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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
ओखला लैंडफिल साइट, एन सी टी दिल्ली
Okhla, Landfill Site, N.C.T Delhi

N.C.T Delhi
2024

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भारत सरकार

Government of India

जल शक्ति मंत्रालय

Ministry of Jal Shakti

जल संसाध नविभाग, नदी विकास और गंगा संरक्षण

Department of Water Resources

River Development and Ganga Rejuvenation

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Central Ground Water Board

जलभृत प्रबंधन योजना

Aquifer Management Plan

ओखला लैंडफिल साइट,एन.सी.टी दिल्ली

Okhla, Landfill Site, N.C.T Delhi

प्राथमिकताप्रकार: जल प्रदूषित क्षेत्र

Priority Type: Water Contaminated Area

N.C.T Delhi

2024

CENTRAL GROUND WATER BOARD

MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT &

GANGA REJUVENATION

MINISTRY OF JAL SHAKTI
GOVERNMENT OF INDIA

GROUND WATER CONTAMINATION STUDIES AROUND OKHLA LANDFILL SITE, N.C.T, DELHI

CONTRIBUTORS

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STATE UNIT OFFICE, NCT, DELHI

JUNE 2024

डॉ.सुनील कुमार अम्बास्ट
Dr. Sunil Kumar Ambast

सत्यमेव जयते

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

MESSAGE

It gives me immense pleasure to present the "Ground Water Contamination Studies around Okhla Landfill Site." This report is a significant step towards the sustainable management of groundwater resources in the region, reflecting our ongoing commitment to safe guarding this vital resource.

The NAQUIM 2.0 initiative has been developed with the goal of providing detailed, issue-specific groundwater management solutions tailored to the needs of the Okhla Landfill Site. Through meticulous aquifer mapping, data collection, and chemical analysis, this report offers valuable insights into the groundwater dynamics of the area and proposes scientifically backed management strategies for its sustainable use. This report will also helpful for identification of flow direction of contaminants.

I extend my sincere gratitude to the dedicated team of hydrogeologists, geophysists, and other experts whose tireless efforts have made this report possible. Their collaborative work exemplifies our commitment to addressing groundwater challenges with precision and care.

I am confident that this report will serve as a crucial resource for policymakers, planners, and stakeholders involved in groundwater management, ensuring the long-term availability and quality of groundwater in Okhla Landfill Site. Together, let us continue to work towards a water-secure future.

Dr. Sunil Kumar Ambast
Chairman

टी. बी. एन. सिंह
T.B.N. Singh

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

सत्यमेव जयते

MESSAGE

I am pleased to present the "Ground Water Contamination Studies around Okhla Landfill Site." This report is a testament to our dedication to advancing groundwater management practices in landfill areas and ensuring the sustainable use of this precious resource in the region.

The NAQUIM 2.0 project represents a significant leap forward in our understanding of the complex groundwater systems in Okhla Landfill Site. By integrating cutting-edge technology with traditional hydrogeological methods, this report provides a comprehensive analysis of the area's aquifers, offering actionable insights for effective management and conservation.

I commend the entire team of experts, including hydrogeologists, geophysicist, and support staff, for their unwavering commitment and collaborative efforts in bringing this report to fruition. Their expertise and diligence are reflected in the detailed findings and recommendations presented here, which will undoubtedly serve as a valuable guide for sustainable groundwater management.

This report is not just a document but a call to action for all stakeholders involved in groundwater management. It is my hope that the strategies outlined within will be implemented effectively, contributing to the long-term water security and resilience of Okhla Landfill Site.

31/01/2025
T B N Singh
Member (CGWA)

सय्येद क मोहिद्दिन
S K Mohiddin

भारत सरकार
जल शक्ति मंत्रालय
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FOREWORD

"Ground Water Contamination Studies around Okhla Landfill Site" study addresses the significant challenges Okhla Landfill Site faces, including severe groundwater contamination, over-extraction for urban, industrial, and agricultural needs, and deteriorating water quality. These issues, compounded by rapid urbanization and inadequate recharge, highlight the urgent need for effective and sustainable groundwater management strategies.

The NAQUIM 2.0 study for the Okhla Landfill Site offers an in-depth understanding of the region's aquifer systems. The study proposes scientifically robust and practically implementable management strategies by conducting detailed hydrogeological mapping, geophysical surveys, and water quality assessments.

This report is the result of the dedicated efforts of an exceptional team. I extend my heartfelt gratitude to Sh. Gyanendra Rai, Senior Technical Assistant (Hydrogeology) Smt. Mamta, Geophysicist (STA), and Chandan Gupta Geophysicist (STA) whose specialized knowledge and collaborative efforts have enriched the quality of this report.

This report is intended to serve as a vital resource for policymakers, planners, and stakeholders, providing them with the tools to make informed decisions for Ground Water Contamination Studies around Okhla Landfill Site. I am confident that the strategies outlined here will significantly contribute to addressing the groundwater challenges and ensuring the block's water security and overall economic growth.

S. K. Mohiddin
Regional Director

ACKNOWLEDGEMENT

The author acknowledges with deep gratitude Dr. Sunil Kumar Ambast, chairman, Central Ground Water Board, for providing the opportunity to prepare the "Ground Water Contamination Studies around Okhla Landfill Site”. Sincere thanks are extended to T.B.N. Singh, Member, CGWA, for his in valuable guidance, encouragement, and suggestions during the preparation of this report. The author also expresses heartfelt thanks to Shri S. K. Mohiddin, Regional Director and Team Leader Central Ground Water Board, State Unit Office, NCT, Delhi for his valuable guidance and constant encouragement throughout the process.

I am also grateful to Ms. Kriti Mishra, Sc-C, Sh. Gyanendra Rai, and STA-HG for providing guidance at various stages of the study. Thanks are also due to Sh. S. Ashok Kumar, STA-HG, who carefully went through the draft copy of this report, corrections and his help in map preparation.

I would like to give thanks to Mrs. Prachi Gupta, Scientist – ‘D’, regarding the report correction The author extended their thanks to CWC Chemical Laboratory officials for the Bacteriological Analysis Jaipur lab for Basic parameter analysis and Lucknow lab for heavy metal analysis. And Sh. Chandan Gupta, STA (GP) for geophysical surveys.

The author is grateful to the technical section, RODC, and library of the CGWB, SUO, Delhi, as well as to state agencies, for providing various necessary data, without which this report would not have been completed.

Lastly, I would like to thank all those who helped in various stages of this effort.

Sh. Gyanendra Rai
Senior Technical Assistant (HG)

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EXECUTIVE SUMMARY

National Capital Territory of Delhi occupies an area of 1483 sq. km. For administrative purposes, NCT Delhi is divided into 11 districts and 33 tehsils. The study area covers parts of three districts i.e., North, Northwest, and Central, and five tehsils namely Alipur, Model Town, Saraswati Vihar, Rohini, and Civil Lines. The normal annual rainfall of NCT Delhi is 611.8 mm. The rainfall increases from the southwest to the northwest. About 81% of the annual rainfall is received during the monsoon months July, August and September. The rest of the annual rainfall is received as winter rain and as thunderstorm rain in the pre and post-monsoon months.

NCT Delhi is occupied by quartzite inter-bedded with mica schist belonging to Delhi Super Group (Delhi ridge) overlain by unconsolidated sediments of Quaternary to Recent age. The thickness of overlying alluvium is highly variable on the eastern and western sides of the ridge. It is generally thicker (>300m) on west of the ridge. The study area falls under alluvial deposits. The aquifer mapping programme (NAQUIM) has been taken up by Central Ground Water Board during the XII Five Year Plan for sustainable development and management of groundwater resources with the objective of generating micro-level hydrogeological data for understanding the groundwater system, to prepare Aquifer maps on 1:50,000 scale, depicting the extent and geometry of the aquifer system and to formulate suitable aquifer management plans.

Large-scale implementation of NAQUIM recommendations at ground level by the user agencies has been lacking. Keeping the 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 density of dynamic data like groundwater level, groundwater quality, etc. ii) providing issue-based scientific inputs for groundwater management up to Panchayat level, iii) providing printed maps to the users and iv) putting in place a strategy to ensure implementation of the recommended strategies. Involving state agencies in the studies for a sense of ownership.

All the available scientific data generated so far during the course of various scientific studies was compiled and data gap analysis was carried out to identify the data gaps. Based on the outcome of data gap analysis Vertical Electrical Soundings. VES data indicates that fresh water sediments are followed by the saline water sediments. The thickness of fresh water sediments is thin in major in study area. The depth to fresh saline water interface varies from 22 to 65m bgl. Ground water quality below fresh saline water interface is saline all through up to the bedrock. The Depth to water level recorded in Study area during June, 2023 varied from 10.6 to 44.9 metres below ground level (mbgl). Ground water level data of a total of 22 observation wells have been analysed. The Depth to water level recorded in study area during November, 2023 varied 9.31 to 43.97mbgl. Ground water level data of a total of 22 observation wells have been analysed. Based on the water table elevation follows the topography of the area and overall ground water flow direction is towards Yamuna River. Internal ground water flow direction is different. In the western part of the study area flow direction is towards a trough near landfill area and southern part ground water flow direction is towards north. Bhalaswa

Lake acting as divider regarding ground water flow. Electrical conductivity value of pre-monsoon ground water samples in Okhla study area has been found to vary from 850 to 3866 µS/cm at 25ºC and in post-monsoon it varies from 289- 4980 µS/cm at 25ºC. EC in excess of 3000 µS/cm value has been observed more than 16% of study area. Nitrate in excess of the maximum permissible limit has been reported from 55% of post-monsoon samples.

In heavy metal analysis, two leachate samples have shown more than the permissible limit for Fe, Cr, As, and Ni. Only one leachate sample has shown more than the permissible limit for U, Mn, Pb and Cd. In Basic analysis, Leachate samples have been shown exceed the permissible limit for EC, Cl, Flouride, and Nitrate. And for Bacteriological analysis both the leachate samples have shown total and faecal coliform. In Basic analysis, 37.5% of wells showing Chloride and 6.25% of wells are showing Fluoride beyond the permissible limit in pre-monsoon. And 18.42%, 13.15% and 26.31% of wells are showing beyond permissible of CL, F and No3 respectively. Excess Fluoride has been reported from isolated pockets in the study area. The concentration of Iron (Fe) has been found to range from BDL to 6.7mg/l and exceeded the maximum permissible limit of 1 mg/l in 12.5% of the total analyzed pre-monsoon groundwater samples. For post-monsoon, the concentration of Iron (Fe) has been found to range from 0.075mg/l to 9.75mg/l and exceeded the maximum permissible limit of 1 mg/l in 21%.

In pre-monsoon, the concentration of Arsenic (As) in groundwater has been found to vary from BDL to 0.038 mg/l. In post-monsoon, the concentration of Arsenic varies from Below the Detectable Limit to 0.129mg/l. 6.2% of pre-monsoon samples and 13% of post-monsoon samples exceed the maximum permissible limit of 0.01 mg/l prescribed by BIS in drinking water (IS-10500:2012). Lead (Pb) concentration has been reported to vary from BDL to 0.0016 mg/l in pre-monsoon and it varies from 0.001-0.011 mg/l in post-monsoon. Sporadic occurrence of Pb in excess of the maximum permissible limit of 0.01 mg/l (IS-10500:2012) has been reported in 2.6% of post-monsoon samples. Excess Pb in groundwater may be due to pollution from industries and landfill sites. The concentration of Uranium (U) has been found to vary from BDL to 0.01769 mg/l in pre- monsoon and it varies from 0.003 to 0.035 mg/l in post-monsoon. Concentration of Uranium. The bacteriological test carried out in four groundwater samples bacteriological samples not traceable in this area.

All the available data as well as data generated during the course of present study were integrated and aquifer disposition maps were prepared. Okhla Study area covers five assessments i.e., Kalaka ji. The annual extractable groundwater resource is 6374 ha. m. The total annual groundwater recharge has been estimated as 6957.85 ham. The total annual groundwater draft (as on 2023) has been estimated to be 4808.83 ha. M. Out of 5 tehsils in the study area, 2 are ‘Safe’, 2 are ‘Semi-Critical’, and the remaining 1 tehsil is ‘Critical’. In addition, most of the study areas are shallow water levels where groundwater withdrawal is limited due to the presence of poor-quality water. Groundwater withdrawal is recommended for its use after blending. This will create void space in the aquifer, which would be recharged during subsequent monsoons and help in improving groundwater quality. In areas, where fresh groundwater is underlain by saline water, it is recommended that saline water occurring at deeper levels may be withdrawn and used after blending or may be used for uses other than drinking and domestic. Rain water harvesting and artificial recharge measures are recommended in areas having water levels deeper than 8 mbgl.

कार्यकारी सारांश

राष्ट्रीय राजधानी क्षेत्र दिल्ली का क्षेत्रफल 1483 वर्ग किलोमीटर है। प्रशासनिक दृष्टि से, NCT दिल्ली को 11 जिलों और 33 तहसीलों में विभाजित किया गया है। अध्ययन क्षेत्र तीन जिलोंउत्तर–, उत्तर पश्चिम- के कुछ हिस्सों तथा–और मध्य दिल्लीपाँच तहसीलोंअलीपुर–, मॉडल टाउन, सरस्वती विहार, रोहिणी और सिविल लाइन्सको कवर करता है।– NCT दिल्ली में सामान्य वार्षिक वर्षा 611.8 मिमी होती है। वर्षा दक्षिण पश्चिम की ओर बढ़ती है। वार्षिक वर्षा का लगभग-पश्चिम से उत्तर-81% भाग मानसून के महीनोंजुलाई–, अगस्त और सितंबर के दौरान प्राप्त होता है। शेष वार्षिक वर्षा सर्दियों की बारिश तथा–चमक के साथ होने वाली बारिश के रूप में प्राप्त-मानसून अवधि में गरज-मानसून और पोस्ट-प्री होती है।

NCT दिल्ली में दिल्ली सुपर ग्रुप से संबंधित क्वार्ट्जाइट पाया जाता है, जो माइका शिस्ट के साथ इंटर-डेड है और इसके ऊपर क्वाटर्नरी से लेकर नवीनतम युग तक के अपसंपृक्त अवसादी निक्षेप हैं।ब निक्षेपों के अंतर्गत आता है। भूजल संसाधनों के सतत विकास और प्रबंधन के लिए केंद्रीय भूजल बोर्ड द्वारा XII पंचवर्षीय योजना के दौरान जलभृत मानचित्रण कार्यक्रम शुरू किया गया। इसका उद्देश्य भूजल प्रणाली की समझ के लिए सूक्ष्मस्तरीय हाइड्र-ोजियोलॉजिकल डेटा उत्पन्न करना, 1:50,000 के पैमाने पर जलभृत मानचित्र तैयार करना, जो जलभृत प्रणाली के विस्तार और ज्यामिति को प्रदर्शित करें, और उपयुक्त जलभृत प्रबंधन योजनाएँ तैयार करना है।

NAQUIM की सिफारिशों का बड़े पैमाने पर उपयोगकर्ता एजेंसियों द्वारा जमीनी स्तर पर क्रियान्वयन अब तक अपर्याप्त रहा है। सीमाओं को ध्यान में रखते हुए और भविष्य की आवश्यकताओं को देखते हुए, NAQUIM 2.0 अध्ययन के मुख्य उद्देश्य होंगे: i) उच्च granularity के साथ जानकारी प्रदान करना, जिसमें जल स्तर, जल गुणवत्ता जैसे गतिशील डेटा की घनत्व को बढ़ाने पर ध्यान केंद्रित किया जाएगा। ii) पंचायती स्तर तक जलभृत प्रबंधन के लिए मुद्दा-आधारित वैज्ञानिक इनपुट प्रदान करना। iii)उपयोगकर्ताओं के लिए मुद्रित मानचित्र प्रदान करना। iv) सिफारिश की गई रणनीतियों के क्रियान्वयन को सुनिश्चित करने के लिए एक रणनीति बनाना। राज्य एजेंसियों को अध्ययन में शामिल करना ताकि वे इसे अपना समझें।

अब तक विभिन्न वैज्ञानिक अध्ययन के दौरान उत्पन्न सभी उपलब्ध वैज्ञानिक डेटा को संकलित किया गया और डेटा गैप विश्लेषण (data gap analysis) किया गया ताकि डेटा की कमी को पहचाना जा सके।

डेटा गैप विश्लेषण के परिणामों के आधार पर, वर्टिकल इलेक्ट्रिकल साउंडिंग (VES) डेटा यह संकेत देता है कि ताजे पानी के निक्षेपों के बाद खारा पानी के निक्षेप हैं। ताजे पानी के निक्षेपों की मोटाई अध्ययन क्षेत्र में मुख्य रूप से पतली है। ताजे पानी और खारे पानी के बीच का इंटरफ़ेस 22 से 65 मीटर नीचे तक पाया गया है। ताजे पानी और खारे पानी के इंटरफ़ेस के नीचे जल गुणवत्ता खारा है और यह पूरी तरह से बेडरॉक तक खारा रहता है। अध्ययन क्षेत्र में जून 2023 के दौरान जल स्तर की गहराई 10.6 से 44.9 मीटर तक मापी गई। 22 अवलोकन कुंओं के जल स्तर डेटा का विश्लेषण किया गया है। नवंबर 2023 में अध्ययन क्षेत्र में जल स्तर की गहराई 9.31 से 43.97 मीटर तक मापी गई। जल तालिका का उत्थान क्षेत्र की स्थलाकृतिक स्थिति का पालन करता है और कुल मिलाकर भूजल प्रवाह की दिशा यमुनापार की ओर है। आंतरिक भूजल प्रवाह की दिशा अलग है। अध्ययन क्षेत्र के पश्चिमी भाग में प्रवाह दिशा लैंडफिल क्षेत्र के पास एक खड्ड की ओर है और दक्षिणी भाग में भूजल प्रवाह की दिशा उत्तर की ओर है। **भलस्वा झील** भूजल प्रवाह के संदर्भ में एक विभाजक के रूप में कार्य कर रही है। **ओखला अध्ययन क्षेत्र** में प्री-मानसून भूजल नमूनों की विद्युत चालकता (EC) 25ºC पर 850 से 3866 µS/cm के बीच पाई गई है, जबकि पोस्ट-मानसून में यह 289 से 4980 µS/cm के बीच भिन्न रही। अध्ययन क्षेत्र के 16% से अधिक हिस्से में EC मान 3000 µS/cm से अधिक देखा गया। पोस्ट-मानसून नमूनों में **नाइट्रेट** की मात्रा अधिकतम अनुमत सीमा से अधिक पाई गई, जो 55% नमूनों में रिपोर्ट की गई है।

भारी धातु विश्लेषण में, दो लीचेट नमूनों में Fe (लोहा), Cr (क्रोमियम), As (आर्सेनिक), और Ni (निकल) के लिए अनुमत सीमा से अधिक पाया गया है। एक लीचेट नमूने में U (यूरेनियम), Mn (मैंगनीज), Pb (सीसा), और Cd (कैडमियम) के लिए अनुमत सीमा से अधिक पाया गया है। बेसिक विश्लेषण में, लीचेट नमूनों ने EC (विद्युत चालकता), Cl (क्लोराइड), फ्लोरीड, और नाइट्रेट के लिए अनुमत सीमा को पार किया है। और बैटरीयोलॉजिकल विश्लेषण में, दोनों लीचेट नमूनों में टोटल और फीकल कोलिफॉर्म पाए गए हैं। बेसिक विश्लेषण में, प्री-मानसून में 37.5 % कुओं में क्लोराइड और 6.25 % कुओं में फ्लोरीड अनुमत सीमा से अधिक पाया गया। और पोस्ट-मानसून में 18.42 %, 13.15 % और 26.31 % कुओं में क्रमशः क्लोराइड, फ्लोरीड और नाइट्रेट अनुमत सीमा से अधिक पाए गए। अध्ययन क्षेत्र में अलग-अलग स्थानों से अधिक फ्लोरीड रिपोर्ट किया गया है। लोहा (Fe) का सांद्रण BDL (नापे जाने योग्य नहीं) से लेकर 6.7mg/l तक पाया गया है और यह 1 mg/l की अधिकतम अनुमत सीमा को 12.5 % प्री-मानसून भूजल नमूनों में पार करता है। पोस्ट-मानसून में लोहा (Fe) का सांद्रण 0.075 mg/l से लेकर 9.75 mg/l तक पाया गया और यह 21 % नमूनों में 1 mg/l की अनुमत सीमा से अधिक था।

प्री-मानसून में, आर्सेनिक (As) का सांद्रण भूजल में BDL (नापे जाने योग्य नहीं) से लेकर 0.038 mg/l तक पाया गया है। पोस्ट-मानसून में, आर्सेनिक का सांद्रण BDL से लेकर 0.129 mg/l तक पाया गया है। 6.2 % प्री-मानसून नमूनों और 13 % पोस्ट-मानसून नमूनों में BIS द्वारा निर्धारित अधिकतम अनुमत

सीमा (0.01 mg/l) को पार किया गया है, जो पीने के पानी के लिए IS-10500:2012 के तहत निर्धारित है। सीसा (Pb) का सांद्रण प्री-मानसून में BDL से लेकर 0.0016 mg/l तक पाया गया, जबकि पोस्ट-मानसून में यह 0.001 से 0.011 mg/l के बीच था। पोस्ट-मानसून नमूनों के 2.6 % में सीसा की सांद्रता अधिकतम अनुमत सीमा 0.01 mg/l (IS-10500:2012) से अधिक पाई गई है। भूजल में अधिक सीसा की उपस्थिति औद्योगिक प्रदूषण और लैंडफिल साइटों के कारण हो सकती है। यूरेनियम (U) का सांद्रण प्री-मानसून में BDL से लेकर 0.01769 mg/l तक पाया गया और पोस्ट-मानसून में यह 0.003 से 0.035 mg/l के बीच पाया गया। बैक्टीरियोलॉजिकल परीक्षण चार भूजल नमूनों में किया गया था, लेकिन इस क्षेत्र में बैक्टीरियोलॉजिकल नमूने का कोई पता नहीं चल सका।

सभी उपलब्ध डेटा और वर्तमान अध्ययन के दौरान उत्पन्न डेटा को एकीकृत किया गया और जलभृत वितरण मानचित्र (aquifer disposition maps) तैयार किए गए। ओखला अध्ययन क्षेत्र में पांच आकलन क्षेत्र हैं, जैसे कि कालकाजी। वार्षिक निष्कर्षण योग्य भूजल संसाधन 6374 हेक्टेयर मीटर (ham) के रूप में अनुमानित किया गया है। कुल वार्षिक भूजल पुनर्भरण (recharge) को 6957.85 हेक्टेयर मीटर (ham) के रूप में अनुमानित किया गया है। कुल वार्षिक भूजल ड्राफ्ट (2023 तक) 4808.83 हेक्टेयर मीटर (ham) अनुमानित किया गया है। अध्ययन क्षेत्र के 5 तहसीलों में से 2 'सुरक्षित' (Safe), 2 'सेमी-क्रिटिकल' (Semi-Critical) और 1 तहसील 'क्रिटिकल' (Critical) है। इसके अतिरिक्त, अध्ययन क्षेत्र के अधिकांश भागों में जल स्तर उथले हैं, जहां भूजल की निकासी सीमित है क्योंकि वहां खराब गुणवत्ता वाला पानी मौजूद है। भूजल निकासी का उपयोग मिश्रण के बाद करने की सिफारिश की जाती है। इससे जलभृत में रिक्त स्थान (void space) बनेगा, जिसे अगले मानसून के दौरान पुनर्भरित किया जाएगा और इससे भूजल गुणवत्ता में सुधार होगा। उन क्षेत्रों में, जहां ताजे भूजल के नीचे खारा पानी मौजूद है, यह सिफारिश की जाती है कि गहरे स्तरों पर मौजूद खारा पानी निकाला जाए और मिश्रण के बाद उपयोग किया जाए, या इसे पीने और घरेलू उपयोग के अलावा अन्य उपयोगों के लिए उपयोग किया जा सकता है। उन क्षेत्रों में, जहां जल स्तर 8 मीटर से अधिक गहरे हैं, वर्षा जल संचयन और कृत्रिम पुनर्भरण उपायों की सिफारिश की जाती है।

1 Introduction

1.1 General Remarks

The National Aquifer Mapping and Management Programme (NAQUIM) was carried out CGWB from 2012 to 2023 in which detailed mapping of aquifers of India were carried out in the entire country, covering a mappable area of ~25 Lakh km2. The findings of NAQUIM studies are being utilized by many agencies, especially the State government agencies involved in groundwater management and water supply. Major areas where NAQUIM outputs have been used include

- Drinking water source finding and source sustainability
- Sites for Artificial Recharge
- Safe Drinking water sources in Arsenic affected areas
- Assured irrigation through groundwater in areas that have adequate groundwater potential.
- Implementation of water conservation and AR schemes
- Ground Water Regulation based on NAQUIM recommendation
- Rejuvenation of Hot springs
- Atal Bhujal Yojana – Participatory Ground Water Management

Under NAQUIM programme, aquifer management plan for NCT, Delhi was prepared during 2016-17, which was circulated all the stakeholders for implementation. Though the NAQUIM outputs have been useful for sustainable ground water 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 NAQUIM studies include i) non availability of printed maps at usable scales and ii) lack of site-specific recommendations for implementation at Panchayat or village level. Keeping the above limitations in mind and considering the future requirements, broad objectives of NAQUIM 2.0 studies will be i) providing information in higher granularity with a focus on increasing density of dynamic data like ground water level, ground water quality etc. ii) providing issue based scientific inputs for ground water management up to Panchayat level, iii) providing printed maps to the users and iv) putting in place a strategy to ensure implementation of the recommended strategies. The present study "Groundwater contamination studies around Okhla landfill site, NCT, Delhi was carried out under NAQUIM 2.0 during AAP 2023-24.

