BEFORE THE NATIONAL GREEN TRIBUNAL PRINCIPAL BENCH, NEW DELHI

MA No. 103/2022
IN
Original Application No. 169/2021

IN THE MATTER OF:

H.C. ARORA **...PETITIONER**

VERSUS

STATE OF PUNJAB & ORS. **...RESPONDENTS**

L.D.O.H.: 21.03.2024
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INDEX

DELHI

21/5/24

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Report

Detailed Environmental Site Assessment and Remediation of Contaminated ground water and Soil and control the further spread of the Contamination - M/s. Matharu Chemical Industries Village Aloarakh Tehsil Bhawanigarh, District Sangrur, Punjab

Sponsor

Punjab Pollution Control Board, Patiala

CSIR-National Environmental Engineering Research Institute (NEERI)

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May 2024

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FOREWORD

M/s Matharu Chemical Industries (later renamed as Mahalaxmi Organochem Industries) situated at Nabha Road, Bhawanigarh, Sangrur District (Punjab) was established in 1991 and manufacturing H-Acid till 2005, when the plant was closed by the Management. The plant was designed to generate 580 kg of H-Acid per batch and 35 batches per month. Most of the solid wastes such as iron and gypsum sludge generated in the plant were stored in plant premises and wastewaters generated in the plant were discharged into solar evaporation pond located within the plant. These environmentally unsound practices ultimately resulted in noticeable soil and groundwater contamination in the vicinity of the plant.

Keeping in compliance with honorable National Green Tribunal, the Punjab Pollution Control Board (PPCB), in August 2023, retained CSIR-national Environmental Engineering Research Institute (CSIR-NEERI) for detailed site investigations and to delineate action plan for remediation of the contaminated site. Accordingly, CSIR-NEERI conducted a detailed investigation during August 2023 to May 2024 through many field visits, which covered groundwater level measurements, aquifer performance tests, hydrogeology of the area, groundwater chemistry, geophysical survey, exhaustive post and pre-monsoon soil and water sampling, and elaborate physico-chemical analysis following standard protocols and methods. These studies indicated that soil over an area of 21266 m^2 is contaminated whereas groundwater contamination is expected to be approximately 2.198 MCM up to 300 feet depth.

On the basis of these findings, necessary short-term and long-term remedial measures are also suggested.

The cooperation from PPCB and RWSS of the Government of Punjab is gratefully acknowledged.

18/5/2024

(A.N.Vaidya)
Director

May 18, 2024

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List of Acronym

AMSL	Above Mean Sea Level
APHA	American Public Health Association
BGL	Below Ground Level
BOD	Biochemical Oxygen Demand
BW	Bore Well
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CSIR	Council of Scientific and Industrial Research
DW	Dug Well
ERT	Electrical Resistivity Tomography
GPS	Global Positioning System
GSI	Geological Survey of India
HP	Hand Pump
HDPE	High density PolyEthylene
HWSS	Hazardous Waste Storage Shed
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OES	Inductively coupled plasma - optical emission spectrometry
LULC	Land Use/ Land Cover
NEERI	National Environmental Engineering Research Institute
NGT	National Green Tribunal
PPCB	Punjab Pollution Control Board
RL	Reduced Level
RWSS	Rural Drinking Water and Sanitation
SEP	Solar Evaporation Plant
TCIRD	Thapar Centre for Industrial Research and Development
TDFS	Total Dissolved fired solid
TDS	Total dissolved solids
TDVS	Total Dissolved Volatile Solid
TOC	Total Organic Carbon
USEPA	United States Environmental State Agency

Executive Summary

M/s Matharu Chemical Industries (later renamed as Mahalaxmi Organmochem Industries) situated at Nabha Road, Bhawanigarh, Sangrur District (Punjab) was established in 1991 and manufacturing H-Acid till 2005 when the plant was closed by the Management. The plant was designed to generate 580 kg of H-Acid per batch and 35 batches per month.

Except selling some of the iron and gypsum sludge to outside agencies, the plant was storing most of the generated waste on site. The plant was discharging the generated waste water inside the Solar Evaporation Ponds located inside the premises of the plant. Groundwater wells located close to the plant started giving colored water since 2006, and the water is still used by the well owners for their agricultural activity.

The unscientific disposal of the waste has led to soil and groundwater contamination in the vicinity of the plant. The Punjab Pollution Control Board (PPCB) sponsored a study in August 2023 for detailed site investigations and delineate action plan for remediation of the contaminated site.

The studies were carried out by CSIR-NEERI during the period August 2023 to May 2024.The detailed studies involved Hydrogeology (Groundwater level measurement, Aquifer Performance test, Groundwater chemistry, Geophysical studies, Soil sampling and Analysis).

The reconnaissance survey of the site revealed that the plant and machineries within M/S Matharu Chemical Industries were dismantled and the site had mounds of soil deposited over the probable locations of the Solar Evaporation Pond (SEP) and Hazardous Waste Storage shed (HWSS). Part of the property is used for agriculture by the land owner. Some part of the property is being used by a brick factory owner for brick molding.

Based on the site conditions, observation well network (35 nos of wells) was set up for groundwater level monitoring and groundwater quality in an area of 5km radius around the plant. The well network included the wells still giving coloured water. It was observed that the groundwater level (below ground level) was in the range 34m-44m. The well development details provided by the Rural water Supply and Sanitation department indicated that the study area is characterized by multi aquifer system and most of the well are tapping the deeper aquifer.

Aquifer Performance Test was conducted at the well located inside the premises of the plant and it was observed that the transmissibility (95.83 m^2/day) was in the intermediate class and close to the High class. It suggests that the region will be more vulnerable to contamination.

The groundwater analysis indicated the presence of elevated colour, TOC and COD in few samples close to the industry in pre-monsoon as well as post-monsoon seasons. The colour concentration contours was in the south west direction. The groundwater chemistry indicated the organic nature of pollution. The contaminated wells with high colour had also high Sulphate which can be attributed to the waste generated in the manufacturing process. The groundwater contamination is already noticed upto 300 ft depth as attested by the groundwater chemistry of the wells and the well development details provided by the well owners.

Geophysical investigation (Electrical Resistivity Tomography and Ground Penetrating Radar) was carried out by CSIR-NEERI at the probable locations of the Solar Evaporation Pond (SEP), Hazardous Waste Storage Shed (HWSS) and its vicinity. The Electrical Resistivity Tomography (ERT) indicated presence of highly conductive anomalous zones in the ERT sections at locations overlapping with the probable location of the SEP. The highly conductive anomalous zones were conspicuously present in all the ERT profiles. The ERT also indicated presence of highly conductive anomalous zones near the SEP, which indicated the possible overflow of the effluent. Ground Penetrating Radar (GPR) scanning at the SEP and HWSS indicated strong reflections at the depth of 2-3m, which can be linked to the brick surface of the SEP and HWSS.

Soil sampling was carried out at different locations inside the premises and outside. The samples collected from the SEP had elevated concentration of Sodium and Sulphate while the ones collected from the HWSS had high concentration of iron. Sampling (3m depth) carried out at the SEP indicated the presence of dark colour fluid which had very high TDS (>100000 mg/L), which indicates that effluent is still present in the SEP. Based on the soil analysis results and the field conditions, it is estimated that the contamination is spread over 21266 sq.m area.

Immediate and well as long term measures for remediation of impacted area have been identified. Under immediate measures, the contaminated zones as identified need to be transferred to the TSDF site. Under long term measures, remediation of contaminated groundwater through activated carbon based pump and treat system is suggested. The contaminated wells, MG-3, MG-4, MG-5, MG-6 and MG-8 can be used as abstraction sources. The treated water from the pump and treat system can be provided to the farmers as the source water meets the criteria for irrigation as per the Sodium Adsorption Ratio.

Chapter 1:

Introduction

1.1 Background

M/s Matharu Steel Private Limited established the Industrial unit in July 1991 by the name "M/s Matharu Chemical Industries" in Village Toori, Tehsil Bhawanigarh, District Sangrur for manufacturing H-acid (Sodium Salt). The name of the unit was later changed to M/s Mahalaxmi Orgochem Industries.

M/s Matharu Chemicals Industries had obtained the NOC from the PPCB vide letter No:WPCC/SGR-7/11/EE-I/15205/ dated 7.7.89. PPCB granted NOC from pollution angle vide letter no: 4035 dated 24.7.90. The NOC was issued for production of H-Acid @600 kg/batch. The Industry was issued consent under Section 25/26 of the Water (prevention and control of pollution) Act, 1974 (Consent No: SGR/WPC/ETP/1993-94/F-91 dated 7.10.93). The consent was subsequently renewed from time to time and the last consent to operate under the Water (prevention and control of pollution) Act, 1974 was issued in 1995 (SGR/ETA/95-10/f-173). The industry was issued last consent under section 21 of the Air (prevention and control of pollution) Act 1981 in 1997 (SGR/APC/97-09/R-157). The unit continued manufacturing H-Acid till it was closed on 01.03.2005. Closure of the Industry citing adverse market conditions was intimated to the PPCB vide letter dated 18.3.2005. The fact was verified by the PPCB during the site visit on 21.3.2005. The Industrial unit was again visited by the officers of the answering respondents on 2.1.2006 and it was found that the industry has dismantled the plant up to plinth level. But the hazardous waste was lying in bags in the storage pit.

Following the closure of the industry, villagers (10 nos) living close to the Industry filed a Civil Writ Petition (no. 3481/ 2007) on the file of the High Court of Punjab & Haryana, alleging that Respondents 4 to 7 were polluting the environment by not complying with the provisions of Hazardous Wastes (Management and Handling) Rules 1989, affecting their Fundamental Rights guaranteed under article 14 and 21 of the Constitution of India. The petitioners are 4 aggrieved from the fact that the said Industry, M/S Matharu Chemical Industries did not dispose of the waste material from the manufacturing process, including by-products, all of which is hazardous in nature in accordance with the provisions of 'the Environment (Protection) Act, 1986', 'Hazardous Wastes (Management and Handling) Rules, 1989' as amended in May 2003, The Water (Prevention and Control of Pollution) Act, 1974 and 'The Air (Prevention and Control of Pollution) Act, 1981 and dumped the same at the site in violation of the said rules. The above writ petition was being heard by the Hon'ble High Court of Punjab & Haryana at Chandigarh till 2013, when it was transferred to the NGT vide HC order dated 29.01.2013 and was registered in NGT as Application No. 35/2013.

1.2 Chronology of events

A brief chronology of the event post admission of the Civil Write Petition is provided as under.

I. Hon'ble High Court directed the PPCB on April 02, 2009 to inspect the site and analyse the samples taken from there and submit the status report

II. PPCB submitted an affidavit along with the report to Hon'ble High Court on July 15, 2009

III. PPCB engaged Thapar Centre for Industrial Research Development (TCIRD), Patiala on April 01, 2009 to carry out a detailed investigation regarding the length, breadth and depth of ground water contamination as well as hazardous waste

IV. Hon'ble High Court, allowed the PPCB on August 17, 2009 to go ahead with the detailed investigations by TCIRD

V. TCIRD completed the study during the course of one year, November, 2009 – November, 2010. The final report was submitted and taken on the record by the Hon'ble High Court on January 10, 2011

VI. The Hon'ble High Court in the order dated August 29, 2011 has directed landowner Mr Tara Singh to deposit the expenses for restoration of damages. Mr Tara Singh filed C.M.P. No.12551/2011for discharging him from the liability, as he was a bonafide purchaser. By an order dated December 20, 2011, the Hon'ble High Court, while discharging Mr Tara Singh directed the industry to deposit the said amount

VII. In response to the TCIRD Report, a submission was made in September, 2012 before the Hon'ble High Court by the industry through Prof. Barun Kumar Guha (Retired) Chemical Engineering Department, Indian Institute of Technology, Delhi

VIII. PPCB subsequently filed a counter an affidavit on the comments of Prof. B. Guha

IX. The industry submitted Reply Affidavit file in Civil Misc. No. 17279 of 2012

X. Hon'ble Punjab and Haryana High Court transferred the case to National Green Tribunal on January 29, 2013

XI. NGT directed the Central Pollution Control Board (CPCB) on July 4, 2013 to depute an expert or a team of experts to examine the locations of the sites and to give a report

XII. CPCB team visited the industry and nearby area in Sangrur during July 24 - 26, 2013. CPCB submitted the final report to NGT in September, 2013.

XIII. Prof. B. K. Guha (Retired), IIT, New Delhi, engaged by Industry, gave comments on the Report of CPCB on September 25, 2013

XIV. NGT directed CPCB vide order dated May 08, 2014 to conduct tests for identifying the presence of sulfonated phenolic compounds in the groundwater and for assessment and also to suggest methodology for restitution/remediation of the contaminated water

XV. CPCB team visited the site on June 24, 2014 and collected ground water samples from 8 locations, which were subsequently analysed. CPCB filed a report in June, 2014

XVI. NGT Bench directed the NEERI to undertake the analysis of the ground water at the disputed site.

XVII. NEERI filed its report titled "Assessment of Ground Water Contamination in and Around Mahalaxmi Organochem Industries, Bhawanigarh" in the NGT on November 13, 2014 after collecting groundwater samples on October 17,

Figure 2.2 Schematic site layout of M/S Matharu Chemical Industries (PPCB old

records)2014 from the same tube wells wherefrom CPCB had collected samples earlier in June, 2014.

XVIII. NGT asked a scientist from CPCB on December 19, 2014 to explain the basis on which CPCB team had termed the ground water not to be contaminated.

XIX. On the direction of the NGT, NEERI scientists also appeared before the Tribunal on January 07, 2015

XX. NGT Order in 2015 imposed penalty of Rs. 2 Crore on industry

XXI. A complaint filed by Mr H C Arora in NGT in 2021 regarding failure to take remedial measures for contaminated groundwater

XXII. NGT order for the formation of an Executing cum Monitoring Committee by the Chief Secretary - 31-03-2022

XXIII. Executing cum Monitoring Committee decided to issue Letter of Award to CSIR-NEERI - August 09, 2023

Subsequently, PPCB engaged CSIR-NEERI for undertaking the study with the following objectives and scope of work.

1.3 Objectives

Detailed Environmental Site Assessment and Delineation of Remediation Action Plan in 5 km radius of the M/S Matharu Chemical Industries, Bhawanigarh village, District: Sangrur, Punjab

1.4 Scope of Work

- Reconnaissance visit to the Plant and its buffer zone (5 km radius) and meetings with the PPCB, State Groundwater Department and CGWB

- Collection and review of all the reports pertaining to the Plant operations, characteristics of waste water and waste management practice

- Detailed LULC of the study area

- Inventorization of well network (existing wells with in the plant premises) and wells within 5 km of the study area. The well network will include shallow wells (open wells) and deep wells (bore wells)

- Deciphering the groundwater flow direction

- Sampling and analysis of groundwater samples from the well network for different parameters (major cations, anions, heavy metal, Organics, BOD, COD and colour) in pre-monsoon and post-monsoon seasons

- Geophysical investigations (GPR, ERT) in the plant premises for near sub surface characterization (spread of plumes/ buried drums) and aquifer geometry

- Sampling of soil samples (at different depth from pit up to 2-3 m depth) and analysis for different parameters for relevant contaminants of concern (cations, anions, heavy metals, organics etc.) in pre-monsoon and post-monsoon seasons

- Assessment of extent, quantum and volume of soil and groundwater contamination

- Delineation of remedial action plan

1.5 Approach for the study

The study involved reconnaissance visit, review of reports submitted by different Institutes to PPCB and Honorable Court/NGT and detailed site visit (5 nos) by the CSIR-NEERI team for primary data collection. During the primary data collection, discussions took place with owners of the private wells. Besides, Engineers of the Rural Water supply and sanitation department, responsible for installing the water supply wells for drinking and domestic requirements were also consulted on the well development. The details on well development provided by the private well owners and the Rural Water Supply and Sanitation Department were taken cognizance to draw inferences on the groundwater scenario in the study area.

Review of Reports: The following reports were perused.

i) Analysis report submitted by the Shriram Lab (2009)

ii) Report prepared by the TCIRD (2009, 2012)

iii) CPCB Report (2013)

iv) CPCB report (2014)

v) NEERI report (2014)

vi) Joint Committee report (2022)

vii) Joint Committee report (2023)

viii) Monitoring data of the effluents collected from the Solar Evaporation Ponds of M/S Matharu Chemical Industries (Annexure-I)

ix) Lithologs and well development details provided by the Rural Water Supply and Sanitation Department of the Punjab Government (Annexure-II)

Primary data collection: Field campaign was carried out over six (6 nos.) phases starting from September 12, 2023 to May 1, 2024 **(Table 1.1).**

Table 1.1: Details on the site visits

Sr.No	Visit duration	Tasks undertaken
1	Reconnaissance visit (August 22, 2023)	Site visit with the staff of PPCB, Meeting with Deputy Commissioner
2	September (12-17, 2023)	Well Inventorization, Post-monsoon groundwater level measurement, groundwater sampling, Soil sampling
3	November 2-3, 2023	Well Inventorization and post-monsoon water level measurement
4	December 28, 2023 to January 8, 2024	Electrical Resistivity Tomography (ERT) Measurements, Soil sampling
5	March 28, 2024 to April 11, 2024	Electrical Resistivity Tomography measurement (ERT), Ground Penetrating Radar (GPR) survey, Pumping test, Interaction with the Engineers of Rural Water Supply and Sanitation Department, Soil sampling
6	April 22, 2024 to May 1, 2024	Pre-monsoon water level measurement and groundwater sampling, Soil sampling

1.6 Report Layout

The site reconnaissance and study area details **Chapter II. Chapter III** discusses the field investigation for assessment of contamination and delineation of the volume of contaminated soil and groundwater is delineated. The Action plan for remediation is delineated in **Chapter-IV**. The conclusions and recommendations are discussed in **Chapter-V**.

Chapter -2

Site Reconnaissance and Study Area details

2.1 Reconnaissance

The reconnaissance visit was undertaken to the site of M/S Matharu Chemical Industries on August 22, 2023. The site is located in Bhawanigarh town and block of Sangrur district, Punjab (Figure 2.1). The town lies 19 kilometres east of Sangrur on the Patiala-Sangrur road. Nearest railway station is Nabha, which is about 13 km and the nearest Airport is Sahnewal (Ludhiana), which is about 87 km from M/C Matharu Chemical industry. The study area, which constitutes 5 km buffer of M/S Matharu Chemical Industry lies in between Latitudes of 30^0 16' 45.99" and 30^0 17' 0.85" North, and longitudes of 76^0 04' 39.21" and 76^0 04' 47.49" East (Survey of India Toposheet Nos. 53/B3 and 53/B4) on 1:50,000 scale.

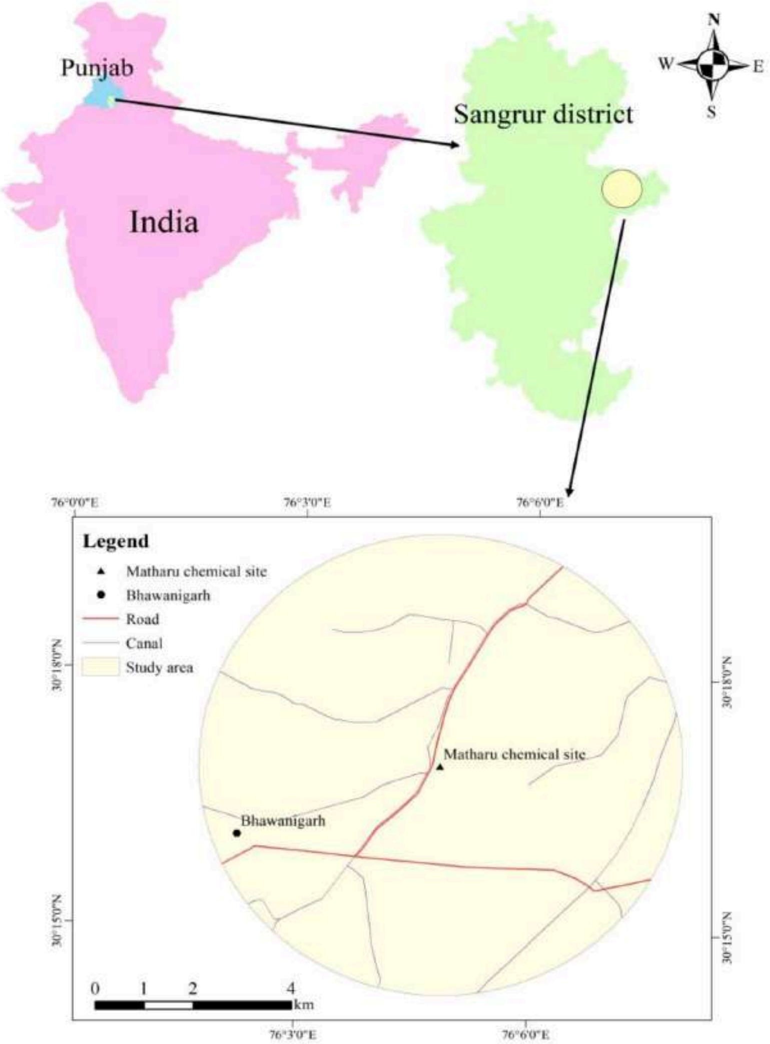

Figure 2.1: Location map of the study area

CSIR-NEERI team was joined by the PPCB officials posted at the Regional office, Sangrur. The visiting team found that the different structures at the site were dismantled. Part of the land was used for agriculture and part of it was leased out to a brick manufacturer. There were mounds soil at many places in the site. The mounds covered the area, which were earlier used as Solar Evaporation Pond and Hazardous waste storage shed. CSIR-NEERI team pointed out to the PPCB officials that the site is not fit for undertaking any Geophysical measurement, unless the mounds of soil are removed from the site. CSIR-NEERI team was shown the contaminated wells giving coloured water. Few other wells in the vicinity of the site were also shown to the NEERI team. The site visit was followed by a meeting with the Deputy Commissioner of Sangrur District. NEERI team also mentioned to Deputy Commissioner about clearing the site by removing the mounds of soil, which can enable proper Geophysical survey at the site. This was followed by meeting with the MS-PPCB and Chairman-PPCB at the office of PPCB at Patiala.

A schematic layout of the industry as obtained from the earlier is depicted in Figure 2.2. The present status of the site and the surrounding area is depicted in Figure 2.3.

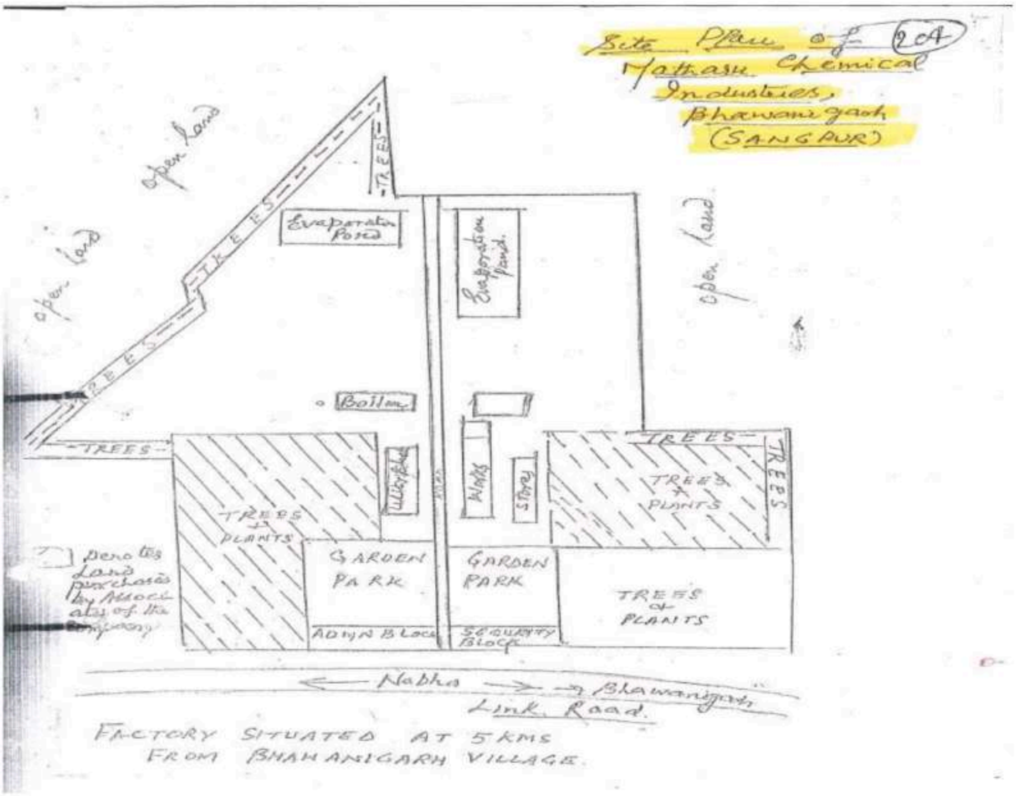

Figure 2.2 Schematic site layout of M/S Matharu Chemical Industries (PPCB old records)

Figure 2.3 Google Earth Image of Site condition in May 2023

2.2 Manufacturing Process, Waste Generation and Waste Management Practices of M/S Matharu Chemical Industries

2.2.1 H-acid Manufacturing process

The process involved in the manufacturing of H-acid at the closed Matharu Chemicals Limited and its associated details provided in this chapter, is based on the secondary data shared by Punjab Pollution Control Board (PPCB). The source of this data are the documents submitted by Matharu Chemicals Limited to PPCB for obtaining of statutory clearances such as No Objection Certificate (NOC), Consent to Operate(CTO) and Authorization to handle hazardous wastes generated in the processes. The chapter also consists of certain details based on literature review of H-acid manufacturing processes.

H-acid is a crystalline acid with the chemical name 1-amino, 8-naphthol, 3, 6 - disulfonic acid ($C10H8NO7S2Na2$). The chemical is an intermediate used in the manufacturing of dyes. H-acid appears as grey powder, that is highly soluble in water, alcohol and ether.

The steps involved in the manufacturing of H-Acid is provided as below,

I. The first step involves **Sulfonation** of naphthalene ($C_{10}H_8$) with 65% oleum ($H_2S_2O_7$) and sulfuric acid (H_2SO_4) which during the reaction emits sulphur oxide fumes.

II. The second step involves **Nitration** process with 60% nitric acid (HNO_3), which during the reaction emits nitrogen oxide fumes.

III. The third step involves **Neutralization** of the resultant acids with lime slurry (10%).

IV. The fourth steps involve **Filtration** of the neutralized mixer in Nutch filters during which gypsum ($CaSO_4$) sludge (solid waste) is generated.

