prevailing crop.		
Available Market for the crop	Yes	Yes	Yes
Average unit cost of production			
Average unit cost of selling			
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar — NO —	○ Is it connected to grid ○ 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?~~ ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel — NO —	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

Water Market* NO	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs)
—NA—	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc NO issues, white layer inside the bucket

- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.

Farmer Feedback Form

Photograph

Name	Daljeet		
Village	Balad Kalan		
Block	Bhawanigarh		
District	Sangrur		
Address			
Mobile Number (optional)	9417980333		
Type and number of structures			
Type	TW		
Number	2		
(coordinates of the structures are to be obtained by the field officer)	30.262765	76.103428	
Drill time discharge (lps)			
Depth of installation of pump	140 feet		
Casing depth (Bore wells) HR			
Fracture encountered depth-HR			
Slotted pipe depths (TW) SR	400 ft deep TW with	86ft at 310-340, 360-370 ft	
Average water levels – pre-monsoon	44 to 47 mbgl		
Average water levels – post-monsoon	47 mbgl to 48.7mbgl		
The well is used for	Drinking + Irrigation		
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)	Depends upon the water req. in field	2/3 hrs	

Kharif (no of months to be specified) June – oct	30 days	6 hrs / day	
Others (no of months to be specified)			
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	5 Acre	wheat	
Khariff (no of months to be specified)	5 acre	Rice	
Others (no of months to be specified)	1 acre	Veg	
Cropping patterns (past and present) in the village			
Traditional Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	vegetables
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	vegetable
Area under crop	5 acre	5 acre	1 acre
Reasons for change in cropping pattern in last 20 years.			
If the cropping pattern is to be changed, which are the suitable crops that can be grown	Depends	upon MSP of	crop
Available Market for the crop	Yes	Yes	Yes
Average unit cost of production	25000/acre	16000/acre	
Average unit cost of selling	70000/acre	40000/acre	Variable
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar –NA–	○ Is it connected to grid ○ 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? ✓ ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel –NA–	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

Water Market*	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif (depends upon req.) ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs) free (cousin)
	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc NO issues

- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.

Farmer Feedback Form

	Photograph
Name	Nagar Singh
Village	Kheri Gillan
Block	Bhawanigarh
District	Sangrur
Address	
Mobile Number (optional)	9417892420
Type and number of structures	
Type	TW
Number	1
(coordinates of the structures are to be obtained by the field officer)	30.29987 - 76.16019
Drill time discharge (lps)	
Depth of installation of pump	80 meters
Casing depth (Bore wells) HR	-NA-
Fracture encountered depth-HR	-NA-
Slotted pipe depths (TW) SR	112-118 meters, depth of well = 122 meters app.
Average water levels – pre-monsoon	44 to 47 mbgl
Average water levels – post-monsoon	47 mbgl to 48.7 mbgl
The well is used for	Irrigation
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) 0	Depends upon water requirement in field	Tentatively 4 hours a days for initial week then 3 waters in rest season	

Kharif (no of months to be specified) June - oct	watering till Sept last then watering stopped due to harvesting. 6 hours for 2 months.		
Others (no of months to be specified)			
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	4 acre	wheat	
Khariff (no of months to be specified)	4 acre	Rice	
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	Cotton	vegetables	
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	—
Area under crop	4 acre	4 acre	
Reasons for change in cropping pattern in last 20 years.	MSP of	Rice, wheat	
If the cropping pattern is to be changed, which are the suitable crops that can be grown	Depends	upon MSP	of crop
Available Market for the crop	yes	Yes	
Average unit cost of production	19,000	13,000	
Average unit cost of selling	70,000	40,000	
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			

Source of Energy

Solar NO	○ Is it connected to grid ○ If yes how much incentive do you get per month on an average for feeding electricity to the grid (Rs per month)
Electric Yes	○ Do you get free electricity for irrigation? ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----
Diesel NO	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi

Water Market* NO	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs)
	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc NO problem except white layer on buckets
- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.	