1.2 Sanitary Landfill Sites

The rate of urbanization is very high in developing countries like India. The level of urbanization of the country is expected to rise to 38% by the year 2026. Provision for civic services like water supply and sanitation has become an uphill task as the state is unable to provide and augment the required resources, both natural and human resources, for the maintenance of the cities. In the past municipal garbage dumps (sanitary landfills are only a recent technology) were unlined and sited with little regard to local hydrogeology. The disposal of such huge volumes of solid waste by open dumping has many environmental impacts. When solid waste is dumped in low-lying areas, it comes in contact with groundwater or rainwater along with run-off resulting the generation of leachate, a mineralized liquid with high dissolved organic matter, inorganic substances, and heavy metals. Open dumping of Municipal solid waste (MSW) leads to degradation of groundwater by generating leachate and its seepage into the ground. Management of domestic and industrial waste, which includes collection and scientific disposal of these waste materials, needs to be given top priority. Lack of proper collection and disposal of the waste is resulting into secondary problems like pollution of ground water, surface water, soil and air pollution. Ground water contamination is one of the major problems associated with improper waste disposal. Moreover, presence of dumping grounds in highly urbanized environments is directly resulting in health hazards for the people residing in the surrounding areas. Leaching of hazardous elements in the ground water in surrounding areas of landfill sites is reported from different sanitary landfill sites of all over the world. But areal depth demarcation and movement of pollutant plume is highly unpredictable and comprehensive studies of both hydrogeology and hydrogeo chemistry is required to demonstrate and predict plume movement.

1.3 Solid Waste Generation in NCT, Delhi

The Municipal Corporation of Delhi (MCD), New Delhi Municipal Council (NDMC) and Delhi Cantonment Board (DCB) manage waste collection and disposal in different parts of Delhi. Before the year 1994, the solid waste disposal in Delhi was not thoroughly systematic and the solid wastes were dumped into nearby low lying areas. A few of the low lying areas have been developed into major landfill, which cover almost entire municipal and industrial dumps. Though, these sites were not scientifically designed with proper linings precaution is being taken to properly maintain these sites through clay cover and construction of drains to drain off the leachates generated in the landfills. These sites may be major point source of pollution due to absence of proper lining. At present, in Delhi estimated quantity of waste generated was 11352 TPD and disposal of solid waste was 10000 TPD. Year wise daily solid waste generation given in ***Table 1.1.***

The continuous generation of solid waste has developed several landfill areas and the land is retrieved for various purposes. There are four major categories of landfills in Delhi.

1. Landfills depleted and retrieved land is used for various purposes. The various landfill sites under this category with their areal extension and year of completion is given in ***Annexure-I.***
2. Active landfills where present filling is taking place. At present filling is being taking place in four sites ***Fig.1.1.*** The sites are:
   - **i.** Gazipur near dairy farm. The total area of the site is 70 acres. About 2500 MT/day of solid waste is received here. Filling in this landfill site commenced in 1993 and the service zones for this landfill site is East Delhi, New Delhi, Central Delhi
   - **ii.** Bhalsawa -I & Bhalsawa-II. The total area of the site is about 50 acres and about 2500 MT/day of solid waste is also dumped here. The dumping of solid waste started in 1984 and the service zone is Rohini, West Delhi, Najafgarh, Narela
   - **iii.** Okhla Phase-III. The total area of the site is 32 acres. About 1000 MT per day solid waste is being dumped here. The filling of this site commenced in 1994 and service zone for this site is South Delhi and parts of Central Delhi.
   - **iv.** Narela-Bawana-The first engineered landfill site in Delhi and is spread over 150 acres. In 2011, the Municipal Corporation of Delhi (MCD) has begun operations at this site. This Site will take handle from Rohini and Civil Lines zones and has an initial capacity to handle 1000 tonnes per day, and later on expanded to that of 4000 tonnes per day.

Table 1.1:*Year-wise Daily Solid Waste Generation*

Year	Solid waste Generation (TPD)
2018-19	10614
2019-20	10470.57
2020-21	10990
2021-22	11108
2022-23	11352

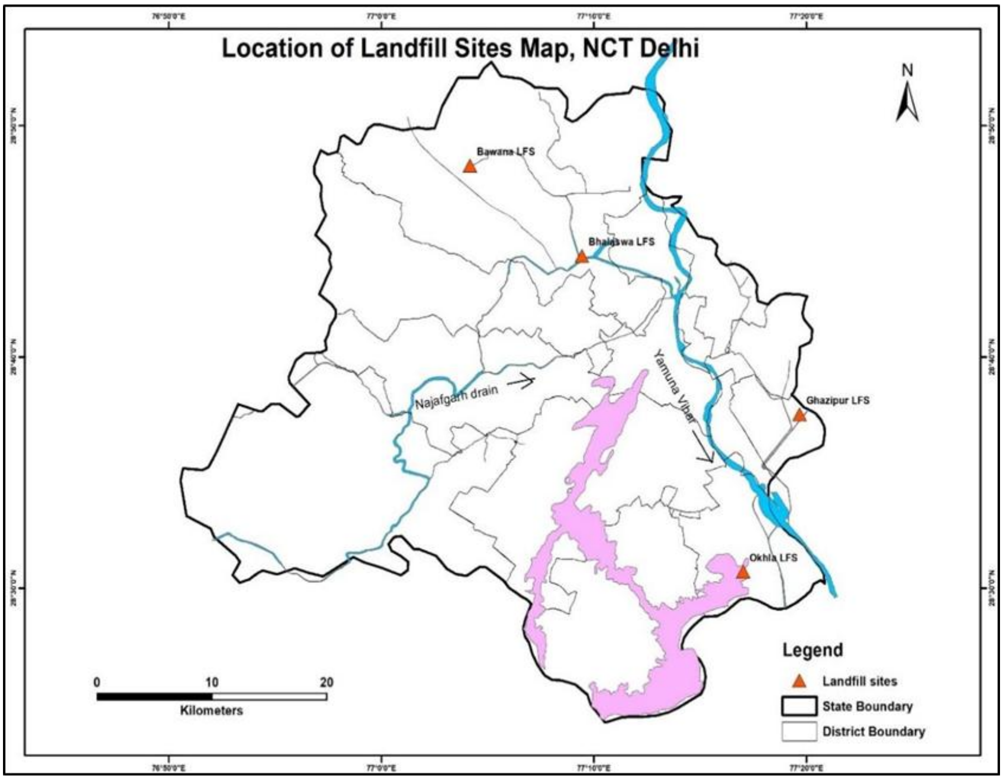


Figure 1.1: Active Landfill sites location map, NCT Delhi

1.4 Physico-chemical characters of Solid Waste in NCT, Delhi

The solid waste ***Fig.1.2*** disposal sites in Delhi receive both domestic and industrial solid waste, as there are no separate waste disposal sites for industries. The physical and chemical characters of solid wastes generated in Delhi are given in ***Table 1.2*** and ***1.3*** respectively.

From the physical characters of the solid waste, it is observed the waste is being generated from domestic as well as other sectors like industries and constructional activities. The organic material is just 44.17% and the inorganic material is 55.83%. Chemically solid waste consists of high percentage of inorganic material, the calorific value is very low as compared to the global solid waste.

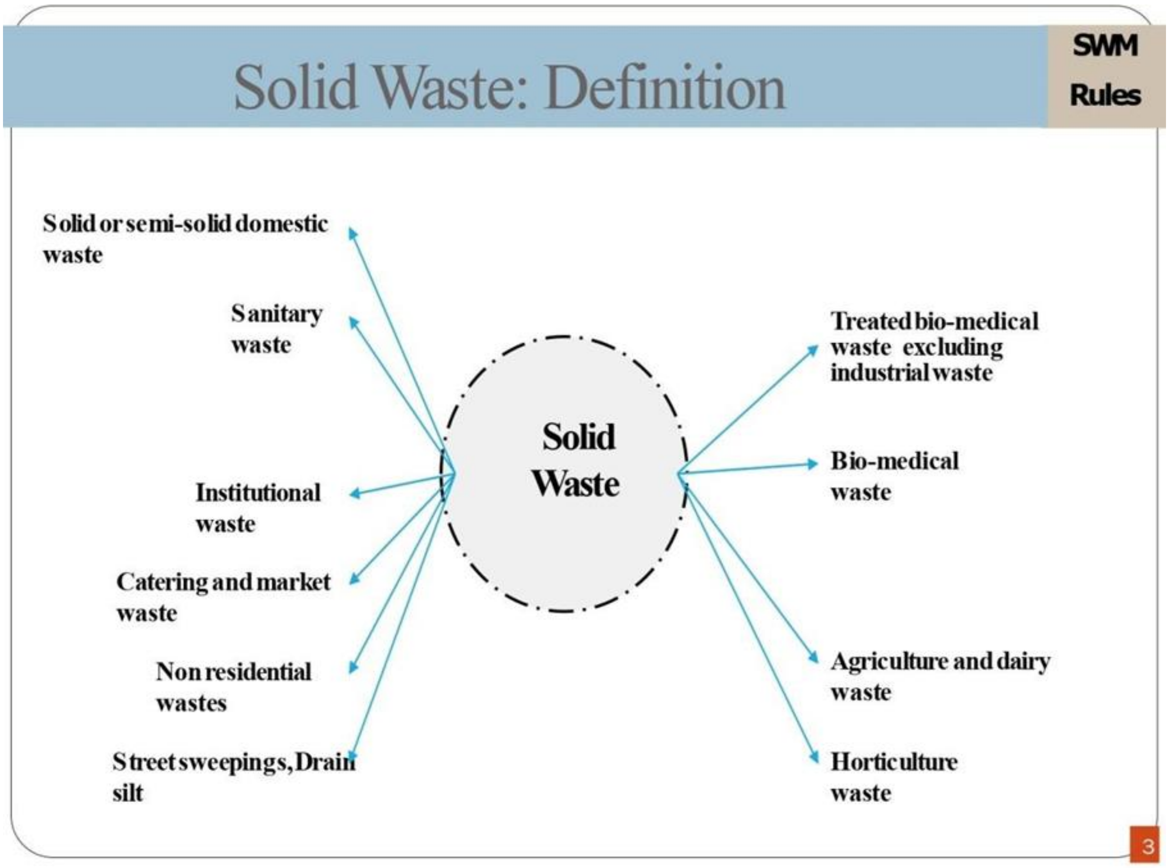


Figure 1.2: Solid Waste Definition

Table 1.2: Physical Characters of solid waste

parameters	Nature of Material	Average percentage
Bio-degradable	Organic material	38.6%
Paper		5.57%
Plastic	Inorganic material	6.03%
Metal		0.23%
Glass & Crockery		0.99%
Bio resistant (Leather, Rubber & Synthetic)		13.89%
Inert (stone, brick, ashes)		34.7%

Table 1.3: Chemical Characters of Solid Waste

Parameters	Average share in Percentage
Moisture	43.65%
Organic Carbon	20.47%
Nitrogen as N	0.85%
Phosphorous as P205	0.34%
Potassium as K20	0.69%
C/N Ratio	24.08%
Calorific Value	712.50 K Cal/kg

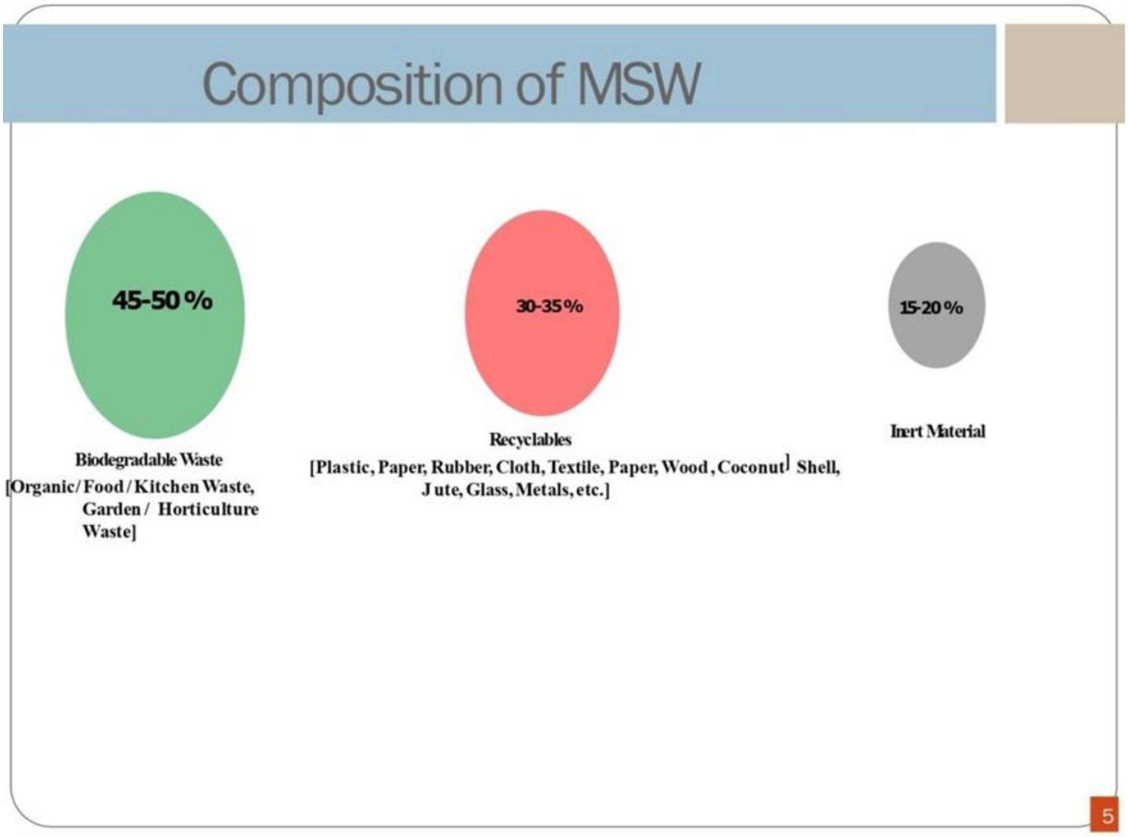


Figure 1.3: Composition of Municipal Solid Waste (MSW)

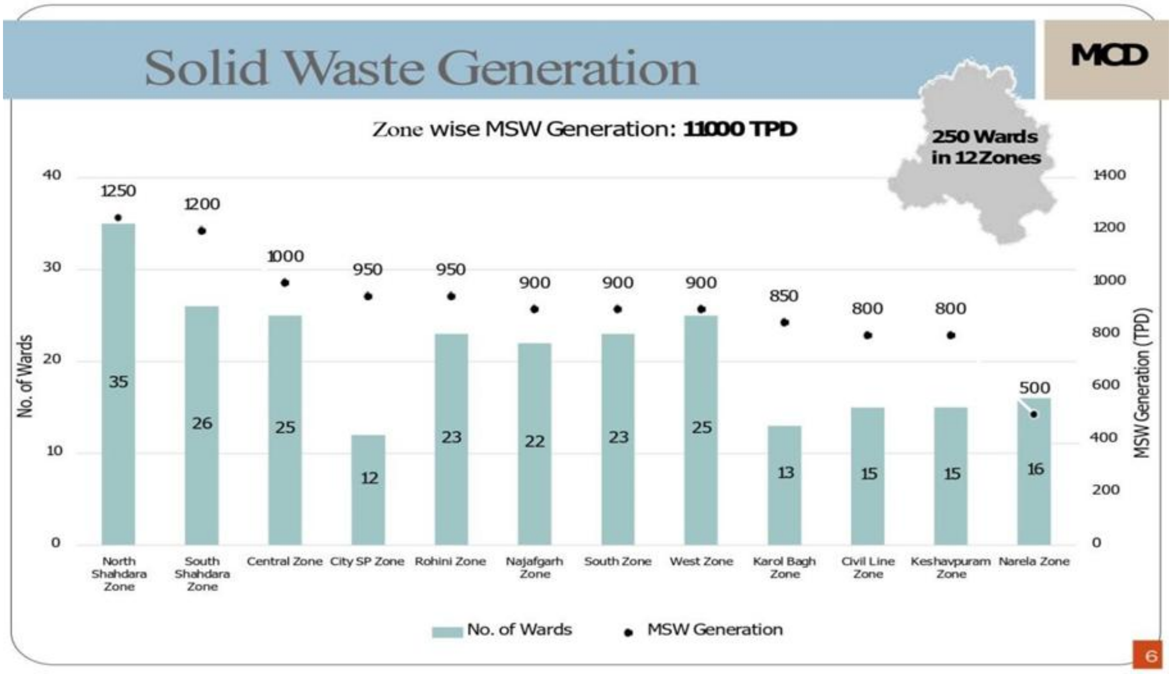


Figure 1.4: Solid Waste Generation zone wise in NCT Delhi

The sanitary landfill (SFL) site at Okhla is one of the four major landfill sites in Delhi and it is situated in the South East District. The total area of the SFL, Okhla is 32 acres. About 1000 MT/day solid waste is being dumped at this site and the filling of this site was commissioned in 1994. Study Area given in Fig1.5. Okhla Sanitary landfills site is located near Tugalkanbd village on the road of Ma Anadmayi Marg in Kalka Ji tehsil South East district of NCT Delhi and its coordinate Latitude 28.512146°E Longitude 77.282945°N. Total area further consideration taken for a one km radius two km radius and 5 km radius taken to establish piezometer and chemical sample collection.

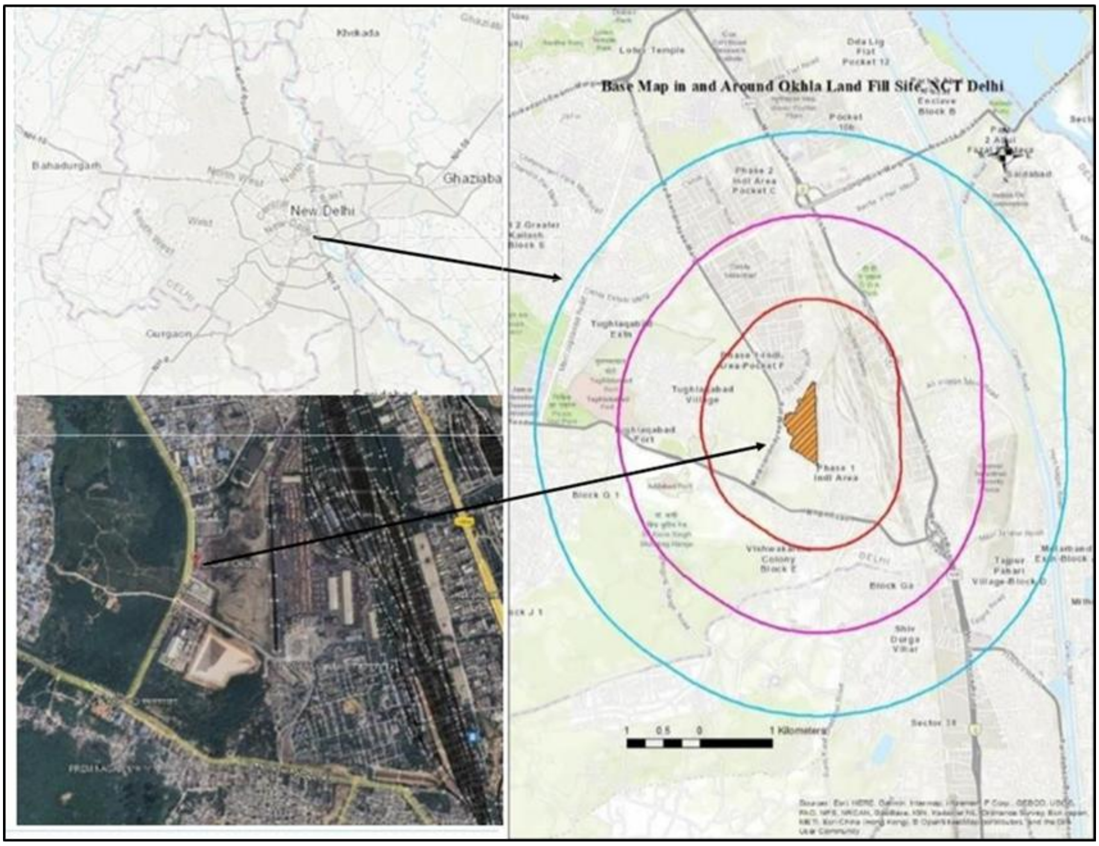


Figure 1.5: Base Map Okhla SLF

1.5 Leachate

Solid waste undergoes many physical chemical and biological changes on a landfill site, this process degrades the organic fraction of the waste along with the moisture content and suitable temperature. The percolating rainwater leads to the generation of a highly contaminated liquid called leachate, which contains large amounts of organic matter like Ammonia nitrogen, heavy metal, and chlorinated organic compounds with inorganic salt. The composition and characteristics of landfill leachate vary with the age, precipitation waste type and composition and weather variation. That can be classified into three types based on the landfill leachate: old, intermediate and young. The classification and characteristics of landfill leachate is given in the table-4. BOD and COD of young leachate is generally found high (4000-13000 mg/l) and (30000-60000 mg/l) respectively. BOD/ COD ratio ranging from 0.4 to 0.7, ammonium nitrogen varies from 500 to 2,000 mg/l, and the pH was found to be very low up to 4 with VFAs. As the landfill age increases and the fatty acid decomposition by anaerobic bacteria it about a period of 10 years it changes the characteristics of the leachate with a low COD, less than 4000 mg per litre and pH range is 7.5 - 8.5 with low biodegradability.

Table 1.4: Classification of leachate

S. No	Type of Leachate	Young	Intermediate	Old
1.	Age (Year)	<5	5-10	>10
2.	pH	<6.5	6.5-7.5	>7.5
3.	COD (mg/l)	>10000	4000-10000	<4000
4.	Organic Compound	80% VFA	5% to 30% VFA + Humic & Fluvic Acid	Humic Fluvic Acid
5.	Ammonia Nitrogen (mg/l)	<400	NA	>400
6.	TOC/COD	<0.3	0.3-0.5	>0.5
7.	Heavy Metals (mg/l)	Low to Med	Low	Low
8.	Biodegradability	Important	Medium	Low

If the leachate is not properly handled, the landfill from which it originates can become a highly serious source of hydrogeological pollution, due to the possibility of leachate penetration into the soil, surface, and groundwater.

2 Previous Studies

1. CGWB, 2016: NAQUIM Report
2. CGWB, 2022: Dynamic Ground Water Resource Estimation, NCT, Delhi as on March 2022
3. CGWB,2022: Ground Water Year Book of NCT, Delhi (groundwater level and quality Monitoring)
4. CGWB,1999: Ground Water Quality Report of NCT, Delhi
5. CGWB,2001: Ground Water pollution studies of SLF Sites in NCT, Delhi during1999- 2001
6. CGWB,2006: Application of isotope techniques in groundwater contamination studies in selected sanitary landfill sites in NCT, Delhi

CGWB has carried out various hydrogeological studies in NCT, Delhi. The first detailed groundwater quality studies were carried out in 2001 in collaboration with CPCB. The report has reported that the groundwater around the SLF sites is being polluted due to leachate movement to groundwater. The studies revealed the groundwater pollution around the Okhla Landfill site. A detailed study of landfill sites located in the IP depot are has also been carried out which is present in similar hydrogeological environments.

Again in 2001, detailed studies were carried out around SLF sites and are port on ground water pollution in SLF sites. In 2003-04, CGWB in Collaboration with BARC, Mumbai carried out pollution studies using the Isotope techniques and demarcated the pollution plume movement in SLF sites of Bhalsawa, Gazipur and Indraprastha Park SLF sites. The report was published in 2006. Apart from these studies CGWB has carried out NAQUIM studies in 2016 and also preparing Ground Water Year Books and CGWB, resource estimation yearly, and preparing the reports.

3 Objectives of the study

A sizable number of the population in NCT, Delhi depends on are dependent on groundwater for their domestic and in some are for drinking purposes. The objective of this study is

- Groundwater conditions in the proposed study area including detailed quality analysis
- Groundwater flow pattern mapping.
- Decipher the Aquifer Geometry and Aquifer properties.
- Identification of areal extent of groundwater pollution due to pollution plume movement. Comparison with earlier groundwater pollution studies and identifications of the direction of plume movements
- Conservation of aquifers from Landfill pollution
- Identification of recharge sources and recharge zones near landfill sites.
- Preparation of suitable recharge plans for the proposed area to arrest the pollution plume movement and preparation of alternate water supply plan for the people living in the vicinity of the SLF site.