V. The fifth steps involve reduction of the filtrate by addition of iron powder, hydrochloric acid (HCl), soda ash (Na_2CO_3) and acetic acid (CH_3COOH).

VI. The sixth step involves filtration of the mixer in a filter press for the reduced product, during which the residual chemicals and certain byproducts are formed. The separation process results in the generation of solid waste ie., iron oxide (Fe_2O_3) sludge (at 30% consistency).

VII. The filtrate later undergoes concentration followed by cooling down of the concentrated solution

VIII. The cooled down concentrated solution is mixed with HCl and NaCl, following by filtering in nutch filters to obtain Koch cake. This process generates wastewater (mother liquor), which is rich in naphthalene-based compounds, sodium and chloride

IX. The Koch cake is then charged with caustic lye/ caustic flakes (NaOH) and then fused in an autoclave. Following the process, the fused mass with water is added with sulfuric acid and is boiled-off to remove sulphur dioxide.

X. Finally, the boiled off mass is cooled down and is filtered through nutch filters to produce sodium salt of H-acid. The process also generates wastewater (mother liquor) rich in phenolic compounds and residual H-acid.

XI. The final process involves washing of H-acid cake in water followed by centrifugal dewatering, drying and milling the cake to obtain sodium salt of H-acid in powdered form.

The unit manufactured H-acid in batch processes (about 35 batches per month) and each batch produces 580 kg sodium salt of H-acid. The list of raw material that are used in the manufacturing process and its quantities are presented (**Table 2.1**). The byproducts and wastes generated in the manufacturing are presented (**Table 2.2**). The calculation is based on 35 batches of H-acid manufacturing per month for 12 months.

Table 2.1: Material inputs of H-acid manufacturing (Source : TCIRD, 2009)

S.No.	**Input material**	**Quantity (kg/batch)**	**Quantity (ton/year)**	**Consumption for 1994-95 (tons/year)**
1.	Naphthalene	600	252	345
2.	Sulfuric acid	3039	1276	1703
3.	Oleum (65%)	1790	752	1000
4.	Nitric acid	372	156	518
5.	Lime stone	1637	689	1464
6.	Hydrochloric acid (100% purity)	72	30.2	120
7.	Soda ash (sodium carbonate)	900	378	554
8.	Sodium hydroxide	860	361	560
9.	Iron powder	650	273	291
10.	Common salt	2700	1134	??
11.	Acetic acid	10.4	4.383	6

Table 2.2: Byproducts/wastes generated from the H-acid manufacturing (Source : TCIRD, 2009)

S.No.	**Product/byproduct/waste**	**Quantity (kg/batch)**	**Quantity@ (ton/year)**
--	**Sodium salt of H-acid (product)**	**580 (681)***	**243.6 (286)***
1.	Gypsum on dry weight basis	3082	1294
2.	Iron oxide on dry weight basis	1109	466
3.	Sodium bisulfate lost in wastewater	---	---
4.	Sodium nitrite and nitrate lost in wastewater	---	---
5.	Common salt lost in wastewater	~2750	~1155
6.	Glauber salt lost in wastewater	---	---
7.	**Naphthalene lost in the wastewater**	**396 (360.5)***	**166 (151)***

2.2.2 Details of Water Consumption in H-acid manufacturing process

The fresh water consumption steps in the manufacturing of H-Acid is listed below,

- Preparation of the lime slurry for neutralization process
- Washing of nutch filters and filter presses that are used in the filtration
- Dilution of fused mass
- Washing of H-acid cake
- In addition to this, water was also used in boiler feed at a rate of 1 ton/hr capacity and as makeup water in the cooling tower and circulating cooling water system. PPCB records indicates that the consumption of about 34 KLD of water (26 KLD in the manufacturing process, 5 m3/day in the boiler and 3 m3/day in the circulating cooling system).

2.2.3 Details of Wastes generated from the H-acid manufacturing

The H-acid manufacturing process generates the following wastes:

I. Gypsum (calcium sulphate) sludge: The sludge is generated from the reaction mixer through filtering in step-IV of the manufacturing process
II. Iron oxide sludge: The sludge is generated from the reaction mixer through filtering in step-VI of the manufacturing process
III. Foul condensate: Generated in the multi-effect evaporator in step-VII of the manufacturing process
IV. Mother liquor: Generated after the filtration removal of Koch cake in step-VIII of the manufacturing process.
V. Discarded liquor: Generated from the filtration removal of the H-acid in step-XI of the manufacturing process
VI. Product wash water: Generated from the washing of the H-acid cake in step-XII of the manufacturing process (moderate strength wastewater and can be reused for dissolving the fused mass in step-10).

The product specifications indicates that about 40% of the naphthalene consumed in the process is present in the product (H-acid) and the rest >60% is carried in the wastewater (generated at step-VIII, step-XI and step-XII) as naphthalene-based compounds, sulfonated phenolic compounds and condensation products of fusion. Due to limited water solubility and higher sludge consistencies, gypsum and iron oxide sludges will have only negligible quantity of these organics substances, which might also be lost as organic vapours in the process.

The byproducts generated from the process namely sodium sulphate, sodium bi-sulphite, sodium chloride, sodium nitrite and sodium nitrate shall be present in the wastewaters generated. Very minor quantity of the aforementioned chemicals would be present in the gypsum and iron oxide sludges (may depend on the sludge consistency). There is no data that clarifies on the sodium sulphate recovery from the wastewater (mother liquor) during its treatment (neutralization, filtration, concentration and filtration) and its reuse in the H-acid manufacturing process (as an alternate to soda ash).

The details on the inputs (Table 2.1) and the outputs (Table 2.2) reveals that of the total quantity of input chemicals at the rate 12,640 kg/batch, of which, gypsum and iron oxide sludge amounts to 4,191 kg/batch and the product (H-acid) quantifies to 681 kg/batch. Rest of the material (7,768 kg/batch) should consist of Glauber Salt recovered from the process (of which no clear details are available), spent acid (no data) and the remaining shall be present in the wastewater generated and a small portion of it would have been in the process as sulphur oxides and nitrogen oxides.

2.3 Waste Management Practices

2.3.1 Wastewater

Wastewater generation might have been around 20 m^3/batch of H-acid processed or 23 - 24 m^3/day. Generation rates of different wastewaters have been assessed as following:

- Mother liquor (assessed at about 3-4 m^3/batch)
- Foul condensate (assessed at about 5-6 m^3/batch)
- Nutch filters' and filter presses' washwater (about 1 m^3/batch)
- Discarded liquor (assessed at about 5 m^3/batch)
- H-acid wash water (assessed at about 5 m^3/batch)

In addition to these process wastewaters, the industrial unit shall also generate the following effluent stream:

- Steam condensate that is not recovered and allowed to flow into the drain
- Cooling tower blow down water
- Regeneration wastewater generated from the generation of boiler feedwater plant (soft water plant)

The industrial unit used an incinerator since late 1996 for the disposal of the mother liquor. For the disposal of the wastewater, the industrial unit, according to records, used forced spray evaporation. The documented information from PPCB also indicates use of 4 evaporation ponds, each of dimensions with 24 m x 24 m x 1.5 m and a tank of dimension 50 m x 26 m x 2 m dimensions. During field survey activities, the evaporation pond area was identified with bags of solid waste (organics) buried and covered with soil. It need to be mentioned that the Solar Evaporation Ponds were constructed in early 1991 and installation of HDPE liners were not in practice during that period. It was also observed during the visit of NEERI team that some kind of liner sheet was found at places. In the long term, the integrity of such sheets can not be ensured. In the long term, the percolation of leachate from the SEP can not be ruled out and can be potential source of soil and groundwater contamination.

As per the information available in the PPCB records, the industrial unit had installed an incinerator in 1996 for the disposal of the mother liquor generated in step-8. Further, the records say that 100 kg/day (at certain other places indicated as 50 kg/day) of ash was generated from the incineration of the mother liquor. 100 kg/day ash is grossly understated. Almost all the chloride used in the manufacturing process, both as NaCl and as HCl, is expected to get into the mother liquor and then become part of the incineration ash.

2.3.2 Solid and hazardous waste

The solid and hazardous wastes generated include

- Gypsum sludge: 3,082 kg/batch on dry weight basis. Assuming 30% moisture about 1850 tons per year gypsum sludge was generated.
- Iron oxide sludge: 1,109 kg/batch on dry weight basis. Assuming 70% moisture about 466 tons per year of iron oxide sludge was generated.

- Incineration ash: 100 kg/batch or 30 tons per year (as informed by the industrial unit). This is grossly understated and may be possible if glauber salt can be used in place of common salt, and if the used glauber salt can be recovered from the wastewater and reused. Sodium chloride use might have generated about 2.7 tons/batch of incineration ash.

2.3.3 Past Waste Disposal Data

Three sludge tanks/pits, each of 20 m x 12 m x 2 m dimensions (480 m^3 volume), were apparently used for the storage of the generated gypsum sludge, iron oxide sludge and incineration ash. Apparently some of the organic sludge accumulated in the solar evaporation ponds was also collected and stored in the tank meant for the incineration ash storage.

Unconfirmed information indicates that unknown quantity of the iron oxide sludge and of the gypsum sludge was billed and sold out to outside parties for reuse. Records available are not complete for accounting the amount of sludge thus sold out. During 14-10-1993 and 18-03-1994, 633 tons of iron oxide sludge, and during 03-4-1993 and 24-03-1994, 293 tons of gypsum sludge were sold out. Similarly, during 1995, 1035 tons of gypsum and 945 tons of iron sludge were sold out. After the closure of the industrial unit, 103 tons of incineration ash was reportedly lifted from the incineration ash storage tank and transported to the TSDF of Nimbua, Dera Bassi for disposal.

2.4 Rainfall and climate

The precipitation in the area occurs mainly due to south west and north east monsoon. However, most of the precipitation is received through south west monsoon during June to August. The average annual rainfall in the area was approximately 491.71 mm during 2012 to 2023 period (Table 2.3: Source: https://indiawris.gov.in/wris/#/rainfall). During the period, the area received minimum of 316.99mm in the year 2014 and maximum of 695.47 mm in the year 2012 **(Table-2.3, Figure 2.4).**

Table 2.3 Temporal variation in Rainfall (mm) of the study area [2012-2023]

Year	Rainfall (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total rainfall (mm)
2012	33.4	1.54	1.98	33.78	0.08	8.91	180.93	311.44	105.27	0.05	3.03	15.05	695.47
2013	8.09	60.52	14.56	0.51	0.77	116.11	76.28	112.06	17.04	10.77	1.31	5.37	423.59
2014	22.27	11.71	31.69	12.59	24.78	22.52	34.05	24.96	94.18	12.99	0.82	24.42	316.99
2015	14.45	19.99	54.93	33.18	14.83	61.35	143.97	69.52	69.47	4.72	1.31	0.05	487.77
2016	0.52	4.31	42.1	0.09	36.22	59.54	130.55	100.95	1.06	0.6	0.09	0.58	376.58
2017	54.23	1.52	12.37	6.7	5	80.65	49.99	82.18	50.65	0	1.69	10.27	355.25
2018	11.13	6.08	0.6	14.02	14.7	89.68	187.4	68.84	171.27	1.44	0.52	13.07	578.76
2019	22.42	43.2	11.45	22.43	20.09	28.99	177.03	127.2	48.4	2	31.14	11.83	546.19
2020	37.53	4.51	71.59	11.41	40.72	50.2	189.78	84.96	9.21	0	8.99	4.35	513.26
2021	6.75	3.76	7.77	10.05	28.27	40.07	173.83	80.18	104.27	39.96	0	0.93	495.86
2022	90.44	16.34	0.05	0.04	40.56	35.13	237.42	31.05	145.09	19.66	0.03	0.06	615.86
2023	12.66	0	55.14	13.29	62.96	46.56	173.8	24.39	77.27	18.99	4.13	5.83	495.02

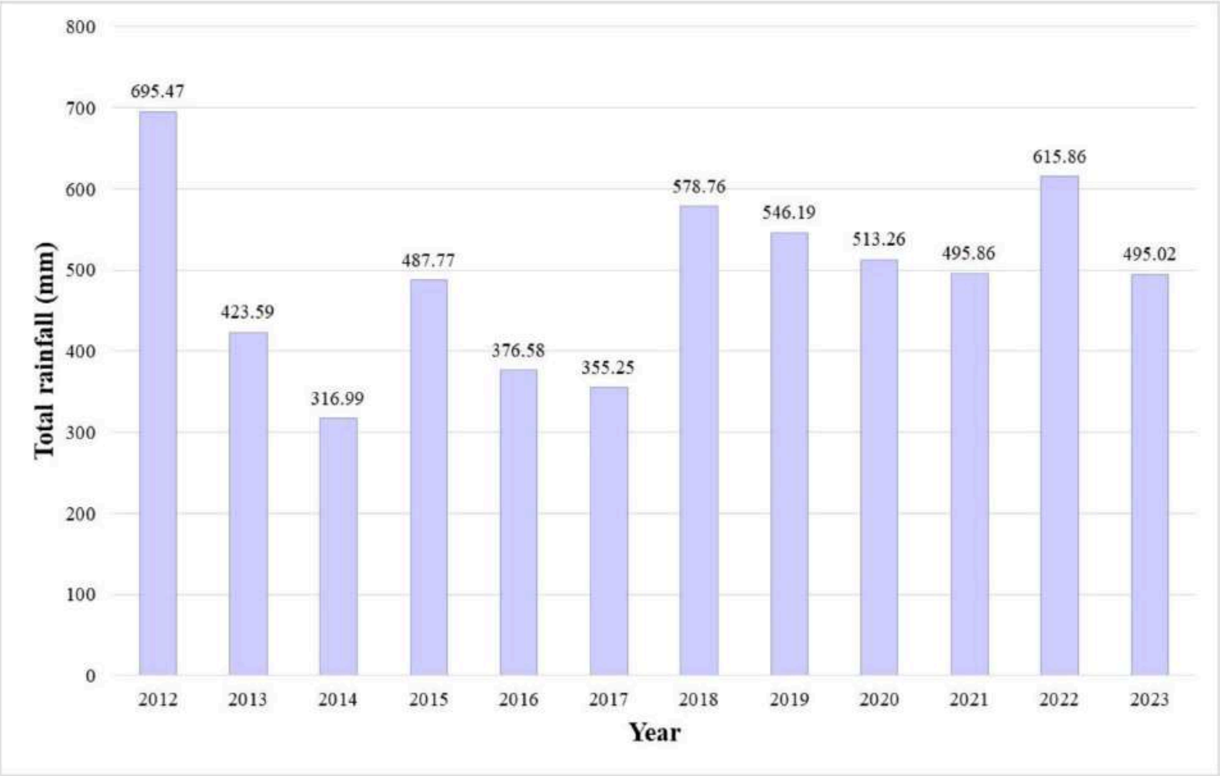

Figure 2.4: Annual rainfall (2012-2023) of the study area

2.5 Topography and Drainage

In general, the study area is part of Indo Gangetic plain which belongs to pediplain geomorphological unit. The slope of the study area is towards the south-west direction and the elevation varied from about 173 m to 211 m above mean sea level (AMSL) (**Figure 2.5**). In the study area, drainage system namely Bhawanigarh and Nabha distributaries including small minor irrigation canal (lined) network are present. The study area (5 km buffer) does not have any natural stream network. The existing drainage system are carrying flood water, when heavy rainfall occurs in the catchment area.

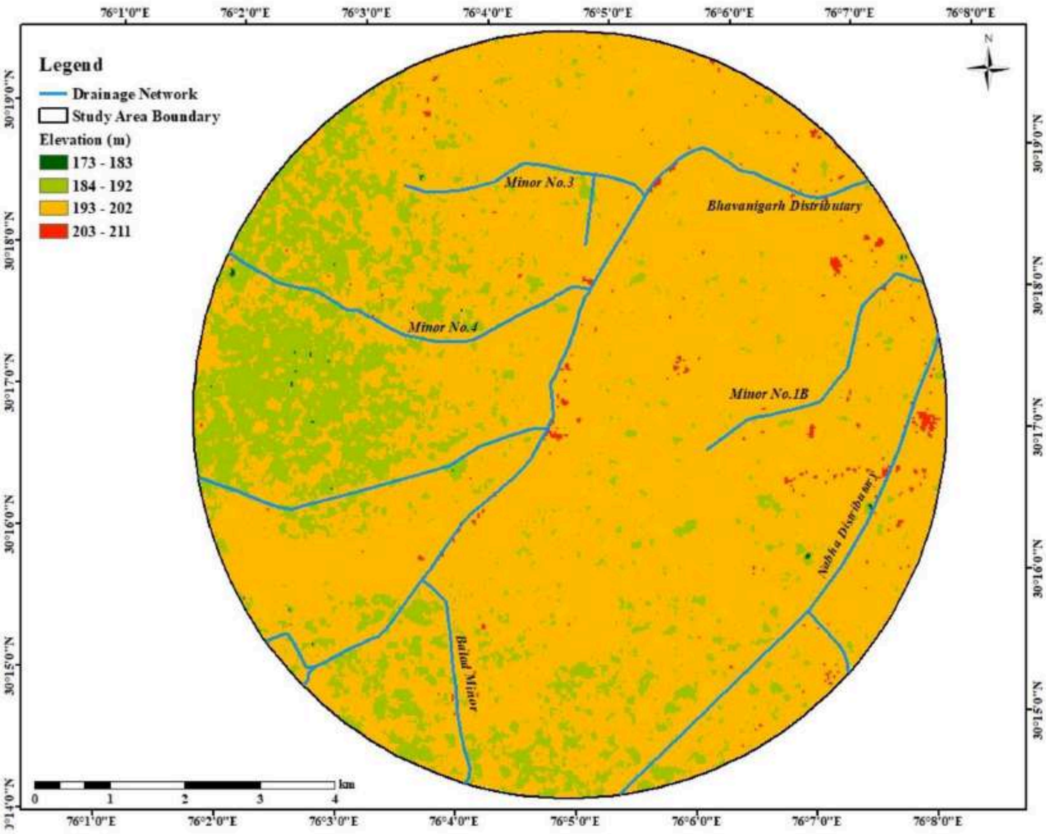

Figure 2.5: Drainage network and elevation map of study area

2.6 Land use and Land cover

The land-use/land-cover (LU/LC) was prepared using Landsat - 8 satellite imagery of 29/09/2023 with 30-meter resolution (Source:earthexplorer.usgs.gov/). The LU/LC classification of the study area (**Figure 2.6 & Table 2.4**) indicates that the major part of the study area is covered by Agriculture (68.83%), built-up area (16.62%). vegetation (13.34%) and water bodies (1.21%).

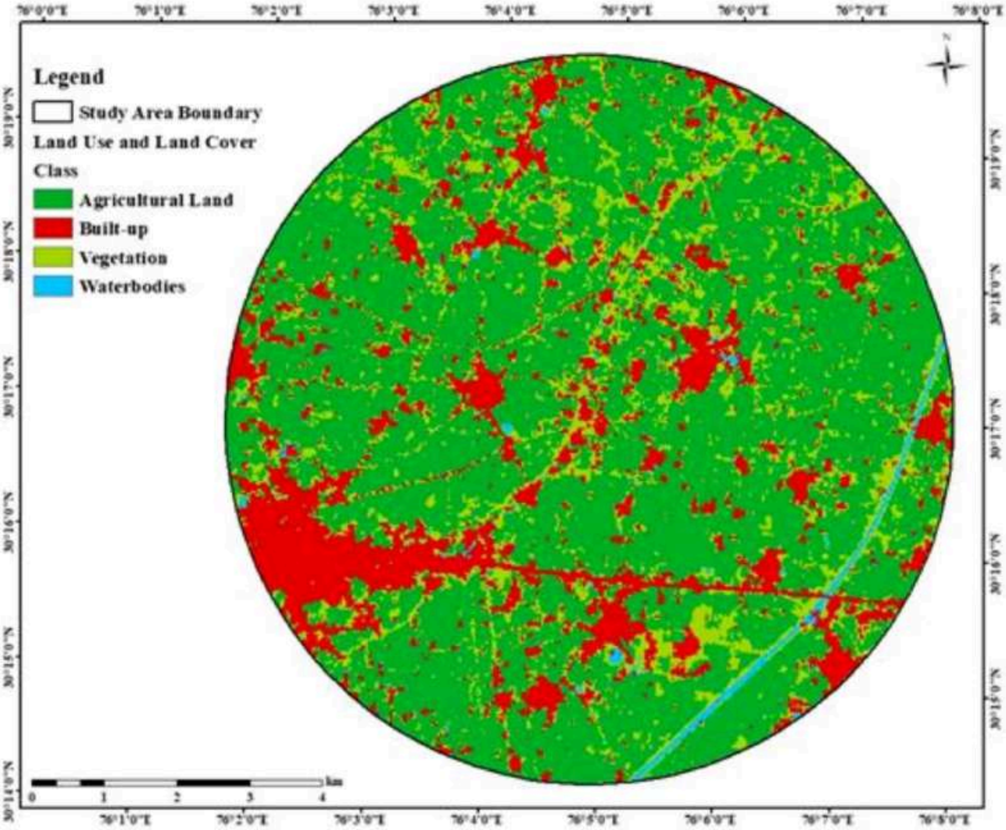

Figure 2.6: LU/LC classification of the 5 km buffer of the study area

Table 2.4: LU/LC area and percentage distribution

Sr. No.	Class	Area (km^2)	Percentage
1.	Agriculture	53.99	68.83
2.	Built-up	13.04	16.62
3.	Vegetation	10.46	13.34
4.	Water bodies	00.95	01.21
Total		**78.44**	**100%**

2.7 Geology and Hydrogeology

The study area is covered by Indo-Gangetic alluvium of Quaternary age, which comprises sand, gravel, pebble, kankar and clay (CGWB, 2017). Blown sands occur in the form of dunes in western, northern and north-western part of the district (CGWB, 2017). Lithologically, the study area (**Figure 2.7**), is part of the Indo-Gangetic alluvial plain. It is located in the Ghaggar sub-basin. Most of the study area is covered by oxidized silt clay with kankar and micaceous sand and the yellowish brown loose sand with without kankar from north to south direction as well as in the patches of east and west parts of the study area (https://bhukosh.gsi.gov.in/).

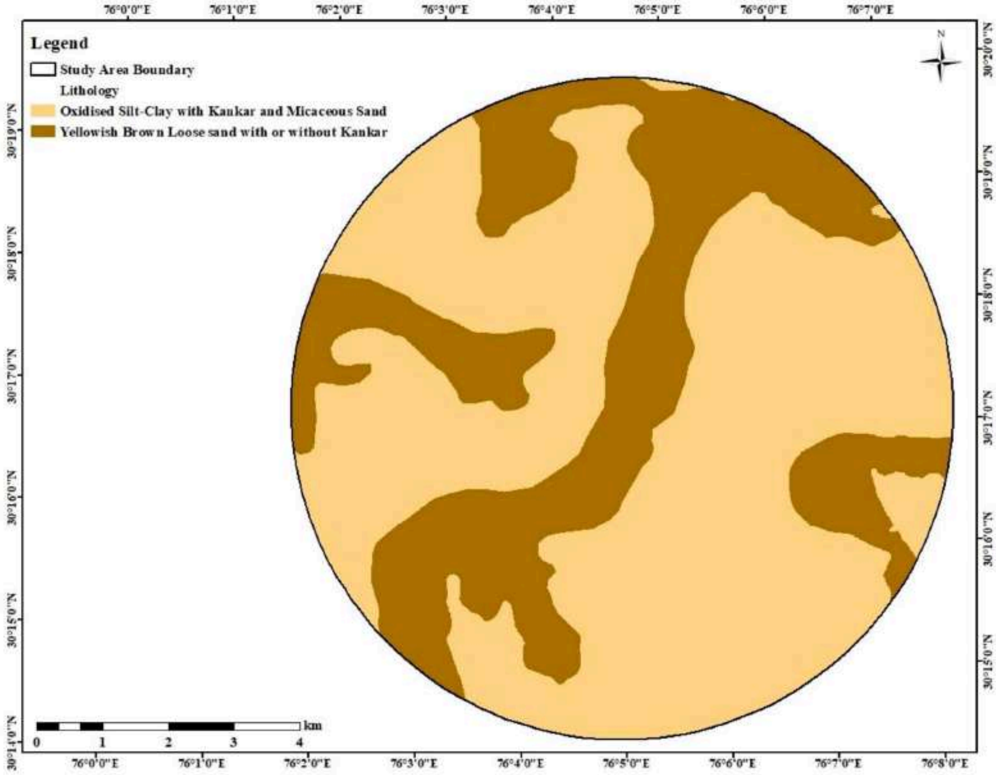

Figure 2.7: Geology of the study Area

The study area is dependent on Bore well and canals for irrigation, with significant water sources being Bhawanigarh and Nabha canal distributaries. Groundwater and Canals account for 91% and 9% of the irrigation in the District respectively, which attests the ground water regime being under severe stress.

It is reported (CGWB, 2017) that shallow aquifers up to the depth of 60 m is either in the form of isolated lenses of sand embedded in clay beds or well-connected granular zones that have pinching and swelling disposition. These aquifers comprising fine to coarse sand are often intercepted with kankar horizons. Deeper aquifers in the range of 60 m and above are composed of fine to coarse sand, silt, gravel and kankar. The groundwater occurs in alluvium formations comprising fine to coarse sand, which forms the potential aquifers. In the shallow aquifer (up to 50m), groundwater occurs under unconfined/water table conditions, where as in deeper aquifer, semi-confined/confined conditions exist (CGWB, 2017). The lithological logs (Figures 2.8-2.13) provided by the RWSS department indicate the prevalence of multi-aquifer system in the study area, which is characteristic of the aquifer disposition in the Indo-Gangetic Plains.