Farmer Feedback Form

Photograph

Name	Ajeet Singh
Village	Fatehgarh Bhadson
Block	Bhawanigarh
District	Sangrur
Address	
Mobile Number (optional)	
Type and number of structures	
Type	Tubewell
Number	1
(coordinates of the structures are to be obtained by the field officer)	
Drill time discharge (lps)	
Depth of installation of pump	310 feet
Casing depth (Bore wells) HR	– NA –
Fracture encountered depth-HR	– NA –
Slotted pipe depths (TW) SR	370 – 390 ft
Average water levels – pre-monsoon	42 to 45 mbgl
Average water levels – post-monsoon	44 to 46 mbgl
The well is used for	Irrigation
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) Nov – March	15 - 20 days	5 hrs/day	

Kharif (no of months to be specified) June - oct	4-5 days	3-4 hrs / day	
Others (no of months to be specified) vegetable	1-2 days	2-4 hrs / day	
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	2 acre	wheat	
Khariff (no of months to be specified)	2 acre	Rice	
Others (no of months to be specified)	0.5 acre	vegitables	
Cropping patterns (past and present) in the village			
Traditional Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	
Area under crop			
Reasons for change in cropping pattern in last 20 years.	MSP for the Rice, wheat		
If the cropping pattern is to be changed, which are the suitable crops that can be grown	depends upon the prevailing MSP at that time		
Available Market for the crop			
Average unit cost of production	20K-25K	12K-15K	
Average unit cost of selling	70,000	40,000	
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar (NO)	○ Is it connected to grid ○ 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? ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel -NO-	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

Water Market* (Individual)	o Do you share the pumped water with other farmers o If yes o For how many days do you share pumped water in Kharif o For how many days do you share pumped water in Rabi Period o On an average how much do you charge per annum (in Rs)
	o Do you receive additional water from boreholes of nearby farmers o If yes o For how many days do you receive pumped water in Kharif o For how many days do you receive pumped water in Rabi Period o On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc No Issues
- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.	

Farmer Feedback Form

			Photograph
Name	Malwinder Nath		
Village	Harditpura		
Block	Bhawanigarh		
District	Sangrur		
Address	5-047, Harditpura		
Mobile Number (optional)	98888 43629		
Type and number of structures			
Type	Submersible		
Number	1		
(coordinates of the structures are to be obtained by the field officer)			
Drill time discharge (lps)			
Depth of installation of pump	~ 250 ft (4wt)		
Casing depth (Bore wells) HR	— NA —		
Fracture encountered depth-HR	— NA —		
Slotted pipe depths (TW) SR	270 - 280 feet		
Average water levels – pre-monsoon	44 to 47 mbgl		
Average water levels – post-monsoon	47 to 48.7 mbgl		
The well is used for			
Is water available throughout the year	Irrigation		
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 twice a month Oct - April	6 -7	

24 hours for 2 months (1 1/2 month)

Kharif (no of months to be specified)	20th June – oct	alternate 10 days, 1/m gap of 10 days	
Others (no of months to be specified)			
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	Cabbage,	lady finger,	Tomato – 5 Bigga organic.
Khariff (no of months to be specified)			
Others (no of months to be specified)	all irrigated		
Cropping patterns (past and present) in the village			
Traditional Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Cotton		
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	vegetables
Area under crop	3.1 acre	3.1 acre	1 acre
Reasons for change in cropping pattern in last 20 years.	More economic value of Rice		
If the cropping pattern is to be changed, which are the suitable crops that can be grown			
Available Market for the crop			
Average unit cost of production	20K – 25K	12K – 15K	
Average unit cost of selling	70K	40K	
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar — NA —	○ Is it connected to grid ○ 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? ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel — NA —	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

5 Bigga (3.1 acre)

Water Market* (Individual)	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs)
Individual	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks NO	e.g. common problems in drilling of wells, common health issues in the area etc

- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.

Farmer Feedback Form

		Photograph
Name	Jaswant Singh	
Village	Bharo	
Block	Bhawanigarh	
District	Sangrur	
Address		
Mobile Number (optional)		
Type and number of structures		
Type	TW	
Number	2	
(coordinates of the structures are to be obtained by the field officer)		
Drill time discharge (lps)		
Depth of installation of pump	160-170 ft	
Casing depth (Bore wells) HR	-NA-	
Fracture encountered depth-HR	-NA-	
Slotted pipe depths (TW) SR	380 - 400 ft	(depth of well 400 ft app.)
Average water levels – pre-monsoon	42-46 mbgl	
Average water levels – post-monsoon	44-47 mbgl	
The well is used for	Irrigation	
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) Oct - March	In total 15-20 days whole season	Based on 6 hours functioning. In total 3 to 4 watering in whole season is required.	