4 Methodology

This study has been done to analyze the groundwater contamination in and around the Bhalaswa landfill site.

- Three buffer zones have been drawn for assessment of the contamination of groundwater i.e., 1 Km Buffer Zone, 2 Km Buffer Zone & 5 Km Buffer Zone. The density of sampling & water level monitoring is high at 1 Km buffer zone and gradually reducing the sample locations.
- 11 no. of VES have been done around the landfill site to delineate the 2D aquifer disposition of the study area on a larger scale.

- Pre- and post-monsoon groundwater sampling was done from shallow tube wells around the landfill site for chemical and bacteriological analysis.
- Pre-monsoon & post-monsoon Groundwater monitoring has been done to know the groundwater flow direction.
- Compiled of existing data per the current study's GW assessment unit.

5 Existing data:

The NAQUIM studies indicate that the South District of the National Capital Territory (NCT) of Delhi, encompassing both the South and Southeast districts, spans an area of 158 square kilometers. Within this, approximately 45.2 square kilometers feature mountainous and undulating terrain with exposed Delhi quartzite. The district also includes the Chhattarpur Basin, a central saucer-shaped alluvial plain characterized by valley-fill deposits. The alluvium here reaches a thickness of up to 140 meters below ground level (mbgl), underlain by quartzite basement rock. Areas such as Chhattarpur, Gadaipur, and Mandi lie within this extensive alluvial stretch. The overburden comprises unconsolidated clay, silt, sand, and varying amounts of kankars. In hard rock areas, the weathered zone is present throughout, though its thickness varies. Groundwater in both the Chhattarpur Basin and hard rock terrain was found to be fresh. In the alluvial aquifers, the interface between fresh and saline water shifts from 27 meters near Okhla Barrage to 58 meters in Sarita Vihar.

The Central Ground Water Board (CGWB) conducts periodic monitoring of groundwater levels across India through a network of observation wells. To analyze long-term trends, groundwater levels measured in May 2021 and 2022 were compared with the decadal mean for May (2011–2020). In the Southeast District, all monitored wells showed a decline in water levels.

According to the 2022 Dynamic Ground Water Estimation conducted by the CGWB in collaboration with the Delhi Government, groundwater data for key tehsils is as follows ***Table 5.1.***

Table 5.1: Ground water Resource

SI. No.	Tehsil	Total Annual Ground Water Recharge	Annual Extractable Ground Water	Annual Ground Water Extraction for all	Stage of Ground Water Extraction*	Category

		(ham)	Resource (ham)	uses(ham)	(%)	
1	Defence Colony	1042.35	938.12	916.23	97.7	Critical
2	Kalkaji	1206.98	1086.28	1085.62	99.9	Critical
3	Sarita Vihar	694.14	624.73	613.34	98.2	Critical

As per the latest (March2021) groundwater quality data of NCT Delhi generated by the CGWB, the contaminants found above BIS for drinking water are as follows ***Table 5.2.***

Table 5.2: Ground water Quality

SI. No.	Tehsil	Salinity (ECabove3000 micro mhos/ cm) (EC: Electrical Conductivity)	Fluoride (above1.5 mg/l)	Nitrate (above45 mg/l)
1	Defence Colony	NIL	NIL	NIL
2	Kalkaji	NIL	NIL	NIL
3	Sarita Vihar	NIL	NIL	NIL

As per the Ground Water Quality Report, 1999, the contaminants found above BIS for drinking water are as follows ***Table 5.3.***

Table 5.3: Ground water Quality for drinking

SI. No.	District	Salinity (EC above 3000 micro mhos/ cm) (EC: Electrical Conductivity)	Fluoride (above1.5 mg/l)	Nitrate (above45 mg/l)
1	South east (part of rest while Mehrauli Block)	01/40 samples (2.5%)	02/40 samples (5%)	14/40 samples (35%)

5.1 Data gap analysis and New Data generation

There are 10 Piezometers established in the Kalkaji Tehsil. However, one dug well (key well) has been monitored in the Kalkaji Tehsil. Since no dug wells were observed from the proposed study, new key wells need to be established. It is proposed to establish 15 no's of key wells. However, the study area is taken as consideration of 5km 2km and 1 km to check the impact on land fill on groundwater.

One piezometers locatedinthestudyareaand20additionalkeywellsare established in the demarcated study area to know the actual groundwater condition in and of Okhla landfills. Delhi Jal board and private tube well taken as key wells for monitoring the water level. In the thematic map, total monitoring stations are depicted in ***Fig 5.1.***

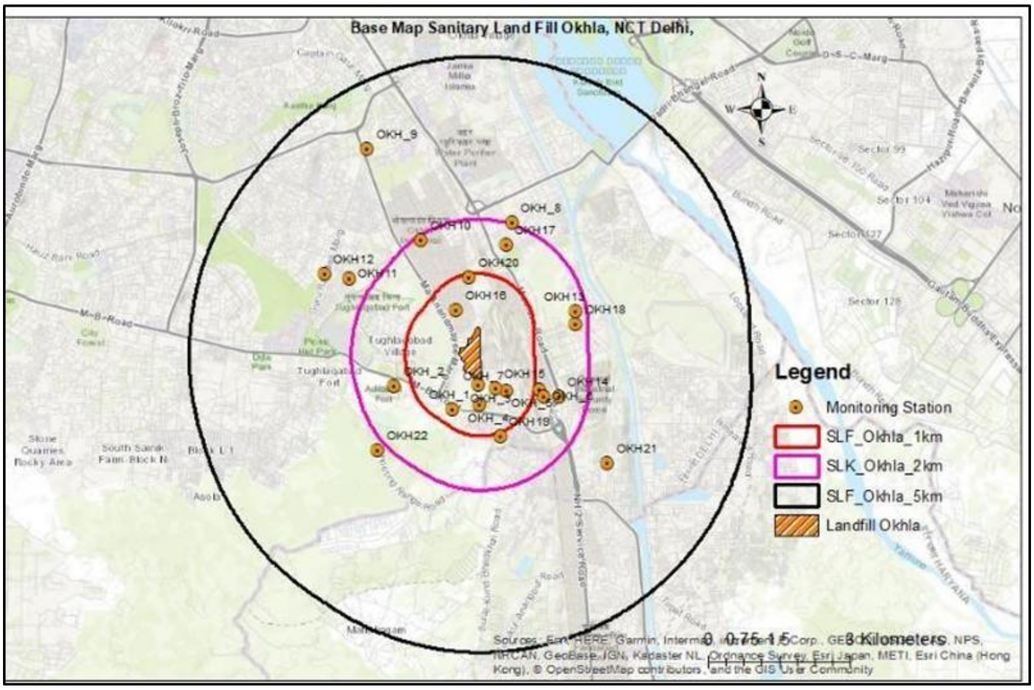


Figure 5.1: Base Map of Okhla land fills

Quality network: One NHS point is located near the Asola bird sanctuary. A total of 7 pre-monsoon samples were collected during the pre-monsoon period and 32 chemical samples were collected during the post-monsoon sample. Out of which three samples collected leachate analysis. Details of the location sampled are shown in the thematic map ***Fig5.2.***

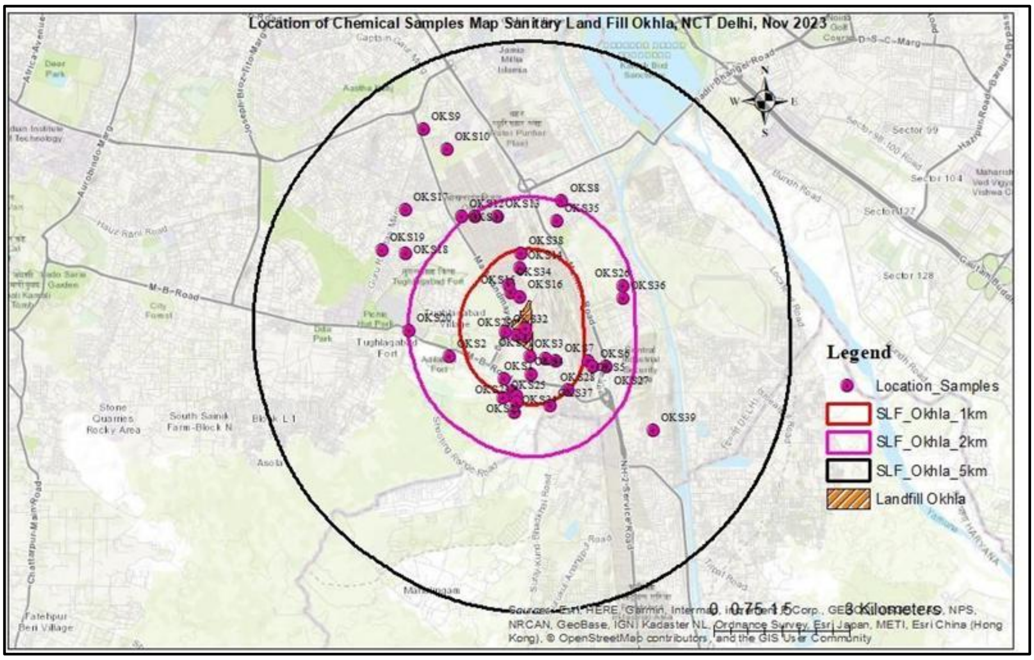


Figure 5.2: Location of Chemical samples Okhla land fills

Subsurface information. For delineation of the aquifer and their disposition, total of 4 bore wells exited in the study area and 11 Vertical electrical sounding data were generated near the Okhla landfills through Sulzberger methods Details of location given in thematic map ***Fig5.2.***

5.2 Geomorphology

The groundwater availability in the Okhla area is controlled by the hydrogeological situation characterized by different landforms developed on different geological formations. The geomorphological map of up to 5km from Okhla landfills is presented in ***Fig 5.3*** and the Study area can be grouped into three broad geomorphic units.

- Rocky surface
- Older Alluvial Plain
- Flood Plain of Yamuna River
- Rocky Surface: The rocky surface represents structurally controlled relict linear ridges and isolated hillocks comprising of rocks of Delhi Super group and isolated hills mostly occurring in the NW and SW of the study area. Tughlakabad- Greater Kailash-Nehru Place and Okhla Ridge are present in the study area which is bifurcated from Mahipalpur, one arm extends towards Mandi and further south while the other arm takes a turn towards the southeast and extends up to Tughlakabad-Greater Kailash-Nehru Place and Okhla. Study area of 279 m above msl.
- Older Alluvial Plain: The gently undulatory terrain on either side of the rocky surface is described as Older Alluvial Plain. This surface is separated from the Yamuna Flood Plain by a bluff. The gently sloping surface including the covered pediment along the eastern flank of the ridge represents the Delhi Older Alluvial Plain. In study area is located towards the northeast and south eastern parts of the area.
- Flood Plain of River Yamuna: The low-lying flat surface representing the Flood Plain of River Yamuna occupying, north eastern and eastern parts of the Okhla and fills is an important geomorphic unit. Northern Eastern side of the Okhla landfill the width of the floodplain varies from1 kmto1.5km and on the eastern side of the land it extends up to3km width. The wider Older Yamuna flood plain indicates lateral migration of river Yamuna over large areas. This belt has good potential for groundwater development. It forms the erosional terrace. The Yamuna Active Flood Plain represents the wide belt bounded on both sides by Eastern and Western bunds and is naturally prone to annual/ periodic floods being in the flood way and flood fringe zone

of river Yamuna. It forms a depositional terrace and is characterized by abandoned channels, point bars,

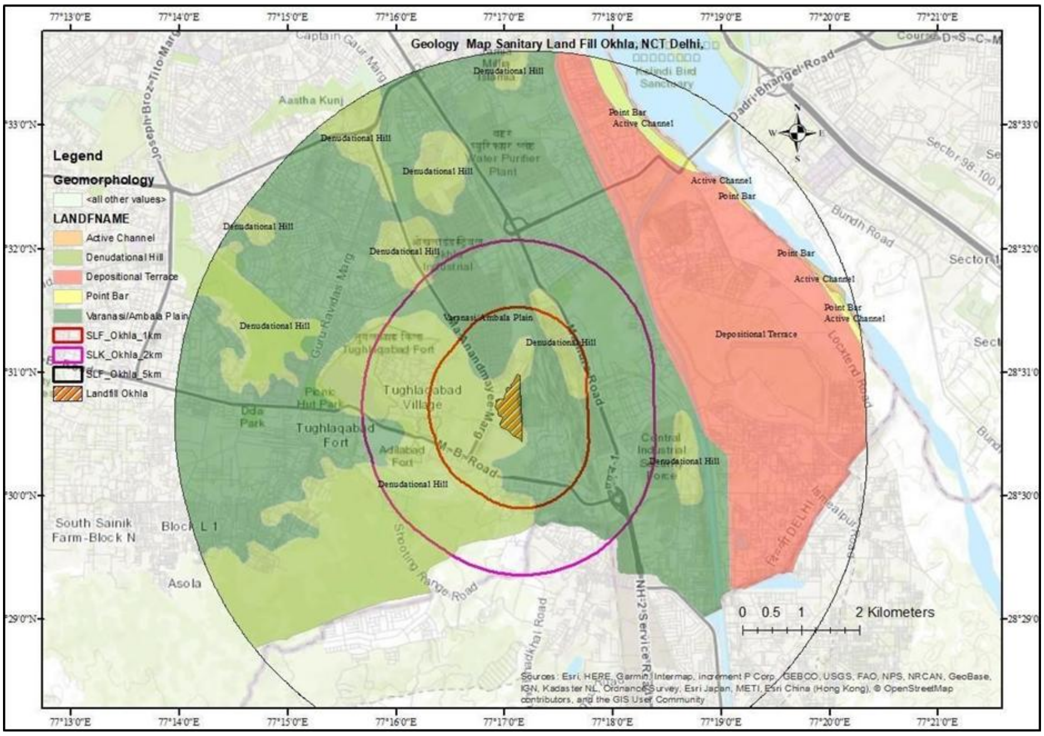


Figure 5.3: Geology map of Okhla land fills

And channel bars in the study area. The presence of several cut-of meanders in the Yamuna Flood Plain suggests oscillatory shifting of the river.

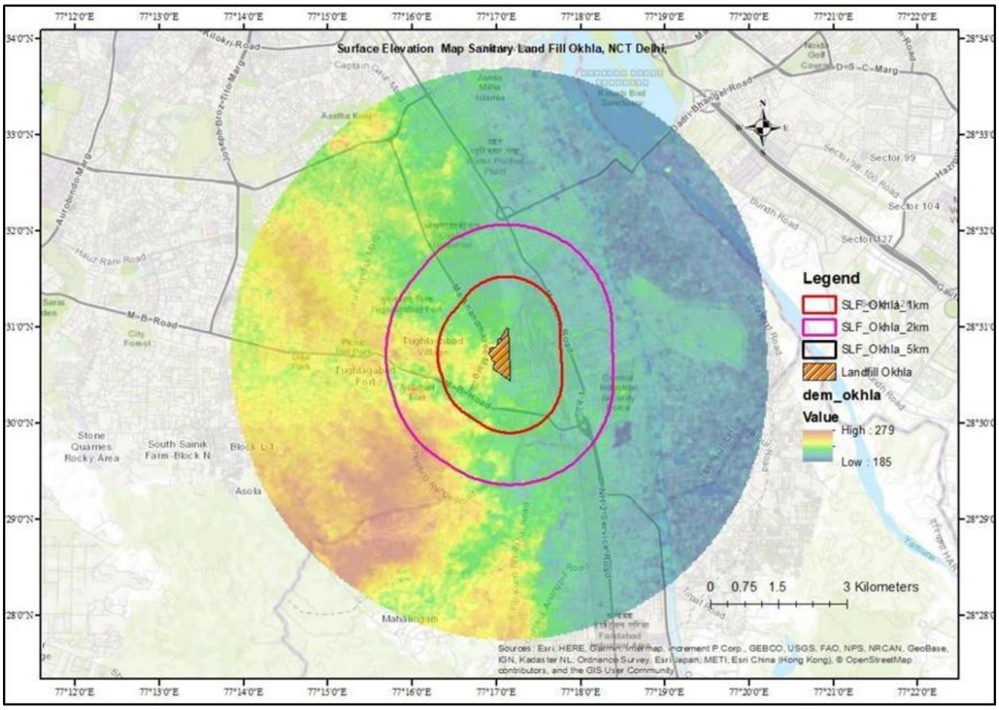


Figure 5.4: Subsurface Elevation map of Okhla land fills

5.3 Soil

The soils of the study area are mostly light with a subordinate amount of medium-texture soils. The texture soils are represented by sandy loam; whereas medium texture soils are represented by loam and silty loam. The soils that occur in the study are generally suitable for irrigating moderately salt-resistant crops such as wheat, barley, and mustard. Two dominant types of soil are present in this area 1.0 Fluventic Ustochrepts &Typic Ustifluvents 2.0 Lithic Ustorthents & Typic Ustorthents fall in the demarcated study area.

5.4 Soil Infiltration Test

Soil infiltration is the process by which water on the ground surface enters into the soil. Infiltration rate in soil science is a measure of the rate at which soil can absorb rainfall or irrigation water. Infiltration rate is defined the volume flux of water flowing into the soil profile per unit of soil surface area and measured in inches per hour or millimetres per hour. The depth (in mm) of the water layer that can enter the soil in one hour usually measures it. The infiltration rate decreases as the soil becomes saturated. Infiltration rates decline to a steady or quasi-steady state as the soil becomes increasingly moist over the period of a storm or experimental wetting. The infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred as the steady-infiltration rate. In dry soil, water infiltrates rapidly in initial phases and called as the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches

Determination of infiltration rates is essential for reliable prediction of surface runoff, saturated hydraulic conductivity of the surface layer, and groundwater recharge, and in developing or selecting the most efficient irrigation methods. Quantifying the soil infiltration capacity is of great importance to understanding and describing the hydrologic analysis and modelling. The measure of infiltration of water into the soil is an important parameter that helps in planning recharge interventions. The classification of infiltration rate is given in ***Table 5.4***

Table 5.4: Classification of Soil Infiltration Rate

Class	Rate of infiltration(mm/hour)	Remarks
Very Slow	<2.5	Soil in this group has a very high percentage of clay.
Low	2.5 – 12.5	Most of these soils are shallow, high in clay, and low in organic matter contents
Medium	12.5 – 25.0	Soils in this group are loam sand silts
High	>25	These soils are deep sands, deep well-aggregated Silt loams, and some tropical soils with porosity.

5.5 Rate of Soil Infiltration in Nearby Okhla SLF, Delhi

In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile need proper chemical management to ensure the protection of groundwater and surface water resources. Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases the detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions. Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions, which reduce biological activity and fertilizer use efficiencies.

Soil infiltration tests using a double-ring infiltrometer were carried out at 2 locations in the study area. Arrange of variations in the infiltration rate has been observed in the study area. The initial infiltration rate in the study area varies from 90 mm/hr to 210 mm/hr and the final infiltration rate is between 3 mm/hr and 12 mm/hr. The average initial and final infiltration rate for the study area is found to be 150mm/hr and 7.5 mm/hr respectively. The average infiltration rate for the study area is estimated as 79 mm/hr. The observed low basic infiltration rates at

certain sites indicate poor percolation of excess water through the sub-surface due to the presence of a hard pan ultimately causing a water logging problem in the area.
The clay percentage in the soil also influences the infiltration rate. Clay particles in the soil may swell as they become wet thereby reducing the size of the pores and reducing the infiltration rate. This explains why the infiltration rates of sandy clay and loamy clay are lower than those of sandy loam soils.

5.6 Hydrology and Drainage in Okhla SLF Study Area:

Drainage is an important element of physical infrastructure and constitutes the removal and disposal of surplus rain/irrigation water from the land. It has two aspects namely flood protection and removal of storm water. The perennial Yamuna River, which flows in the eastern boundary of the state from north to south, plays an important role in the groundwater system of Delhi. The Yamuna River and terminal part of the Aravalli hill range are the two main geographical features of the city. The extremely gentle gradient that spreads almost all over the region restricts the degradation activities of the streams/drains.

The river Yamuna is the only perennial river flowing in a southerly direction. Either side of the river Yamuna is marked by the extensive alluvial floodplain. In general, the alluvial flood plain slope is towards the south. The average slope of the Yamuna River bed from north to south is 0.4 m/km. Eastern and Western Canal and Agra Canal are the three major canals originating from the river. The Agra canal originates from Okhla, about 5km Northeast direction from Okhla Land Fills. Major Kalndi Bird Sanctuary is located 5 km North eastern direction from the Okhla landfills Asola Bird Sanctuary is located 3.5km Southwest direction of the landfills and recently Tuglakabad Biodiversity Park was located adjacent to landfills

6 Hydrogeological framework

6.1 Geology

The rock formations exposed in the National Capital Territory of Delhi are mainly quartzite of the Alwar series of the Delhi Super group that are interbedded with thin micaceous schist bands. Srivastava et al. (1980) grouped these rocks of the Delhi are as the Alwar Formation of the Delhi Super group while Kachroo and Bagchi (1999) classified them as the Barkhol Formation of the Ajabgarh Group of the Delhi Super group. Proterozoic rocks occur along the ridge, extending from Harchandpur (Haryana) in the South to Wazirabad (Delhi) in the North.

Quaternary sediments directly overlie the Proterozoic rocks. The Stratigraphic succession of these rocks reviewed by Kachroo and Bagchi (1999) is given in ***Table 6.1.***

Table 6.1: Stratigraphic succession of rocks in Delhi area (modified after Kachroo and Bagchi, 1999).

Holocene	Yamuna channel alluvium	Grey, fine to medium sand, Grit with coarse sand, silt and clay	Point bars channel deposits
	Yamuna Older Flood Plain &Terrace	Grey sand, coarse grit, pebble beds and minor clays	Paleo channels, meander scrolls, ox- bow lakes
	Older Alluvium	Sequence of sand-silt-clay with yellowish brown medium sand with silt, Kankar with brown Aeolian sand	Abandoned channels, meander scrolls
Unconformity			
Neoproterozoic	Post Delhi Intrusive	Pegmatite, tourmaline-quartz veins, and quartz veins	
Mesoproterozoic	Delhi Super group	Ajabgarh Group–Bharkol Formation	Quartzite with minor schist, tuff and ash beds

Srivastava et al. (1974) and Kachroo and Bagchi (1999) have carried out systematic geological and geomorphological mapping of Delhi and identified three distinct surfaces. The highest is the erosional surface forming the top of denudational hills. The second surface is the Older Alluvial plain and the third is the depositional Younger Alluvial plain (Yamuna). The geomorphologic features have changed due to widespread and uncontrolled urban activity.

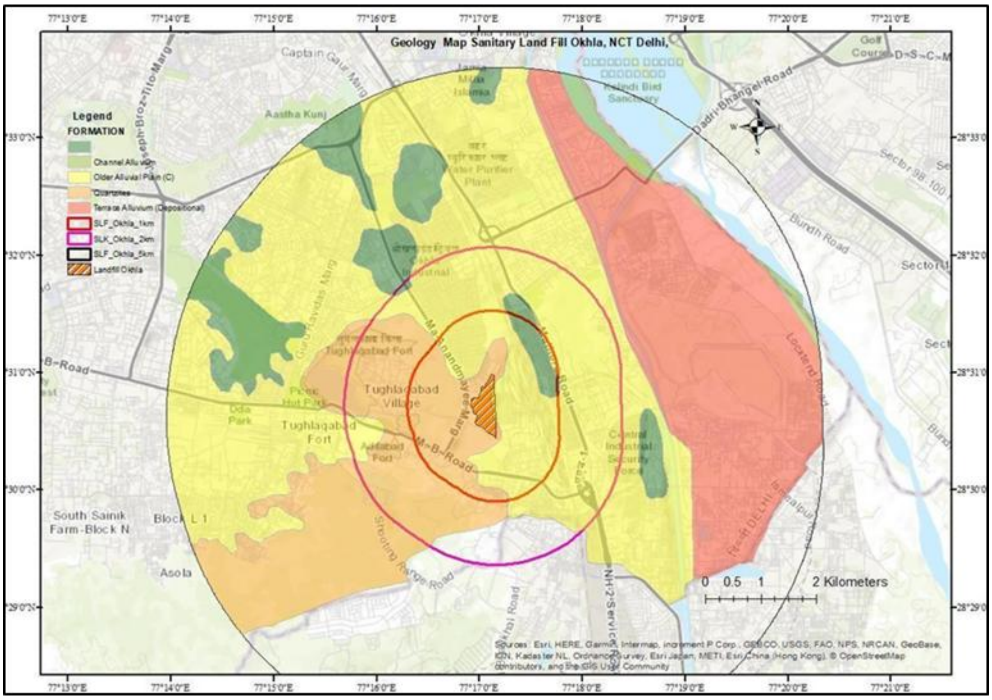


Figure 6.1: Geological map of the Study area.