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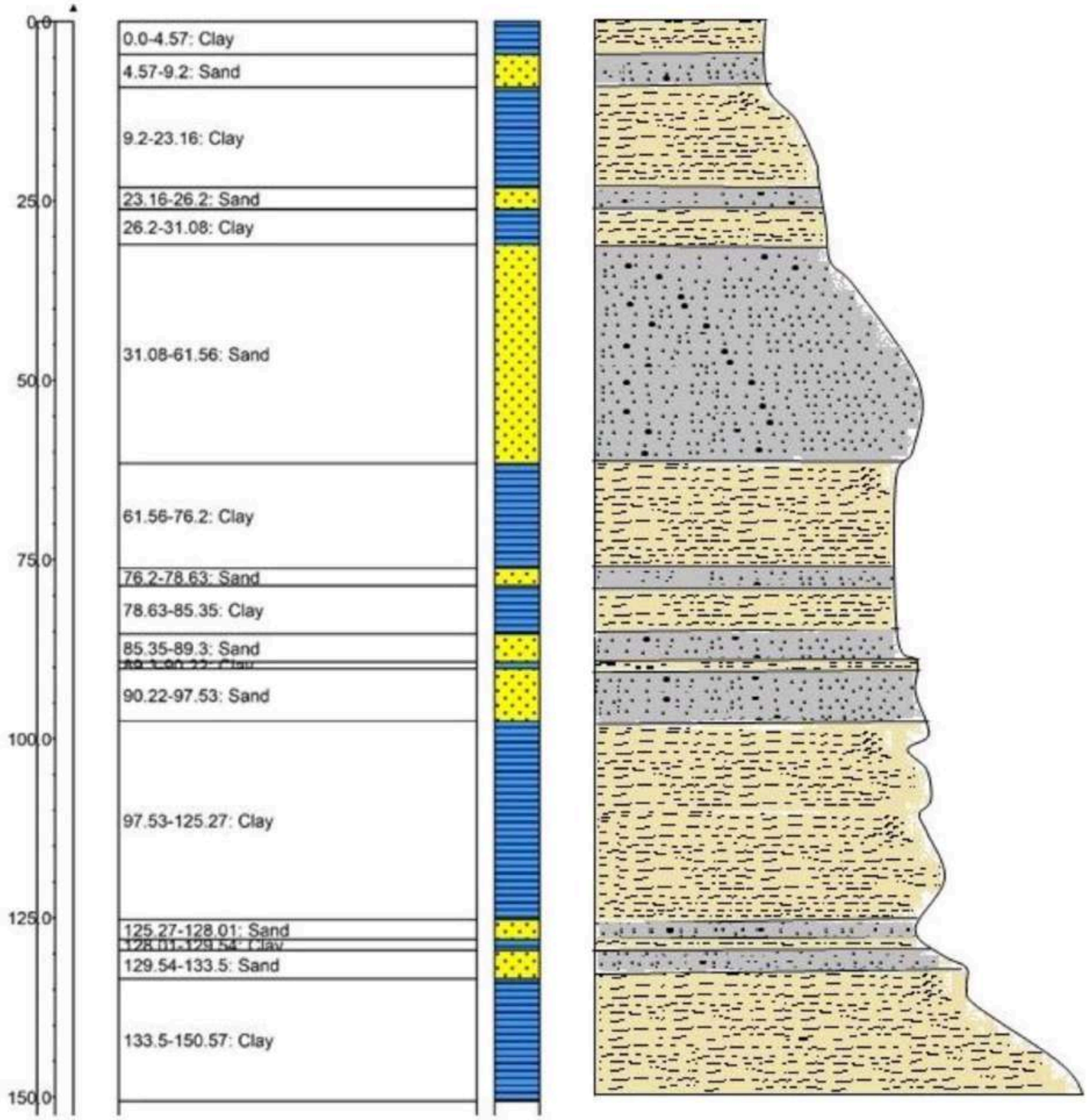


Figure 2.8 Litholog at Aloarkh (Source: RWSS, Punjab)

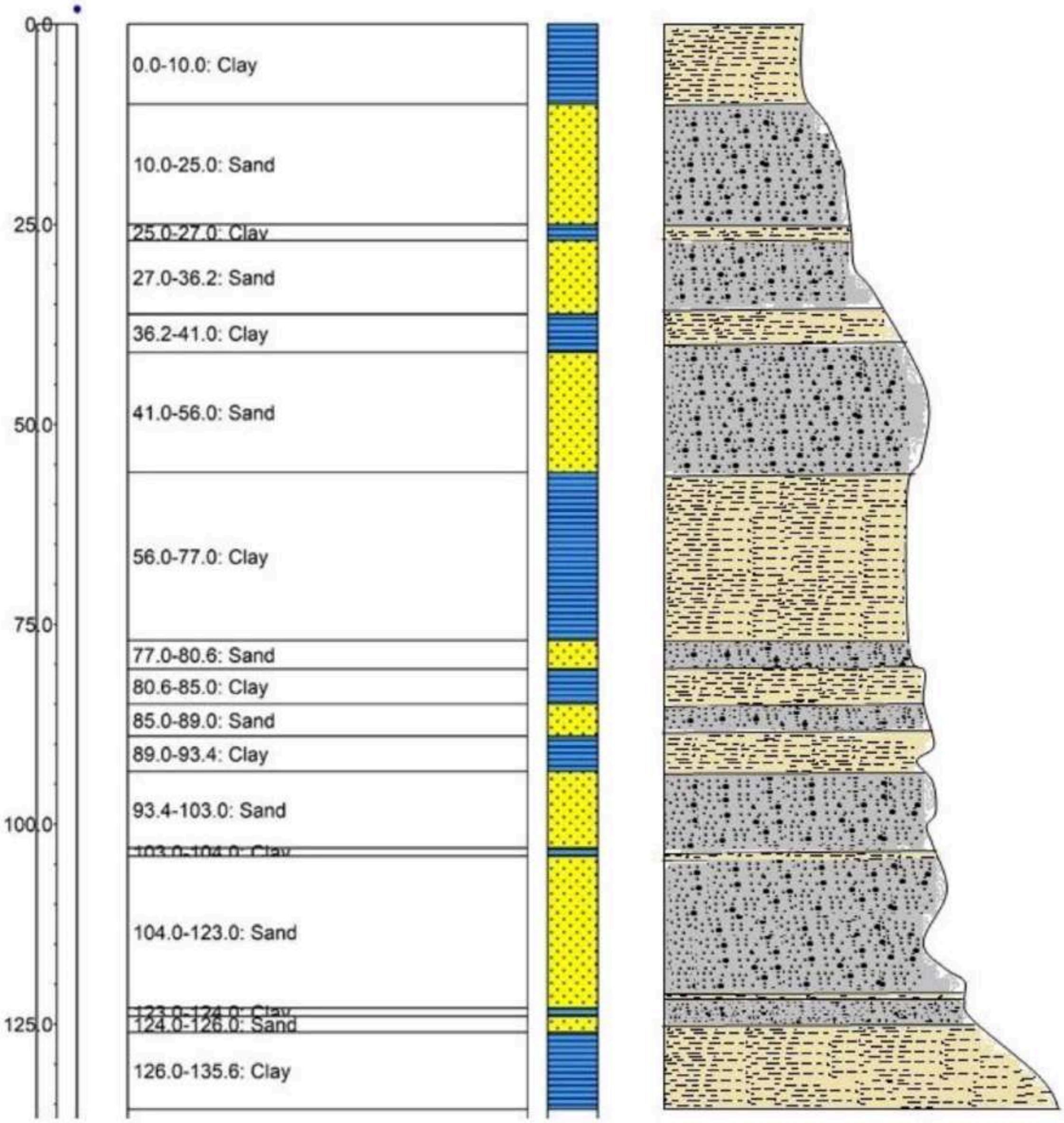


Figure 2.9 Litholog at Bhaktara village (Source: RWSS, Punjab)

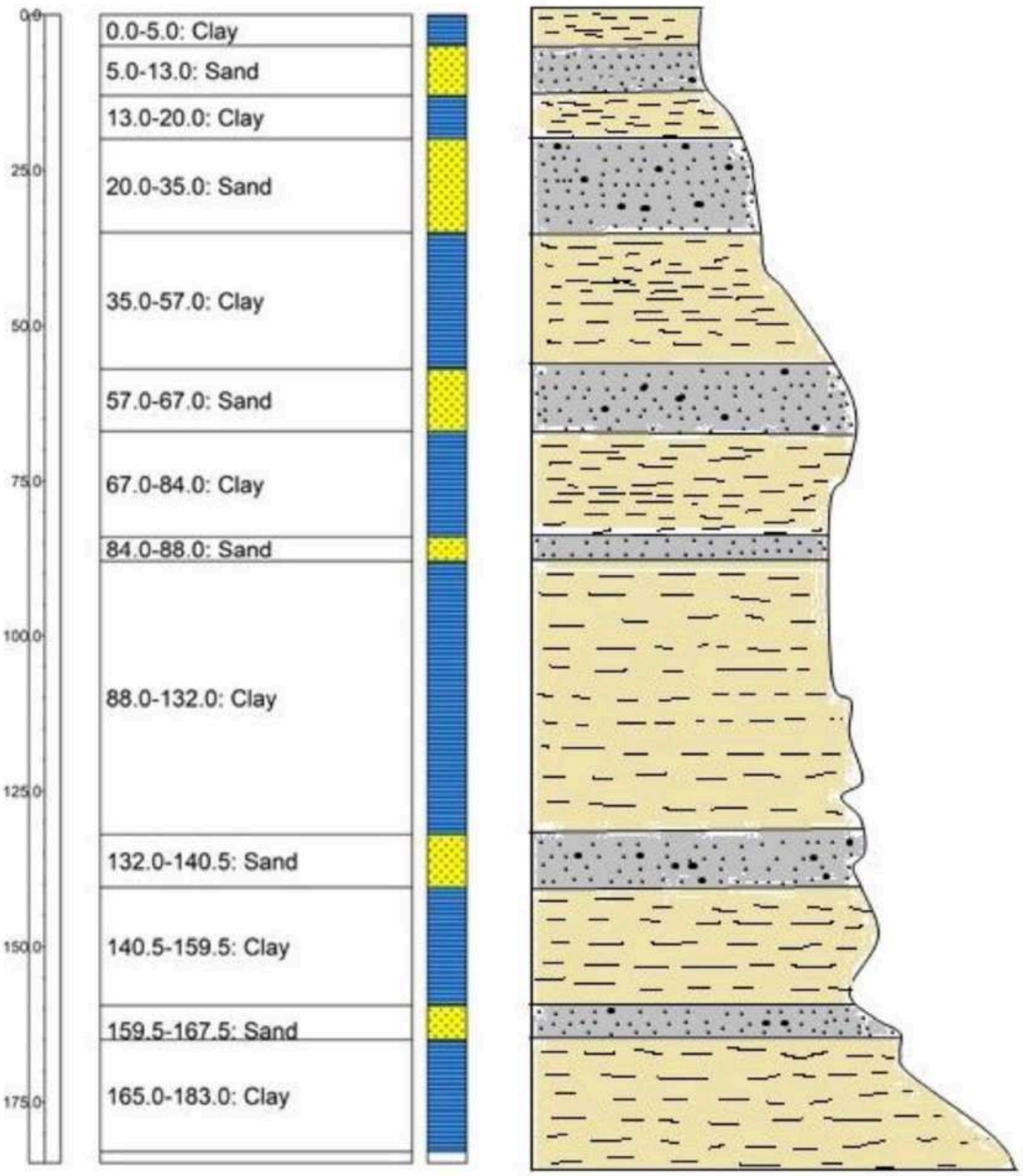


Figure 2.10: Litholog at Bhakati village (Source: RWSS, Punjab)

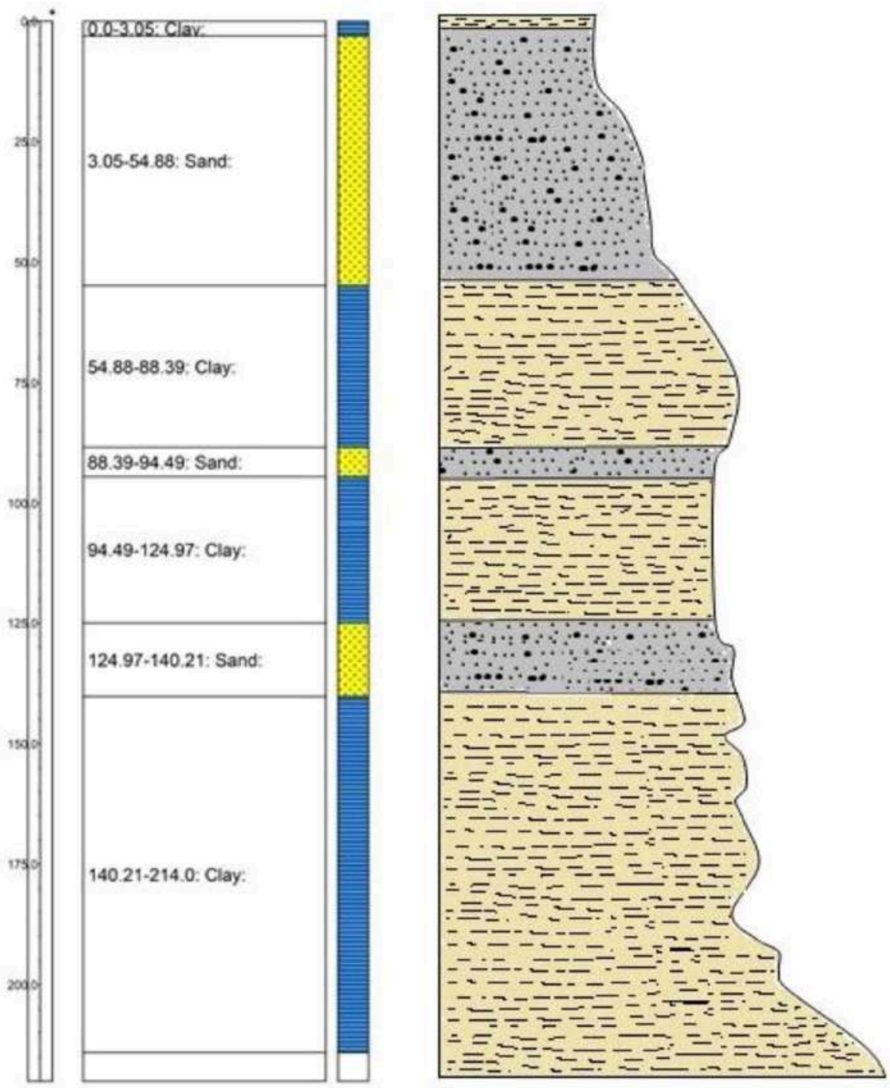


Figure 2.11: Litholog at Dayalgarh (Source: RWSS, Punjab)

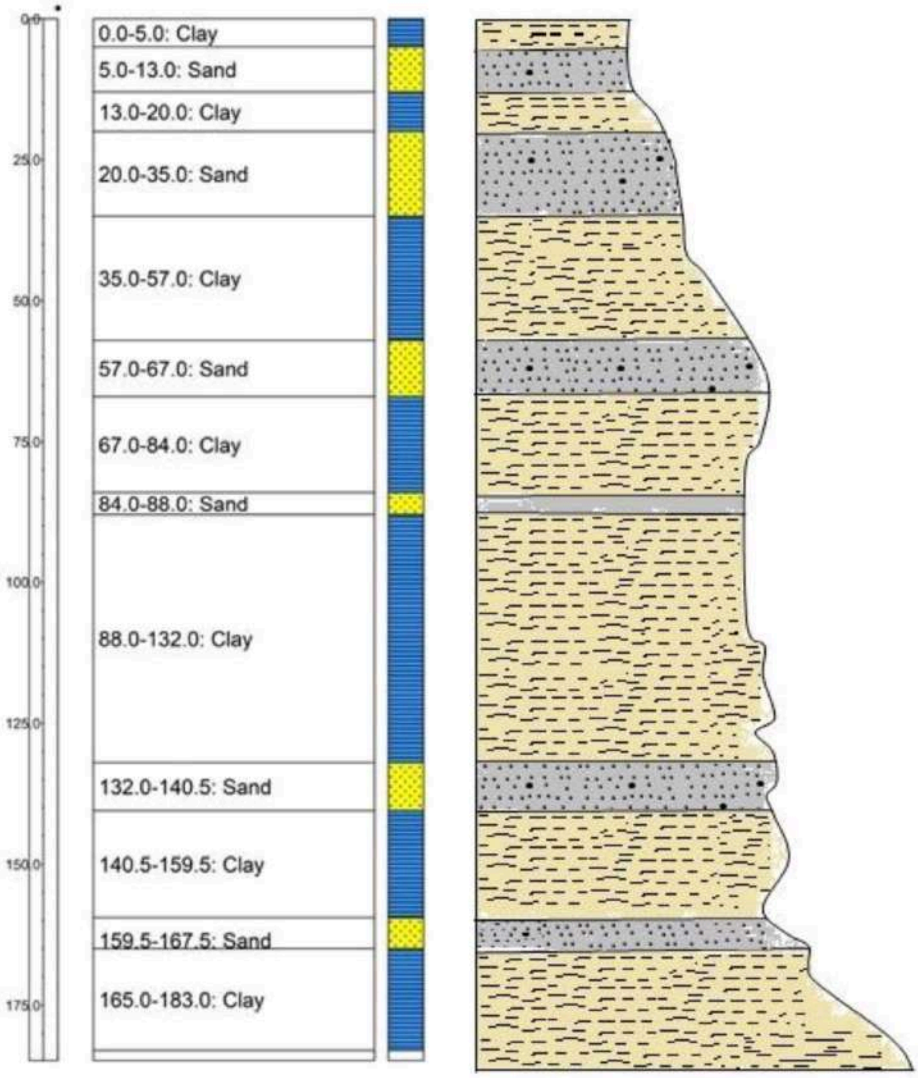


Figure 2.12: Litholog at Majhi village (Source: RWSS, Punjab)

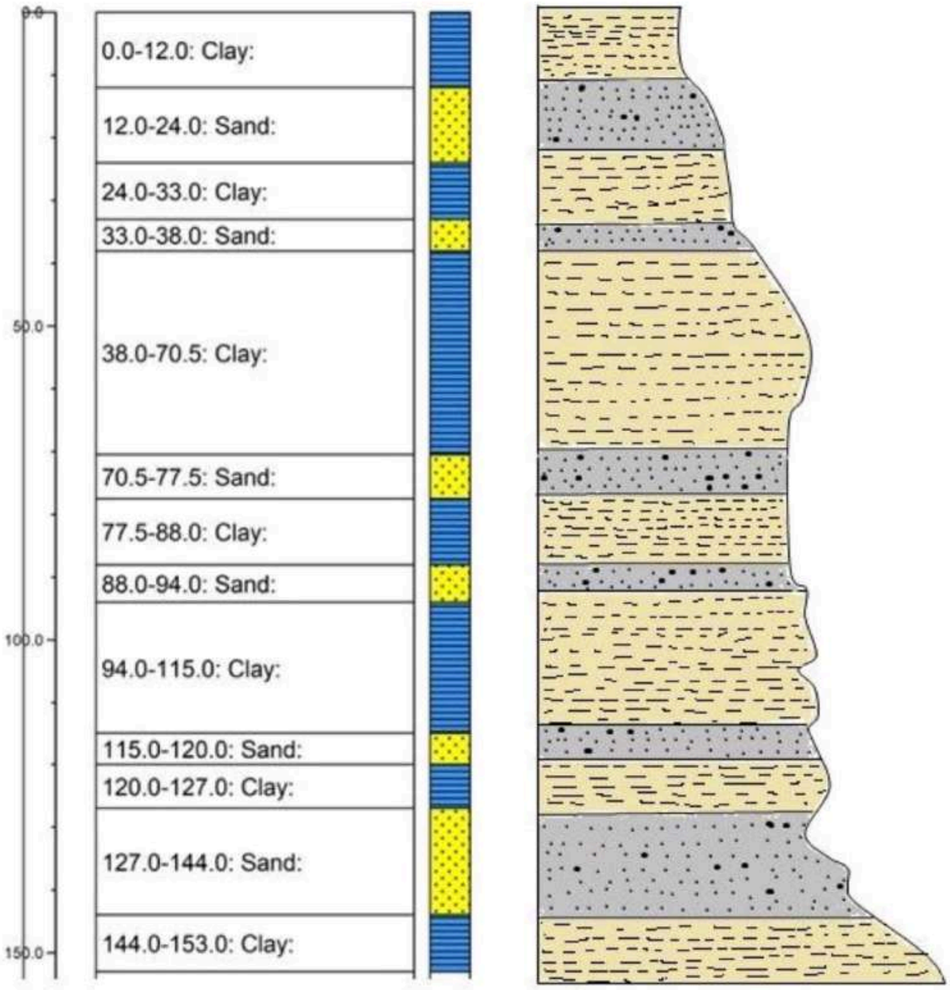


Figure 2.13: Litholog at Majha village (Source: RWSS, Punjab)

It is reported (CGWB, 2017) that the Bhawanigarh block, which covers the study area is under alarming situation with the groundwater stage development at 212%. It comes under over-exploited zone. It is evident in the declining groundwater levels. In view of the stage development being 212%, the dynamic resource is exhausted and new wells drilled are tapping the deeper aquifer. It was also reported by the Engineer of the Rural Water Supply and Sanitation department that in view of the salinity and other quality issues, the deeper aquifer is being tapped. The well development details provided by the RWSS indicate that the slotting is provided to draw water from the deeper aquifer.

Most of the bore wells installed by the villagers are equipped with 15-20 HP pumps and approximately 8 hours of electricity is provided to the farmers for running the pumps. The local villagers are pumping groundwater at the rate of 2400 to 2680 liters per minute (lpm) for their regular irrigation activities. Discharge measurement performed in the site indicated that the discharge was approximately 20 lps (at well-MG-2). Besides the agricultural pumping, groundwater (wells drilled by RWSS) is provided to the villagers in Alourkh, Bakhtri, Bhaktara, Dayalgarh, Baladkalan, Nakte, Majhi, Majha and Bimber.

Chapter -3

Field Investigations for assessment of contamination

3.1 Approach

Extensive Primary data on Hydrogeology (Groundwater level measurement and Aquifer Performance Test), Groundwater Chemistry, Geophysical studies (Electrical Resistivity Tomography and Ground Penetrating Radar), Soil quality have been generated through detailed field investigation spread over five (5 nos) phases during the period September 2023 to May, 2024. The secondary data shared by PPCB and the discussions with the field officials of PPCB have been referred as and when necessary to plan the field investigations.

3.2 Hydrogeology and Groundwater Chemistry

3.2.1 Groundwater level measurement

A network of observation wells (35 nos) (**Figure 3.1, Table 3.1**) was established for groundwater level (below ground level– bgl) measurement and collection of groundwater samples for quality analysis. The observation well network includes the contaminated wells (wells giving coloured water). The coordinates of the observation wells were marked with the help of hand-held Global Positioning System (GPS) of Garmin make. The general topography trend as evident in the Survey of India toposheet (Nos. 53/B3 and 53/B4) was considered while designing the observation well network. The network includes the wells (2 nos.) located inside M/S Matharu Chemical Industries. During well Inventorization, the well development details (Depth of well, Position of blank pipes and slotted pipes) were sought from the well owners (farmers/Rural Water Supply and Sanitation department).

Table - 3.1: Observation well network for groundwater monitoring in the study area

Sample Code	Source	Latitude	Longitude	Location Details/Remarks
MG-1	BW	30° 17' 0.8"N	76° 4' 48"E	Bhawanigarh village - temporary settlement nearby Matharu Chemical Industry
MG-2	BW	30° 16' 57.0"N	76° 04' 53.2"E	Bhawanigarh village - Back side of Matharu Chemical Industry
MG-3	BW	30° 16' 57.1"N	76° 04' 41"E	Bhawanigarh village - at Mr. Kulvinder Singh agricultural field area, 300 ft well with Blank pipe upto 250 ft followed by 50ft slotted pipe

Sample Code	Source	Latitude	Longitude	Location Details/Remarks
MG-4	BW	30° 17' 3.6"N	76° 04' 40"E	Bhawanigarh village - agricultural field area. 220 ft well having 180ft blank pipe followed by 40 ft slotted pipe
MG-5	BW	30° 17' 4"N	76° 04' 33.4"E	Bhawanigarh village - At Mr. Dilbrang Singh agricultural field area
MG-6	BW	30° 16' 54.5"N	76° 04' 40"E	Bhawanigarh village - At Mr. Amritpal Singh agricultural field area, 240 ft well having 220 ft blank pipe followed by 20 ft slotted pipe
MG-7	BW	30°17'3.5"N	76°04'43.3"E	Aloarkh village - At Bharat petrol pump (Randhawa filling station)
MG-8	BW	30° 16' 50.7"N	76° 04' 38.3"E	At Mr. Amritpal Singh agricultural field area
MG-9	BW	30° 16' 38.3"N	76° 04' 9.6"E	Aloarkh village - At Gurudwara (Shi Manji Saheb)
MG-10	BW	30° 16' 59.6"N	76° 03' 56.6"E	Aloarkh village - Water supply department (water works): Blank Pipe upto 85 m followed by slotted pipe at zones (85.8m to 88.8 m, (90.8m to 96.8m), (125.65m to 127.65m), (127.9m to 132.9m)
MG-11	BW	30° 16' 57.4"N	76° 03' 39.7"E	Aloarkh village - At Mr. Kewal Singh house
MG-12	BW	30° 18' 8.5"N	76° 04' 50.9"E	Bakhtri village - Water supply department (water works) Depth 220 ft, Blank pipe upto 120ft, followed by slotted pipe between 120-160 ft and blank pipe from 160-220 ft
MG-13	BW	30° 17' 57"N	76° 04' 26"E	Bakhtri village – well owned by Mr. Manprit Singh agricultural field area
MG-14	BW	30° 17' 19.4"N	76° 04' 4.8"E	Aloarkh village - Mr. Hardev singh agricultural field area
MG-15	BW	30° 18' 10.3"N	76° 04' 17.2"E	Bakhopir village - Mrs. Lakhveer Kaur (Sarpanch, Bakhopir)
MG-16	BW	30° 18' 42.7"N	76° 04' 05.8"E	Bhaktara village - Water supply department (water works): Blank pipe provided upto 96m followed by slotted pipe in the zones, 96m to 102m and 110m to 119m.
MG-17	BW	30°18'20.3"N	76°03'5.7"E	Dayalgarh village - Water supply department (water works), 152.2 m depth well with Blank pipe provided upto 89.89m followed by slotted pipe in the zones 98.89m to 93.89m, 127.21m to 132.21m and 134.21m to 139.21m