Kharif (no of months to be specified)	Rice	6 hours daily for initial & rains then little water req till sept end	
Others (no of months to be specified)	vegetables	As per need.	
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	10 acres	wheat	
Khariff (no of months to be specified)	10 acres	Rice	
Others (no of months to be specified)	5 acres	vegetables	
Cropping patterns (past and present) in the village			
Traditional Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	— Cotton	—	
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	Maize / vegetables
Area under crop			
Reasons for change in cropping pattern in last 20 years.	MSP for	the Rice	
If the cropping pattern is to be changed, which are the suitable crops that can be grown			
Available Market for the crop	Yes	Yes	Yes
Average unit cost of production	20-25,000	12-15000	
Average unit cost of selling	70,000	40,000	Varies
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar — No —	○ Is it connected to grid ○ 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? ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel — No —	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

Water Market* (Individual)	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs)
	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc No problem
- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.	

Farmer Feedback Form

Photograph

Name	Balwinder Singh
Village	Channo
Block	Bhawanigarh
District	Sangrur
Address	
Mobile Number (optional)	
Type and number of structures	
Type	TW
Number	2
(coordinates of the structures are to be obtained by the field officer)	30.31182 76.15108
Drill time discharge (lps)	
Depth of installation of pump	
Casing depth (Bore wells) HR	– NA –
Fracture encountered depth-HR	– NA –
Slotted pipe depths (TW) SR	
Average water levels – pre-monsoon	42 - 46 mbgl
Average water levels – post-monsoon	44 - 49 mbgl
The well is used for	Drinking + Irrigation
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 (twice) a month Oct to April	6-7 hours	

Kharif (no of months to be specified) 20 June – Oct	6 hours daily for gap of 10 days	[illegible] 1½ month till last of Sept	में after that
Others (no of months to be specified)	vegetables.		
Area Irrigated			
	Area Irrigated	Type of crop taken	Remarks
Rabi (no of months to be specified)	12acre	wheat	
Khariff (no of months to be specified)	12acre	Rice	
Others (no of months to be specified)	vegetables	3acre	2acre oil seed
Cropping patterns (past and present) in the village			
Traditional Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	cotton	vegetables	
Area under crop			
Prevailing Cropping pattern in the village	Kharif	Rabi	Other
Type of Crop	Rice	wheat	vegetables, oil seed
Area under crop	12acre	12acre	2acre, 2acre
Reasons for change in cropping pattern in last 20 years.	Economic growth		
If the cropping pattern is to be changed, which are the suitable crops that can be grown	Depends upon the MSP of crop at that time		
Available Market for the crop	Yes	Yes	Yes
Average unit cost of production	20-25,000	12-15000	
Average unit cost of selling	70,000	40,000	
Existing MSP and other related information	Crop wise details are to be collected		
Other subsidies, facilities, restrictions.			
Source of Energy			
Solar — NO —	○ Is it connected to grid ○ 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? ○ Do you pay a fixed charge ○ If a fixed charge is paid, what is the per month charge ○ If unit-based charges are paid what is the average monthly charges in rupees ○ During kharif---- ○ During Rabi-----		
Diesel —NO—	○ Average consumption of diesel (liters) per month ○ During Kharif ○ During Rabi		

Water Market* (Individual)	○ Do you share the pumped water with other farmers ○ If yes ○ For how many days do you share pumped water in Kharif ○ For how many days do you share pumped water in Rabi Period ○ On an average how much do you charge per annum (in Rs)
	○ Do you receive additional water from boreholes of nearby farmers ○ If yes ○ For how many days do you receive pumped water in Kharif ○ For how many days do you receive pumped water in Rabi Period ○ On an average how much do you pay per annum (in Rs)
Other issues/Remarks	e.g. common problems in drilling of wells, common health issues in the area etc NO problem

- Feedback of the local users will form an important input for problem identification and characterization. Feedbacks are to be obtained in case of Urban areas, Industrial clusters also. Feedbacks on drinking water availability, dependence on ground water etc are also to be obtained. The above feedback form can be customized to the type of priority area and objective of the study.

Central Ground Water Board
North Western Region
Bhujal Bhawan
Plot- 3B
Sector-27 A
Chandigarh - 160019
Email: rdnwr-cgwb@nic.in