The Delhi Quartzite ridge acts as the recharge zone. The Quaternary deposits in the form of aeolian and alluvial deposits constitute the major repository of groundwater in the area. In the East of the ridge, the thickness of unconsolidated sediments gradually increases away from the ridge, with the maximum reported thickness being 170m. Older alluvial deposits consist mostly of interbedded, lenticular, and inter-fingering deposits of clay, silt, and sand along with kankar. Newer Alluvium which occurs mostly in the flood plains of river Yamuna.

The rocks of the Delhi system have undergone multiple folding and different phases of metamorphism with time (Naha et al., 1984 and 1987 and Roy, 1988). Three generations of folding have been found in the rocks of Delhi (Gangopadhyay and Sen, 1968). Second-generation folds trending NE-SW are observed in the Tughlaqabad - Mehrauli area,

6.2 Ground Water Exploration

Central Ground Water Board has been engaged in Ground Water Exploration in the National Capital Territory, Delhi since its inception in1972. In the first phase, the work was undertaken during 1972-74 and was resumed in 1985-86, which continued till 1991-92. Exploratory drilling was again taken up in1994-95. Ground Water Exploration since1994-95 was mainly concentrated in the Yamuna Flood Plain area for a detailed study considering the importance of the area from a groundwater point of view. Several piezometers were constructed to monitor the groundwater levels of the state. As per old data available in the district.

Formation: Alluvium

Sl. No.	District	EW	Pz /OW	SH	Depth of the well (mbgl)	Discharge m3/hr	Drawdown (m.)	Transmissivity/ (m2/day)
1	South-East	23	27	00	17-119	7-93	1-12	50-1400

Formation: Quartzite

Sl. No.	District	EW	Pz/OW	SH	Depth of the well (mbgl)	Discharge m3/hr	Drawdown (m.)
1	South-east	08	08	00	51-200	5-31	2-12

Okhla landfill study area is the part In the South East district, the depth explored varies from 18 to 207 m in alluvium and 51 to 200 m in hard rock. In areas underlain by hard rock, the ferruginous and gritty quartzite, on weathering and subsequent disintegration, produces coarse sands commonly known as Badarpur. The overburden is comprised of unconsolidated clay, silt, sand, and varying proportions of kankars. The depth of fresh/saline water interface in the alluvial aquifers away from the ridge varies from 27 m near Okhla barrage to 58 m in Sarita Vihar. Tube wells constructed in alluvium varying in depth from17 –119 m have yielded 7 – 93 m3/hour for a drawdown of 1-12 m. Transmissivity of alluvium varies from 50 – 1400 m2/day. Tube wells constructed in hard rock down to the depth of 51 to 200 m have yielded discharge of 5 to 31 m3/hour with a drawdown of 2-12 m.

6.3 Geophysical investigations

Both surface and borehole geophysical techniques have been used to decipher the aquifer disposition of Study area. Surface geophysical techniques are generally used as a predictive tool, by detecting the anomalies in physical properties and interpreting in terms of surface geophysical and/or hydrogeological conditions responsible for producing the anomalies, whereas the borehole geophysical techniques are used after drilling of a water well to demarcate suitable granular zones in a borehole for optimum development of resources

During exploratory drilling by the Central Ground Water Board, boreholes were electrically logged and depending on the granular zones with fresh groundwater identified by lithology and geophysical logs, assembly to be lowered in the boreholes was recommended. Resistivity surveys have been carried out by CGWB in the study area. South-East districts of Delhi. A total of 11 VES were carried out in the study area.

The Vertical Electrical Sounding (VES) method is effective for determining the variation of Resistivity layering with depth at a given location. This method is based on the response of the earth to the flow of electrical current. Measurement of resistivity is, in general, a measure of water saturation and connectivity of pore spaces. The depth of penetration of resistivity measurements depends on the separation of the potential and current electrodes in the survey and is interpreted in terms of a lithologic and/ or geohydrology model of the subsurface. Data are termed Apparent Resistivity because the resistivity values measured are averages over the total current path length but are plotted at one depth point for each potential electrode pair.

The resistivity data has been interpreted (analysed) in terms of physical parameters viz. resistivity and thickness of the litho-units. These parameters in turn, along with known subsurface geological information have been used to infer the nature of subsurface information. The general ranges of resistivity for different layers in NCT, Delhi are given in ***Table 6.2.***

Table 6.2: Formation/quality-wise range of resistivity in Okhla SLF Study area

Lithology/Quality of groundwater	Resistivity
Top layer with clay	Up to 60 ohm m
Dry sand	> 80 ohm m
Predominantly sand saturated with fresh water	>15to 50 ohm m
Predominantly sand mixed with clay saturated with fresh to brackish water	10-15ohm m
Sand mixed with clay saturated with saline water	< 10 ohm m
Finer sediments with saline water	< 4 ohm m
Hardrock	Rising trend of Curve

6.4 Rainfall:

The climate of the district is mainly influenced by its inland position and the prevalence of air of the continental type during the major part of the year. Extreme dryness with intensely hot summers and cold winters are characteristics of the climate. The cold season starts towards the latter half of November when both day and night temperatures drop rapidly with the advance of the season. January is the coldest month with the mean daily maximum temperature at 21.3ºC and the mean daily minimum temperature at 7.3ºC. May and June are the hottest months. In May and June, maximum temperature may sometimes reach 46 or 47ºC.

6.5 Temperature

The cold season starts towards the latter half of November when both day and night temperature drop rapidly with the advance of the season. January is the coldest month with the mean daily maximum temperature at 21.3ºC and the mean daily minimum at 7.3ºC. In the winter months during cold waves which affect the State in the wake of western disturbances passing across north India, minimum temperatures may sometimes go down to the freezing point of water. From about the middle of March, temperature begins to rise fairly rapidly. May and June are the hottest months. While day temperature is higher in May, the nights are warmer in June. From April the hot wind known locally as ‘loo’ blows and the weather is unpleasant. In May and June maximum temperature may sometimes reach 46 or 47 ºC. With the advance of the monsoon into the area towards the end of June or the beginning of July, day temperatures drop appreciably while the night temperatures remain high. In October the day temperatures are as in the monsoon months but the nights are cooler.

6.6 Rainfall Pattern

The normal annual rainfall in the State is 611.8 mm. About 81% of the annual rainfall is received during the monsoon months July, August and September. The rest of the annual rainfall is received as winter rain and as thunderstorm rain in the pre and post monsoon months. There is large variation of rainfall from year to year. During the 113 year period 1901-2013, 1933 was the year with the highest annual rainfall, which amounted to 251% of the normal. In 1951, the year with the lowest rainfall only 44% of the normal annual rainfall was received.

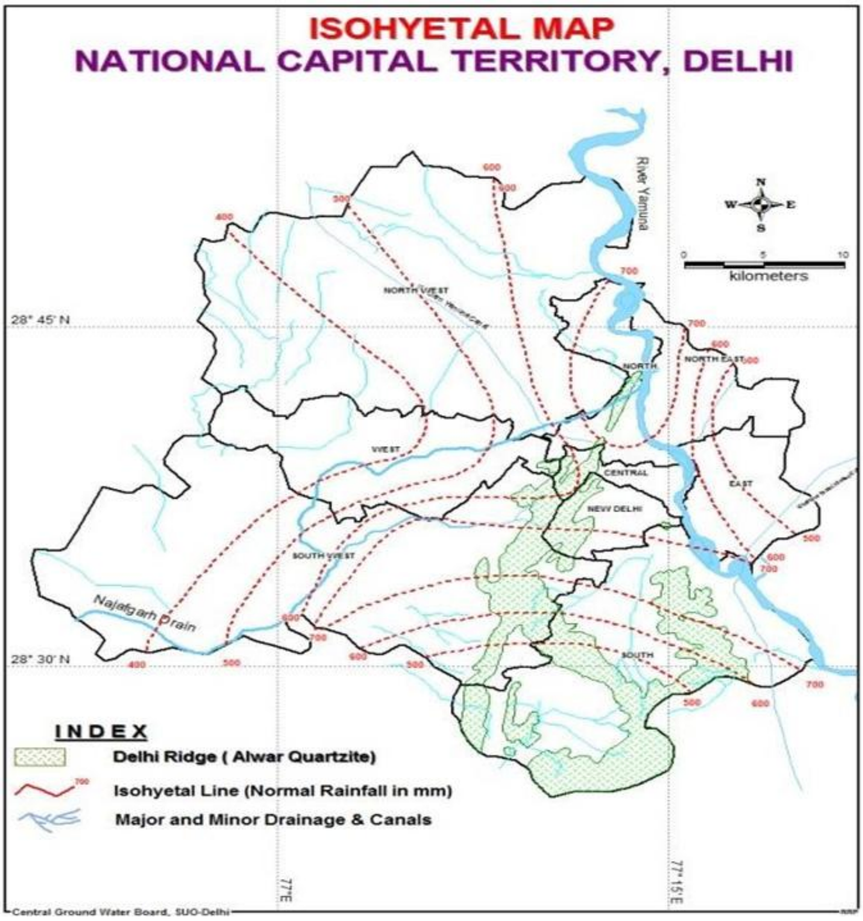


Figure 6.2: Isohyetal Map of NCT Delhi

On an average, rainfall intensity of 2.5 mm or more falls on 27 rainy days in a year. Of these, 19 days are during the monsoon months. Two to three days in June are rainy. In other months, except in November and in the first half of December when it is practically rainless, rain falls on a day or two only in each month. The heaviest rainfall in 24 hours recorded at any station in the State was 495.3 mm at Delhi (Safdarjung) on September 9, 1875. The rainfall in NCT Delhi increases from the Southwest to the Northwest ***Fig.6.2.*** However, a slight increase in rainfall is observed towards Yamuna River. Rainfall in last ten years in NCT, Delhi is given in ***Table.6.3.***

Table 6.3: Year-wise rainfall from 2014 to 2023

Year	Rainfall (mm)
2014	440.4
2015	547.5
2016	656.1
2017	512.49
2018	543.97
2019	499.44
2020	485.4

2021	972.34
2022	668.58
2023	746.58

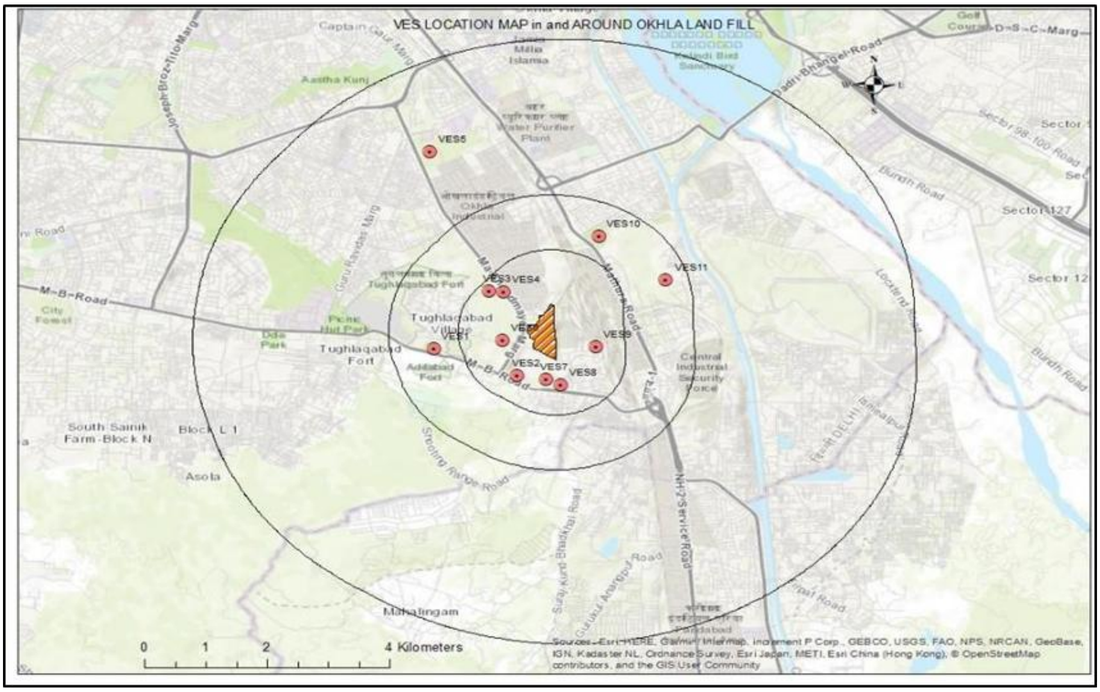


Figure 6.3: VES Location Map of NCT Delhi

6.7 Summary of Exiting Data and New data generated in the study area:

Table 6.4: Data Generated in the study area

S. No	Exploratory data	Chemical data	Geophysical data	Soil Infiltration
Exiting	4	1	0	2
New data	0	39	11	0

Groundwater conditions in the proposed study area:

The Depth to water level recorded in demarcated Area Okhla SLF during June 2023 ranges from 10.19 to 44.9 meters below ground level (mbgl). Groundwater level data from 22 observation wells have been analyzed in the study area. It is observed that 32% of wells in the South Western Part of the Okhla SLF district have shown water levels of more than 30 mbgl and 14% of wells had a water level in the range of 25 to 30 mbgl north eastern and North Western parts of Okhla SLF. In 41% of the wells on the south eastern side of the Lal Kuan area, the water level varied from 20-25 mbgl, and in 9% area water level ranged from 10-20mbgl.

Depth to water level during Post-monsoon (November2023)

The Depth to water level recorded in Okhla SLF during November 2023 varied from 9.1 to 43.97 mbgl. It is observed that 32% of the wells monitored on the South Western Side of Okhla SLF due to hard rock formation water levels of more than 30 mbgl and 15% had water levels ranging in depth from 25 to 30mbgl. In 45% of the wells on the south eastern side respectively water level varied from 20-25 mbgl, in 14% of the area water level ranged from less than 10-20mbgl

Seasonal water level fluctuation:

The fluctuation of water levels between Pre-monsoon (June 2023) and post-monsoon (November 2023) shows a -0.27m to -0.038 m fall in 13% of the wells. Most parts of the study area have registered risen water levels, which varies from 0.01to8.82m. A few localized pockets in Southwest, South, West, New Delhi, East and a major part of Northeast and Northwest districts have registered a decline ***Fig. 6.4.***

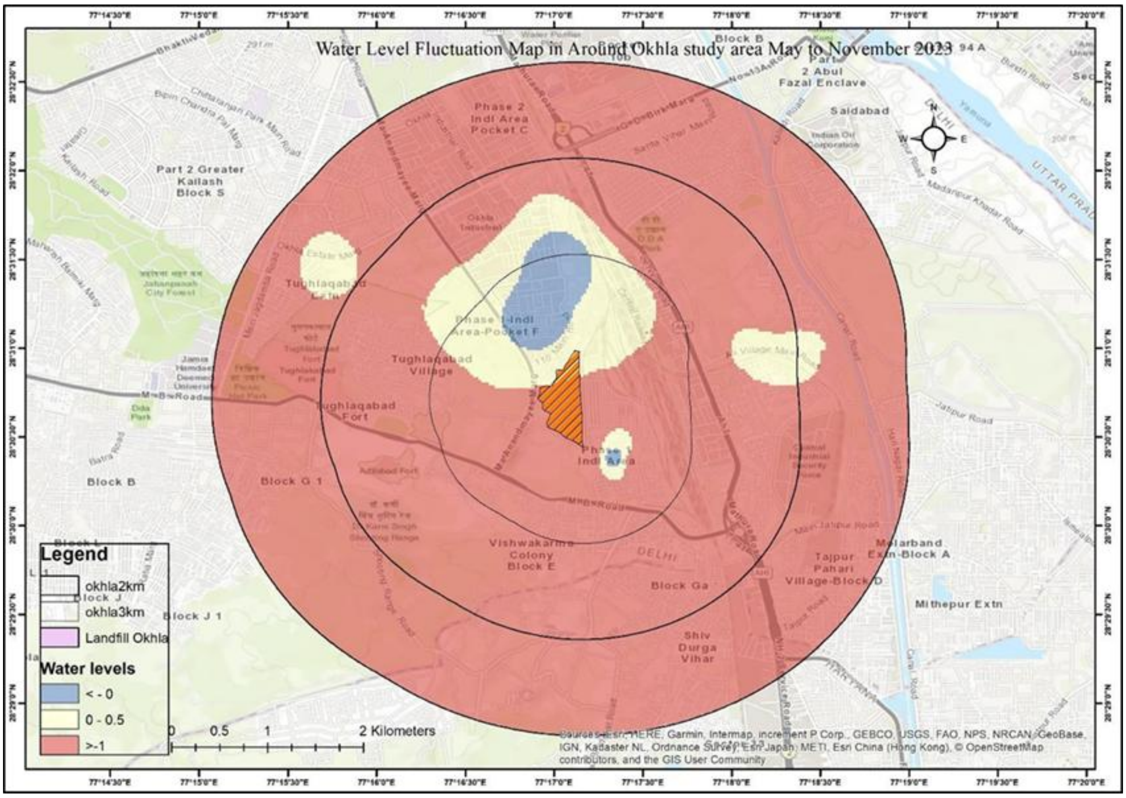


Figure 6.4: Water level Fluctuation map May - Nov 2023

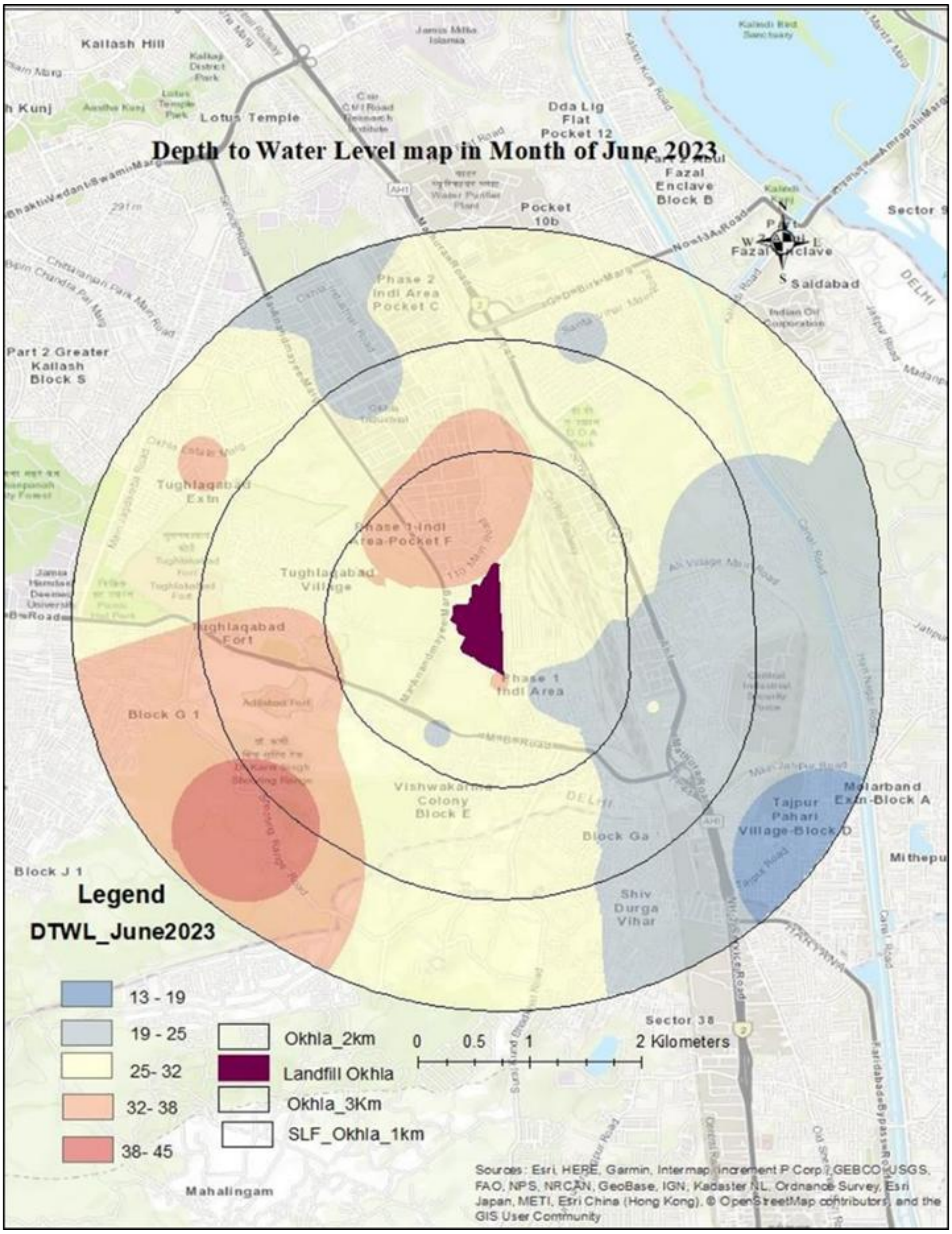


Figure 6.5: Depth of Water level map June 2023

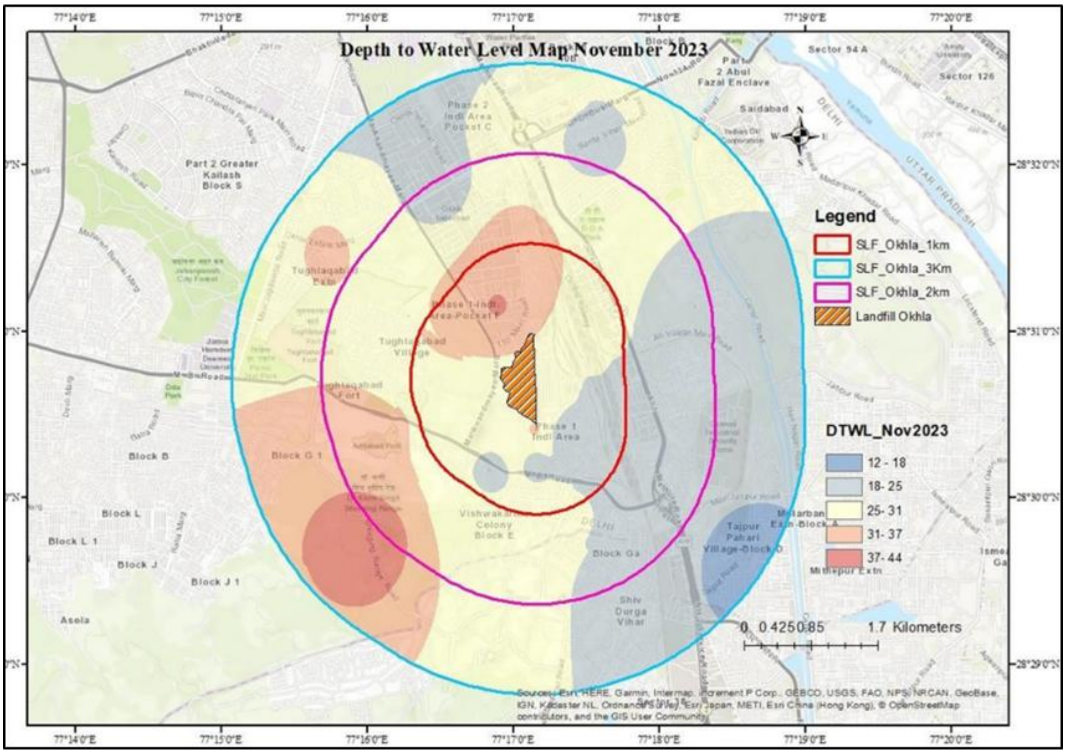


Figure 6.6: Depth of Water level map Nov 2023

Table 6.5: Depth to water level in June, 2023

No. of wells Analyzed	Depth to Water Level (mbgl)		Number& Percentage of Wells Showing Depth to Water Level (mbgl) in the Range of							
			(10-20)		(20-25)		(25-30)		(>30)	
	Min	Max	No	%	No	%	No	%	No	%
22	10.6	44.9	2	9%	9	41%	4	18%	7	32%

Table 6.6: Depth to Water Levels in November, 2023

No. of wells Analyzed	Depth to Water Level (mbgl)		Number & Percentage of Wells Showing Depth to Water Level (mbgl) in the Range of							
			(<10-20)		(20-25)		(25-30)		(>30)	
	Min	Max	No	%	No	%	No	%	No	%
22	9.1	43.97	3	14%	10	45%	2	14%	7	32%

7 Groundwater flow

The water table contour map of June 2023 is presented in ***Fig. 7.1*** the perusal of the map shows that the water table elevation follows the topography of the area and the groundwater flow direction is towards major drainage lines. In Okhla SLF study area Delhi Ridge is located in the North West and South West relative to Okhla SLF. Regional Groundwater flows north eastwards from the ridge towards the river Yamuna. Southern and South eastern sides make mounds due to the undulating topography of the Kaya Maya park area and Lal Kuan area and Groundwater flow follows the slope and overall direction toward the Yamuna River while widely spaced contours on the North western side of the Okhla SLF indicate a gentle slope. In the southwest and toward Ali Village, the water Table contour is almost the same in pre monsoon and post-monsoon.