Sample Code	Source	Latitude	Longitude	Location Details/Remarks
MG-18	BW	30° 15' 56.7"N	76° 02' 29"E	Bhawanigarh village - Mr. Nirmal Singh, House No. 520
MG-19	BW	30° 14' 57.8"N	76° 04' 44.3"E	Baladkalan village - Water supply department (water works)
MG-20	BW	30° 15' 29.9"N	76° 05' 1.3"E	Balab kala village - At Government primary school
MG-21	BW	30° 16' 37.3"N	76° 05' 20.3"E	Turi village - At Government primary school
MG-22	BW	30° 16' 42.8"N	76° 06' 24.6"E	Nakte village - Water supply department (water works) Well depth 144ft, blank pipe upto 97 ft, followed by slotted pipe between 97-105 ft, blank pipe at 105-133.5 ft, slotted pipe at 133.5-140.ft and blank pile at 140.5-144ft
MG-23	BW	30° 17' 14.1"N	76° 06' 13.9"E	Majhi village - Water supply department (water works). 183M depth with Blank pipe upto 84.5m and slotted pipes in the range 84.5m to 87.5m, 133m to 139m and 160.5m to 166.5m
MG-24	BW	30° 17' 35.5"N	76° 05' 49.5"E	Majha village - Water supply department (water works). 152m depth well with Blank file upto 91n and slotted pipe in the zones 91-93m, 128-133m and 135-143m
MG-25	BW	30° 18' 10.4"N	76° 07' 01."E	Bimber village - Water supply department (water works)
MG-26	BW	30° 16' 58.87"N	76° 3' 55.69"E	Aloarkh village - Sh. Kashmir Singh, S/o Sh. Joga Singh,
MG-27	BW	30° 17' 8.63"N	76° 3' 50.00"E	Aloarkh village - Sh. Devinder SinghS/oSh.Jaspal Singh
MG-28	BW	30° 17' 14.60"N	76° 4' 5.16"E	Aloarkh village - Sh.DarsanSingh, S/o Sh. Lal Singh
MG-29	BW	30° 17' 15.94"N	76° 4' 12.72"E	Aloarkh village - Sh. Karam Singh S/o Sh. Bachan Singh
MG-30	BW	30° 17' 15.47"N	76° 4' 18.44"	Aloarkh village - Sh. Diplreet Singh S/o Sh. Harminder Singh
MG-31	BW	30° 18' 7.34"N	76° 4' 48.07"E	Bakhtari village - Sh. Gurjant Singh, S/o Sh. Bachan Singh
MG-32	BW	30° 18' 9.65"N	76° 4' 48.32"E	Bakhtari village - Sh. Asha Singh, S/o Sh. Makand Singh
MG-33	BW	30° 18' 6.73"N	76° 4' 45.95"E	Bakhtari village - Sh. Nail Singh, S/o Sh. Gurjit Singh, S/o Sh. Bachan Singh

Sample Code	Source	Latitude	Longitude	Location Details/Remarks
MG-34	BW	30° 17' 13.78"N	76° 5' 36.28"E	Majhi village - Sh. Mahinder Singh (Pardhan)
MG-35	BW	30° 17' 6.43"N	76° 4' 42.20"E	Alo Arkh village - Randhawa Filling Station, Behind Petrol Pump

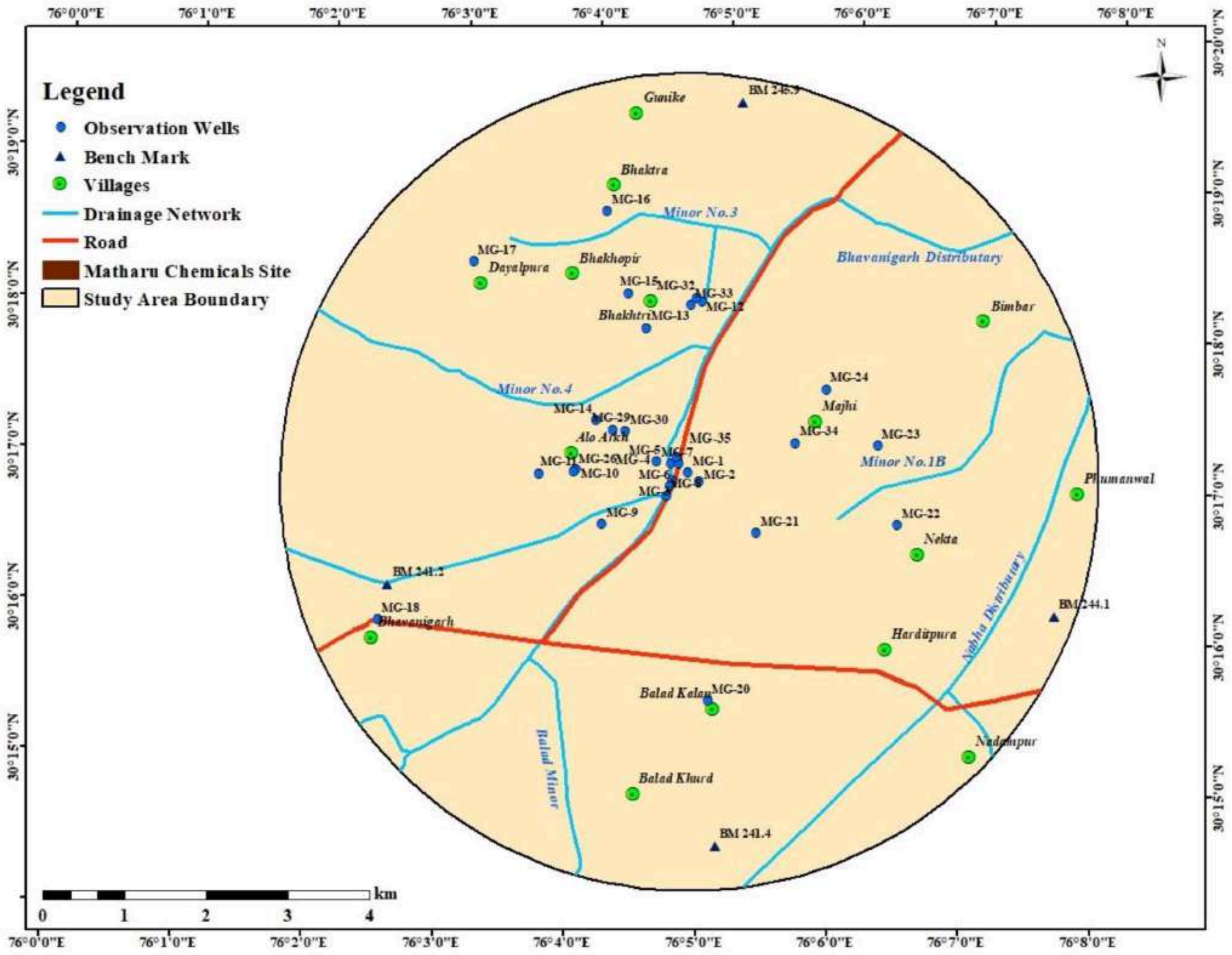


Figure-3.1: Observation well network map of the study area

The groundwater level of the of the wells from the established well network in the area of 5 km radius in the vicinity of core and buffer zones of the Matharu plant was measured **(Figure 3.2)** using automatic water level indicator (Make – Encardio Rite Model – EPP – 10/6) during the post-monsoon (September, 2023) and Pre-monsoon (April, 2024) seasons.

Figure 3.2: Groundwater level measurement in the study area (September 2023)

The groundwater level reflects the overall groundwater scenario as regards to its withdrawal, the recharge due to precipitation and recharge from agricultural return flow, seepage from surface water bodies, etc.

The groundwater level (BGL) varied from 36.71 m (MG-23) to 43.08 m (MG-2) during post monsoon period i.e., October 2023 and 36.81m (MG-25) to 44.08m (MG-7) during pre-monsoon period i.e., April 2024 **(Table 3.2).**

Table 3.2: Groundwater level (bgl-m) in the study area during 2023-24

Sample Id No.	Groundwater level (bgl-m)	
	Post monsoon (Sept'23)	Pre monsoon (April'24)
MG-1	41.22	42.38
MG-2	41.96	43.17
MG-3	41.86	42.56
MG-4	41.9	42.51
MG-5	40.87	41.71
MG-6	40.86	42.27
MG-7	43.08	44.08
MG-8	40.9	*
MG-9	41.57	42.71
MG-10	41.62	43.2

Sample Id No.	Groundwater level (bgl-m)	
	Post monsoon (Sept'23)	Pre monsoon (April'24)
MG-11	42.53	43.32
MG-12	39.63	40.83
MG-13	40.4	41.21
MG-14	39.05	41.73
MG-15	39.9	40.93
MG-16	40.93	42.17
MG-17	40.78	42.15
MG-18	41.47	*
MG-19	*	40.19
MG-20	38.78	42.18
MG-21	39.27	40.21
MG-22	37.94	38.56
MG-23	36.71	38.65
MG-24	39.46	40.68
MG-25	*	36.81
MG-26	40.86	43.2
MG-27	*	*
MG-28	*	41.63
MG-29	38.45	41.4
MG-30	42.15	*
MG-31	*	*
MG-32	39.5	41.63
MG-33	38.69	41.08
MG-34	38.95	41.46
MG-35	42.93	44.01

***Groundwater level could not be taken due to opening issues**

The field observations indicate that the bore wells used for irrigation are pumping groundwater for approximately 8-10 hours for which the electricity is provided. The indiscriminate withdrawal of groundwater has led to steady decline in groundwater in the region. It was mentioned by the RWSS officials that there is a steady decline of groundwater level by 0.5-1.0 m per year in the region.

Based on the topographic data from the CartoDEM satellite, groundwater level (AMSL) was obtained for the observation wells, and it is observed that the groundwater flow direction (indicated by arrows) is from East to west (**Figures 3.3-3.4**).

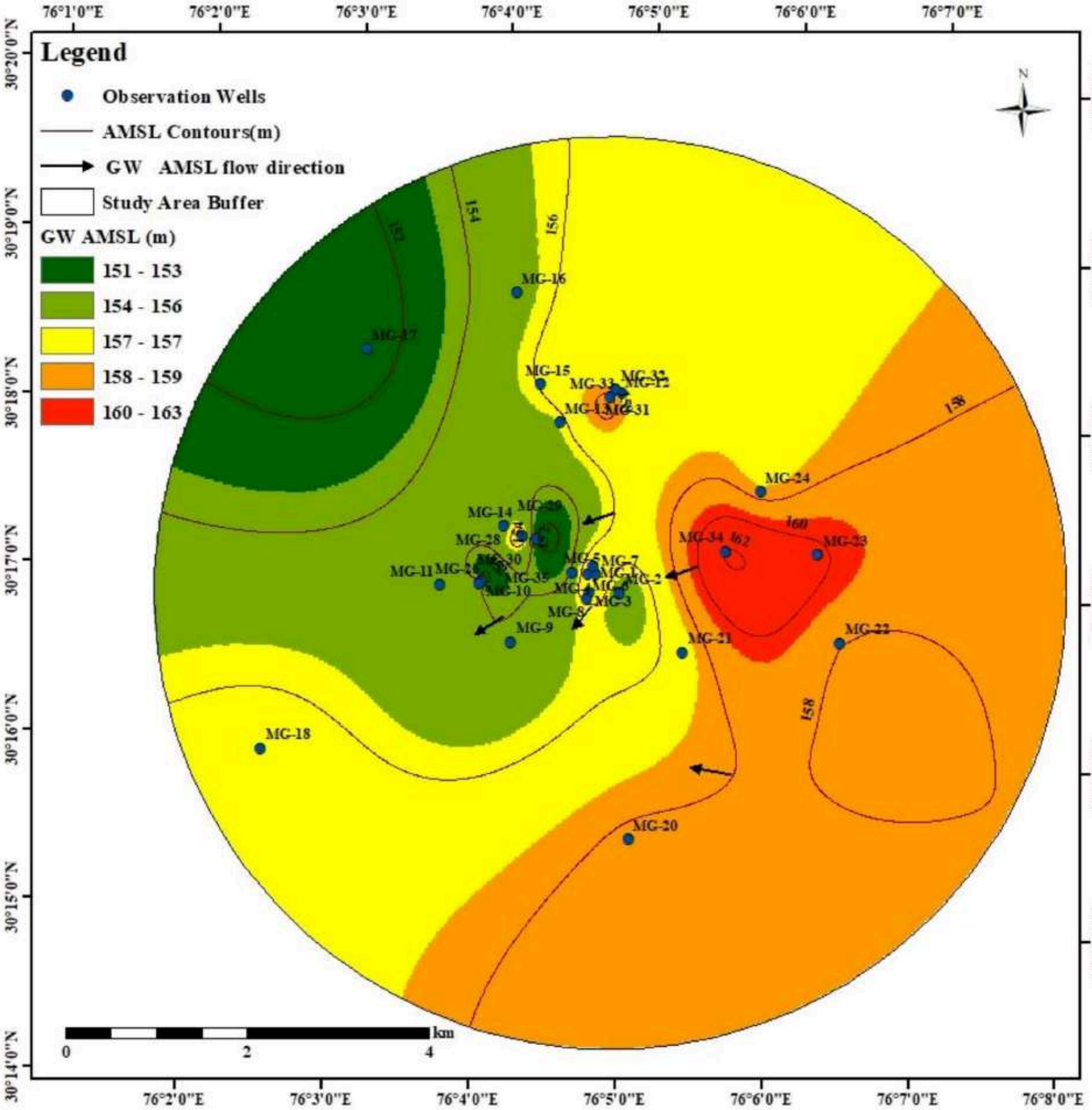


Figure 3.3: Groundwater level contours (Post-monsoon 2023)

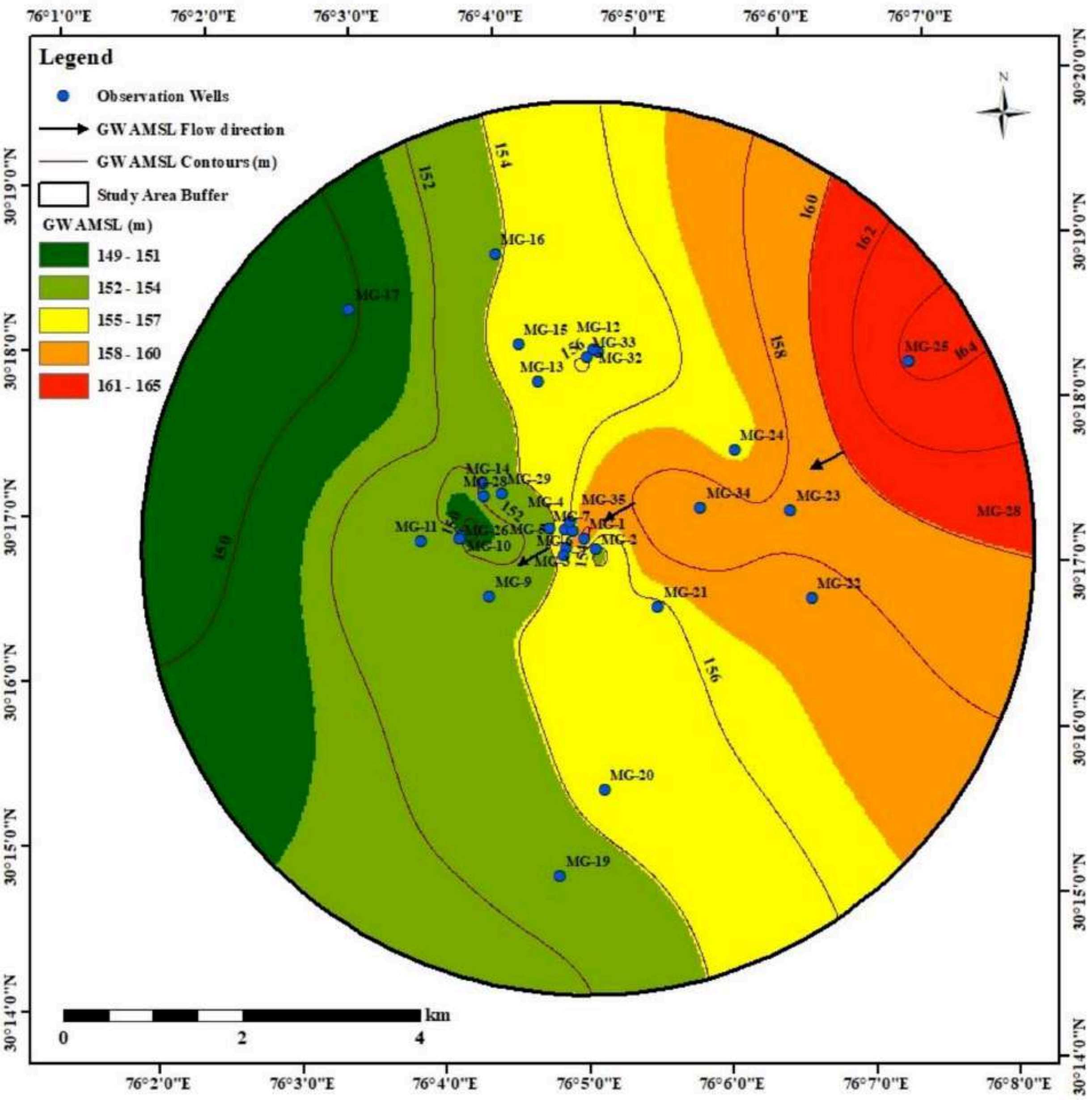


Figure 3.4: Groundwater level contours (Pre-monsoon 2024)

3.2.2 Groundwater Sampling and Analysis

The ground water samples were collected during September 12-15, 2023 and April 23-25, 2024 in the presence of PPCB officials. A total 35 number of groundwater sources (bore wells) were inventorised (Table 3.2) based on the general understanding of topography and the availability of the existing groundwater sources. For physico-chemical and heavy metal parameters analysis, the groundwater samples were collected in pre-cleaned 500 ml and 100 ml polyethylene bottles respectively. During sampling (Figure 3.5), the samples were collected and preserved at the site for various physicochemical parameters as per standard procedures **(APHA 2017)**.

Figure 3.5: Groundwater samples collection from observation well network

The samples were analyzed at the site for parameters namely, pH and Temperature using field test meter (Make:Hanna). The samples were transported to CSIR-NEERI, Nagpur for further analysis and stored and analyzed as per standard protocol (APHA 2017). The dissolved heavy metals analysis samples were filtered by a 43-micron plastic filter and preserved on-site by adding high-purity ultrapure nitric acid. Dissolved heavy metals were analyzed by Inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Model iCAP 6300 DUO, Make: Thermo Scientific).

Total Organic Carbon (TOC) in the samples was analysed by using TOC analyser Analytik Jena AG, Germany **(**Model no.: Multi N/C 3100 (TOC/TN$_b$ Analyzer)**.** The phenolic compounds in the samples were measured using the standard method APHA 5530 D.

3.2.2.1 Color of the groundwater Samples

Post-monsoon, 2023: The colour of collected groundwater samples was measured using the standards method (APHA 2017; 2120 C) using a PFXi-series spectrocolorimeter (Levibond make). The colour in the surface and groundwater samples is due to soluble organic and inorganic compounds. The colour in the collected samples is mainly due to the dissolution of targeted industry waste, which may be organic or inorganic. The intensity of colour increases with increasing the concentration of impurities.

Samples (6 nos), namely MG-2, MG-3, MG-4, MG-5, MG-6 and MG-8 in the close vicinity of industry, mainly on the downside, show a very high colour (**Table 3.3**). The maximum colour of up to 1900 Hazen, 1195 Hazen and 352 Hazen was found in the samples, namely MG-3, MG-6 and MG-8, respectively (**Figure 3.6a, 3.6b & 3.6c**). The samples MG-4, MG-5 and MG-2 also show a light brown colour in the samples. Sample, MG-1, which is on the right corner of the industry plot, and MG-7 (near the petrol pump), which is around 200 meters from the industry, did not have any colour. The contour maps for color (**Figures 3.7-3.10**) indicate the high concentration for samples (MG-3, MG-6 and MG-8) close to the Industry. The high colour in the samples indicates the high content of dissolved organic chemicals in the groundwater samples. The samples other than those in close vicinity to the industry do not show any colour, and their quantification in Hazen is within the acceptable limits for most of the samples.

Table 3.3: Color, COD, TOC and Phenolic compounds in the monitoring wells

(Sampling period: September 12-14, 2023 and Nov 2-3, 2023)

Sr. No.	Sample Code	Colour (Hazan)	COD (mg/l)	TOC (mg/l)	Phenolic compounds (mg/l)
1.	**MG-1**	23.6	2	6.5	---
2.	**MG-2**	**38.4**	**8**	7.1	---
3.	**MG-3**	**1900**	**360**	**132.4**	**0.613**
4.	**MG-4**	**203**	**30**	11.8	**0.129**
5.	**MG-5**	**185**	**22**	12.4	**0.394**
6.	**MG-6**	**1195**	**130**	**47.8**	**0.266**
7.	**MG-7**	20	2	6.6	ND
8.	**MG-8**	**352**	**88**	**17.7**	---
9.	**MG-9**	11.5	ND	0.21	ND
10.	**MG-10**	13	4	0.9	--
11.	**MG-11**	24.7	ND	0.8	--
12.	**MG-12**	12.1	2	2.1	--
13.	**MG-13**	18.2	4	2.0	--
14.	**MG-14**	16.1	ND	0.6	--
15.	**MG-15**	15.6	4	2.1	--
16.	**MG-16**	11.8	2	1.5	--
17.	**MG-17**	21.0	6	3.0	--
18.	**MG-18**	25.9	**10**	**4.3**	--
19.	**MG-19**	5.2	ND	0.9	--
20.	**MG-20**	11.2	ND	0.9	--
21.	**MG-21**	20.3	**6**	**4.1**	--
22.	**MG-22**	6.1	2	0.1	--
23.	**MG-23**	15.5	2	1.7	--
24.	**MG-24**	18.1	2	1.0	--
25.	**MG-25**	14.5	2	1.5	--
26.	**MG-26**	12.1	ND	--	--
27.	**MG-27**	17.2	ND	--	--
28.	**MG-28**	9.9	8	--	--
29.	**MG-29**	18.1	4	--	--
30.	**MG-30**	15.1	2	--	--
31.	**MG-31**	10.9	ND	--	--
32.	**MG-32**	12.4	2	--	--
33.	**MG-33**	17.3	ND	--	--
34.	**MG-34**	15.7	2	--	--
35.	**MG-35**	10.5	ND	--	--

***-- Not analysed**

Figure 3.6a: Bore well (MG-3) with coloured water at the site used for irrigation purposes at present

Figure 3.6b: Bore well (MG-6) with coloured water at the site used for irrigation purpose at present

Figure 3.6c: Bore well (MG-8) with coloured water at the site used for irrigation purpose at present

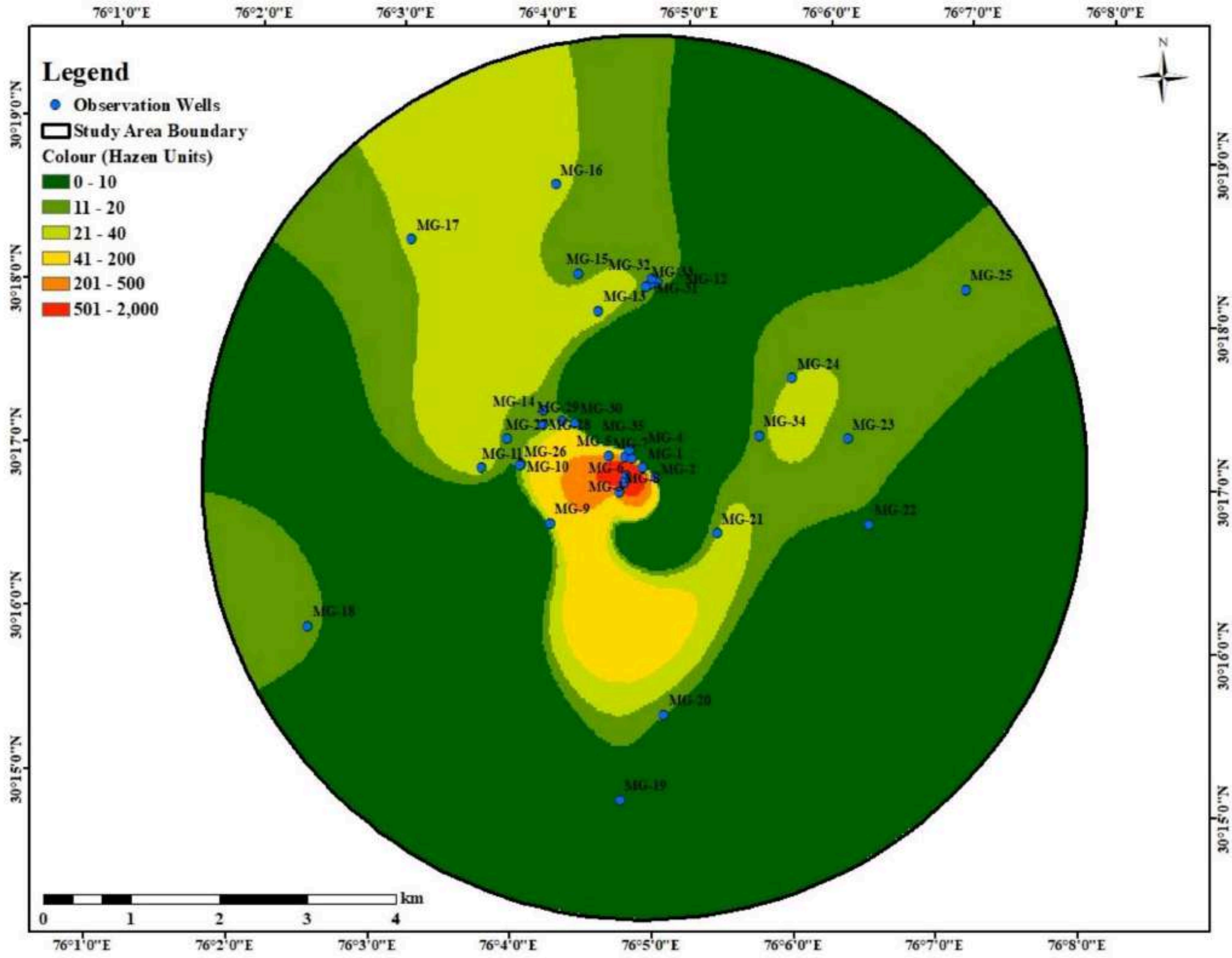


Figure 3.7: Contour map of Colour concentration within the 5 KM radius from the Matharu Chemicals Pvt. Ltd (Sampling: Post-monsoon 2023)