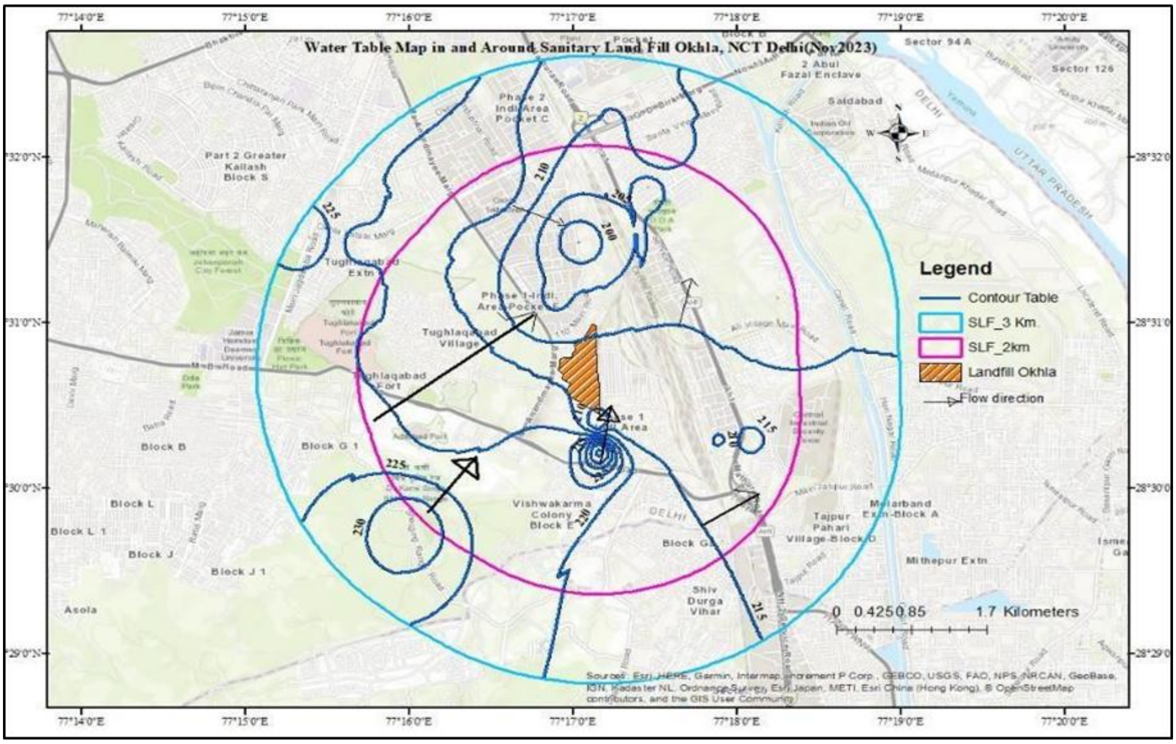


Figure 7.1: Water table map

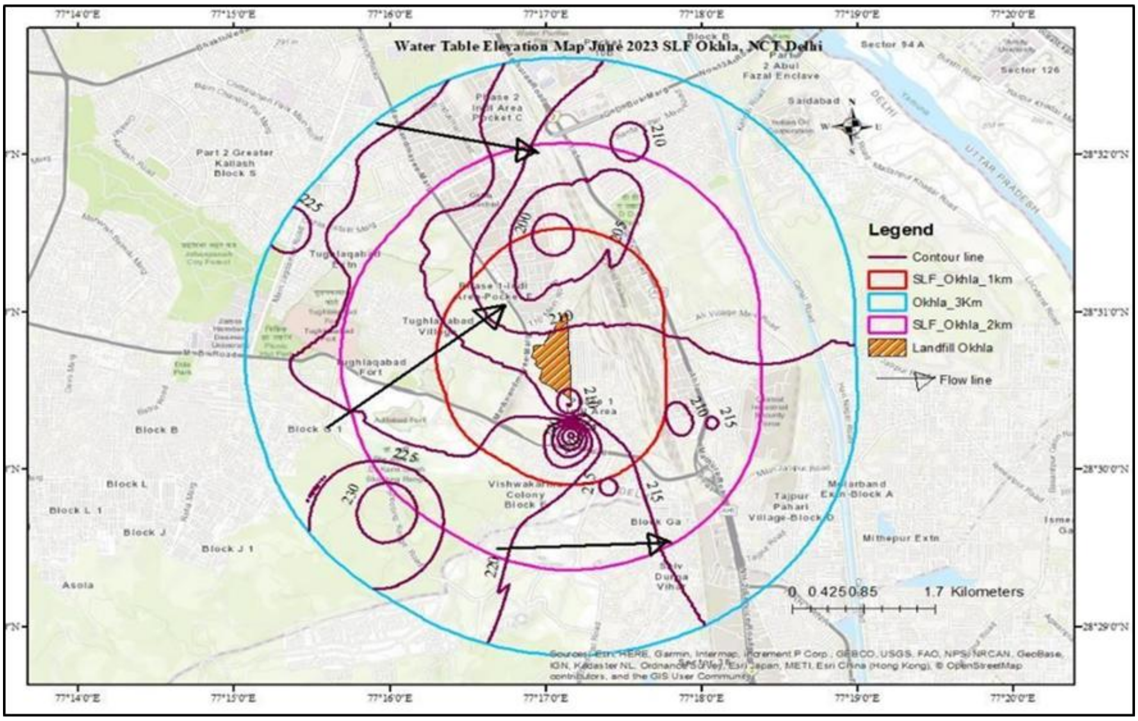


Figure 7.2: Water Table Elevation map

7.1 Aquifer Disposition in Okhla SLF:

Virtually this is the valley-fill deposit and the alluvium thickness varies from 0 to 140 mbgl, below which quarzitic basement rock prevails. The over burden is comprised of unconsolidated clay, silt, sand, and varying proportions of kankars. In the deep basin area, a depth zone of 38 m to 55 m is characterized as a prominent gravel zone admixed with silt and fine sand followed by clayey silt and fine sand with occasional kankar nodules. At deeper levels, medium sand and angular gravels (ferruginous and gritty type quartzites) are also encountered. The areas across southern Delhi Ridge namely Hauz Khas, Saket, Pushp Vihar, Lalkuan, and Sarita Vihar are characterized by marginal alluvium deposits comprising of alternate layers of sand, silt with kankar and clay. The depth of overburden in these areas ranges from 60 to 94m. Below this quarzitic basement rock occurs. The boreholes constructed in quarzitic formation (Jaunapur, Asola, Mandi, and Tugalakabad) reveal that moderately fractured zones are prevalent in the depth range of 30 to 90 m and the fractures gradually decrease as depth increases. The weathered zone is found at every place above hard rock but the thickness of the weathered zone varies from place to place. In hard rock terrain and Chhattarpur basin groundwater is fresh. The depth of fresh/saline water interface in the alluvial aquifers away from the ridge varies from 27 m near Okhla barrage to 58 m in Sarita Vihar.

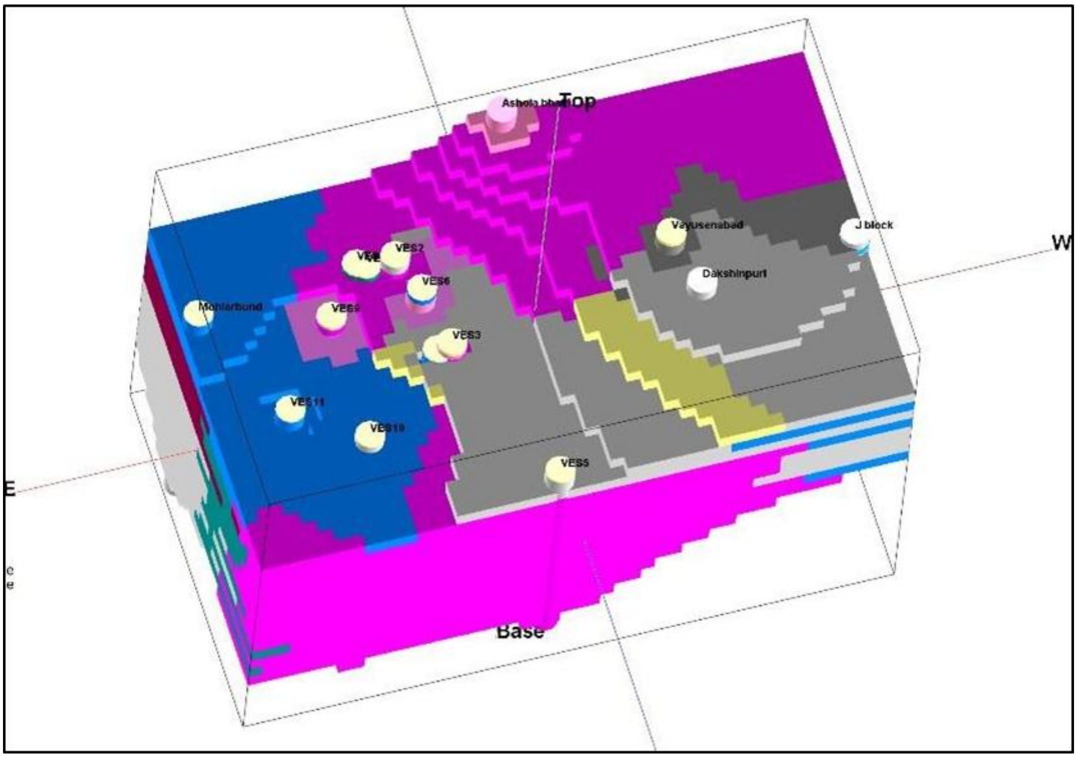


Figure 7.3: VES data

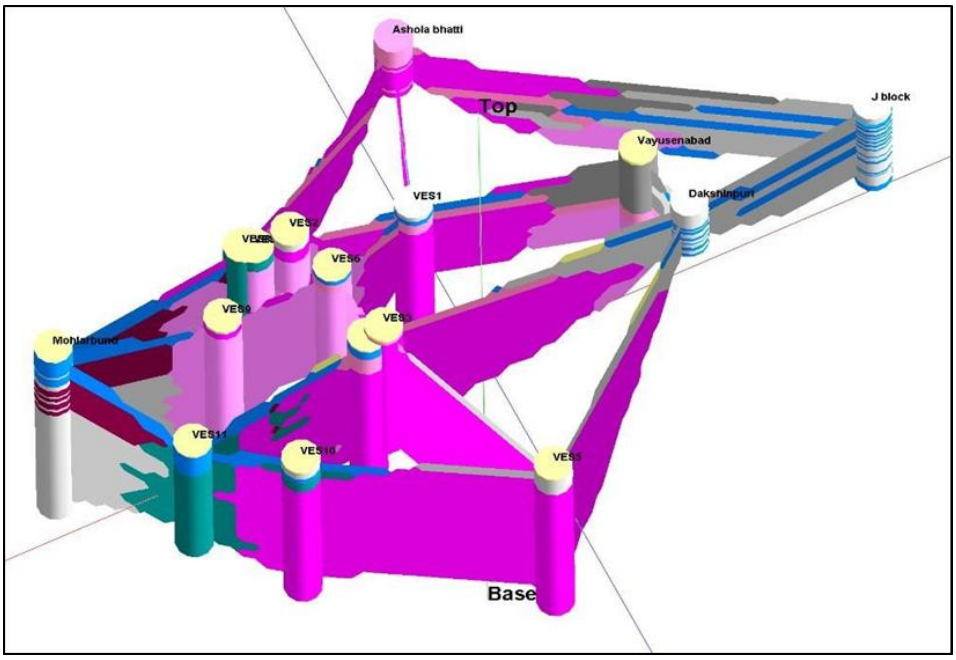


Figure 7.4: VES Cross section

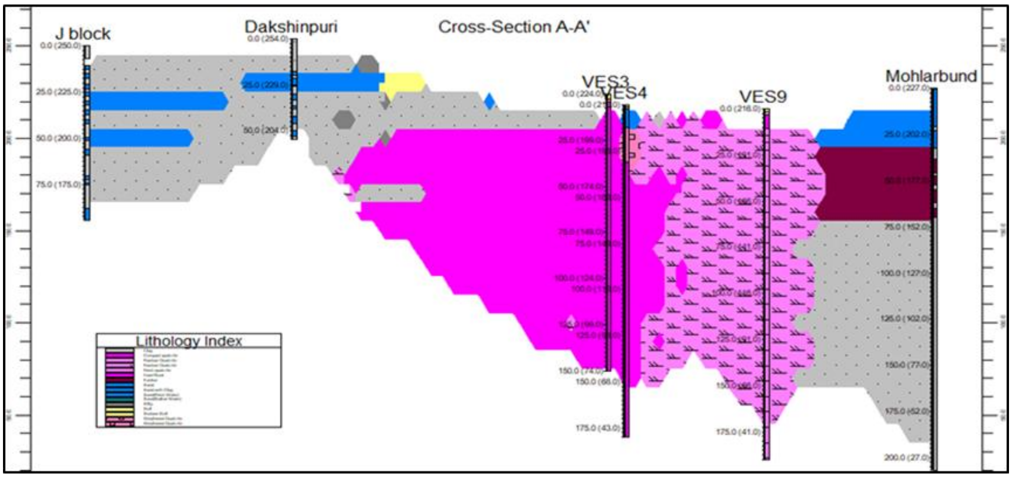


Figure 7.5: VES cross section AA'

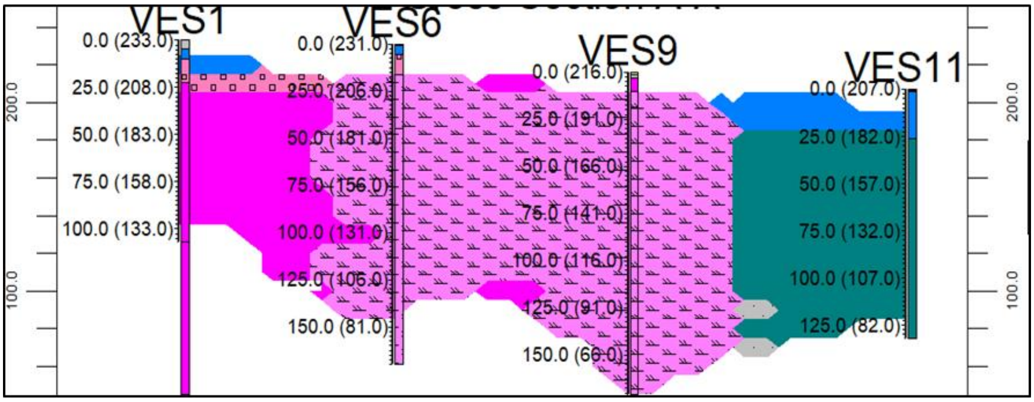


Figure 7.6: VES 1, 6, 9 &11

8 Water Quality

The water quality samples were collected under the NAQUIM Programme from 37 locations distributed throughout the NCT Delhi. In addition, data on groundwater quality available with the Central Ground Water Board has also been utilized for the present study. Summarized data of basic parameters is furnished in ***Table 8.1.***

Table 8.1: Summary of chemical analysis data for basic parameters 37samples)

	Electrical conductivity (µSiemens/cm at 25°C)	Cl(mg/l)	SO4 (mg/l)	F(mg/l)	NO3(mg/l)
Range	289 – 4980	28 - 1030	5 – 705	0.09 – 8.19	1 to 220
The maximum permissible limit as per BIS (IS-10500:2012)	--	1000	400	1.5	45
Samples having basic parameters in excess of the Maximum Permissible Limit)	4	1	4	1	19
Leachates sample range	17680-37680	--	-	0.88-0.95	-

8.1 pH:

The pH of the analysed samples varies from 6.97 – 8.68 indicating mildly acidic to alkaline nature of the groundwater. The pH values are well within the safe limit of 6.5-8.5, prescribed by BIS for drinking water (IS10500:2012). One sample is located in the Lal Kuan parking area having pH of 8.54.

8.2 Total Hardness (TH)

Classification of groundwater samples based on Total Hardness is given in Table 5.2. TH has been found to vary between 80 mg/l and 1340 mg/l, indicating hard to very hard types of groundwater. 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, anencephaly, parental mortality, and cardiovascular disorders. In the Okhla landfills study area, total Hardness exceeds the recommended maximum permissible limit of 600 mg/l (IS-10500: 2012) in 17% of the total analyzed ground water samples. Total hardness over the maximum impermissible limit tube well located in the low laying area near Hanuman Temple, Tuglakabad Railway station, Tuglakabad Fort, Okhla area.

Table 8.2: Hardness Classification of water

Hardness(mg/l)	Water Class	%Sample
0-75	Soft	Nil
75-150	Moderately Hard	3%
150-300	Hard	27%
>300	Very Hard	70%

8.3 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 ground water are controlled by the mineral dissolution rate, chemical character of groundwater, and ionic saturation status of the solution. The concentration of total dissolved solids in the groundwater has been found to vary generally between 188 mg/l to 3302 mg/l. TDS of 39% of analyzed water samples falls in the category of fresh water,while61%ofsamples have TDS in therangeof1000 -10,000 mg/l and fall in the brackish water category (Table 5.3).TDS over the maximum permissible limit of 2000 mg/l (IS-10500:2012) has been reported for 4 samples, the lalkuan area near the landfill site, Tuglakabad railway station. All three samples of leachates have more than 2000mg/l.

Table 8.3: Classification of water based on Total Dissolved Solids

TDS(mg/l)	Water Quality	%Samples
0-1000	Fresh water	43
1000-10,000	Brackish water	57
10,000-100,000	Saline water	Nil
>100,000	Brine	Nil

8.4 Electrical Conductivity (EC)

The distribution of Electrical Conductivity in groundwater in Okhla landfills Study area ***Fig. 8.4.*** 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 Delhi has been found to vary from 289 to 4980 µS/cm at 25ºC. A maximum concentration of 4980 µS/ cm has been reported from a low-laying area near landfill site

Lalkua. The spatial variation of EC shows a relatively higher value at some sites. EC in excess of 3000 µS/cm value has been observed in parts of South East, and Southern Direction of Landfills districts. Because of finer sediments in the aquifer, flushing of groundwater is not proper, and the 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. Leachate samples have a range of 17680-37680 µS/ cm.

8.5 Major Anions (F^{-}, Cl^{-}, $HCO3^{-}$, $SO\ 2^{-}$ and $NO3^{-}$)

The anion chemistry of the analyzed samples shows that $HCO3^{-}$ and Cl^{-} are the dominant anions both in shallow and deep aquifers and follow the abundance order of $HCO3^{-}>Cl^{-}>SO\ 2^{-}>NO3^{-}> F^{-}$ in majority of the groundwater samples. The contribution of anions towards the total anionic charge balance is shown in ***Fig. 8-1.***

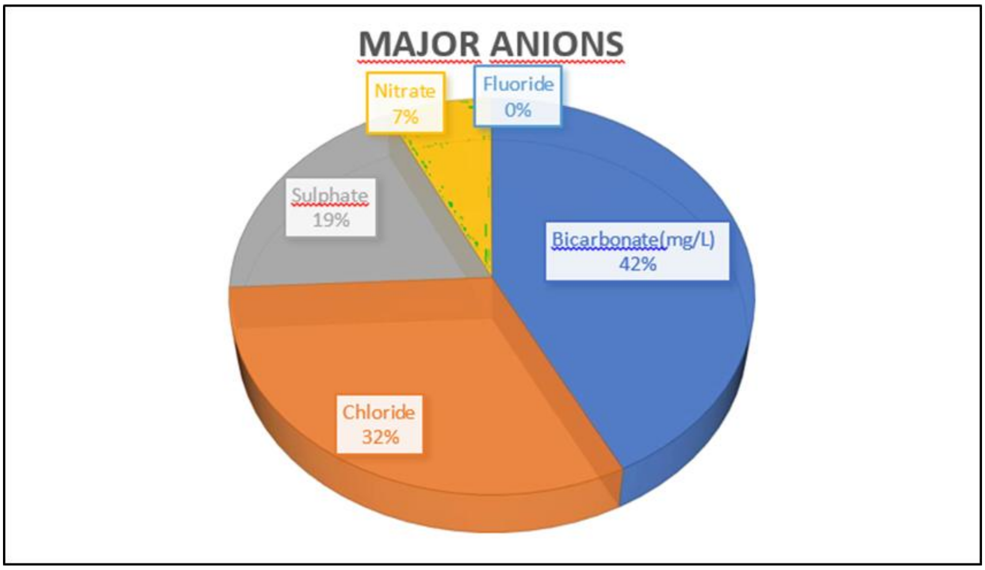


Figure 8.1: Major Anions

Bicarbonate ($HCO3^{-}$) is the most dominant anion, contributing 42% of the total anionic (TZ-) mass balance in equivalent units ***Fig 8.1.*** Concentration of bicarbonate varies from 98 mg/l to 683 mg/l. The highest concentration of bicarbonate has been reported from the Tuglakabad Fort Tubewell. Bicarbonates are derived mainly from the soil zone CO2 and at the time of weathering of parent minerals or from the dissolution of carbonates and/ or silicate minerals by the carbonic acid.

Chloride (Cl^{-}) concentration varies between 28 and 1030 mg/l. On average, chloride contributes32% to the total anionic mass balance in equivalent units ***Fig 8.1.*** The large lateral variation in the chloride concentration and observed high concentration in some samples indicate local recharge and may be attributed to contamination by untreated industrial and domestic waste effluents from nearby areas. A higher concentration of Cl^{-} in drinking water gives a salty taste and has a laxative effect in people not accustomed to it. The concentration of Cl^{-} exceeds the desirable limit of 250 mg/l (IS-10500: 2012) in 45% of analyzed samples and the maximum permissible limit of 1000 mg/l in only one analyzed sample. The chloride concentration of more than the maximum permissible limit has been reported from localized pockets in the Northwest, of the landfill site.

The concentration of sulfate varies from 5mg/l to705mg/l and it accounts for 19% of the total anionic charge balance ***Fig. 8.1.*** Sulfate concentration exceeded the desirable and maximum permissible drinking water limits of 200 mg/l and 400 mg/l values respectively (per IS-10500:2012) The observed high concentration in some samples indicates the effects of industrial and anthropogenic activities in the area. High sulfate concentration may have a laxative effect with an excess of Mg in water. Waters with 200 - 400 mg/l of sulfate have a bitter taste and those with 1000 mg/or more of sulphate may cause intestinal disorders and respiratory problems. Sulphate may also cause corrosion of metals in the distribution system, particularly in water having low alkalinity.

The concentration of nitrate has been found to vary from 1.0 mg/l to 220 mg/l. On average, nitrate contributes 7% to the total anionic charge balance Nitrate concentration marginally exceeds the maximum permissible limit of 45mg/l in drinking water prescribed by BIS(IS-10500:2012) in around 54% of the total groundwater samples. Nitrate in excess of the maximum permissible limit has been reported from localized pockets in all directions of the Okhal landfill, High nitrate concentration in groundwater has been reported along the drains carrying sewage and thus can be attributed to contamination from domestic sewage ***Fig. 8.1*** Excess nitrate in drinking water can cause methemoglobinemia in infants, gastric cancer, goiter, birth malformations, and hypertension.

Fluoride is an essential element for maintaining normal development of healthy teeth and bones. However, higher F- concentration causes dental and skeletal fluorosis such as mottling of teeth, deformation of ligaments, and bending of the spinal cord. The concentration of fluoride in ground water samples has been found to vary between 0.09 and 8.19 mg/l. Fluoride is contributing <1.0% to the total anionic charge balance ***Fig. 8.1.*** The concentration of F- exceeds the maximum permissible limit of 1.5 mg/l (IS-10500: 2012) in 34% of the total analyzed samples ***Fig. 8.1.***

8.6 Major Cations (Ca, Mg, Na, K)

The major cations include Ca, Mg, Na and K. The water chemistry of the Okhla landfill study area marginally dominated by alkali (Na + K) metals over the alkaline earths (Ca +Mg). $Ca2+$ and$Mg2+$together constitute 40% of the total cations (TZ+). The cation chemistry indicates that in general ground water belongs to Na>Ca>Mg>K water type. The weathering and cation exchange processes normally control the levels of these cations in the ground water. Contribution of various cations towards the total cationic charge balance is shown in ***Fig. 8.2.***

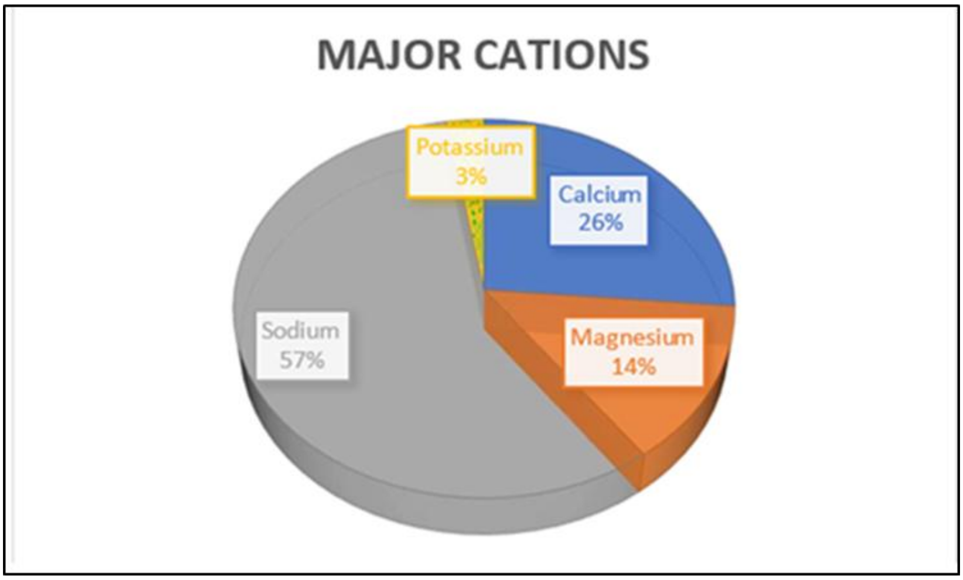


Figure 8.2: Major Cations

Sodium (Na+) is the most dominant cation in ground water in in the Okhla landfills study area contributing 57% in the cationic charge balance ***Fig. 8.2.*** Concentration of sodium has been found to vary from 7 to 515 mg/l. Sodium is the most important for human health. A higher sodium intake may cause hypertension, congenial heart diseases, and nervous disorder and kidney problems. Contamination of ground water by Na and Cl is common in growing urban areas. Sources of these ions are related to human activities including road salt, effluent from industries, leachate from landfills, some agricultural chemicals. Natural sources include rock water interactions, saline seeps and minor atmospheric contributions.