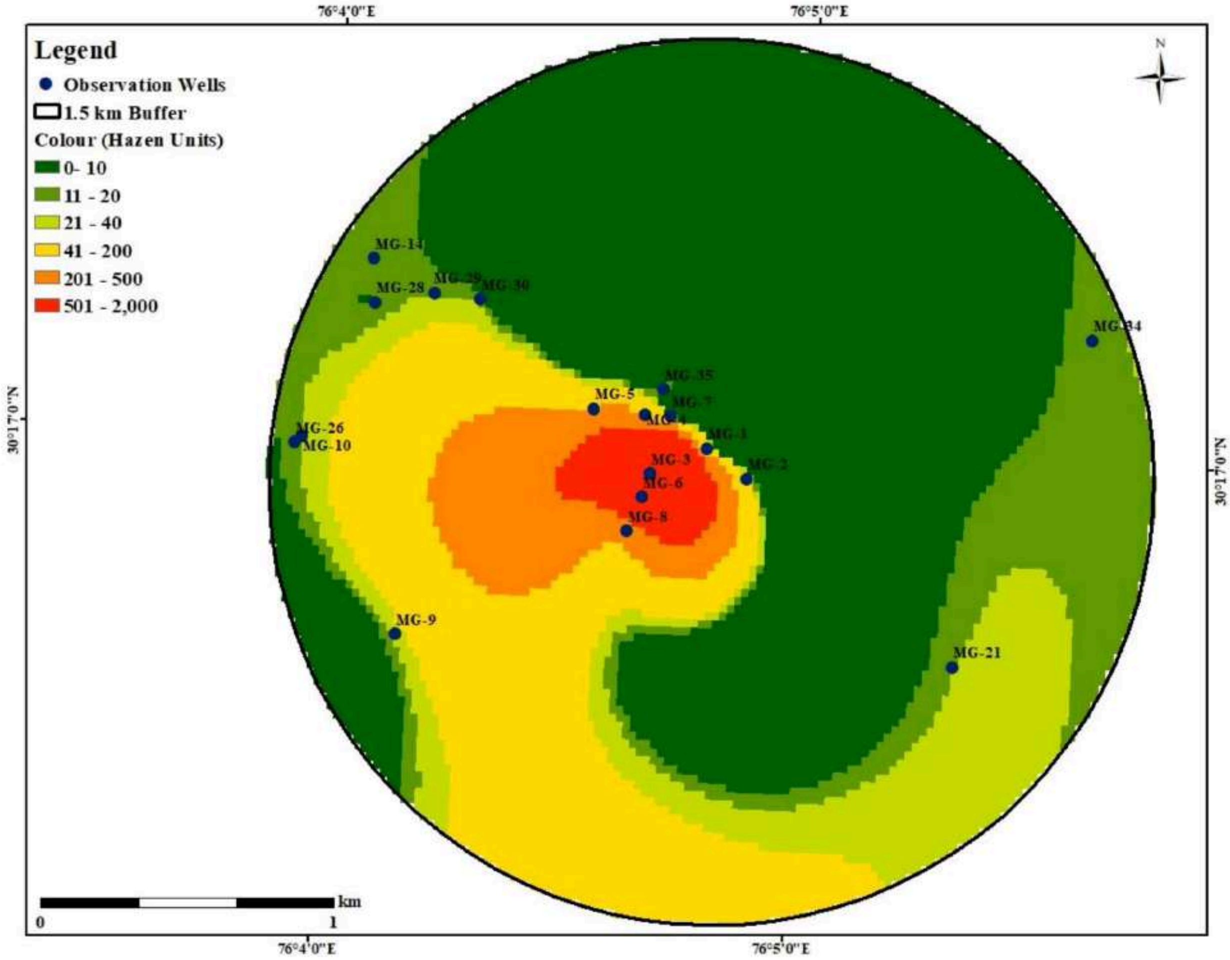


Figure 3.8: Contour map of colour concentration within the 1.5 KM radius from the Matharu Chemicals Pvt. Ltd (Sampling: Post-monsoon 2023)

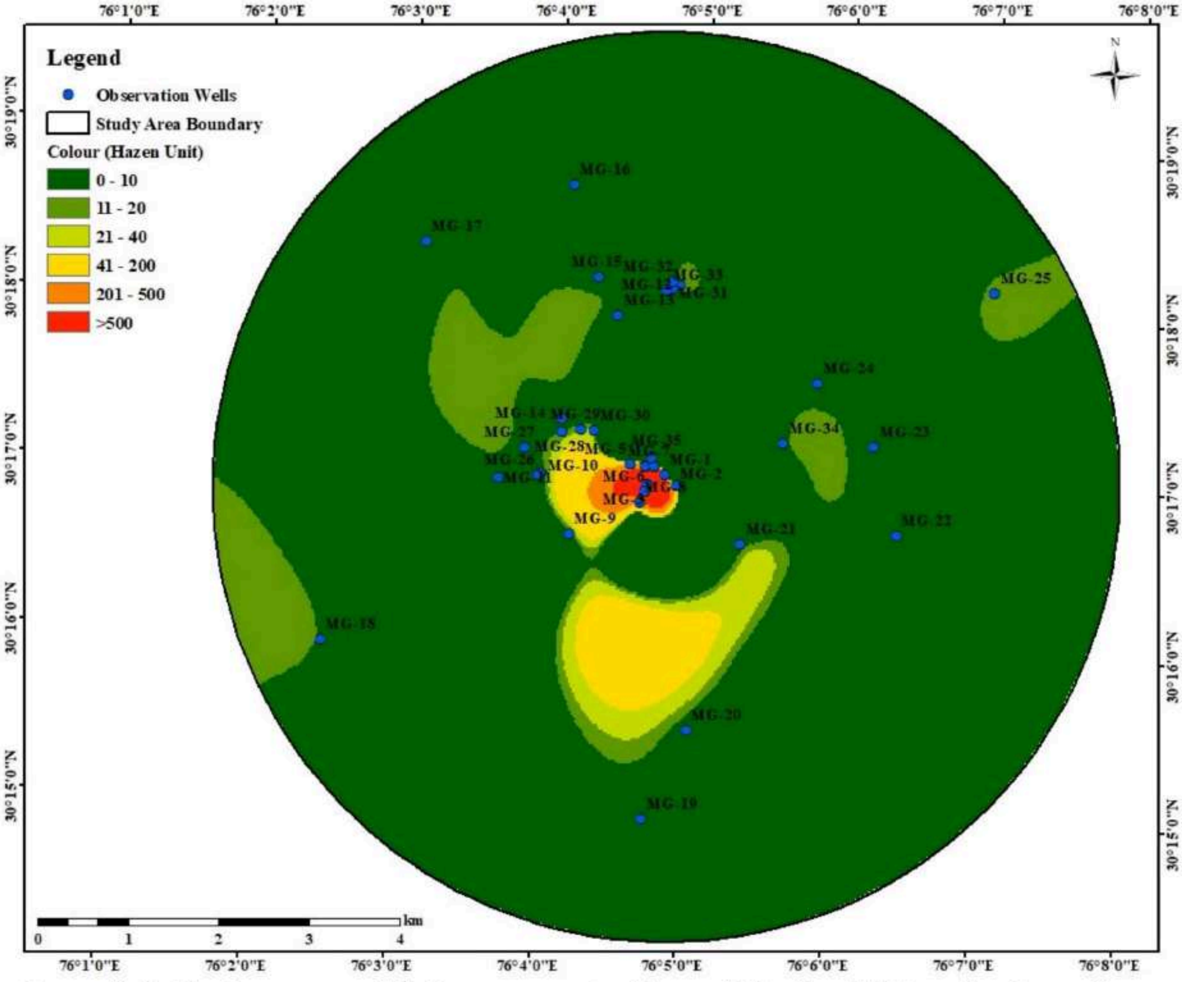


Figure 3.9: Contour map of Colour concentration within the 5 KM radius from the Matharu Chemicals Pvt. Ltd (Sampling: Pre-monsoon 2024)

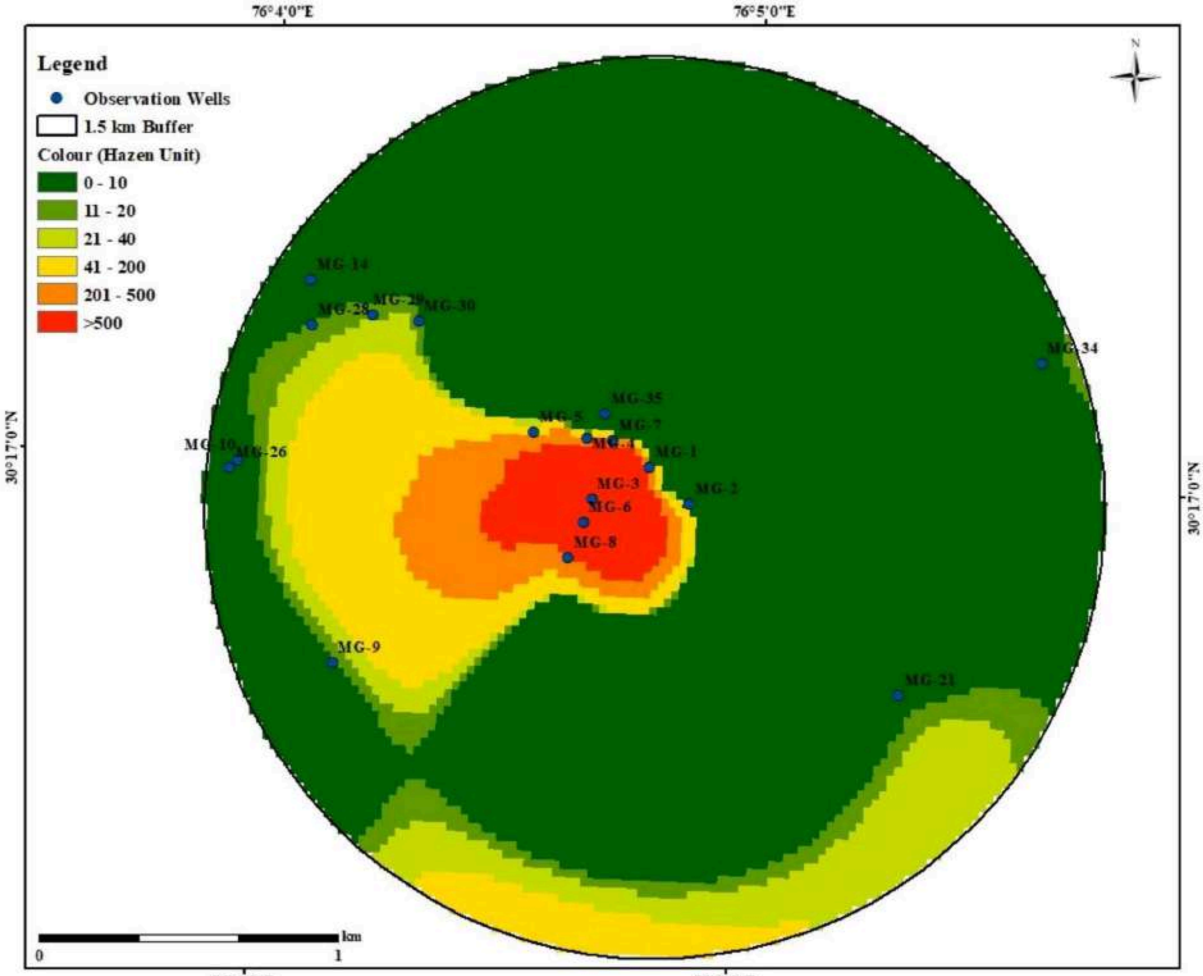


Figure 3.10: Contour map of colour concentration within the 1.5 KM radius from the Matharu Chemicals Pvt. Ltd (Sampling: Post-monsoon 2023)

The colour in the surface and groundwater results from soluble organic matter including aquatic humic matter. In this case, all samples are groundwater, and the colour developed in the samples is mainly due to the dissolution of targeted industry waste, which is organic and inorganic. The colour of samples was measured as per standard method (APHA 2120C) using PFXI-series spectro colorimeter (Lavibond make).

COD for all samples was determined after filtration to assess the quantum of contamination by the organic load (**Table 3.3**). The water sources close to the industry (MG-3, MG-4, MG-5, MG-6, MG-8) show that high COD indicates a high pollution load in the samples. The TOC and colour data support the COD data, confirming that the contamination is of organic origin and has colour. The concentration of soluble phenolic compounds was also analysed for the selected samples (**Table 3.3**), and it confirms the contamination is of phenolic origin.

The other samples did not show COD or TOC contamination except for sample numbers MG-18 and MG-22. This may be attributed to other anthropogenic origin,

Pre-monsoon 2024:

In pre-monsoon **(Table 3.4),** the colour was present in elevated concentration in samples, namely, MG-2, MG-3, MG-4, MG-4, MG-5, MG-6 and MG-8. The maximum concentration was noticed in case of MG-3 which was more than the concentration in Post-monsoon. Overall, the color concentration is more in pre-monsoon as compared to post-monsoon. It is observed that chemical oxygen demand (COD), Total organic carbon (TOC) and Phenolic compounds are present in the samples collected during the pre-monsoon session in April 2024. As shown in the table the sample number MG-3, MG-4, MG-6 and MG-8 shows the high COD indicating a high pollution load in the samples. The colour and TOC data also support the COD data confirming that the contamination is of organic origin and has colour. The data is in alignment with the data obtained in post-monsoon season 2023.

Table 3.4: Color, COD, TOC and Phenolic compounds (April 2024)

Sr. No.	Sample Code	Colour (Hazan)	COD (mg/l)	TOC (mg/l)	Phenolic compounds (mg/l)
1	MG-1	18.3	4	10.7	ND
2	MG-2	29.2	8	11.6	ND
3	MG-3	2472	420	125.2	0.648
4	MG-4	100.3	32	16.6	0.103
5	MG-5 (New)	22.9	ND	3.0	ND
6	MG-6	1404	110	59.9	0.412
7	MG-7	17.5	8	6.6	ND
8	MG-8	337.5	52	14.6	0.189
9	MG-9	9.2	2	1.2	ND
10	MG-10	13	6	0.0	ND
11	MG-11	20.4	ND	1.0	ND
12	MG-12	14.4	ND	2.0	ND
13	MG-13	9.1	4	2.8	ND
14	MG-14	6.1	2	1.0	ND
15	MG-15	7.5	2	1.4	ND
16	MG-16	4.6	4	2.2	---
17	MG-17	9.7	4	3.0	ND
18	MG-18	9	6	2.8	---
19	MG-19	5.7	2	2.8	---
20	MG-20	9.6	ND	0.7	-----
21	MG-21	13.4	6	5.2	ND
22	MG-22	7.2	ND	0.2	---
23	MG-23	12.3	ND	1.7	---
24	MG-24	14.5	ND	1.3	---
25	MG-25	11.4	6	0.6	---
26	MG-26	5.5	ND	2.4	---
27	MG-27	6.6	2	2.1	---
28	MG-28	7.1	ND	2.9	---
29	MG-29	11.9	6	1.6	----
30	MG-30	7.5	ND	0.0	----
31	MG-31	9.1	ND	3.3	---
32	MG-32	6.4	ND	0.5	---
33	MG-33	7.4	2	2.5	---
34	MG-34	8.9	2	1.8	---

--: Not analysed for phenolic compounds

3.2.2.2 Dissolved, suspended and Volatile solids

Post-monsoon 2023:

The total dissolved solids (TDS) are calculated from electrical conductivity and by a standard evaporation method; Total dissolved Fixed solids (TDFS) and Total dissolved volatile solids (TDVS) in the collected water samples are determined by standard methods (APHA 2017). Total solids are obtained by evaporating the measured amount of sample at 103 to 105 ^{0}C as per the standards method (APHA 2017; 2540 B). The total dissolved solid is the summation of dissolved inorganic ions and organic compounds that remain in the dissolved form and are obtained in the filtrate after filtration and determined at 180 ^{0}C (APHA 2017; 2540 C). The residue obtained from the total dissolved solids is ignited at 550 ^{0}C. The remaining solids are the fixed dissolved solids (APHA 2017; 2540 D), and the weight loss is the dissolved volatile solids. Determining volatile solids provides a rough estimation of soluble organic matter and volatile matter in the water samples in different forms. In our case, the weight loss obtained at 550 ^{0}C, i.e., the volatile solids obtained, indicates the tentative proportion of organic hydrocarbons/ compounds in the collected water samples.

Table 3.5 summarises the TDS, TDFS, and TDVS concentrations samples. The TDS calculated from the EC for the samples collected near the industry is comparatively high compared to those from other locations. The sample collected near industry along the roadside (MG-3, MG-4, MG-5, MG-6 and MG-8) shows a very high amount of dissolved fixed and volatile solids. The very high amount of volatile solids indicates the presence of an equal proportion of soluble organic compounds in the water samples. These organic compounds were mainly being contributed by industry. These soluble organic compounds impart colour to all samples as per their concentration. The results of volatile solids are in line with the colour data (Table 4.8). The other samples that were collected had very low concentrations of volatile solids. This is mainly because of humic acids and naturally soluble organic carbon.

Table 3.5: Physical parameters, dissolved fixed and volatile solids in collected water samples (Post-monsoon 2023)

Sr. No	Sample ID	Electrical Conductivity (EC) (µs/cm)	Turbidity (NTU)	Total Dissolved solids from EC (mg/l)	Total Dissolved Solid (TDS) (mg/l)	Total Dissolved Fixed solid (TDFS) (mg/l)	Total Dissolved Volatile solids (TDVS) (mg/l)
1	MG1	698	0.66	419	456	438	18
2	MG2	516	2.13	309	360	325	**35**
3	MG3	2176	1.6	1306	2360	1399	**961**
4	MG4	882	0.41	529	656	552	**104**
5	MG5	859	1.33	515	654	530	**124**
6	MG6	1977	1.46	1186	1648	1246	**402**
7	MG7	838	0.73	503	562	520	42
8	MG8	920	1.6	552	892	572	**320**
9	MG9	1075	2.73	645	678	648	30
10	MG10	777	0.3	466	526	486	40
11	MG11	965	0.3	579	590	572	18
12	MG12	589	0.4	353	380	366	14
13	MG13	866	0.23	520	540	522	18
14	MG14	822	0.31	493	502	485	17
15	MG15	1101	0.26	661	652	637	10
16	MG16	581	0.18	349	342	326	16
17	MG17	634	0.93	380	376	356	20
18	MG18	1405	0.5	843	848	827	21
19	MG19	664	1.43	398	394	372	22
20	MG20	1384	0.46	830	812	798	14
21	MG21	1495	3	897	908	872	36
22	MG22	626	2.53	376	380	358	22
23	MG23	608	0.85	365	374	352	22
24	MG24	581	0.95	349	352	326	26
25	MG25	691	0.3	415	406	392	14

Pre-monsoon 2024:

In pre-monsoon 2024 (Table 3.6), it is noted that the samples collected near M/S Matharu Industry along the roadside (MG-3, MG-4, MG-6 and MG-8) shows a very high amount of dissolved fixed and volatile solids. These results are in agreement with the results obtained during the post-monsoon sampling (September 2023).

Table 3.6: Physical parameters, dissolved fixed and volatile solids in collected water samples (Pre-monsoon 2024)

Sr. No	Sample ID	Electrical Conductivity (EC) (µs/cm)	Turbidity (NTU)	Total Dissolved solids from EC (mg/l)	Total Dissolved Solid (TDS) (mg/l)	Total Dissolved Fixed solid (TDFS) (mg/l)	Total Dissolved Volatile solids (TDVS) (mg/l)
1	MG1	705	0.25	423	468	448	20
2	MG2	508	5.9	325	356	318	38
3	MG3	2270	1.2	1362	**2356**	**1438**	**918**
4	MG4	869	0.25	521	**636**	**540**	**96**
5	MG5/ (New)	570	0.9	342	364	324	40
6	MG6	2210	1.4	1326	**1760**	**1396**	**364**
7	MG7	806	0.8	518	544	504	40
8	MG8	844	2.1	542	**920**	**584**	**336**
9	MG9	670	0.3	432	492	478	14
10	MG10	789	0.4	506	480	460	20
11	MG11	937	0.3	562	582	566	16
12	MG12	513	0.5	331	376	354	22
13	MG13	748	0.25	477	464	446	18
14	MG14	831	0.2	499	540	520	20
15	MG15	998	0.3	636	674	660	14
16	MG16	516	0.35	330	360	348	12
17	MG17	559	0.25	359	386	370	16
18	MG18	1201	0.3	770	804	786	18
19	MG19	688	0.3	413	472	448	24
20	MG20	1293	0.35	828	892	866	26
21	MG21	1349	0.5	864	910	884	26
22	MG22	540	0.45	345	390	386	4
23	MG23	529	0.3	335	350	338	12
24	MG24	502	0.35	321	340	330	10
25	MG25	534	0.45	341	370	362	8
26	MG26	1011	0.25	607	688	678	10
27	MG27	842	0.3	538	548	540	8
28	MG28	928	0.5	596	622	608	14
29	MG29	618	1.1	371	382	372	10
30	MG30	919	0.4	588	632	628	4
31	MG31	663	0.4	429	442	424	18
32	MG32	676	0.65	430	446	428	18
33	MG33	797	0.55	509	540	520	20
34	MG34	502	0.6	319	350	336	14

3.2.2.3 Physico-chemical and Heavy metals

Post-monsoon 2023:

The physicochemical parameters for all the collected samples (**Table 3.7**) were compared with the drinking water standard, BIS-10500. The water quality parameters for most samples were within the acceptable permissible limits except for a few samples. The dissolved fixed solids mainly contain the cations and anions for most of the samples, which are well within the limits as per standards. The samples have a dark to light brown colour, ie. MG-3, MG-4, MG-5, MG-6 and MG-8 have comparatively higher solids and sulphate concentrations. These samples also have the high soluble volatile solids. The physicochemical parameters for the samples MG-1 and MG-2, which are in the industry plot and on the backside of the industry plot, show that normal water quality does not seem to be affected by industry activity.

The concentration of soluble trace and heavy metals for the collected water samples was analysed by ICP-OES. The heavy metals data shows the concentration of soluble metals was within the acceptable range for most metals (**Table 3.8**).

Pre-monsoon 2024:

The water quality parameters for most the samples were within the acceptable permissible limits except for a few samples (Table 3.9). The samples have a dark to light brown colour, i.e. MG-3, MG-6 and MG-8 and comparatively higher TDS and sulphate concentrations (Table 3.9). Contaminated samples MG-3 and MG-6 have marginal increase in TDS during pre-monsoon 2024 as compared to the Post-monsoon 2023. The heavy metals data shows the concentration of soluble metals was within the acceptable range for most metals (**Table 3.10**).

3.2.3 Aquifer performance test Analysis

The aquifer performance test, also called Pumping test, is a controlled field experiment that aims to determine the basic aquifer parameters such as Transmissivity and Storativity.

During the pumping test, a well is subjected to pumping at a constant rate, and the change in water level (drawdown) with respect to time is recorded in the same pumping well and/or in one or more observation wells in the vicinity. In the present case, the information on drawdown and discharge was used to determine the aquifer parameters, calculated by the Jacob method (Cooper and Jacob, 1946). The pumping test is performed over a considerable time duration to determine the effects of the pumping. The groundwater level is measured in the well before the well is subjected to pumping. Once the pumping is completed, the water level is measured in the observation well to see the recovery in the well till the initial water level was restored.

In the present study, pumping test was carried out inside the premises of M/S Matharu Chemical Industry (at MG-2). The field conditions required the recuperation to be measured in the same pumping well. The pumping was carried out for approximately 6 hours of pumping followed by 6 hours of recuperation, when the static water level was fully recovered (**Figure 3.11**). Groundwater level was measured in prescribed time intervals during the recuperation using an automatic water level recorder during the pumping test.