Concentration of potassium ranges between 2mg/l and 37.1mg/l. Maximum concentration has been reported from South West direction of landfills. Potassium is accounting for only 3% of the total cationic mass balance ***Fig. 8.2.***

Calcium (Ca) accounts for 26% of the total cationic mass balance ***Fig. 8.2.*** It is an essential element for bone, nervous system, and cell development. Ca2+ and Mg2+ are the main contributors to hardness. The possible adverse effect of ingesting high concentrations of Ca for long periods may be an increased risk of kidney stones. Concentrations of Ca^{2+} and Mg^{2+} are exceeding the drinking water desirable levels (IS-10500:2012) of 75 mg/l and 30 mg/l respectively in about 51% and 54%of the analyzed samples. However, concentrations of both these ions are exceeding the maximum permissible levels of 200 and 100 mg/l respectively in 8.5% and 12% of the total samples. The concentration of Ca in groundwater varied from 0 mg/l to 324 mg/l. Calcium in excess of the maximum permissible limit has been reported from localized pockets in. The concentration of Mg varies from 5 mg/l to 207 mg/l constituting about 14% of the total cationic charge balance ***Fig. 8.2.*** Magnesium in excess of the maximum permissible limit has been reported from the major part of. Sporadic instances of excess Mg have been reported from in all directions of the landfills.

8.7 Water Type and Hydro-chemical Facies

The Hill and Piper plot is very useful in determining relationships of different dissolved constituents and the classification of water based on its chemical characteristics. The triangular cationic field of the Piper diagram reveals that the groundwater samples fall into no dominant and Na + K class, whereas in the anionic triangle majority of the samples fall into bicarbonate, Chloride, and no dominant fields ***Fig. 8.3.*** The plot of chemical data on the diamond-shaped filled toward Ca and Mg, which relates the cation and anion triangles revealed that the major water types in Okhla landfill studyareaNa-K-Cl-SO_4, Ca-Mg-HCO_3, and of mixed chemical character i.e. Ca-Mg-Cl-SO_4, Na-K-HCO_3-Cl.In the majority of the groundwater samples, alkali metal cations (Na^++K^+) are slightly exceed the alkaline earth-metals (Ca^{2+}+Mg^{2+}).In general, the groundwater exhibits the dominance of SO_4^{2-}+Cl^-(strong acid) over weak(HCO_3) acid. The facies mapping approach applied to the present study shows that Ca-Mg-Cl- SO_4 and Na-K—Cl- SO_4 are the dominant hydro geochemical facies in the groundwater.

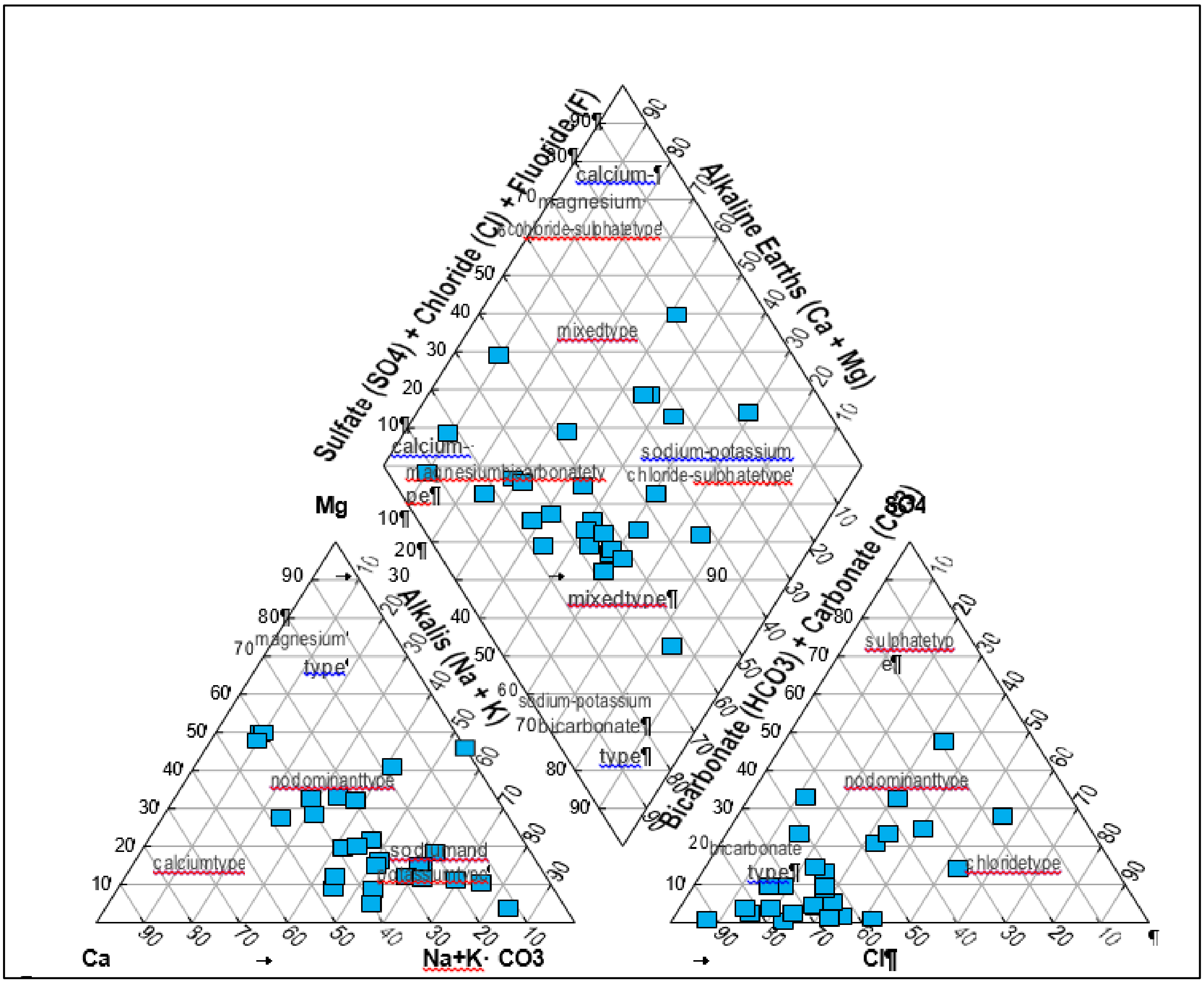


Figure 8.3: Hill and Piper plot showing water type and hydro-chemical facies

8.8 Heavy/Trace Metal Distribution

Summarized data of chemical analysis results in respect of heavy metals is furnished in ***Table 8.4.***

Table 8.4: Summary of Heavy Metal analysis data

(Units in mg/l)	Range	Maximum Permissible Limit as prescribed by BIS (IS-10500:2012)	Samples having heavy metals in excess of Maximum Permissible Limit (%)
Fe	0.058– 2.79	1.0	2
Mn	<0.003 – 4.709	0.3	3
Zn	0.052-1.79	15	Nil
Cu	<0.002 - 0.021	1.5	Nil
Cr	<0.00-0.052	0.05	1
As	BDL-0.003	0.05	Nil
Pb	0.001to0.005	0.01	Nil

The concentration of Iron (Fe) has been found to range from 0.052 mg/l to 2.79 mg/l and exceeded the maximum permissible limit of 1 mg/l in 6% of the total analyzed groundwater samples. Iron in excess of the maximum permissible limit has been reported from –C block near landfills site southern side and Tuglakabad railway colony's eastern side of landfills. The concentration of iron in natural water is controlled by both physicochemical and microbiological factors. Manganese (Mn) concentration in groundwater was found to vary from <0.003 mg/l to 4.709 mg/l. The concentration of Mn exceeds the prescribed maximum permissible limit of 0.3 mg/l(IS-10500:2012) in 9% of groundwater samples. Sporadic occurrences of excess Manganese have been reported toward Lal Kuan on south eastern side of the landfills. Most common sources of iron and manganese in groundwater are naturally occurring, for example from weathering of iron and manganese-bearing minerals and rocks. But here natural sources are not available. Industrial effluent, sewage, and landfill leachate may also contribute iron and manganese to local groundwater.

Zinc (Zn) concentration in groundwater varies between 0.052 and 1.787 mg/l, which is well within the maximum permissible limit of 15 mg/l as prescribed by BIS Drinking Water Standards (IS-10500:2012).

Concentrations of Copper (Cu) and Chromium (Cr) varied from 0.002 mg/l to 0.021/l and BDL to 00.052 mg/l respectively in the analyzed groundwater samples. The concentration of Cu is well within the maximum permissible limit of 1.5 mg/l (IS- 10500:2012). Sporadic instances of Cr concentration exceeding the maximum permissible limit of 0.05mg/l have been reported from the Okhla phase 2 market area.

The concentration of Arsenic (As) in groundwater has been found to vary from Below the Detection Limit to 0.003 mg/l. All the samples analysed fall within the maximum permissible limit of 0.05 mg/l prescribed by BIS in drinking water (IS-10500:2012).

8.9 Bacteriological Contamination

The bacteriological test carried out in twelve groundwater samples of the Okhla and fills study area shows the presence of total coliform in one sample and fecal coliform in nil samples ***Table 8-5***. As per BIS (IS-10500:2012), coliforms should not be detectable in any 100 ml sample. Groundwater contamination from fecal-coliform bacteria is generally caused by water percolation in to the aquifer from a contamination source like domestic sewage, drains, and Septic tanks The poor sanitation around the source water also causes bacteriological contamination. Shallow wells are particularly susceptible to such contamination.

Table 8.5: Bacteriological Testing around water samples around the Okhla landfills

S. No.	Latitude	Longitude	Sample bottle	Source	Total coliform	Fecal coliform
1	28.50677	77.285854	60	TW	Nil	Nil
2	28.50357	77.286024	262	TW	Nil	Nil
3	28.50064	77.2823	209	TW	Nil	Nil
4	28.51732	77.284013	273	TW	20000	Nil

TW=Tube Well

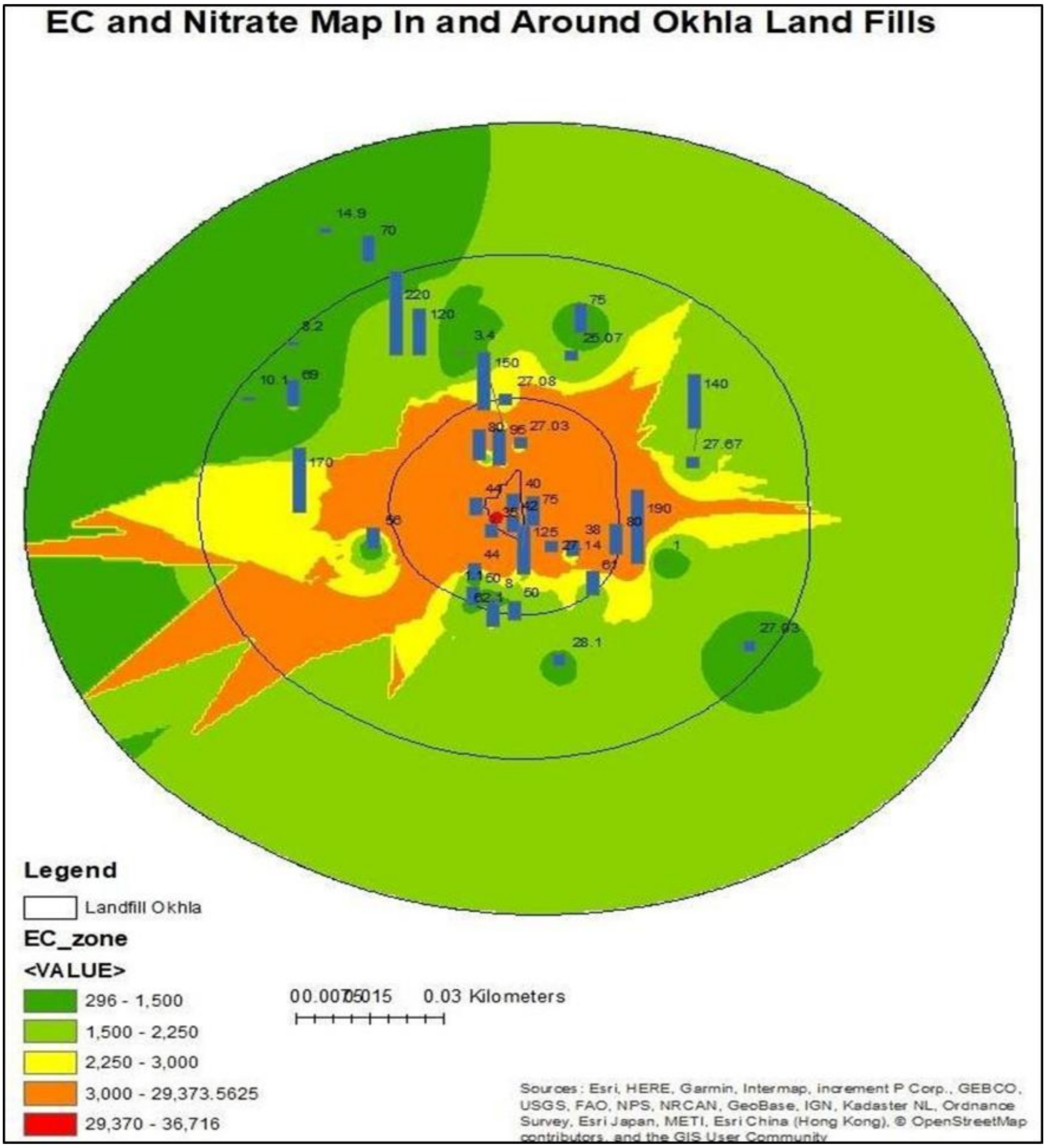


Figure 8.4: EC & Nitrate map

8.10 Suitability for Irrigation:

For assessing the suitability of water for irrigation, total salt concentration (EC), sodium adsorption ratio (SAR),

The total concentration of soluble salts in irrigation water can be expressed as low (EC = <250 µS cm- 1), medium (250 - 750 µS cm-1), high (750 - 2250 µS cm-1), and very high (2250 - 5000 µS cm-1) salinity zone. While a high salt concentration (high EC) in water leads to the formation of saline soil, a high sodium concentration leads to the development of alkaline soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio (SAR). It can be estimated by the formula:

SAR = Na/ [(Ca + Mg)/2]0.5

Irrigation waters are classified into four categories on the basis of sodium adsorption ratio (SAR) and EC ***Table 8.6.***

Table 8.6: Water classification based on SAR and EC

SAR	Water Category	EC µS cm-1	Water Category
0 – 10	Excellent (S-1)	<250	Low (C-1
10 – 18	Good (S-2)	250-750	Medium (C-2)
18 – 26	Fair (S-3)	750-2250	High (C-3)
>26	Poor (S-4)	>2250	Very High (C-4)

The calculated value of SAR in the study area ranged from 0.26 – 33.72. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the water samples fall in the category C3S1, C3S2, C4S2 and C4S3 indicating high to very high salinity and low and very high alkali water. This water can be used only for plants with good salt tolerance ***Fig. 8-5.***

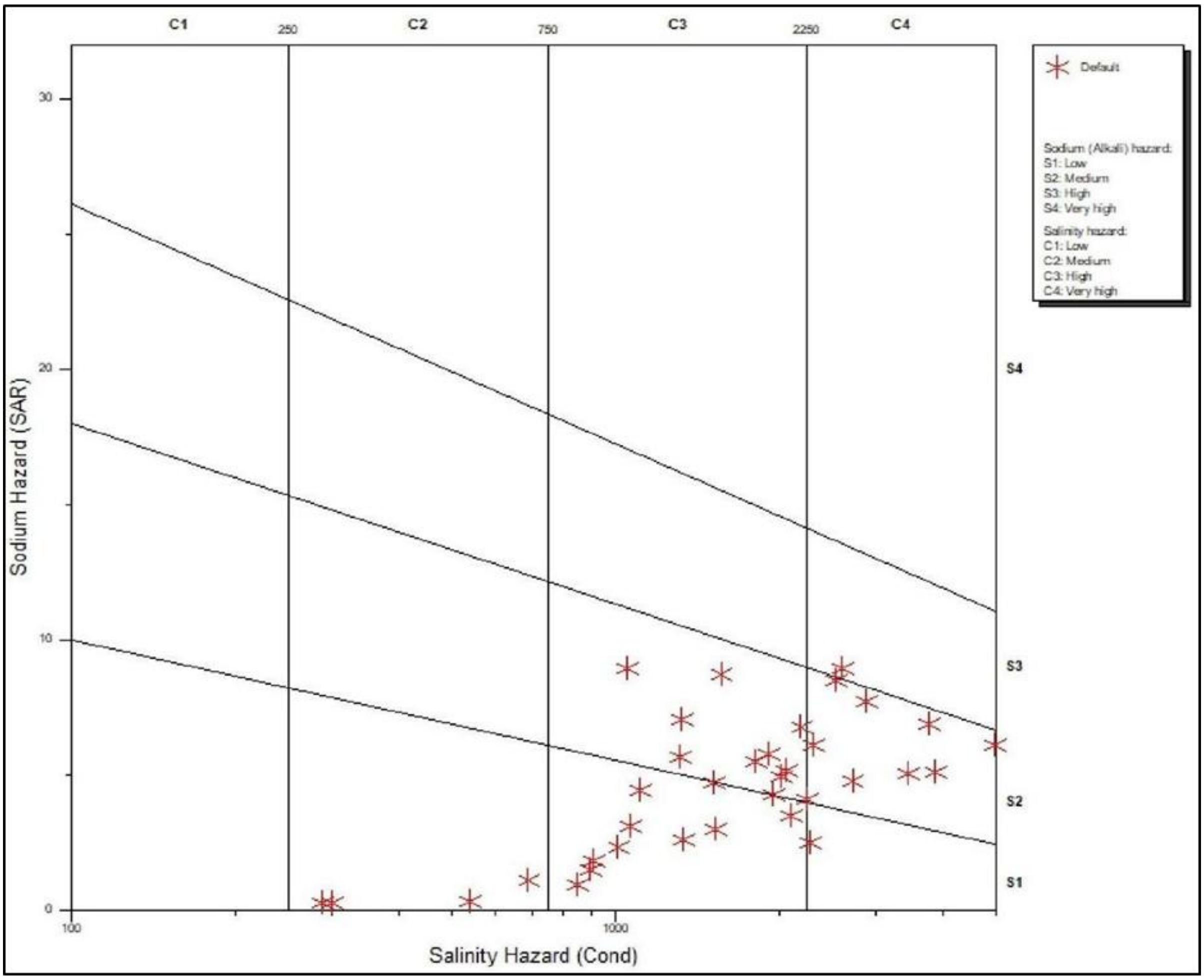


Figure 8.5: US Salinity diagram for classification of irrigation waters

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. Very high saline water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and salt tolerance crops/plants should be selected.

Low sodium (alkali) water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchange able sodium. Medium sodium water will present an appreciable sodium hazard in fine textured soils having high cation exchange capacity especially under low leaching conditions. This water can be used on coarse textured or organic soils with good permeability.

Stakeholder’s feedback: Stakeholder feedback is taken into consideration sample collected from the Basti area located near Hanuman temple shows major skin disease issues and tainted yellowish color water observed in this area. A similar situation was observed in the Lalkuan area they also talked about skin disease. Some areas near the railway colony Tehkhand railway area talked about low water discharge. A total 5 feedback forms were collected

As discussed in the field with the locals, it has been learned that the locals do not consume the groundwater for drinking purposes. Hence the health issues related to the groundwater could not be ascertained. For precise demarcation of groundwater contamination, a total of 32 samples

- Out of 32 samples four samples were collected from leachates.
- Leachates analysis: PH, EC, and nitrate parameter analyses

Preparation of suitable recharge plans for the proposed area to arrest the pollution plume movement and preparation of alternate water supply plan for the people living in the vicinity of the SLF

9 Estimation of Leachate Generation from Municipal Solid Waste Using Standard Methods

The management of municipal solid waste (MSW) poses significant environmental challenges, particularly in the context of leachate generation is a liquid that forms as water permeates through waste material. A standard method for estimating the volume of leachate is recognized for its simplicity and effectiveness, leading to its continued adoption in various countries. This method, characterized by the use of a fixed coefficient, offers a pragmatic approach to gauge leachate volumes while acknowledging inherent limitations.

In this model, a coefficient of 0.15 is employed to account for the varying losses occurring in a landfill over time. Specifically, the quantity of leachate produced is estimated as a fraction of total precipitation, with approximately 75% of rainfall contributing to leachate generation during the active phase of a landfill. Conversely, during the closed phase, this contribution diminishes to less than 10%. This disparity highlights the dynamic nature of leachate production, which correlates directly with both precipitation levels and the waste's physical characteristics, such as its height.

The relationship for estimating leachate volume is expressed mathematically by the equation

$V=0.15\times R\times AV=0.15\times R\times A$

Where VV represents the annual volume of leachate discharge in cubic meters per year

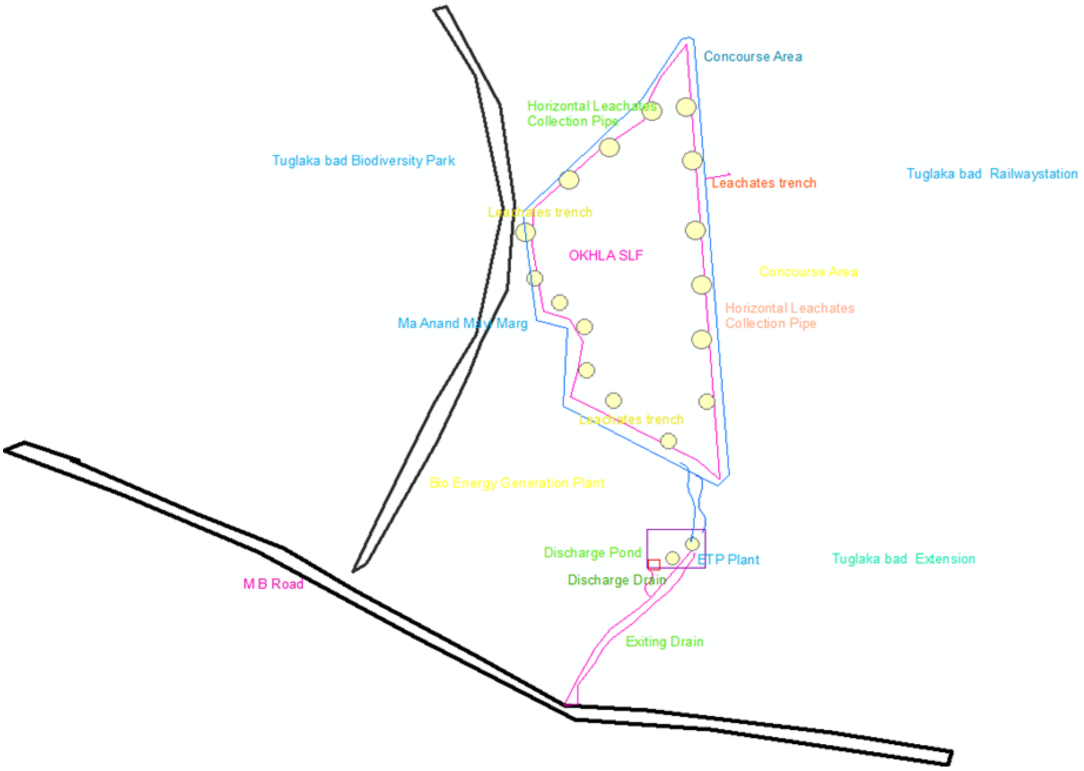
(m^3/year), RR denotes annual rainfall in meters (m), and AA signifies the landfill's surface area in square meters (m^2). For instance, applying this model to the Okhla landfill, which has a surface area of 130,000 m^2 and an annual rainfall of 700 mm (or 0.7 m), the calculation yields a total leachate discharge of 13,650 m^3/year, equivalent to approximately 38 kilolitres per day (KLD).

Beyond this mathematical model, practical planning parameters are essential for effective landfill management. The Okhla landfill's perimeter measures 2,800 meters, with an associated drainage length of 765 meters. The leachate trench, designed at a width of 0.5 meters and covering an area of 1,783 square meters, plays a crucial role in managing this leachate. Furthermore, to ensure proper functioning of the leachate treatment plant (ETP) with a capacity of 50 KLD, various cost estimates have been calculated. For example, the trench construction is estimated at 15,000 per square meter, culminating in a total project cost of approximately ₹36,987,500 or INR 3.7 crore.

In conclusion, while the standard method provides a foundational estimate for leachate generation from municipal solid waste, its efficacy is enhanced when complemented by strategic planning and sound financial management. The ongoing challenge of leachate management underlines the need for continued refinement of methodologies and infrastructure investments to safeguard environmental health. Contribution of leachates since the commissioned of Okhla Landfills 1994 and closed in 2016: The total amount of Leachates: 38*28=1064KLD

Layout plan of Okhla landfills

Figure 9.1: Layout of Okhla



10 Groundwater Pollution Remedial Measures at Okhla SLF Site

1. It is observed that the ground water in surrounding areas of Okhla SLF site is highly contaminated, it is recommended to take proper precautions to arrest further deterioration of ground water quality in the area. Stakeholder feedback forms were collected from stakeholders during the field. Most of the tube wells/Hand Pumps are used for washing & Cleaning, Construction purposes only. For drinking purpose, they are depending on DJB supply water. Some Stake holders informed that the water colour gets transformed to yellow colour after 2-3 hours. As discussed in the field with the locals, it has been learnt that the locals do not consume the ground water for drinking purpose. Hence the health issues related due to the ground water could not be ascertained.
2. To prevent mixing of the leachate at bottom of the SLF site, number of bore wells should be drilled vertically over the entire dumping yard and at the boundary of dumping yard to pump out the contaminated ground water as wells as leachate from the dumping yard. This pumped water and leachate mix shall be treated properly by putting up the ETP adjacent to the dumping yard and after proper treatment may be released to the surface water drains flowing adjacent to the dumping yard.
3. Horizontal collector wells/pipes with slotted pipes may be installed within the dumping yard and the leachate may be collected properly in the pipes and be treated in ETPs.

4. One deep trench of depth about 2 m may be constructed around the dumping yard so that the leachate is collected in the drain and transported to the ETP plant. To prevent the accumulation of storm water and rainwater over the landfill, connecting drains may be constructed crises crossing the dumping yard and connected to peripheral drain.
5. Sub-surface vertical cut-off walls may be constructed to prevent the movement of contaminated water to fresh water areas.
6. It is recommended to operate landfills appropriately at low level with restricting the height of the landfill dumping.
7. Awareness may be created regarding contamination of ground water by putting the boarders at different locations highlighting the health risk of using contaminated ground water.
8. As per the flow directions analysis, the ground water movement is towards north-eastern side of dumping site. It is recommended to reduce the ground water pumping in this area so that the flow pattern varies and contaminated ground water may not move towards highly populated area.

10.1 Management Plan for Okhla Sanitary Landfill:

The Okhla Sanitary Landfill, encompassing an area of 32 acres, faces significant challenges in effectively managing leachate generated from waste decomposition. Annually, this facility produces approximately 38 kilolitres per day (KLD) of leachate, necessitating the implementation of a robust management plan to mitigate environmental impacts and ensure compliance with regulatory standards.

To address the leachate issue, a recommended effluent treatment plant (ETP) with a capacity of 50 KLD has been proposed. This facility is crucial for treating leachate before discharge into local water bodies or further utilization. A strategically designed trench surrounding the landfill perimeter is essential for the collection of leachate. This trench will be integrated with horizontal wells, strategically spaced every 175 meters, totalling 16 wells, to facilitate effective drainage and prevent environmental contamination.

The trench, measuring approximately 1783 square meters, will connect to the existing 765meter drainage system that flows towards the Prahlad Pur Park area, where thermal biomass energy plants are located. The leachate collected in the trench will be directed to the ETP for treatment, after which treated effluent can be discharged into a designated pond or utilized for irrigation in the existing DDA Park.

A cost estimation for the project reveals that the total expenditure amounts to approximately

₹36,987,500. This includes the drilling costs for horizontal wells, trench construction, ETP facility setup, and pond establishment.

A detailed breakdown of the anticipated costs is as follows:

1. ***Drilling Costs for Horizontal Wells: ₹8,000,000 (for 16 wells at a depth of 50 meters each).***
2. ***Leachate Trench Construction Costs: ₹27,737,500 (₹15,000 per square meter for 1,783 square meters).***
3. ***ETP Installation Costs: ₹950,000 (for a 50 KLD treatment facility).***
4. ***Pond Construction Costs: ₹300,000 (dimensions 5m x 5m x 20.5m).***

In conclusion, the proposed management plan for the Okhla Sanitary Landfill is not only a proactive measure to deal with leachate but also an opportunity to harness treated effluent for beneficial use, thereby promoting sustainable waste management practices. The outlined costs and infrastructure efforts underscore the commitment to environmental stewardship and public health protection.

Table 10.1: Project Summary

Summary of the project:				
Items	**Cost in Thousand**	**Number**	**Total Cost**	**Rem ark**
Drilling cost for Horizontal well with all necessary up to 50 meters depth=16 horizon Wells	500000	16	8000000	175 spacing
Cost estimates for leachates trench	15000 per square meter	1783 square meter	27737500	
Rate of ETP 50KLD	950000	1	950000	
Pond	300000	1	300000	5*5*20.5
Total Project Cost			**36987500**	**3.7Cr**

10.2 Hydrogeological Point of Landfill Management Plan: Site Selection and Water Management Strategies

The management and operation of landfills is an essential component of effective waste management strategies. The increasing amount of waste generated globally necessitates the establishment of new landfill sites that are designed and selected with careful consideration of their potential environmental impacts. Adopting a robust Hydrogeological Point of Landfills Management Plan is crucial in the selection of landfill sites in accordance with hydrogeological risk assessments. This essay discusses various factors impacting landfill site selection and the necessary water management strategies that ensure environmental protection and sustainability.

10.3 Hydrological Site Selection Criteria

When identifying potential sites for new landfills, multiple hydrogeological factors must be taken into account. A holistic approach to site selection involves a comprehensive risk assessment that evaluates the suitability of land based on its hydrological characteristics, topography, and proximity to sensitive areas.

Distance from Water Bodies and Drainage Systems: One of the primary criteria for landfill site selection is ensuring that the site is located away from existing drainage systems and water bodies. Proximity to rivers, lakes, or any significant water sources increases the risk of pollution and contamination from leachates. To mitigate these risks, landfill sites should maintain a minimum distance of 100 meters from rivers, 200 meters from ponds, and similar distances from highways and other infrastructure.

Topography: The topography of the selected site plays a critical role in the management of surface water and landfill operations. Ideally, sites should feature flat terrain, which simplifies construction and allows for more effective water runoff management. Flat sites reduce the complexity associated with drainage and leachate collection systems, lower construction costs, and minimize the risk of unintentional water accumulation.

Proximity to Fault and Fracture Zones: Landfills should avoid areas near geological fault lines or fracture zones. These regions are susceptible to seismic activity and can pose a risk of structural failure, potentially leading to environmental contamination through groundwater pathways.

Distance from Sensitive Infrastructure: To protect nearby populations and the environment, landfill sites must adhere to specific distance regulations. This includes being 200 meters away from public parks, water supply wells, and residential areas, as well as a minimum of 20 kilometers from airports or airbases. Exceptions can be granted, subject to a no-objection certificate from civil aviation authorities, if the assessment safely supports such proximity.

Avoidance of Flood Plains and Sensitive Ecosystems: Sites should not be located within historical flood plains or coastal regulation zones, and they must avoid sensitive ecological areas and wetlands. This is crucial for preventing degradation of critical habitats and preserving biodiversity.

Water Management Plan for New Landfills

Effective management of water is essential for mitigating pollution and protecting both surface and groundwater resources. As part of the landfill management strategy, a specific Water Management Plan should be developed that addresses rainwater, surface water, and groundwater management. This plan needs to be tailored to the specific hydrological and climatic conditions of the site.

Intercepting Rainwater: The Water Management Plan must include strategies for intercepting rainwater runoff from areas surrounding the landfill. This involves designing drainage systems that channel rainwater away from construction zones and operational areas, thereby preventing contamination.

Water Balance Calculations: Essential to water management is the development of appropriate water balance calculations. The plan should include accurate data that accounts for seasonal variations, fluctuation in rainfall patterns, and potential impacts of climate change, particularly for sites located near coastlines or rivers prone to flooding.

Leachate Management: Managing rainwater that interacts with landfill waste is critical. Such water is classified as leachate and needs to be carefully monitored and treated. A detailed Leachate Management Plan must be incorporated within the overarching Water Management Plan to handle

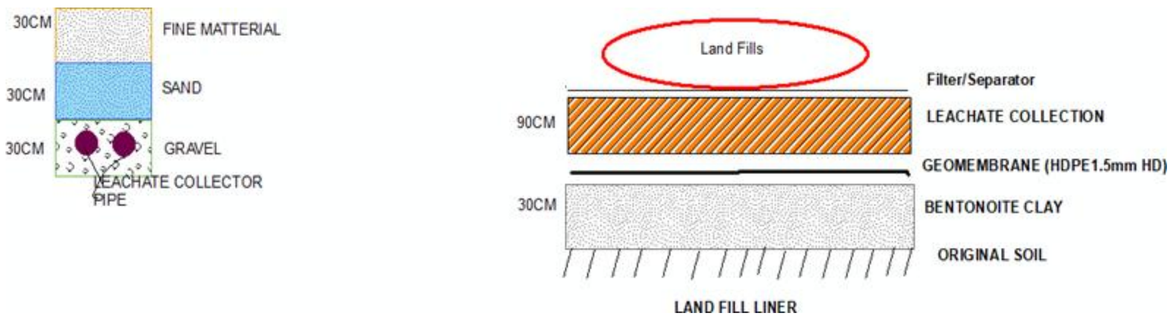


Figure 10.1: Landfill lines

The polluted effluent produced within the landfill. For Leachates collection design at base should be create artificial leachates collection mechanism as shown in ***Fig 10.1.***

Surface Water Treatment: The plan must also include provisions for treating rainwater that does not come into contact with the waste. This water should be treated to remove suspended solids before it is released into the environment or reused within the facility.

Surface Water Collection: Design aspects of the landfill must ensure adequate collection of surface water from capped areas. This involves creating drainage systems that can adapt to variations in design while accommodating future site settlement.

Accommodating Storm Events: The water management systems must have the capacity to handle predicted storm events and natural disaster scenarios to avoid system failures and flooding.

Groundwater Protection: The Water Management Plan must prioritize the protection of groundwater. This involves measures to prevent groundwater intrusion into landfill cells, accommodate calculated groundwater flows, and monitor potential pollution risks from both hazardous and non-hazardous substances.

Monitoring Access: Features such as v-notch weirs can be incorporated for accessible monitoring of surface water quality and levels, ensuring that the necessary data is available for both compliance and safety assessments.

Annexure

Annexure-I: Existing Landfill sites for Waste Management in NCT Delhi

S. No.	Location	Area (in ha.)	Remarks
1	Kailash Nagar, East Delhi	1.8	Filled up
2	Tilak Nagar, West Delhi	16	Filled up
3	Subroto Park	..	Filled up
4	Purana Qila/Bharion Road	2.7	Filled up
5	Timarpur	16	Filled up
6	Sarai Kale Khan	24	Filled up
7	Gopal Pur	4	Filled up
8	Chhaterpur	1.7	Filled up
9	S. G. T Nagar	14.4	Filled up
10	I.P. Depot	1.8	Filled up
11	Sunder Nagar	2.8	Filled up
12	Tuglakabad Extn.	2.4	Filled up
13	HaiderPur	1.6	Filled up
14	Mandawali Fazilpur	2.8	Filled up
15	Rohini Ph-III	4.8	Filled up
16	Near Hastal Village in West Delhi	9.6	Filled up
17	Site Near Ghazipur Dairy Farm	28	In Operation
18	Site Near Jhangirpur/ Bhalaswa	16	In Operation
19	Okhla Phase-I	12.8	In Operation
20	Crossing on G.T.Karnal Road	3.2	In Operation
21	Jaitpur /Tajpur	9.84	New
22	Near Puthkhurd	55	New
23	Bawanato Narela Road	28	New
24	Sultanpur Dabas (Bawana)	16	New

Annexure-II: Hydrogeological Data of monitoring wells around Okhla Landfill Site

S N	Lat.	Long.	Location	Nature Of well	Depth of well	Dia in mm	Aquifer Tapped	Depth zone tapped	M.P (mbgl)	Depth to Water Level, June 23 (mbgl)	Depth to Water Level, Nov 23 (mbgl)	Use
1	28.50273	77.28077	near petrol pump	TW	65	204	Fine sand, weathered part quartzite		0.5	24.56	23.98	Public Use
2	28.50659	77.26987	kaya Maya Park, DJB office	TW	77	204	Fine sand, weathered part quartzite		0.46	33.26	31.1	Horticulture
3	28.50677	77.28585	C block, near land fill site, hanuman temple	TW	45	204	Fine sand, weathered part quartzite		0.46	33.24	31.68	Public Use
4	28.50357	77.28602	Park near land fill site	TW	65	204	Fine sand, Silty sand		0.25	25.1	24.1	Public Use
5	28.50594	77.29732	Tuglakabad railway station, water supply	TW	36	204	Fine sand, Silty sand		0.25	23.52	22.52	Public Use
6	28.50488	77.29814	Public utilities	TW	70	204	Fine sand, Silty sand		0.25	25.32	24.45	Public Use
7	28.50585	77.29097	Nandi Park	TW	56	204	Fine sand, weathered part quartzite		0.5	24.56	23.65	Horticulture
8	28.53379	77.29211	Municipal corporation park	TW	70	204	Fine sand, Silty sand		0.5	23.26	22	Horticulture
9	28.54618	77.26477	NSIC sample	TW	45	204	Fine sand, Silty sand		0.5	10.6	9.1	Public Use
10	28.53094	77.27489	Okhla near phase-2 local market	TW	57	204	Fine sand, weathered part quartzite		0.32	22.6	21.6	Public Use
11	28.52198	77.2839	Premises of govt school	TW	65	204	Fine sand, weathered part quartzite		0.32	33.1	32.76	Public Use
12	28.52462	77.2613	MCD Park , girls school , Tuglakabad extension	TW	70	204	Fine sand, weathered part quartzite		0.5	27.23	26.33	Public Use
13	28.51903	77.30422	Ali cricket ground	TW	30	102	Fine sand, Silty sand	15-25	0.2	23.42	22.74	Public Use
14	28.50491	77.301	Delhi Jal board office Badarpur	TW	70	204	Fine sand, weathered part quartzite	34- 38, 43-47	0.5	20.52	19.72	Public Use

15	28.5063	77.28903	Rani Jhasi Sarvoday Kanaya Vidalaya	TW	65	204	Fine sand, weathered part quartzite		0.5	23.26	23.26	Public Use
16	28.51925	77.28163	GW2	TW	55	204	Fine sand, weathered part quartzite		0.5	37.53	37.53	Public Use
17	28.53025	77.29105	Delhi Jal board Sarita Vihar	TW	56	204	Fine sand, weathered part quartzite		0.5	31.3	30.3	Public Use
18	28.51687	77.30416	Police Rest house	TW	55	102	Fine sand, weathered part quartzite		0.45	23.72	23.52	Public Use
19	28.49821	77.28987	GW6 Park	TW	67	204	Fine sand, weathered part quartzite		0.5	26.35	25.77	Public Use
20	28.52467	77.28399	Govt senior secondary school	TW	65	204	Fine sand, weathered part quartzite		0.5	35.8	36.18	Public Use
21	28.4938	77.31017	Bal Vaishali School	TW	66	204	Fine sand, weathered part quartzite		0.35	13.12	12.57	Public Use
22	28.4958	77.2667	Asola	TW	80	204	Fine sand, weathered part quartzite	56-60m	0.56	44.9	43.97	Monitoring

Annexure-III: Hydrogeological Data of water Quality sampling points (Post-Monsoon) around Okhla Landfill Site:

S. No	Latitude	Longitude	Location	Nature Of well	Depth of well	Dia in mm	Aquifer Tapped	Use
1	28.50273	77.28077	near petrol pump	TW	65	204	Fine sand, weathered part quartzite	Public Use
2	28.50659	77.26987	kaya maya park, DJB office	TW	77	204	Fine sand, weathered part quartzite	Horticulture
3	28.50677	77.28585	C Block, near land fill site, hanuman temple	TW	45	204	Fine sand, weathered part quartzite	Public Use
4	28.50357	77.28602	Park near land fill site	TW	65	204	Fine sand, Silty sand	Public Use
5	28.50594	77.29732	Tuglakabad railway station, water supply	TW	36	204	Fine sand, Silty sand	Public Use
6	28.50488	77.29814	Public utilities	TW	70	204	Fine sand, Silty sand	Public Use
7	28.50585	77.29097	Nandi Park	TW	56	204	Fine sand, weathered part quartzite	Horticulture
8	28.53379	77.29211	Municipal corporation park	TW	70	204	Fine sand, Silty sand	Horticulture
9	28.54618	77.26477	NSIC sample	TW	45	204	Fine sand, Silty sand	Public Use
10	28.54262	77.26935	DDA Chandiwal park	TW	50	204	Fine sand, Silty sand	Horticulture
11	28.53094	77.2723	metro pillar 201 Okhla 1	TW	55	204	Fine sand, Silty sand	Public Use
12	28.53094	77.27489	Okhla near phase-2 local market	TW	57	204	Fine sand, weathered part quartzite	Public Use
13	28.53111	77.27939	Hamdard laboratories in Okhla phase 2	TW	58	204	Fine sand, weathered part quartzite	Public Use
14	28.52198	77.2839	Premises of govt school	TW	65	204	Fine sand, weathered part quartzite	Public Use
15	28.51774	77.28212	Near shiv Temple	TW	55	204	Fine sand, weathered part quartzite	Public Use
16	28.51708	77.28393	In front of Kendriya Bhandar Nigam	TW	56	204	Fine sand, weathered part quartzite	Public Use
17	28.53217	77.2613	Kiran store, Okhla	TW	57	204	Fine sand, weathered part quartzite	Public Use
18	28.52462	77.2613	MCD park, girls' school, Tugalakabad extension	TW	70	204	Fine sand, weathered part quartzite	Public Use
19	28.52528	77.25663	MCD park Ravidas, Tuglakabad extension	TW	66	204	Fine sand, weathered part quartzite	Public Use
20	28.51119	77.26199	near Tuglakabad fort	TW	67	204	Fine sand, weathered part quartzite	Public Use
21	28.50064	77.2823	Lal kua parking forest land	TW	45	204	Fine sand, weathered part quartzite	Public Use
22	28.49997	77.28308	Hanuman Temple Lal kua	TW	50	204	Fine sand, weathered part quartzite	Public Use
23	28.4987	77.28313	Balmiki shiv Shati mandir	TW	50	204	Fine sand, weathered part quartzite	Public Use

24	28.49686	77.28264	Pankaj Medicose	TW	55	204	Fine sand, Silty sand	Public Use
25	28.49947	77.2806	Shitala Mata mandir, Lal Kuan	TW	57	204	Fine sand, weathered part quartzite	Public Use
26	28.51903	77.30422	Ali cricket ground	TW	30	204	Fine sand, Silty sand	Public Use
27	28.50491	77.301	Delhi Jal board office Badarpur	TW	70	204	Fine sand, weathered part quartzite	Public Use

Annexure-IV: Basic Parameter Analysis Results Pre monsoon

S. no	Tehsil Name	Latitude	Longitude	Site Name	pH	EC in µS/cm at 250C	CO3	HCO3	Cl	SO4	NO3	F	Ca	Mg	Na	K	TH as CaCO3
							mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Kalkaji	28.5063	77.28903	Rani Jhasi Sarvoday Kanaya Vidalaya	7.26	3866	nil	415	1030	168	27	0.75	224	143	398	25	1150
2	Kalkaji	28.51925	77.28562	GW2	7.52	2538	nil	610	391	144	27	1.1	68	56	390	7.2	400
3	Kalkaji	28.53025	77.29105	Delhi Jal board Sarita Vihar	8.16	1511	nil	549	192	62	25	1.8	40	66	208	4	370
4	Kalkaji	28.4938	77.31017	Police Rest house	8.41	850	36	122	107	144	27	1.2	52	61	42	22	380
5	Kalkaji	28.51687	77.30416	GW6 Park	8.68	1800	84	134	284	168	28	1.2	32	66	236	7.9	350
6	Kalkaji	28.49205	77.28987	Govt senior secondary school	8.44	1323	36	195	199	192	28	1	28	36	239	5.1	220
7	Kalkaji	28.5247	77.28398	Bal Vaishali School	8.42	2723	36	195	582	264	27	0.63	44	151	296	11	730

Annexure-V: Heavy Metal Analysis Results Pre monsoon

S.No.	Tehsil Name	Latitude	Longitude	Site Name	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Pb	U
					(PPM)						(PPM)				
1	Kalkaji	28.5063	77.289027	Rani Jhasi Sarvodaya Kanaya Vidyalaya	0.001	0.038	0.107	0.003	0.004	0.139	0.175	0.024	0.169	0.531	5.605
2	Kalkaji	28.51924	77.28562	GW2	0	0.025	0.065	0.002	0.005	0.137	0.227	0.047	0.672	0.573	11.573
3	Kalkaji	28.53024	77.291052	Delhi Jal board Sarita Vihar	0	0.009	0.075	0.001	0.005	1.787	0.128	0.314	0.276	0.853	7.241
4	Kalkaji	28.4938	77.310172	Police Rest house	BDL	0.003	0.058	0.002	0.003	0.22	0.273	0.019	0.226	0.816	1.821

5	Kalkaji	28.51686	77.304164	GW6 Park	0	0.003	0.094	0.001	0.002	0.676	0.196	0.149	0.26	3.186	7.312
6	Kalkaji	28.49205	77.289873	Govt senior secondary school	0	0.003	0.097	0.001	0.004	0.431	0.16	0.1	0.4	2.251	4.996
7	Kalkaji	28.5247	77.283979	Bal Vaishali School	0	0.008	0.141	0.003	0.004	0.597	0.167	0.06	0.45	2.423	7.437