Table. 3.7: Physico-chemical parameters of the observation wells in the study area (Post-monsoon, 2023)

Sr. No	Sample Code	pH	Total Dissolved Solids (mg/L)	Calcium (mg/L)	Magne sium (mg/L)	sodium (mg/L)	Potassium (mg/L)	Total Alkalinity as CaCO3 (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Phosph ate (mg/L)	Fluoride (mg/L)
Limits as per BIS 10500		Acceptable	500	75	30	--	--	200	200	250	45	--	1.0
		Permissible	2000	200	100	--	---	600	400	1000	--	--	1.5
1	MG-1	7.8	438	37	18	90	10	224	18	34	23.6	0.3	0.24
2	MG-2	8.3	325	19	11	75	6	176	42.7	10	0.9	1.5	0.33
3	MG-3	7.6	1399	19	138	246	32	156	**678**	104	15.8	3.2	0.19
4	MG-4	7.8	552	11	23	98	19	272	**120**	20	22.4	4.7	0.34
5	MG-5	7.8	530	14	16	93	14	308	**106**	24	8.5	3.8	0.3
6	MG-6	7.7	1246	29	65	263	32	80	**632**	118	13.5	2.9	0.37
7	MG-7	7.5	520	51	28	82	14	264	27	22	59.3	0.3	0.2
8	MG-8	7.8	572	11	46	107	18	232	**160**	26	16.4	3.0	0.32
9	MG-9	7.6	648	27	50	100	25	320	58	26	31.1	0.1	0.29
10	MG-10	8.1	486	30	20	84	10	280	22.7	22	15.6	0.3	0.36
11	MG-11	7.7	572	46	22	102	11	304	39.1	34	20.2	0.1	0.28
12	MG-12	8.1	366	19	30	65	9	232	7.2	22	0.6	0.7	0.32
13	MG-13	7.9	522	18	52	74	10	272	40.9	14	31.9	0.1	0.24
14	MG-14	8.4	485	35	19	103	11	256	46.2	20	25.1	0.3	0.24
15	MG-15	7.8	637	24	45	122	19	348	31.7	36	23.3	0.4	0.26
16	MG-16	8.4	326	19	12	81	7	180	28	18	1.7	0.1	0.41
17	MG-17	8.3	356	14	16	88	6	192	35	16	1.6	0.3	0.35
18	MG-18	7.7	827	10	84	140	24	364	29.1	100	111	0.6	0.23
19	MG-19	8.4	372	26	14	81	8	208	44	12	3.8	0.1	0.48
20	MG-20	7.7	798	64	38	122	19	416	33.2	78	64.1	0.3	0.24
21	MG-21	7.6	871	43	68	150	19	424	29.4	106	65.1	0.6	0.22
22	MG-22	8.3	358	21	12	85	7	204	28	20	0.2	0.2	0.49
23	MG-23	8.5	352	22	9	86	4	184	36.9	12	0.7	0.2	0.41
24	MG-24	8.5	325	26	13	64	11	208	9.2	10	0.1	0.7	0.33
25	MG-25	8.2	392	22	13	80	11	220	23.3	18	7.5	0.0	0.36
26	MG-26	7.3	592	48	24	107	14	300	34	38	24	1.3	0.35
27	MG-27	7.8	322	27	14	63	6	188	12	20	0.1	0.6	0.32
28	MG-28	7.4	630	64	34	98	10	340	37	30	27	0.4	0.28

Sr. No	Sample Code	pH	Total Dissolved Solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	sodium (mg/L)	Potassium (mg/L)	Total Alkalinity as CaCO3 (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Fluoride (mg/L)
Limits as per BIS 10500		Acceptable	500	75	30	--	--	200	200	250	45	--	1.0
		Permissible	2000	200	100	--	---	600	400	1000	--	--	1.5
29	MG-29	7.5	445	48	25	65	9	248	28	20	15	0.4	0.41
30	MG-30	7.4	625	50	33	102	11	320	40	24	28	0.6	0.24
32	MG-31	7.4	432	51	31	44	7	244	26	22	27	0.8	0.56
33	MG-32	7.4	460	54	34	52	9	256	27	20	29	0.8	0.26
34	MG-33	7.5	545	59	36	70	9	288	31	22	42	1.5	0.32
35	MG-34	7.9	317	32	14	57	5	192	9	16	0.1	0.7	0.35
36	MG-35	7.5	510	66	30	60	10	284	16	24	38	0.5	0.26

Table 3.8: Heavy metal parameters of the observation wells in the study area. (Post-monsoon 2023)

Sr. No.	Sample Code	Cu	Cr	Cd	Fe	Ni	Mn	Pb	Co	Al	Zn	B	As	Hg
BIS Limits (ppm)		**0.05-1.5**	**0.05**	**0.003**	**1.0**	**0.02**	**0.1-0.3**	**0.01**	**-**	**0.03-0.2**	**5.0-15**	**0.5-1.0**	**0.01**	**0.001**
ICP detection Limit (ppm)		0.0004	0.0002	0.0001	0.0003	0.0004	0.0001	0.001	0.001	0.0001	0.0002	0.001	0.001	0.000001
1	MG-1	BDL	BDL	BDL	ND	BDL	0.017	0.008	BDL	BDL	0.023	0.143	0.003	BDL
2	MG-2	BDL	BDL	BDL	ND	BDL	0.009	0.003	0.038	BDL	0.038	0.453	BDL	BDL
3	MG-3	BDL	BDL	BDL	0.024	BDL	0.214	0.006	0.024	0.014	0.020	0.177	BDL	BDL
4	MG-4	BDL	BDL	BDL	ND	BDL	0.080	0.004	BDL	0.036	BDL	0.086	0.014	BDL
5	MG-5	BDL	BDL	BDL	0.183	BDL	0.109	0.005	BDL	0.227	0.118	0.140	0.016	BDL
6	MG-6	0.02	BDL	BDL	BDL	BDL	0.177	0.005	BDL	0.015	BDL	0.094	0.007	BDL
7	MG-7	0.001	BDL	BDL	BDL	BDL	0.008	0.006	BDL	0.118	0.052	0.064	0.014	BDL
8	MG-8	0.006	BDL	BDL	BDL	BDL	0.042	0.006	BDL	0.174	0.044	0.060	BDL	BDL
9	MG-9	0.001	BDL	BDL	BDL	BDL	0.005	0.007	BDL	0.127	0.036	0.341	BDL	0.0013
10	MG-10	0.001	BDL	BDL	0.02	BDL	0.015	0.007	BDL	0.183	0.035	0.224	0.009	BDL
11	MG-11	0.003	BDL	BDL	BDL	BDL	0.040	0.007	BDL	0.196	0.026	0.265	0.007	BDL
12	MG-12	BDL	BDL	BDL	BDL	BDL	BDL	0.005	BDL	0.002	0.021	0.020	0.006	BDL
13	MG-13	BDL	BDL	BDL	BDL	BDL	0.009	0.007	BDL	0.233	0.043	0.111	BDL	BDL
14	MG-14	BDL	BDL	BDL	BDL	BDL	ND	0.008	BDL	0.083	0.015	0.101	0.014	BDL
15	MG-15	BDL	BDL	BDL	BDL	BDL	0.003	0.009	BDL	0.05	0.038	0.077	BDL	BDL
16	MG-16	0.004	BDL	BDL	BDL	BDL	BDL	0.004	BDL	0.019	0.016	0.058	0.008	BDL
17	MG-17	BDL	BDL	BDL	BDL	BDL	0.003	0.004	BDL	0.108	0.061	0.26	0.007	BDL
18	MG-18	BDL	BDL	BDL	BDL	0.005	0.007	0.009	BDL	0.082	0.031	0.118	0.012	BDL
19	MG-19	0.003	BDL	BDL	BDL	BDL	0.025	0.005	BDL	0.063	0.17	0.180	BDL	BDL
20	MG-20	BDL	BDL	BDL	0.012	BDL	0.079	0.009	BDL	0.128	0.032	0.197	0.013	BDL
21	MG-21	0.001	BDL	BDL	BDL	BDL	0.017	0.010	BDL	0.116	0.05	0.132	BDL	BDL
22	MG-22	BDL	BDL	BDL	BDL	BDL	0.004	0.004	BDL	0.032	BDL	0.056	0.007	BDL
23	MG-23	0.001	BDL	BDL	BDL	BDL	0.007	0.003	BDL	0.107	0.034	0.306	BDL	BDL
24	MG-24	0.01	BDL	BDL	BDL	BDL	BDL	0.006	BDL	0.043	0.254	0.156	0.006	BDL
25	MG-25	BDL	BDL	BDL	BDL	BDL	0.029	0.005	BDL	0.09	0.089	0.153	BDL	BDL
26	MG-26	0.003	0.009	ND	0.8	0.003	0.02	0.008	BDL	BDL	0.02	0.3	BDL	BDL
27	MG-27	0.002	0.01	ND	0.3	0.002	0.01	0.005	BDL	BDL	0.01	0.2	BDL	BDL
28	MG-28	0.003	0.01	ND	0.06	0.003	0.008	0.007	BDL	BDL	0.12	0.26	ND	BDL
29	MG-29	0.003	0.009	ND	0.17	0.003	0.09	0.008	BDL	BDL	0.06	0.15	BDL	BDL
30	MG-30	BDL	0.009	ND	0.12	0.004	0.01	0.009	BDL	0.15	0.09	0.29	BDL	BDL

Sr. No.	Sample Code	Cu	Cr	Cd	Fe	Ni	Mn	Pb	Co	Al	Zn	B	As	Hg
BIS Limits (ppm)		**0.05-1.5**	**0.05**	**0.003**	**1.0**	**0.02**	**0.1-0.3**	**0.01**	**-**	**0.03-0.2**	**5.0-15**	**0.5-1.0**	**0.01**	**0.001**
ICP detection Limit (ppm)		0.0004	0.0002	0.0001	0.0003	0.0004	0.0001	0.001	0.001	0.0001	0.0002	0.001	0.001	0.000001
31	MG-31	ND	0.009	ND	0.04	0.003	0.001	0.007	BDL	BDL	0.02	0.1	BDL	BDL
32	MG-32	ND	0.008	ND	0.05	0.003	0.002	0.008	BDL	BDL	0.03	0.1	BDL	BDL
33	MG-33	0.001	0.009	ND	0.02	0.003	0.001	0.009	BDL	BDL	0.02	0.18	BDL	BDL
34	MG-34	BDL	0.008	ND	0.03	0.002	0.008	0.006	BDL	BDL	0.01	0.2	BDL	BDL
35	MG-35	0.005	0.008	ND	0.11	0.003	0.011	0.007	BDL	BDL	0.01	0.07	BDL	BDL

Results mentioned in Table **Bold and underlined** are above the Permissible limits of BIS 10500-2012.
ND- Not Detected
BDL- Below Detection Limit

Table 3.9: Physico-chemical parameters of the observation wells in the study area **(April 2024).**

Sr. No	Sample Code	pH	Total Dissolved Solids (mg/L)	Calcium (mg/L)	Magne sium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total Alkalinity as CaCO3 (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Phosph ate (mg/L)	Fluoride (mg/L)
Limits as per BIS 10500		Acceptable	500	75	30	--	--	200	200	250	45	--	1.0
		Permissible	2000	200	100	--	---	600	400	1000	--	--	1.5
1	MG-1	7.7	448	38	18	85	10	228	20	26	24	0.3	0.37
2	MG-2	8.2	318	24	6	69	5	172	40	10	1	0.1	0.52
3	MG-3	7.8	1438	64	34	210	23	156	**700**	142	40	0.6	0.26
4	MG-4	7.9	540	16	38	88	18	212	**115**	16	24	0.4	0.41
5	MG-5	8.2	324	22	10	96	4	120	56	14	0	0.2	0.95
6	MG-6	7.6	1396	67	57	283	24	80	**750**	118	15	0.8	0.41
7	MG-7	7.7	504	58	26	65	12	220	30	24	65	0.5	0.23
8	MG-8	7.8	584	34	32	95	17	208	**140**	60	15	0.6	0.43
9	MG-9	7.7	478	32	38	62	11	200	35	26	32	1.4	0.34
10	MG-10	8.0	460	32	27	74	10	284	38	20	15	0.3	0.45
11	MG-11	7.8	566	48	22	95	12	296	40	26	20	0.5	0.32
12	MG-12	8.2	354	24	15	60	9	212	10	10	0	0.7	0.49
13	MG-13	8.0	446	19	37	60	9	244	45	10	26	0.5	0.37
14	MG-14	7.9	520	56	30	70	12	260	48	16	25	0.8	0.27
15	MG-15	8.0	660	32	44	112	15	340	38	38	24	0.4	0.35
16	MG-16	8.3	348	21	12	71	6	176	30	12	2	0.4	0.58
17	MG-17	8.3	370	18	13	80	5	184	40	20	4	0.7	0.48
18	MG-18	7.9	786	61	36	100	25	320	24	82	100	0.4	0.27
19	MG-19	8.4	448	26	23	91	10	212	54	24	6	0.1	0.62
20	MG-20	7.7	866	59	46	112	19	392	30	80	65	0.4	0.29
21	MG-21	7.6	884	43	40	120	7	388	25	100	55	0.3	0.22

Sr. No	Sample Code	pH	Total Dissolved Solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total Alkalinity as CaCO3 (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Fluoride (mg/L)
Limits as per BIS 10500		Acceptable	500	75	30	--	--	200	200	250	45	--	1.0
		Permissible	2000	200	100	--	---	600	400	1000	--	--	1.5
22	MG-22	8.1	386	18	16	75	8	192	25	12	0	0.1	0.72
23	MG-23	7.6	338	16	19	70	5	180	32	12	0	0.7	0.55
24	MG-24	7.8	330	22	14	54	7	192	12	10	0	0.8	0.44
25	MG-25	7.9	362	26	18	68	8	200	19	16	4	0.6	0.54
26	MG-26	7.3	678	32	27	112	14	320	44	40	32	0.6	0.41
27	MG-27	7.4	540	51	32	81	15	288	24	38	10	1.2	0.3
28	MG-28	7.1	608	61	35	78	11	316	30	22	23	0.3	0.38
29	MG-29	7.7	372	26	12	55	9	204	25	12	0	0.6	0.51
30	MG-30	7.5	628	61	28	80	12	332	30	14	25	0.1	0.32
31	MG-31	7.9	424	48	32	30	10	204	22	14	25	0.2	0.61
32	MG-32	7.3	428	52	28	38	11	220	22	16	23	0.8	0.28
33	MG-33	7.2	520	53	36	60	8	288	25	18	37	0.5	0.26
34	MG-34	7.9	336	27	24	35	8	184	8	10	0	0.2	0.49

Table 3.10: Heavy metal parameters of the observation wells in the study area **(April 2024)**

Sr. No.	Sample Code	Cu	Cr	Cd	Fe	Ni	Mn	Pb	Co	Al	Zn	B	As
BIS Limits (ppm)		**0.05-1.5**	**0.05**	**0.003**	**1.0**	**0.02**	**0.1-0.3**	**0.01**	**0.01**	**0.03-0.2**	**5.0-15**	**0.5-1.0**	**0.01**
ICP detection Limit (ppm)		**0.0004**	**0.0002**	**0.0001**	**0.0003**	**0.0004**	**0.0001**	**0.001**	**0.001**	**0.0001**	**0.0002**		**0.001**
1	MG-1	0.003	0.006	0.001	0.041	0.007	0.042	0.016	0.001	0.09	BDL	0.20	0.023
2	MG-2	ND	0.007	0.001	0.039	0.006	0.012	0.009	ND	0.05	BDL	0.46	0.016
3	MG-3	0.062	0.016	ND	0.335	0.011	0.203	0.013	0.024	0.12	0.26	0.19	0.007
4	MG-4	ND	0.001	ND	0.013	0.005	0.03	0.01	ND	0.07	0.001	0.12	0.009
5	MG-5/ New	BDL	0.002	ND	0.023	0.005	0.009	0.007	ND	0.05	BDL	0.49	0.01
6	MG-6	0.035	0.004	ND	0.057	0.009	0.304	0.013	0.009	0.05	0.018	0.08	0.007
7	MG-7	ND	0.001	ND	BDL	0.006	0.003	0.012	ND	0.01	0.043	0.08	0.004
8	MG-8	0.006	0.001	ND	0.044	0.006	0.148	0.012	0.002	0.01	0.082	0.07	0.004
9	MG-9	ND	0.003	ND	0.015	0.005	0.002	0.012	ND	0.03	BDL	0.21	0.003
10	MG-10	BDL	0.002	ND	0.027	0.006	0.013	0.012	ND	0.06	0.006	0.35	0.005
11	MG-11	ND	0.003	ND	0.019	0.006	0.014	0.012	ND	0.05	0.003	0.28	0.006
12	MG-12	BDL	0.002	ND	0.018	0.005	0.017	0.008	ND	0.02	0.074	0.31	0.002
13	MG-13	0.002	0.001	ND	0.011	0.006	0.008	0.013	ND	0.02	0.026	0.21	0.004
14	MG-14	ND	0.011	ND	0.009	0.006	0.064	0.013	ND	0.05	0.007	0.26	0.003
15	MG-15	BDL	0.001	ND	BDL	0.006	0.029	0.014	ND	0.02	0.024	0.25	0.004
16	MG-16	ND	ND	ND	0.001	0.005	0.005	0.009	ND	BDL	BDL	0.44	0.005
17	MG-17	BDL	0.002	ND	BDL	0.005	0.004	0.008	ND	0.00	0.001	0.52	0.003
18	MG-18	0.017	ND	ND	BDL	0.006	0.004	0.013	ND	BDL	0.007	0.19	0.003
19	MG-19	ND	0.003	ND	0.035	0.005	0.007	0.01	ND	0.01	0.002	0.41	0.005
20	MG-20	ND	0.002	ND	0.021	0.006	0.014	0.013	ND	0.02	BDL	0.28	0.004

Sr. No.	Sample Code	Cu	Cr	Cd	Fe	Ni	Mn	Pb	Co	Al	Zn	B	As
BIS Limits (ppm)		**0.05-1.5**	**0.05**	**0.003**	**1.0**	**0.02**	**0.1-0.3**	**0.01**	**0.01**	**0.03-0.2**	**5.0-15**	**0.5-1.0**	**0.01**
ICP detection Limit (ppm)		**0.0004**	**0.0002**	**0.0001**	**0.0003**	**0.0004**	**0.0001**	**0.001**	**0.001**	**0.0001**	**0.0002**		**0.001**
21	MG-21	ND	0.001	ND	0.007	0.006	0.003	0.013	ND	0.03	0.14	0.26	0.001
22	MG-22	0.029	0.001	ND	0.024	0.005	0.015	0.008	ND	0.06	0.014	0.41	0.001
23	MG-23	ND	0.002	ND	0.048	0.005	0.011	0.008	ND	0.05	0.008	0.45	0.004
24	MG-24	BDL	ND	ND	BDL	0.005	0.005	0.008	ND	0.02	0.005	0.32	0.002
25	MG-25	ND	ND	ND	BDL	0.005	0.016	0.009	ND	0.01	0.004	0.30	0.003
26	MG-26	BDL	0.001	ND	0.022	0.005	0.014	0.012	ND	0.04	0.002	0.34	0.004
27	MG-27	BDL	0.003	ND	0.087	0.006	0.079	0.013	ND	0.03	0.007	0.15	0.003
28	MG-28	BDL	ND	ND	0.002	0.005	0.005	0.012	ND	0.05	0.113	0.28	0.002
29	MG-29	0.002	0.002	ND	0.011	0.006	0.015	0.009	ND	0.05	0.012	0.42	0.003
30	MG-30	BDL	0.001	ND	BDL	0.005	0.033	0.013	ND	0.01	0.004	0.30	0.005
31	MG-31	ND	ND	ND	0.007	0.006	ND	0.012	ND	0.10	0.003	0.14	0.001
32	MG-32	BDL	0.011	ND	0.091	0.006	0.001	0.013	ND	0.07	0.019	0.14	0.003
33	MG-33	ND	0.003	ND	0.031	0.006	0.004	0.012	ND	0.05	0.006	0.19	0.001
34	MG-34	0.001	BDL	ND	BDL	0.006	0.007	0.01	ND	ND	BDL	0.23	0.003

Results mentioned in Table **Bold and underlined** are above the Permissible limits of BIS 10500-2012.
ND- Not Detected
BDL- Below Detection Limit

Figure 3.11: Water level measurement during the recuperation of the pumping well

The pumping test data were analysed by the equation (Cooper and Jacob, 1946) as follows:

$$T = (2.30) \times (Q) / 4 (\pi) \times (\Delta) \times (S) \qquad S = (2.25) \times (T) \times (t_0) \times (r^2)$$

Where,

T = Transmissivity (m^2/day)

Q = Constant pumping discharge (m^3/day)

ΔS = Drawdown over one log cycle time (m) from semi-log graph r = Distance between pumping & observation well (m)

t_o= time of intercept of zero draw down in the day from semi-log graph

In the present case, after completion of the pumping, the pump was shut down for measuring the water level during well recuperation. During recuperation, the water level measurements were recorded in the sequence as per the standard protocol. It was observed that the static water level (measured just before pumping) was recovered in approximately 6 hours duration. The recovery test data is used to compute aquifer parameters based on the Theis' recovery method (Theis, 1935, CGWB,1982). A semi-log plot of recuperation versus time (**Figure 3.12**) was used at the observation well No. MG-2 for estimation of the Aquifer Parameter, T (Transmissivity).

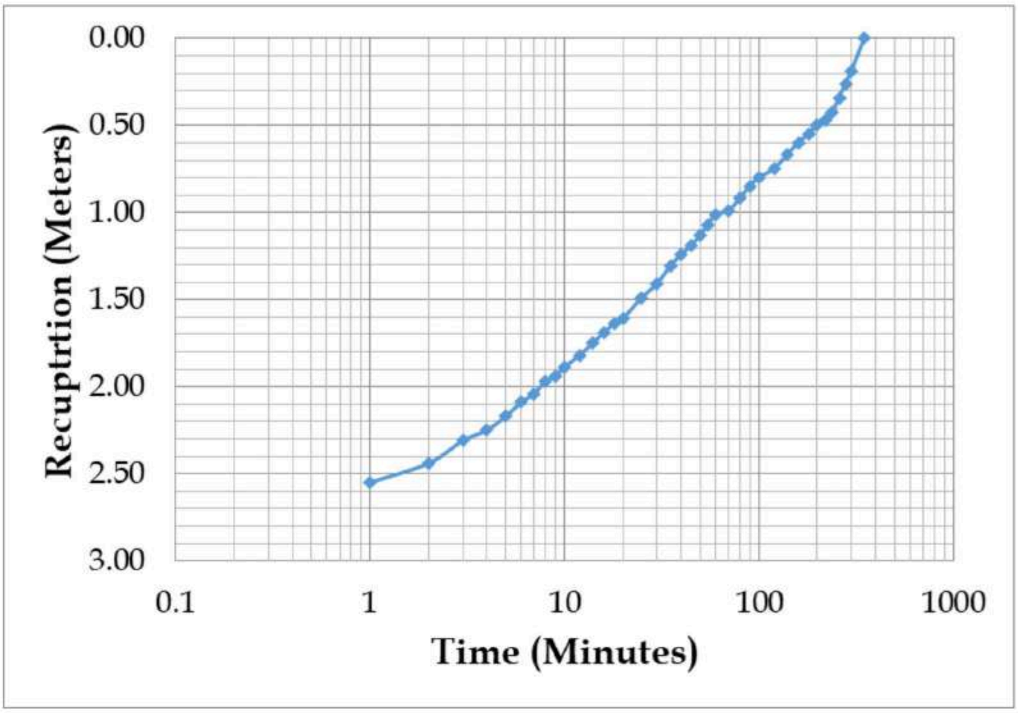


Figure 3.12: Time Vs Recuperation straight-line plot of pumping test at MG-2 observation well of the study area

The transmissivity measured at MG-2, is found to be 95.83 m^2/day (**Table 3.11**). It is to be noted that the well is drawing water through a 13.33m zone, where slotting is provided. The rate of discharge was calculated during the pumping test, and it was considerably good discharge in this area, i.e., 576 m^3/day.

Table 3.11: Aquifer parameters of MG 2 observation well in the study area

Parameter	MG-2
Latitude	30° 16' 57.0"N
Longitude	76° 04' 53.2"E
Static Water Level (bgl-m)	43.41
Well Depth (m)	76.22
Thickness of the aquifer tapped	13.33m
Discharge Rate (m^3/day)	576
Transmissivity (m^2/day)	95.83
Hydraulic Conductivity (m/day)	7.189

The estimated Transmissivity (95.83 m^2/day) comes under the class of Intermediate magnitude class (Table 3.12) (Krasny, 1993).

Table 3.12: Classification of transmissivity: After Jiri Krasny (1993)

Coefficient of Transmissivity(m^2/day)	Class of Transmissivity magnitude	Designation of Transmissivity magnitude
> 1000	I	Very high
100 to 1000	II	High
10 to 100	III	Intermediate
1 to 10	IV	Low
0.1 to 1.0	V	Very low
< 0.1	VI	Imperceptible

3.3 Geophysical Measurements

Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) were employed for mapping the near sub surface in the premises of M/S Matharu Chemical Industries. The objective was to delineate the contaminated region non-invasively and followed by targeted soil sampling for ground truth.

3.3.1 ERT survey

Electrical Resistivity Tomography (ERT) was employed to delineate the contaminated area at the site. The reconnaissance visit indicated that the site had lot of soil mounds scattered all over and it was necessary to get it cleared and render it amenable for Electrical Resistivity Tomography. The ERT survey was undertaken at areas which were supposed to cover the Solar Evaporation Pond (SEP) and the Hazardous waste storage locations. Review of the monitoring data shared by the PPCB (Annexure-I) indicated that the treated effluent had a Total Dissolved Solids (TDS) approximately 7693 mg/L and 13469 mg/L in the solar evaporation ponds. In view of the very high TDS of the effluent in the solar evaporation pond, the back ground medium impact by it can have discernible signature on the resistivity measurements. It is expected that the zone affected due to the disposal of high TDS treated effluent will show a lower resistivity anomaly in the ERT survey.

General

Geophysical tool namely, Electrical Resistivity Tomography (ERT) is a useful tool in near subsurface investigations for Environmental and Geotechnical applications (Loke, 1999, Pujari et al., 2007; Strelec, 2017).

ERT

Methodology:

ERT is an extension of the conventional 4 Electrode Resistivity Method.

The basic principle of the Resistivity Method is the ohm's law i.e. $V=I\times R$.

Where V is the Potential difference

I is the Current and R is the Resistance

Electric potential differences (V) of ground at various locations are measured by introducing a known amount of electric current (I) to ground from different locations. From the data obtained, the electrical resistivity of the subsurface can be derived.

The simplest configuration **(Figure 3.13)** is one having four electrodes wherein electrodes namely, **A** and **B** serve as current electrodes whereas electrodes, namely **M** and **N** is the potential electrodes. The current electrodes **A** and **B** serve as the current source and current sink respectively. A known amount current (I) is sent to the ground by current source **A**. Current travels through the ground with least resistive area creating potential differences across potential electrodes **M** and **N**. Potential difference (V) is measured across **M** and **N**. The measured potential difference (V), known current (I) and the Geometric Constant, K (which depends on the disposition of the current and potential electrodes) are used to calculate the apparent resistivity (Refer Eqn. 1). Calculated resistivity value is associated with a point that lies below the centre of potential electrodes, which is called an investigating point. Collection of these point series can be done in two ways either laterally called profiling or vertically called soundings. Various electrode configurations for this have been introduced like Schlumberger, Wenner, pole-pole, pole-dipole etc. (Telford et al., 1976). The selection of configuration for the survey is dependent on the purpose of the surveys. In this study, the Wenner arrangement is used in view of its ability to provide good horizontal resolution.

$\rho_a = \mathbf{K}\frac{\mathbf{V}}{\mathbf{I}}$ ....Equation 1

Where,

ρ_a = Apparent Resistivity in ohm/m

K= Geometric constant

V= Potential difference across M & N in volt

I= Current injected to ground in ampere

The apparent resistivity estimated by Equation (1) depends on electrode configuration and resistivity of the materials. From the apparent resistivity values, the true resistivity of the subsurface is estimated through an inversion algorithm. The resistivity values are interpreted to provide geological or environmental perspectives.

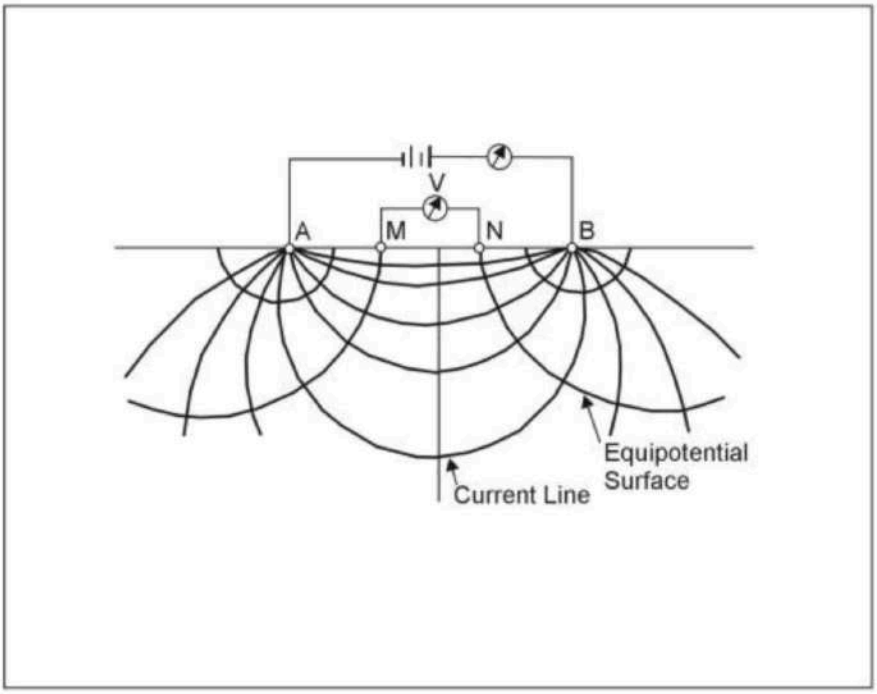


Figure 3.13: Basic Electrode configuration

Electrical Resistivity Tomography

The development of microprocessor technology and advanced interpretation software in 2-D and 3-D led to the development of Electrical Resistivity Tomography. It is a fast and cost-effective technique for mapping the subsurface resistivity (Loke, 1999). Multi electrode cable (48/64/84 electrodes) has replaced the conventional 4 electrode survey. ERT gives resistivity in 2D & 3D clear pictures of subsurface using multi-electrodes. ERT has a dense sampling of apparent resistivity measurements which generates high-density data pseudo sections (**Figure 3.14**). So it gives better and high resolution within less time. With high resolution and 2D resistivity data, subsurface electric strata are directly identified. It is faster and high resolution images in 2-D/3D as compared to the 1-D section, which was obtained from conventional 4 electrode resistivity survey.

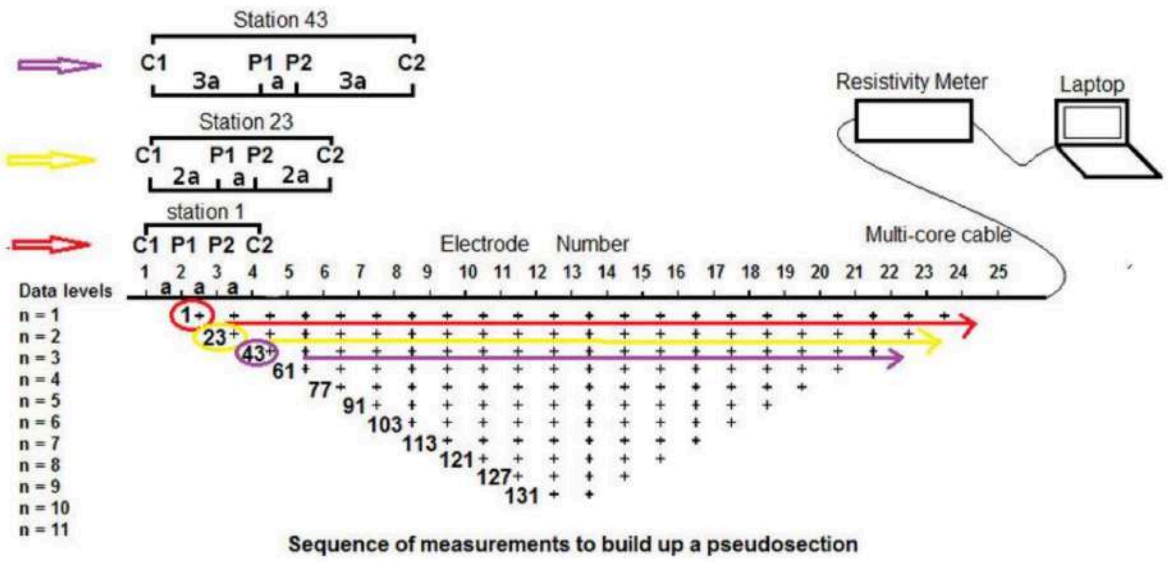


Figure 3.14: Typical Pseudo-section from ERT measurement

Instrumentation

For this purpose, the 4-channel system known as TERAMETER LS (Manufactured by M/s ABEM by, Sweden) is used in the present study. The key features of the LS Imaging System are integrated roll-along function & Automatic electrode contact test which gives full control of the data acquisition process and storage of data. It has a powerful transmitter with 2500 mA maximum current transmission and 250 W output power which gives higher quality data. A high-quality receiver with Input Voltage Range ± 600 V and Input Impedance 200 M-Ohm provides sensitivity which enables high-resolution data recording.

Design of the ERT measurements:

ERT profiles (25 nos) were marked on the probable area of the Solar evaporation pond and the Hazardous waste disposal sites (**Figure 3.15 Figure 3.16**). The profiles were of varying length and each profile length covered the probable area of solar evaporation pond (SEP) area and the area flanking it.

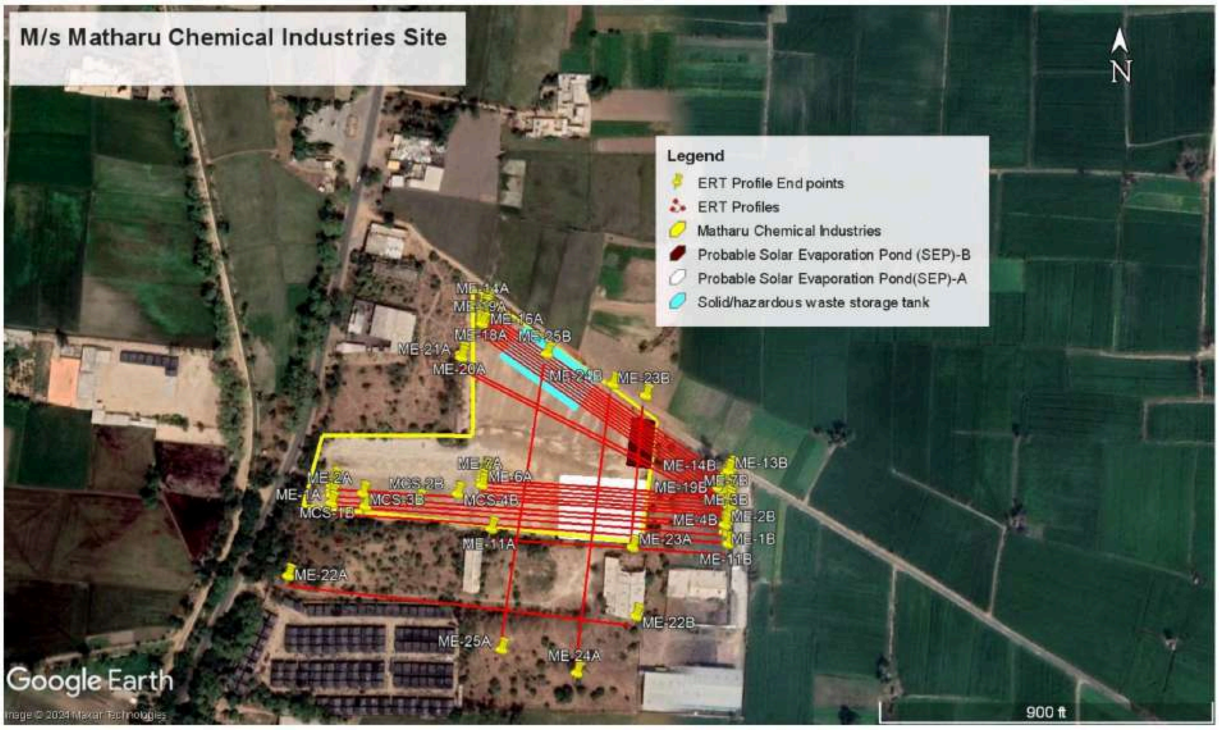


Figure 3.15: ERT survey location in the study area

Figure 3.16: ERT profile at the site

Based on the probable locations of Solar Evaporation Ponds and the Hazardous waste storage locations available in the PPCB records (Annexure-I) in the premises of the Matharu Chemicals, the geophysical field data campaign was planned accordingly. The monitoring data (Annexure-I) shared by the PPCB indicated that the treated effluent had a Total Dissolved Solids (TDS) approximately 7693 mg/L and 13469 mg/L in the solar evaporation ponds. The seepage of Highly conductive effluent from the solar evaporation pond to the host medium will lead to a significant contrast of resistivity value at the seepage locations. In view of the significant contrast in the resistivity parameter between the host medium (alluvium) and the effluent in the solar evaporation pond, the Electrical Resistivity Tomography was undertaken to decipher the signature from the treated effluent on the host medium, i.e. alluvium. It is expected that the zone affected due to the disposal of high TDS (very low resistivity) treated effluent will show a lower resistivity anomaly in the ERT survey. ERT data (**Figure 3.15, Table 3.13**) was collected at the premises of the industry and its vicinity.

Table 3.13: Locations of the ERT profiles within and outside the premises

ERT profiles	Target covered/	Target covered	Total Profile Length
ME-1	Solar Evaporation Pond (A)	186 to 254 (68m)	320m
ME-2		187 to 254 (67m)	320m
ME-3		187 to 255 (68m)	320m
ME-4		187 to 254 (67m)	320m
ME-5		186 to 254 (68m)	320m
ME-6		65 to 135 (70m)	200m
ME-7		67 to 135 (68m)	200m
ME-8		65 to 134 (69m)	200m
ME-9		65 to 134 (69m)	200m
ME-10		64 to 134 (70m)	200m
ME-12	Solar Evaporation Pond (B)	150 to 155 (05m)	240m
ME-13		149 to 168 (19m)	240m
ME-14		149 to 169 (20m)	240m
ME-15		148 to 169 (21m)	240m
ME-16		148 to 169 (21m)	240m

ME-17		149 to 170 (21m)	240m
ME-18		149 to 170 (21m)	240m
ME-19		148 to 169 (21m)	240m
ME-20		155 to 175 (20m)	240m
ME-21		155 to 175 (20m)	240m
ME-12	Hazardous Waste Storage Site (C)	36 to 108 (72m)	240m
ME-13		35 to 107 (72m,)	240m
ME-14		33 to 106 (73m)	240m
ME-15		32 to 105 (73m)	240m
ME-16		30 to 103 (73m)	240m
ME-17		28 to 102 (74m)	240m
ME-18		26 to 101 (75m)	240m
ME-19		25 to 99 (74m)	240m
ME-20	Outside the Industry		200m
ME-21			400m
ME-22			280m

3.3.1.1: ERT profiles covering the probable area of the Solar Evaporation Pond (A)

ME-1 (**Figure 3.17**) was carried out close to the south side campus wall of the site. The survey profile length of approximately 320 m, with a penetration depth of about 54 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<71 Ohm-m) except the segment overlapping with the probable SEP area. A patch of low resistivity zone (2-13 ohm-m) can be demarcated in the depth up to 20 m and horizontal length from 168 m to 256 m. The low resistivity zone (identified by dashed curved line) can be attributed to the impact of the very conductive treated effluent stored in the solar evaporation pond.

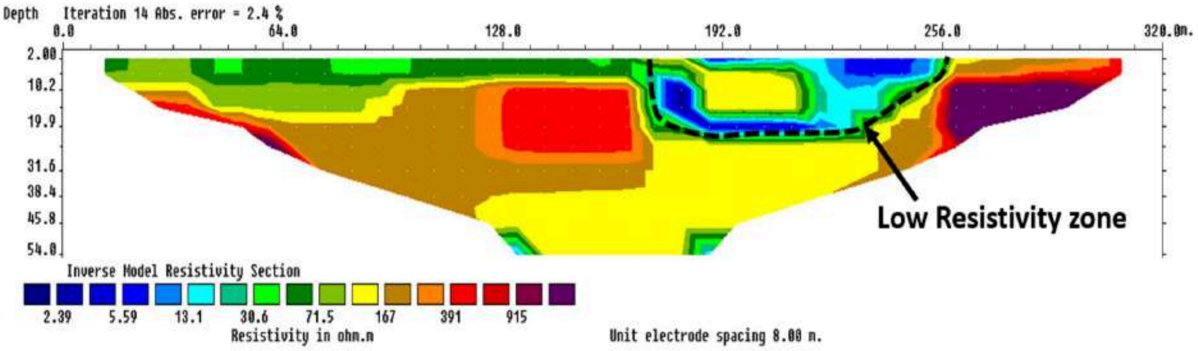


Figure 3.17: Inverted section of ME-1

ME-2 (**Figure 3.18**) was carried out parallel to the profile ME-1. The profile length is 320 m, and has penetration depth of about 54 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<75 Ohm-m). A patch of low resistivity zone (3-15 ohm-m) which can be attributed to the solar evaporation pond can be demarcated in the depth up to 20 m and horizontal length from 176 m to 256 m. The low resistivity anomalous zone can be attributed to the impact of the high TDS effluent in the SEP.

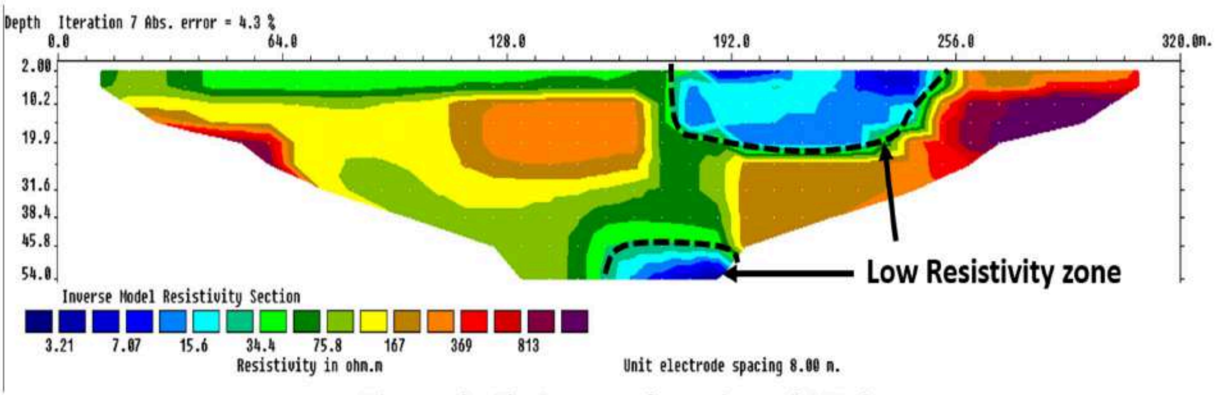


Figure 3.18: Inverted section of ME-2

ME-3 (**Figure 3.19**) was carried out parallel to ME-1 and ME-2. The survey profile length is approximately 320 m, and it provides depth of information upto approximately 54 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a resistivity (<86 Ohm-m). A patch of relatively low resistivity zone in the range 4-19 ohm-m is observed in the depth up to 20 m and horizontal length from 168 m to 248 m. This low resistivity zone overlaps with the probable location of the SEP as per the available records. The underlying zone beyond 20 m exhibits higher resistivity (>167 ohm-m), which can be attributed to the presence of sand. It is followed by lesser resistivity going upto 19 ohm-m, which may be linked to the underlying formation of clay/saturated sand.

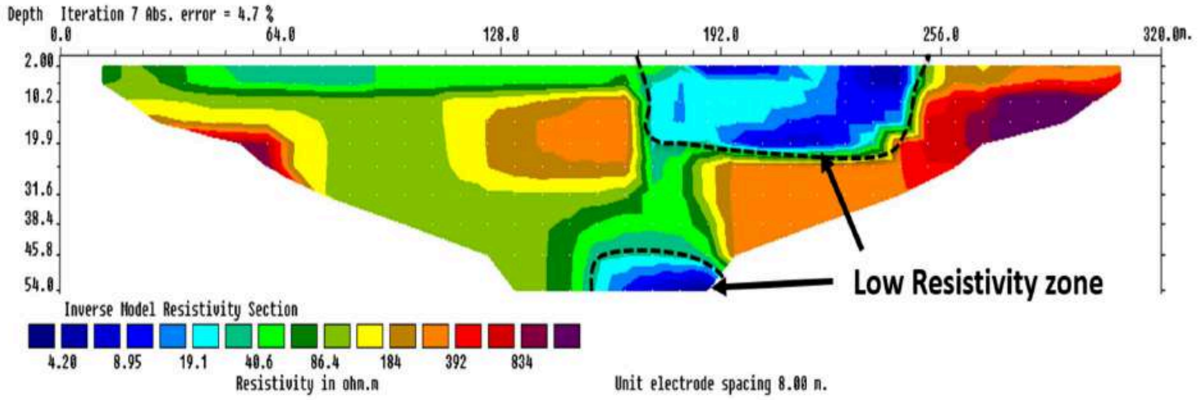


Figure 3.19: Inverted section of ME-3

ME-4 (**Figure 3.20**) was carried out parallel to ME-2 and ME-3. The survey profile length is approximately 320 m, with depth of penetration approximately 54 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<103 Ohm-m). A patch of relatively low resistivity zone (3-19 ohm-m) is observed at the zone, horizontal length from 144 m to 248 m having depth upto 20m. The zone almost overlaps with the probable location of the Solar evaporation pond. The low resistivity can be attributed to the percolation of the high TDS effluent.

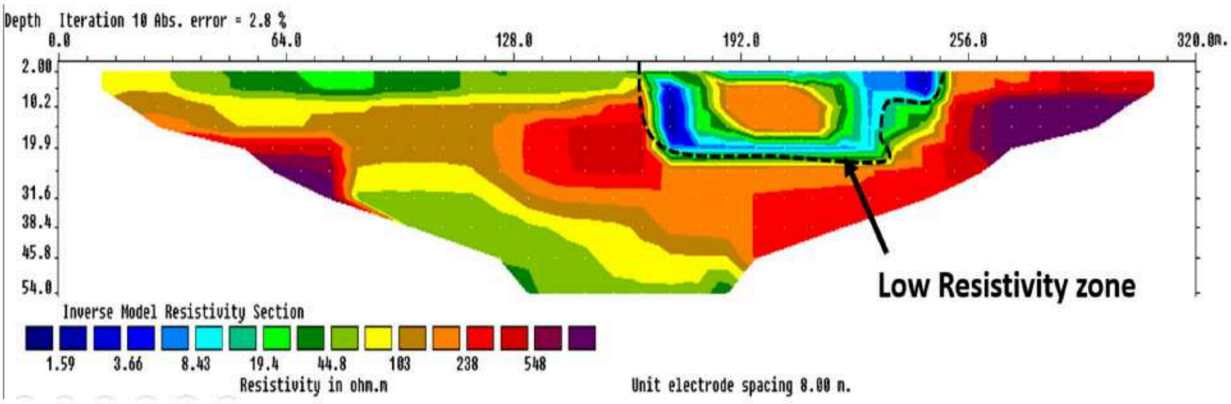


Figure 3.20: Inverted section of ME-4

ME-5 (**Figure 3.21**) was carried out parallel to ME-3 and ME-4. The survey profile length is approximately 320 m, with depth of penetration approximately 54 m. As observed in ME-3 and ME-4, low resistivity zone (3-13 ohm-m) is observed upto approximately 20m depth in the horizontal length from 168 m to 248 m. The underlying zone beyond 20 m exhibits higher resistivity (>126 ohm-m), which can be attributed to the presence of sand.

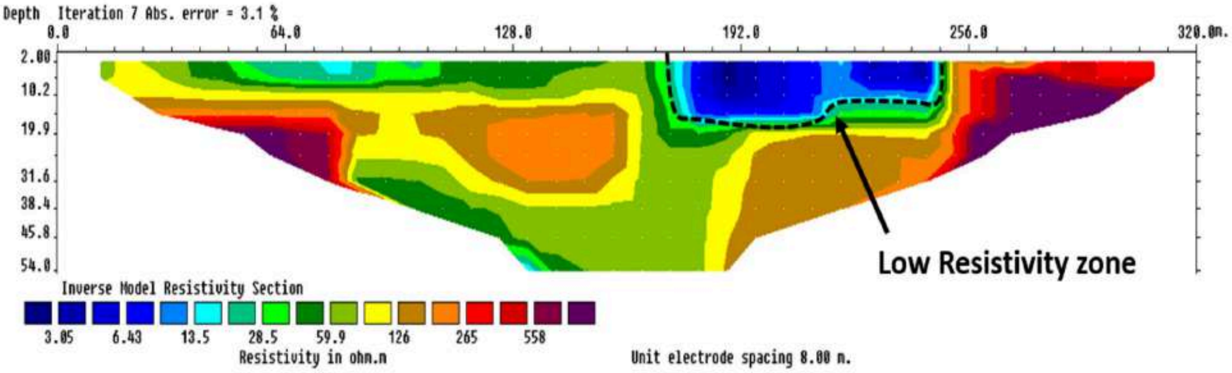


Figure 3.21: Inverted section of ME-5

ME-6 (**Figure 3.22**) was carried out parallel to ME-4 and ME-5. The survey profile length is approximately 200 m, and has a penetration depth of approximately 33m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<89 Ohm-m). Low resistivity anomalous zone (3-13 ohm-m) can be demarcated in the depth 3 m to 24 m and 3 m to 16 m and horizontal length from 50 m to 65 m and 100 m to 130 m respectively. The low resistivity zones indicated overlap with the probable location of the Solar Evaporation Pond.

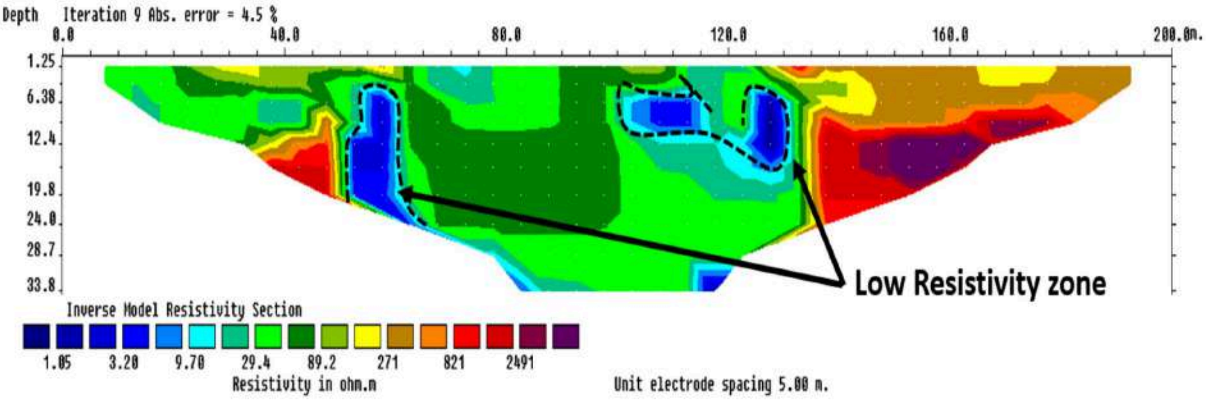


Figure 3.22: Inverted section of ME-6

ME-7 (**Figure 3.23**) was carried out parallel to ME-5 and ME-6. The survey profile length is approximately 200 m, and has a penetration depth of approximately 33 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3 m) reveals resistivity (<249 Ohm-m), wherein low resistivity anomalous zone (2-25 ohm-m) is observed at the depth 3-13m and horizontal length from 100 m to 125 m.

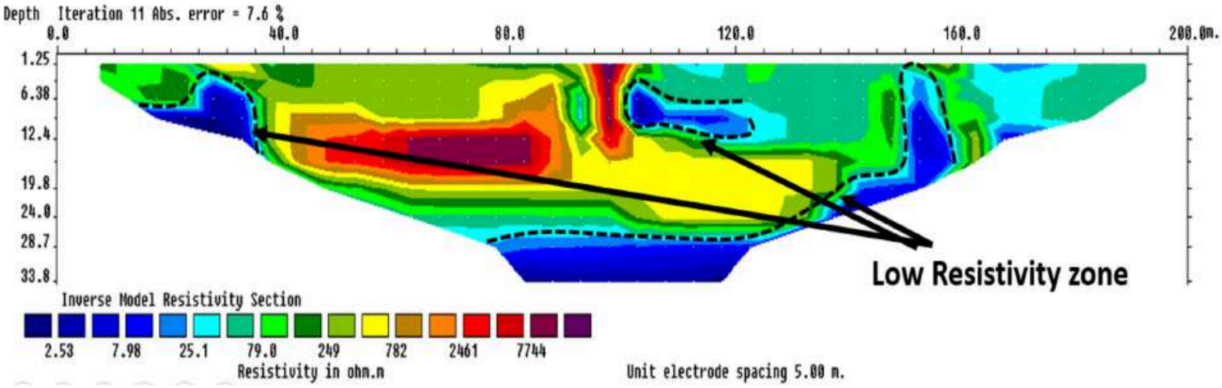


Figure 3.23: Inverted section of ME-7

ME-8 (**Figure 3.24**) was carried out parallel to ME-6 and ME-7. The survey profile length of approximately 200 m, reaching a penetration depth of about 33 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<59 Ohm-m). A patch of low resistivity zone (3-13 ohm-m) is observed at depth from 3 m to 33 m and horizontal length from 50 m to 135 m, which overlaps with the probable SEP.

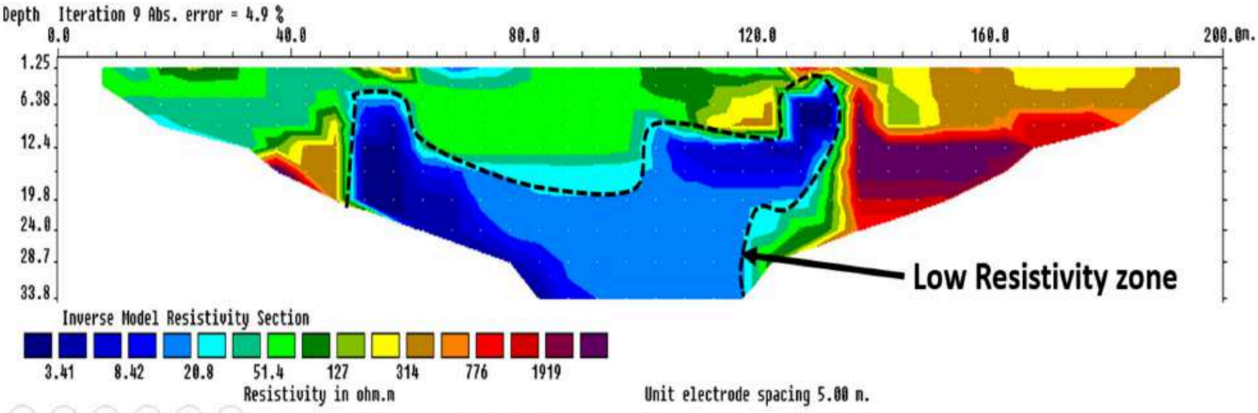


Figure 3.24: Inverted section of ME-8

ME-9 (**Figure 3.25**) was carried out parallel to ME-7 and ME-8. The survey profile length is approximately 200 m, and has a penetration depth of approximately 33 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals resistivity (<57 Ohm-m), wherein a patch of low resistivity zone (3-21 ohm-m) can be demarcated in the depth from 3 m to 33 m and horizontal length from 50 m to 135 m. The patch of low resistivity anomalous zones can be attributed to the percolation of high TDS effluent from the Solar Evaporation Pond. It need to be mentioned that the profile was very close to the surface water drainage created for the wheat field and the brick unit.