Annexure-VI: Post Monsoon Basic Chemical Analysis Result

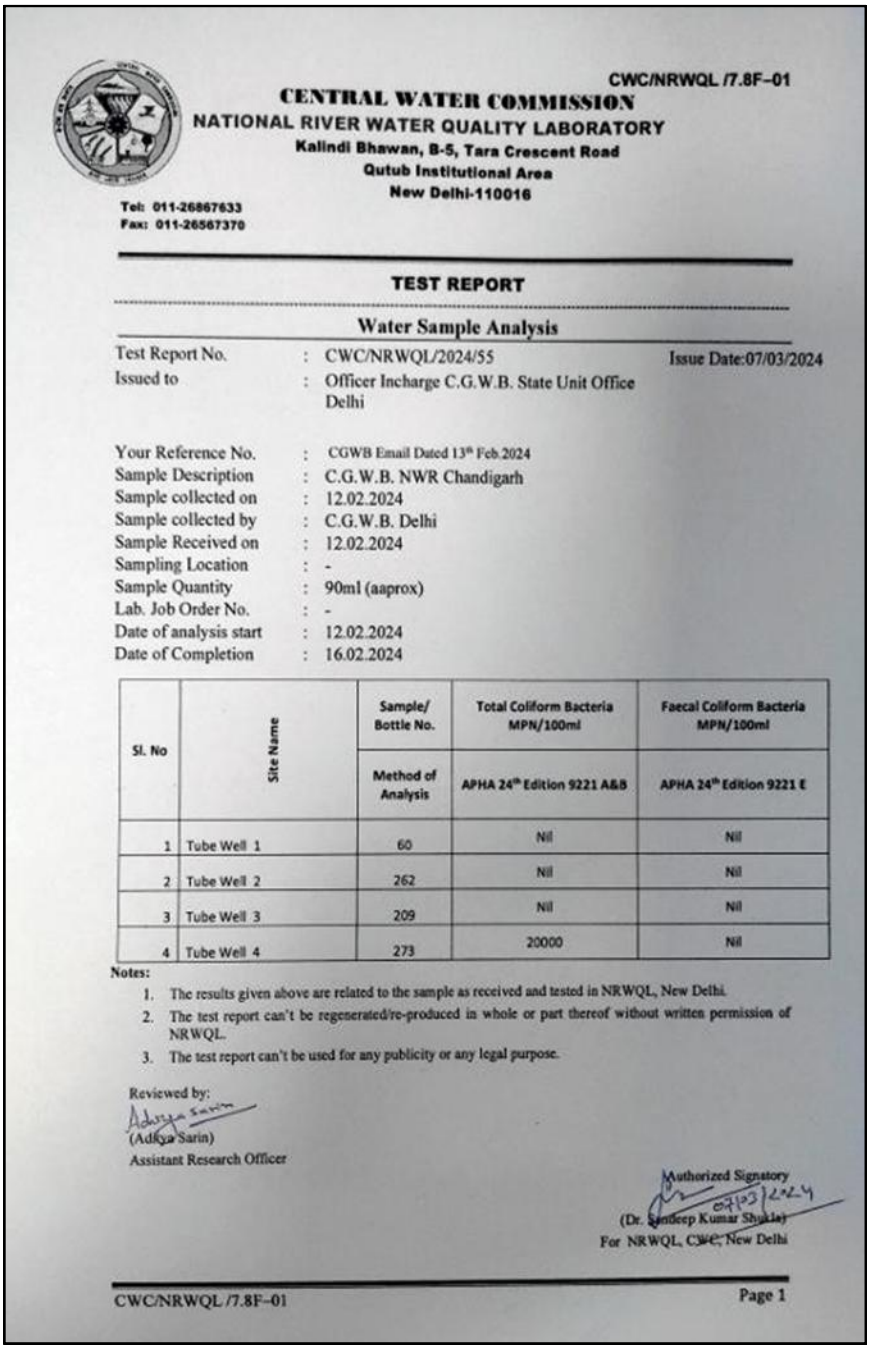
District	Tahsil	Location	Lat.	Long.	Temp.	pH	EC (us/cm)	Carbonate	Bicarbonate	Chloride	Sulphate	Nitrate	Phosphate	Fluoride	TH	Calcium	Magnesium	Sodium	Potassium	TDS
South East	Kalka	near petrol pump	28.50273	77.28077	NM	7.4	1010	Nil	317	99	70	44	0.1	0.48	300	36	51	92	8.7	657
South East	Kalka	Kayamaya park, DJB office	28.50659	77.26987	NM	7.92	908.1	Nil	210	180	7	56	0.12	0.4	320	64	39	74	2.8	590
South East	Kalka	C- Block, near landfill site ,hanuman temple	28.50677	77.28585	NM	6.97	4980	Nil	622	850	705	75	0.25	0.35	1340	316	134	515	35.7	3302
South East	Kalka	Park near landfill site	28.50357	77.28602	NM	7.28	2010	Nil	560	277	55	125	0.14	0.28	470	152	22	245	7.2	1307
South East	Kalka	Tuglakabad railway Station, Water supply	28.50594	77.29732	NM	7.05	3450	Nil	451	461	648	80	0.22	0.25	970	324	39	362	6.5	2386
South East	Kalka	Public utilities	28.50488	77.29814	NM	7.24	3750	Nil	403	766	282	190	0.11	0.22	850	0	207	460	8.9	2438
South East	Kalka	Nandi park	28.50585	77.29097	NM	7.56	1910	Nil	549	291	95	38	0.13	0.2	410	116	29	267.5	3.1	1242
South East	Kalka	Municipal corporation park	28.53379	77.29211	NM	7.8	1310	Nil	342	85	330	75	0.1	1.4	310	64	36	228	3.1	852
South East	Kalka	NSIC sample	28.54618	77.26477	NM	7.62	895	Nil	342	85	70	14.9	0.11	0.75	350	76	39	63	2.8	582
South East	Kalka	DDA Chandiwal park	28.54262	77.26935	NM	7.74	1330	Nil	488	177	5	70	0.15	0.6	440	84	56	124	2	865
South East	Kalka	metro pillar201 okhal1	28.53094	77.2723	NM	7.26	2090	Nil	110	230	445	220	0.19	0.45	620	164	51	200	4.1	1469
South East	Kalka	Okhla near phase2 local market	28.53094	77.27489	NM	7.38	2250	Nil	573	284	205	120	0.02	0.48	660	168	58	240	2.8	1463
South East	Kalka	Hamdard laboratories in Okhla phase2	28.53111	77.27939	NM	7.74	289	Nil	183	40	10	3.4	0.06	0.05	200	36	27	8	2.4	188
South East	Kalka	Premises of govt school	28.52198	77.2839	NM	7.5	2880	Nil	586	482	420	150	0.11	0.55	680	168	63	460	37.1	1872
Southeast	Kalka	Infront of Kendri yabhandarnigam	28.51708	77.28393	NM	7.82	2600	Nil	134	525	360	95	0.14	0.2	400	100	36	410	11.8	1716
Southeast	Kalka	Kiran store, Okhla	28.53217	77.2613	NM	7.45	538	Nil	300	28	5	8.2	0.11	0.05	270	48	36	12	3.1	350
Southeast	Kalka	MCD park, girls school, Tuglakabad extension	28.52462	77.2613	NM	7.3	1520	Nil	512	149	40	69	0.12	0.65	410	128	22	138	16.1	1131
Southeast	Kalka	MCD park ravidas, Tuglakabad extension	28.52528	77.25663	NM	7.63	690.4	Nil	329	64	25	10.1	0.02	0.45	300	76	27	44	2.66	449
Southeast	Kalka	near Tuglakabad fort	28.51119	77.26199	NM	7.46	2270	Nil	683	269	40	170	0.08	0.47	770	180	78	160	3.5	1476
Southeast	Kalka	lalkua parking fore stland	28.50064	77.2823	NM	8.54	1050	12	240	160	12	1.1	0.01	0.59	80	24	5	184	15	683
Southeast	Kalka	Hanuman temple lal kua	28.49997	77.28308	NM	7.74	1110	Nil	366	177	40	8	0.02	0.48	240	60	22	158	12.8	722
Southeast	Kalka	balmiki shivshati mandir	28.4987	77.28313	NM	7.15	1940	Nil	490	284	70	50	0.02	0.8	450	120	36	208	13.7	1261
Southeast	Kalka	Pankaj medicose	28.49686	77.28264	NM	7.33	2310	Nil	659	340	150	62.1	0.03	0.75	510	144	36	315	30.1	1502
Southeast	Kalka	Shitala Mata Mandir,Lalkuan	28.49947	77.2806	NM	7.57	1060	Nil	293	170	10	50	0.11	0.33	260	72	19	114	16.2	722
Southeast	Kalka	Ali cricket ground	28.51903	77.30422	NM	7.56	2190	Nil	586	255	222	140	0.02	0.8	450	124	34	330	16	1424
Southeast	Kalka	Delhi Jal board office Badarpur	28.50491	77.301	NM	7.88	300.8	Nil	98	28	60	1	0.01	0.05	170	32	22	7	2.4	196
Southeast	Kalka	M Broad, Public toilet	28.50086	77.29345	NM	7.4	2050	Nil	525	269	130	61	0.08	0.45	450	160	12	250	3.4	1333

Southeast	Kalka	landfill sites	28.51038	77.28315	NM	8.22	37680	UREDSA	UREDSA	UREDSA	UREDSA	35	UREDSA	0.95	UREDSA	UREDSA	UREDSA	UREDSA	UREDSA	24492
Southeast	Kalka	landfill sites	28.51025	77.28484	NM	6.97	17680	UREDSA	UREDSA	UREDSA	UREDSA	42	UREDSA	0.05	UREDSA	UREDSA	UREDSA	UREDSA	UREDSA	11492
Southeast	Kalka	landfill sites	28.51157	77.28484	NM	8.1	33920	UREDSA	UREDSA	UREDSA	UREDSA	40	UREDSA	0.88	UREDSA	UREDSA	UREDSA	UREDSA	UREDSA	22048
Southeast	Kalka	landfill sites	28.51092	77.28086	NM	7.5	2640	UREDSA	UREDSA	UREDSA	UREDSA	44	UREDSA	0.4	UREDSA	UREDSA	UREDSA	UREDSA	UREDSA	1716

Annexure-VII: Post Monsoon Heavy Metal Analysis Results

S. No.	District	Tahsil	Location	Source	Latitude	Longitude	Date of analysis	Cr	Fe	Mn	Cu	Zn	As	Pb	U
								mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	South East	Kalka	kaya maya park, DJB office	TW	28.5066	77.26987	May, 2024	0.003652	0.1368	BDL	BDL	0.2878	BDL	0.00242	0.01714
2	South East	Kalka	C Bolck, nearv land fill site, hanuman temple	TW	28.5067	77.28585	May, 2024	0.002349	2.7969	4.7092	BDL	0.53477	0.00345	0.00231	0.01319
3	South East	Kalka	Park near land fill site	TW	28.5035	77.28602	May, 2024	0.00176	0.358	BDL	BDL	0.30242	BDL	0.00253	0.00911
4	South East	Kalka	Tuglakabad railway station, water supply	TW	28.5059	77.29732	May, 2024	0.003199	0.1829	BDL	BDL	0.45398	BDL	0.00212	0.00319
5	South East	Kalka	Public utilities	TW	28.5048	77.29814	May, 2024	0.001837	0.0992	BDL	BDL	0.27635	BDL	0.00165	0.00484
6	South East	Kalka	Nandi park	TW	28.5058	77.29097	May, 2024	BDL	1.2759	0.0763	BDL	0.63401	BDL	0.00275	0.00528
7	South East	Kalka	Municipal corporation park	TW	28.5337	77.29211	May, 2024	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.00364
8	South East	Kalka	NSIC sample	TW	28.5461	77.26477	May, 2024	0.008547	0.251	BDL	BDL	0.4614	BDL	0.00302	BDL
9	South East	Kalka	DDA Chandiwal park	TW	28.5426	77.26935	May, 2024	BDL	0.1188	BDL	BDL	0.3255	BDL	0.00249	0.01667
10	South East	Kalka	metro pillar 201 Okhla 1	TW	28.5309	77.2723	May, 2024	BDL	0.1309	BDL	BDL	0.32789	BDL	0.00218	0.01734
11	South East	Kalka	Okhla near phase-2 local market	TW	28.5309	77.27489	May, 2024	0.052318	0.1089	BDL	BDL	0.3977	BDL	0.00212	0.0161
12	South East	Kalka	Hamdard laboratories in Okhla phase 2	TW	28.5311	77.27939	May, 2024	BDL	0.1469	BDL	BDL	0.48713	0.00185	0.00284	BDL
13	South East	Kalka	Premises of govt school	TW	28.5219	77.2839	May, 2024	0.045818	0.1175	BDL	0.02112	1.50995	BDL	0.00284	0.00968
14	South East	Kalka	Near shiv Temple	TW	28.5177	77.28212	May, 2024	0.016085	0.1062	BDL	BDL	0.17271	BDL	0.0013	0.00716
15	South East	Kalka	In front of Kendriya Bhandar Nigam	TW	28.517	77.28393	May, 2024	0.00587	0.1812	0.3684	BDL	0.51638	BDL	0.00289	0.01051
16	South East	Kalka	Kiran store, Okhla	TW	28.5321	77.2613	May, 2024	BDL	0.2374	BDL	BDL	0.84471	BDL	0.00419	BDL
17	South East	Kalka	MCD park, girls school, Tuglakabad extension	TW	28.5246	77.2613	May, 2024	BDL	0.0639	BDL	BDL	0.09801	BDL	0.00135	0.01116
18	South East	Kalka	MCD park Ravidas, Tuglakabad extension	TW	28.5252	77.25663	May, 2024	BDL	0.1227	BDL	BDL	0.15685	BDL	0.00261	BDL
19	South East	Kalka	near Tuglakabad fort	TW	28.5111	77.26199	May, 2024	BDL	0.1962	BDL	BDL	0.22226	BDL	0.00299	0.0484
20	South East	Kalka	Lal Kua parking forest land	TW	28.5006	77.2823	May, 2024	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
21	South East	Kalka	Hanuman temple Lal Kua	TW	28.4999	77.28308	May, 2024	BDL	BDL	BDL	BDL	0.05228	BDL	BDL	BDL
22	South East	Kalka	Balmiki shiv Shati mandir	TW	28.4987	77.28313	May, 2024	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.00649
23	South East	Kalka	Pankaj Medicose	TW	28.4968	77.28264	May, 2024	BDL	BDL	BDL	BDL	BDL	0.00105	BDL	0.0044
24	South East	Kalka	Shitala Mata mandir, Lal Kuan	TW	28.4994	77.2806	May, 2024	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
25	South East	Kalka	Ali cricket ground	TW	28.519	77.30422	May, 2024	BDL	0.1195	BDL	BDL	0.36783	BDL	0.00326	0.00892
26	South East	Kalka	Delhi Jal board office Badarpur	TW	28.5049	77.301	May, 2024	0.00196	0.2084	BDL	BDL	0.57786	BDL	0.00509	BDL
27	South East	Kalka	M B Road, Public toilet	TW	28.5008	77.29345	May, 2024	0.006382	0.1908	BDL	BDL	0.58654	BDL	0.00443	0.00431
28	South East	Kalka	land fill sites	TW	28.5103	77.28315	May, 2024	Coloured sample and not analysed							
29	South East	Kalka	land fill sites	TW	28.5102	77.28484	May, 2024	Coloured sample and not analysed							
30	South East	Kalka	land fill sites	TW	28.5115	77.28484	May, 2024	Coloured sample and not analysed							
31	South East	Kalka	land fill sites	TW	28.5109	77.28086	May, 2024	0.015616	4.9016	0.4078	0.14175	0.50808	0.00475	0.02075	0.00334

Annexure-VIII: Bacteriological analysis:



CWC/NRWQL /7.8F–01

CENTRAL WATER COMMISSION
NATIONAL RIVER WATER QUALITY LABORATORY
Kalindi Bhawan, B-5, Tara Crescent Road
Qutub Institutional Area
New Delhi-110016

Tel: 011-26867633
Fax: 011-26567370

TEST REPORT

Water Sample Analysis

Test Report No.	: CWC/NRWQL/2024/55	**Issue Date:07/03/2024**
Issued to	: Officer Incharge C.G.W.B. State Unit Office Delhi	
Your Reference No.	: CGWB Email Dated 13th Feb.2024	
Sample Description	: C.G.W.B. NWR Chandigarh	
Sample collected on	: 12.02.2024	
Sample collected by	: C.G.W.B. Delhi	
Sample Received on	: 12.02.2024	
Sampling Location	: -	
Sample Quantity	: 90ml (aaprox)	
Lab. Job Order No.	: -	
Date of analysis start	: 12.02.2024	
Date of Completion	: 16.02.2024	

Sl. No	Site Name	Sample/ Bottle No.	Total Coliform Bacteria MPN/100ml	Faecal Coliform Bacteria MPN/100ml
		Method of Analysis	APHA 24th Edition 9221 A&B	APHA 24th Edition 9221 E
1	Tube Well 1	60	Nil	Nil
2	Tube Well 2	262	Nil	Nil
3	Tube Well 3	209	Nil	Nil
4	Tube Well 4	273	20000	Nil

Notes:

1. The results given above are related to the sample as received and tested in NRWQL, New Delhi.
2. The test report can't be regenerated/re-produced in whole or part thereof without written permission of NRWQL.
3. The test report can't be used for any publicity or any legal purpose.

Reviewed by:
Aditya Sarin
(Aditya Sarin)
Assistant Research Officer

Authorized Signatory
07/03/2024
(Dr. Sandeep Kumar Shukla)
For NRWQL, CWC, New Delhi

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Annexure IX: Elevation data

Bore	Latitude	Longitude	Elevation	Collar Elevation	Total Depth
Vayusenabad	28.514779	77.241019	259	259	128.54
Dakshinpuri	28.522374	77.238812	254	254	54.5
Mohlarbund	28.505695	77.311834	227	227	207
J block	28.520501	77.213929	250	250	94.5
Ashola Bhatti	28.493182	77.260194	278	278	60
VES1	28.5079385	77.26628931	233	233	107
VES2	28.504709	77.280472	230	230	65
VES3	28.5186565	77.27644082	224	224	150
VES4	28.51847509	77.27856689	218	218	180
VES5	28.54156641	77.26775409	228	228	180
VES6	28.510563	77.278402	231	231	170
VES7	28.50410813	77.28474909	221	221	120
VES8	28.503466	77.285938	221	221	90
VES9	28.50953083	77.2920598	216	216	190
VES10	28.52770914	77.29252055	212	212	170
VES11	28.520521	77.302401	207	207	132

Annexure X: Vertical electrical Sounding Data

Bore	Depth 1	Depth 2	Lithology	Thickness
VES1	0	4.74	Clay	4.74
VES1	4.74	10.23	Sand	5.49
VES1	10.23	22.23	Weathered Formation	12
VES1	22.23	107.13	Hard Rock	84.9
VES1	107	300	Hard Rock	193
VES2	0	0.964	Soil	0.964
VES2	0.964	9.354	Clay	8.39
VES2	9.354	23.154	Hard rock	13.8
VES2	23.15	65	Fracture Quartzite	41.85
VES3	0	2.89	Surface soil	2.89
VES3	2.89	6.82	Weathered Formation	3.93
VES3	6.82	150	Hard rock	143.18
VES4	0	1.09	Soil	1.09
VES4	1.09	2.23	Clay	1.14
VES4	2.23	11.92	Sand (Fresh Water)	9.69
VES4	11.92	30.92	Weathered Quartzite	19
VES4	30.92	180	Hard rock	149.08
VES5	0	1.32	Soil	1.32
VES5	1.32	20.52	Clay	19.2
VES5	20.52	180	Hard rock	159.48
VES6	0	0.625	Soil	0.625
VES6	0.625	5.685	Sand	5.06
VES6	5.685	16.485	Weathered Quartzite	10.8
VES6	16.485	44.785	Fracture Quartzite	28.3
VES6	44.785	170	Fracture Quartzite	125.215
VES7	0	1.22	Soil	1.22
VES7	1.22	2.63	Sand (Fresh Water)	1.41
VES7	2.63	13.13	Sand (Fresh Water)	10.5
VES7	13.13	28.23	Fracture Quartzite	15.1
VES7	28.23	66.43	Fracture Quartzite	38.2
VES7	66.43	120	Hard Rock	53.57
VES8	0	1.39	Soil	1.39
VES8	1.39	14.69	Sand (Fresh Water)	13.3
VES8	14.69	23.93	Sand (Fresh Water)	9.24

VES8	23.93	90	Sand (Fresh Water)	66.07
VES9	0	1.54	Soil	1.54
VES9	1.54	3.31	Clay	1.77
VES9	3.31	10.44	Hard Rock	7.13
VES9	10.44	18.27	Fracture Quartzite	7.83
VES9	18.27	190	Fracture Quartzite	171.73
VES10	0	0.979	Soil	0.979
VES10	0.979	8.659	Clay	7.68
VES10	8.659	14.419	Sand with Clay	5.76
VES10	14.419	25.619	Sand (Saline water)	11.2
VES10	25.619	170	Hard Rock	144.381
VES11	0	0.81	Surface soil	0.81
VES11	0.81	1.381	Clay	0.571
VES11	1.381	26.181	Sand (Fresh Water)	24.8
VES11	26.181	132.18	Sand (Saline water)	106

Annexure-XI: Lithological Data

Bore	Depth 1	Depth 2	Lithology	Thickness
Vayusenabad	0	3	Soil	3
Vayusenabad	3	7	Silty	4
Vayusenabad	7	28.19	Silty	21.19
Vayusenabad	28.19	43.26	Silty	15.07
Vayusenabad	43.26	61.56	Silty	18.3
Vayusenabad	61.56	67.62	Silty	6.06
Vayusenabad	67.62	76.63	Weathered Quartzite	9.01
Vayusenabad	76.63	79.65	Weathered Quartzite	3.02
Vayusenabad	79.65	88.67	Fresh quartzite	9.02
Vayusenabad	88.67	95	Fresh quartzite	6.33
Vayusenabad	95	101.09	Fracture Quartzite	6.09
Vayusenabad	101.09	110.27	Facture Quartzite	9.18
Vayusenabad	110.27	122.45	Compact quartzite	12.18
Vayusenabad	122.45	125.45	Compact quartzite	3
Vayusenabad	125.45	128.54	Compact quartzite	3.09
Dakshinpuri	0	17.5	Clay	17.5
Dakshinpuri	17.5	20	Sand	2.5
Dakshinpuri	20	21.5	Clay	1.5
Dakshinpuri	21.5	25	Sand	3.5
Dakshinpuri	25.45	30	Clay	4.55
Dakshinpuri	30	33	Sand	3
Dakshinpuri	33	36.5	Clay	3.5
Dakshinpuri	36.5	38	Sand	1.5
Dakshinpuri	38	42	Clay	4
Dakshinpuri	42	46	Sand	4
Dakshinpuri	46	50	Clay	4
Dakshinpuri	50	53	Sand	3
Dakshinpuri	53	54.5	Clay	1.5
Mohlarbund	0	0.2	Soil	0.2
Mohlarbund	0.2	20.5	Sand	20.3
Mohlarbund	20.5	22.5	Clay	2
Mohlarbund	22.5	32.5	Sand	10
Mohlarbund	32.5	38	Clay	5.5
Mohlarbund	38	45.5	Kankar	7.5
Mohlarbund	45.5	47.5	Clay	2
Mohlarbund	47.5	52	Kankar	4.5
Mohlarbund	52	55	Clay	3
Mohlarbund	55	62	Kanker	7
Mohlarbund	62	65	Clay	3

Mohlarbund	65	70	Kankar	5
Mohlarbund	70	207	Clay	137
J block	0	7	Clay	7
J block	10.5	12.5	Sand	2
J block	12.5	14.5	Clay	2
J block	14.5	17.5	Sand	3
J block	17.5	20.5	Clay	3
J block	20.5	23.5	Sand	3
J block	23.5	25	Clay	1.5
J block	25	27	Sand	2
J block	27	29.5	Clay	2.5
J block	29.5	32	Sand	2.5
J block	32	34.3	Clay	2.3
J block	34.3	37	Sand	2.7
J block	37	40	Clay	3
J block	40	42	Sand	2
J block	42	49.5	Clay	7.5
J block	49.5	51	Sand	1.5
J block	51	56	Clay	5
J block	56	59	Sand	3
J block	59	70.5	Clay	11.5
J block	70.5	72.5	Sand	2
J block	72.5	74	Clay	1.5
J block	74	75	Sand	1
J block	75	88	Clay	13
J block	88	94.5	Sand	6.5
Ashola Bhatti	0	21	Weathered Quartzite	21
Ashola Bhatti	21	24	Hard rock	3
Ashola Bhatti	24	27	Weathered Quartzite	3
Ashola Bhatti	27	51	Hard rock	24
Ashola Bhatti	51	54	Weathered Quartzite	3
Ashola Bhatti	54	60	Hard rock	6
VES1	0	4.74	Clay	4.74
VES1	4.74	10.23	Sand	5.49
VES1	10.23	22.23	Weathered Formation	12
VES1	22.23	107.13	Hard Rock	84.9
VES1	107	300	Hard Rock	193
VES2	0	0.964	Soil	0.964
VES2	0.964	9.354	Clay	8.39
VES2	9.354	23.154	Hard rock	13.8
VES2	23.15	65	Fracture Quartzite	41.85

VES3	0	2.89	Surface soil	2.89
VES3	2.89	6.82	Weathered Formation	3.93
VES3	6.82	150	Hard rock	143.18
VES4	0	1.09	Soil	1.09
VES4	1.09	2.23	Clay	1.14
VES4	2.23	11.92	Sand (Fresh Water)	9.69
VES4	11.92	30.92	Weathered Quartzite	19
VES4	30.92	180	Hard rock	149.08
VES5	0	1.32	Soil	1.32
VES5	1.32	20.52	Clay	19.2
VES5	20.52	180	Hard rock	159.48
VES6	0	0.625	Soil	0.625
VES6	0.625	5.685	Sand	5.06
VES6	5.685	16.485	Weathered Quartzite	10.8
VES6	16.485	44.785	Fracture Quartzite	28.3
VES6	44.785	170	Fracture Quartzite	125.215
VES7	0	1.22	Soil	1.22
VES7	1.22	2.63	Sand (Saline Water)	1.41
VES7	2.63	13.13	Sand (Saline Water)	10.5
VES7	13.13	28.23	Fracture Quartzite	15.1
VES7	28.23	66.43	Fracture Quartzite	38.2
VES7	66.43	120	Hard Rock	53.57
VES8	0	1.39	Soil	1.39
VES8	1.39	14.69	Sand (Saline water)	13.3
VES8	14.69	23.93	Sand (Saline water)	9.24
VES8	23.93	90	Sand (Saline water)	66.07
VES9	0	1.54	Soil	1.54
VES9	1.54	3.31	Clay	1.77
VES9	3.31	10.44	Hard Rock	7.13
VES9	10.44	18.27	Fracture Quartzite	7.83
VES9	18.27	190	Fracture Quartzite	171.73
VES10	0	0.979	Soil	0.979
VES10	0.979	8.659	Clay	7.68
VES10	8.659	14.419	Sand with Clay	5.76
VES10	14.419	25.619	Sand (Saline water)	11.2
VES10	25.619	170	Hard Rock	144.381
VES11	0	0.81	Surface soil	0.81
VES11	0.81	1.381	Clay	0.571
VES11	1.381	26.181	Sand (Fresh Water)	24.8
VES11	26.181	132.18	Sand (Saline water)	106

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