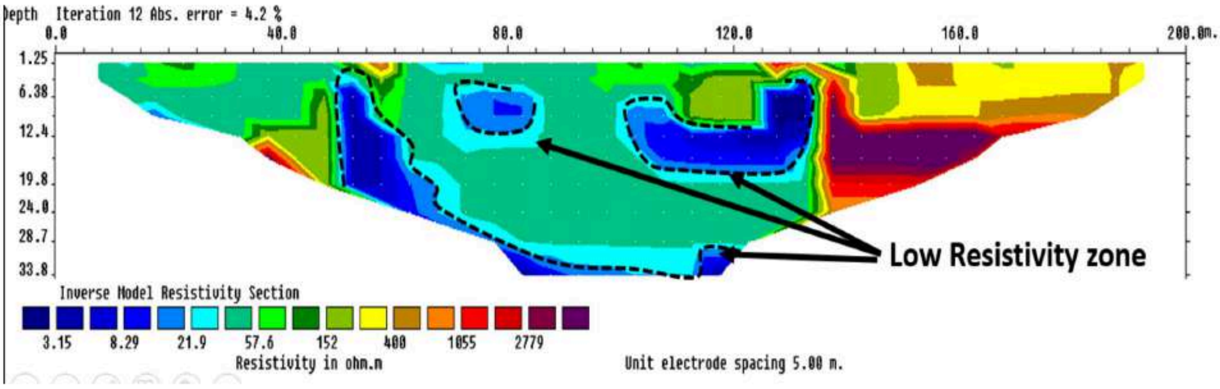
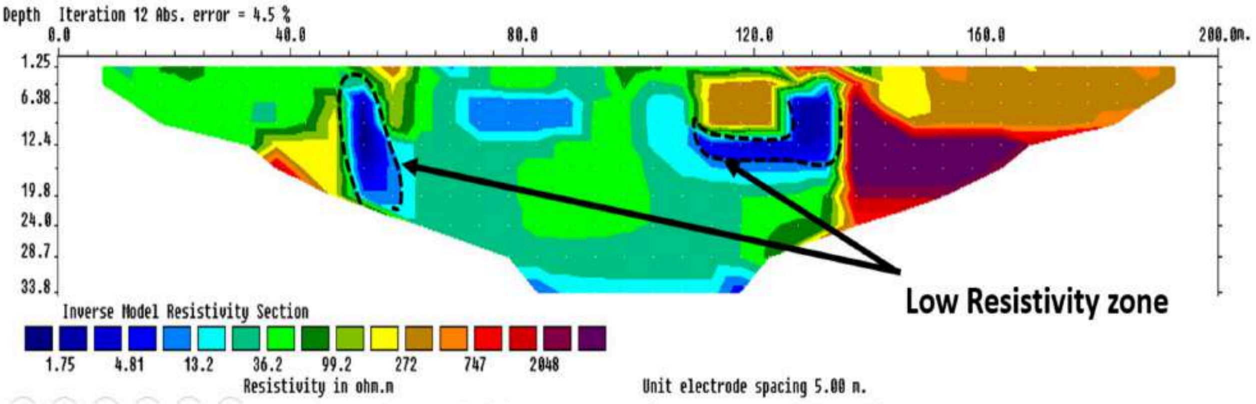


Figure 3.25: Inverted section of ME-9

ME-10 (**Figure 3.26**) was carried out parallel to ME-8 and ME-9. The survey profile length is approximately 200 m, having a penetration depth of about 33 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals low resistivity (<99 Ohm-m). A patch of low resistivity zone (3-36 ohm-m) can be demarcated in the depth from 3 m to 24 m and horizontal length from 50 m to 135 m. The low resistivity zone can be attributed to the impact of the percolating high TDS effluent of the Solar Evaporation Pond.



Low Resistivity zone

Figure 3.26: Inverted section of ME-10

ME-11 (**Figure 3.27**) was carried out outside (control site) the Matharu chemical industries which is parallel to ME-1 and ME-2. The profile is approximately 7m from ME-1. The survey profile length is approximately 200 m, and has a depth of penetration of about 33 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3 m) reveals a low resistivity (<91 Ohm-m) Patches of low resistivity zones (4-36 ohm-m) can be identified at depths ranging from 3 m to 12 m and 3 m to 20 m, with horizontal lengths extending from 55 m to 90 m and 110 m to 125 m respectively.

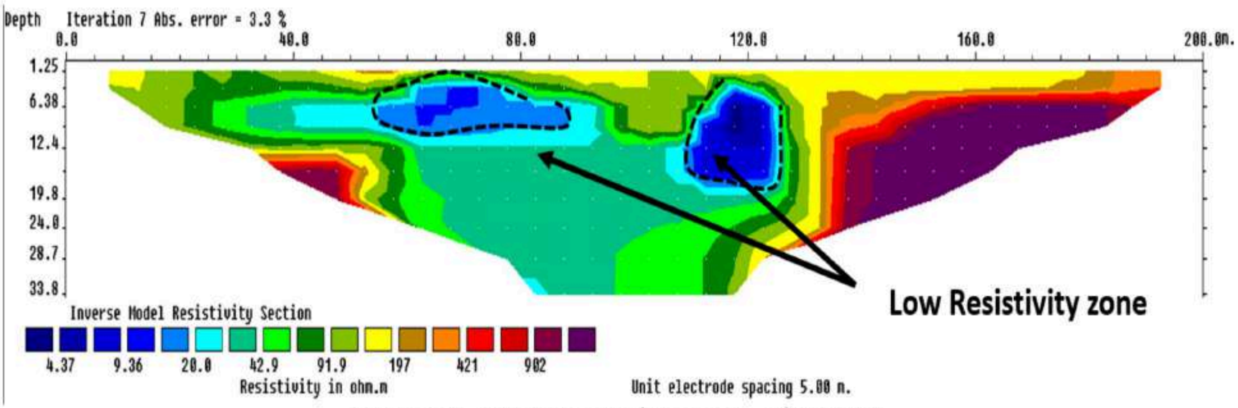


Figure 3.27: Inverted section of ME-11

ME-24 (**Figure 3.28**) was carried out parallel to ME-26 and perpendicular the ME-1 to ME-10 and ME-15 to ME-24. The survey profile length is approximately 240 m, with depth of penetration of approximately 40 m. Patches of low resistivity zones (2-13 ohm-m) can be identified at depths up to 19 m and horizontal lengths vary from 114 m to 174 m and 192 m to 222 m. The zone from horizontal length 114m to 174m overlaps with the probable Solar Evaporation Pond (A). The low resistivity zones extending from approximately 192m to 222m is close to the Solar Evaporation Pond (B) and at an approximate distance of 20m. The underlying zone exhibits high resistivity (>160 ohm-m), which can be attributed to the presence of sand.

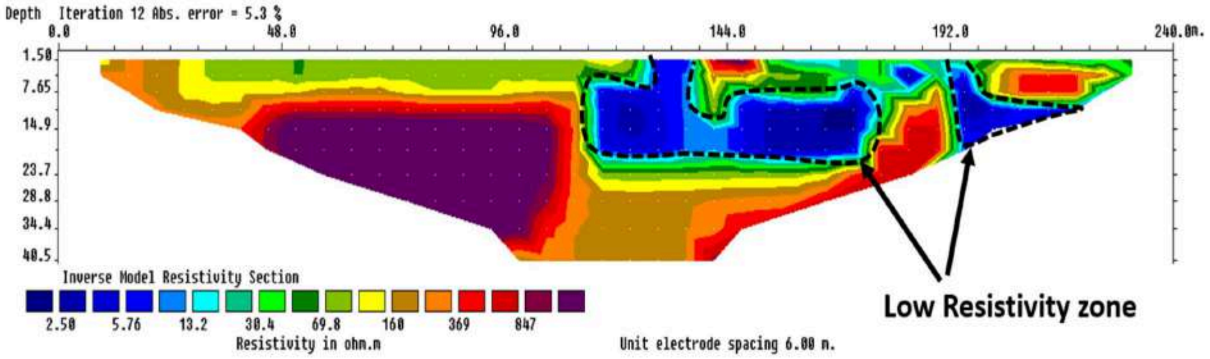


Figure 3.28: Inverted section of ME-24

3.3.1.2: ERT profiles covering the probable area of Solar Evaporation Pond (B)

ME-12 (**Figure 3.29**) was carried out close to the North side campus wall of the site. The survey profile length is approximately 240 m, and has a depth of penetration of approximately 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3 m) reveals a low resistivity (<91 Ohm-m), suggestive of surface sand with admixture of clay. A patch of low resistivity zone (2-13 ohm-m) can be demarcated in the depth up to 11 m and horizontal length from 148 m to 162 m. Low resistivity anomalies (3-14 ohm-m) are also observed in the top 3m at the horizontal length from 42 m to 78m, which is part of the distance covered within the probable location of the Hazardous waste storage site. Another patch of low resistivity zone (<13 Ohm-m) observed in the depth from 14 m and horizontal length from 120 m to 138 m.

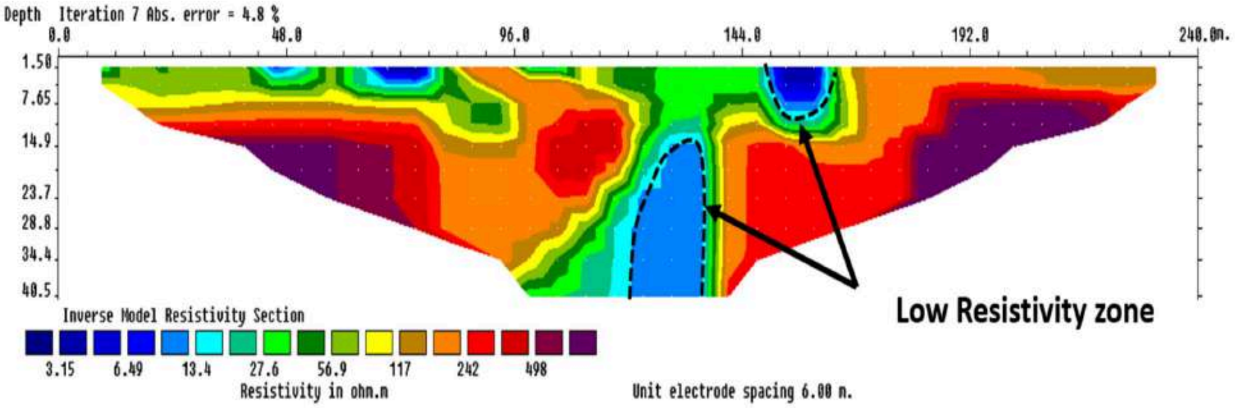


Figure 3.29: Inverted section of ME-12

ME-13 (**Figure 3.30**) was carried out parallel to ME-12 which is near to the North side campus wall of the site. The survey profile length is approximately 240 m, reaching a penetration depth of about 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<95 Ohm-m). A patch of low resistivity zone (1-15 ohm-m) can be demarcated in the depth from 2.5 m to 12 m and horizontal length from 132 m to 168 m. The low resistivity zone can be attributed to the impact of the percolation from the solar evaporation Pond (B). Besides, low resistivity anomaly zone (upto 11 ohm-m) was present upto 4-5m in the horizontal length 42m-78m) which overlaps with the zone covered by the probable location of the Hazardous waste storage site.

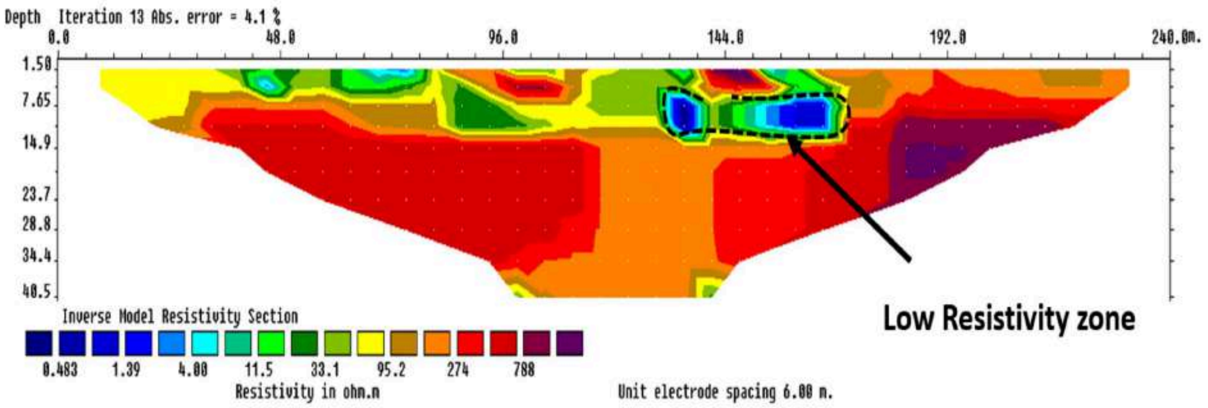


Figure 3.30: Inverted section of ME-13

ME-14 (**Figure 3.31**) was carried out parallel to ME-12 and ME-13. The survey profile length is approximately 240 m, and has depth of penetration of approximately 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<81 Ohm-m), suggestive of soil and surface clay. A patch of low resistivity anomaly (2-14 ohm-m) can be demarcated in the depth up to 15 m and horizontal length from 130 m to 168 m.

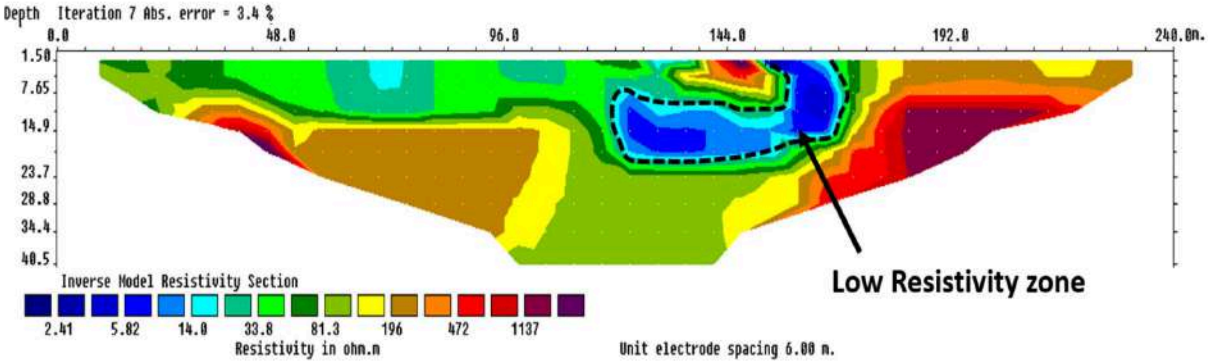


Figure 3.31: Inverted section of ME-14

ME-15 (**Figure 3.32**) was carried out parallel to ME-13 and ME-14. The survey profile length is approximately 240 m, and has a depth of penetration of approximately 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<141 Ohm-m), suggestive of soil. A patch of low resistivity zone (2-7 ohm-m) is prominent at a depth upto 20m and horizontal length from 108 m to 168 m. The low resistivity can be attributed to the impact from the

Solar Evaporation Pond (B). The zone covering the probable location of the Hazardous waste disposal site is also characterized by low resistivity (14 -40 ohm-m).

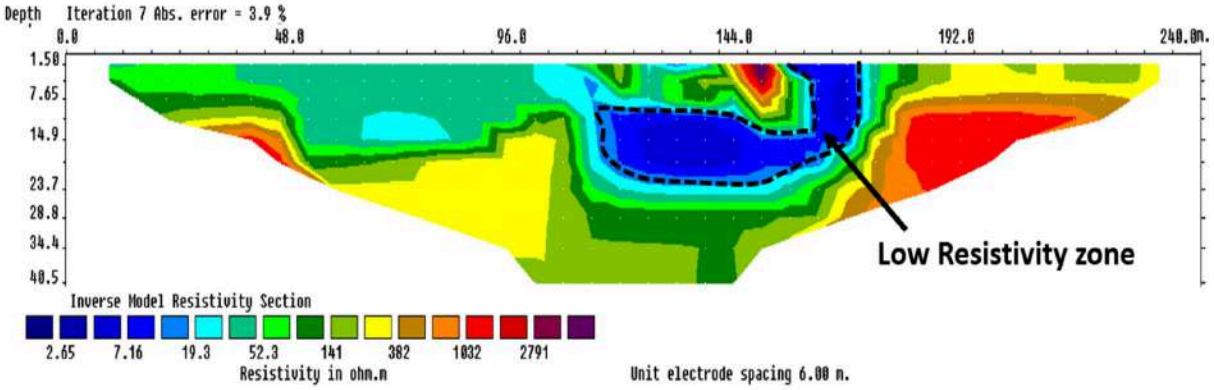


Figure 3.32: Inverted section of ME-15

ME-16 (**Figure 3.33**) was carried out parallel to ME-14 and ME-15. The survey profile length is approximately 240 m, and has a depth of penetration of approximately 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals resistivity (<62 Ohm-m). A patch of low resistivity zone (5-12 ohm-m) is prominently visible at depth upto 20m and 108 m to 168 m. The low resistivity anomaly can be attributed to the impact of the Solar Evaporation Pond (B).

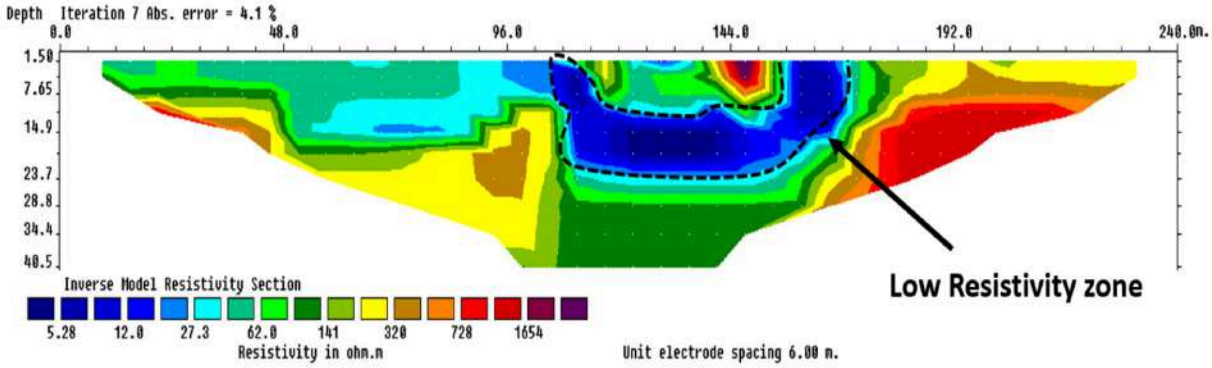


Figure 3.33: Inverted section of ME-16

ME-17 (**Figure 3.34**) was carried out parallel to ME-15 and ME-16. The survey profile length is approximately 240 m, and has a depth of penetration of about 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals resistivity (<59 Ohm-m). A patch of low resistivity zone (2-13 ohm-m) can be demarcated up to 20 m depth and horizontal length from 108 m to 168 m. Low resistivity zone (20-28 ohm-m) is also observed in the zone covered by the probable Hazardous waste storage site.

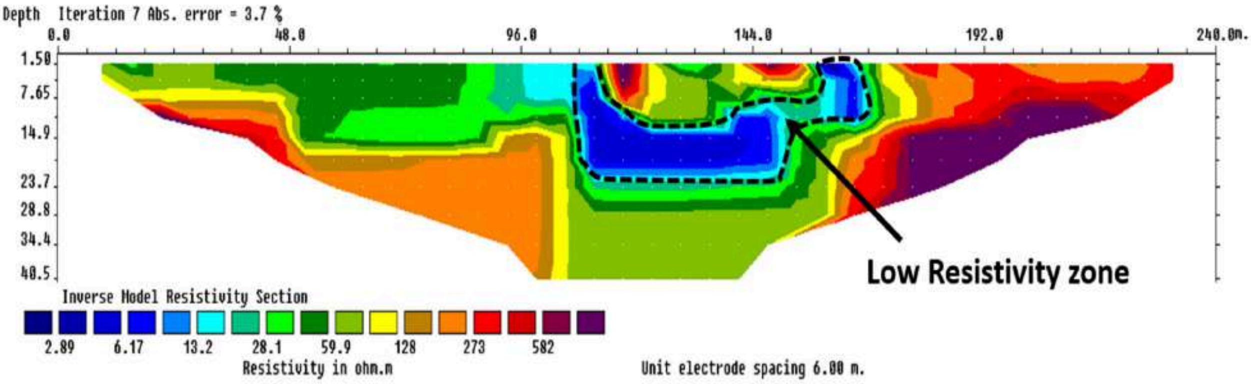


Figure 3.34: Inverted section of ME-17

ME-18 (**Figure 3.35**) was carried out parallel to ME-16 and ME-17. The survey profile length is approximately 240 m, reaching a penetration depth of about 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals resistivity (<78 Ohm-m), suggestive of top soil. A patch of low resistivity anomaly (3-16 ohm-m) is present upto depth 28 m and horizontal length from 90 m to 168 m.

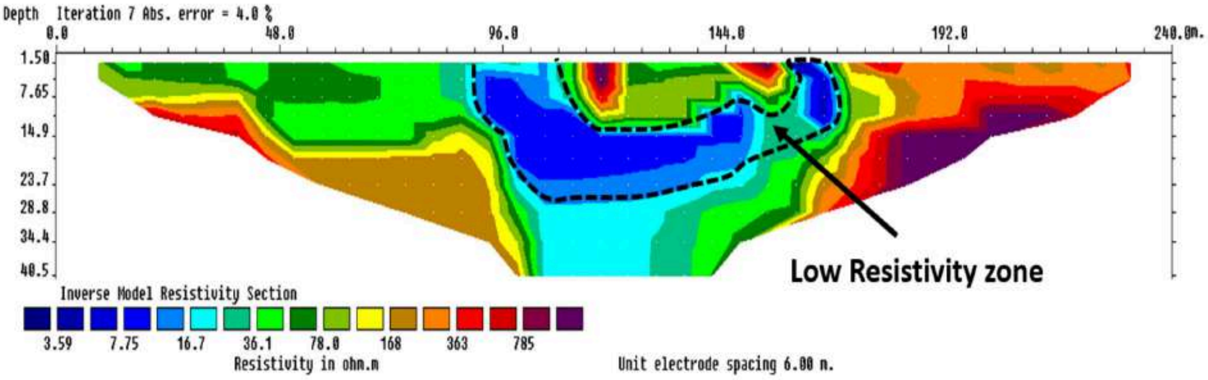


Figure 3.35: Inverted section of ME-18

ME-19 (**Figure 3.36**) was carried out parallel to ME-17 and ME-18. The survey profile length is approximately 240 m, with depth of penetration approximately 40 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 3-4 m) reveals a low resistivity (<110 Ohm-m), suggestive of top surface sand. A patch of low resistivity anomaly (upto 18 ohm-m) is observed upto 24 m and horizontal length from 84 m to 168 m. This zone overlaps with the probable location of the Solar Evaporation Pond (B) and the Hazardous storage waste site.

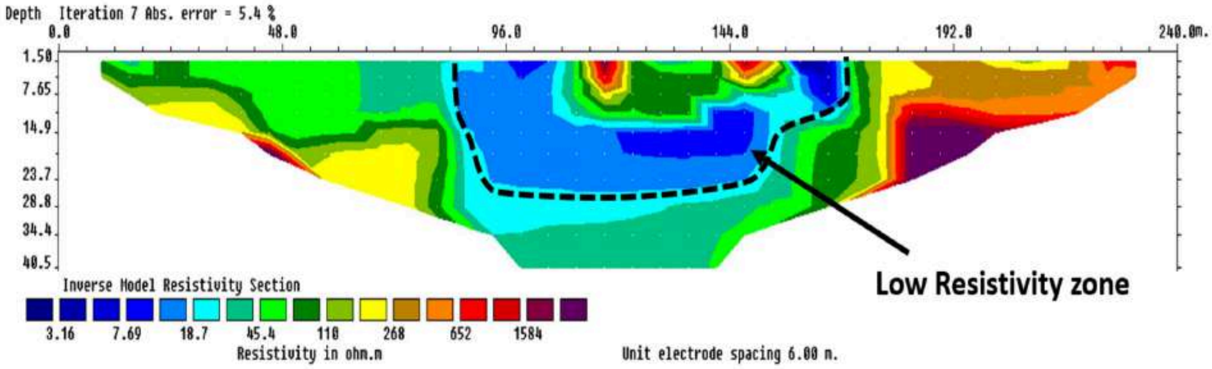


Figure 3.36: Inverted section of ME-19

ME-20 (**Figure 3.37**) was carried out parallel to ME-21. The survey profile length is approximately 240 m, with depth of penetration of approximately 40 m. Low resistivity anomalies (3-17 ohm-m) are present in the horizontal lengths extending from 60 m to 108 m and 120 m to 168 m respectively. The zone extending from 120m to 168m overlaps with the probable location of the Solar Evaporation Pond (B).

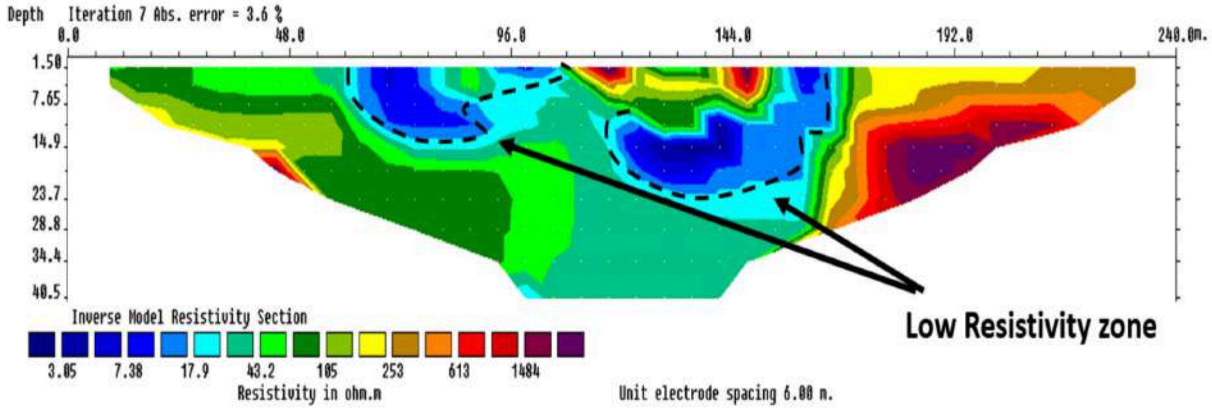


Figure 3.37: Inverted section of ME-20

ME-21 (**Figure 3.38**) was carried out parallel to ME-20. The survey profile length is approximately 240 m, having depth of penetration of about 40 m. Low resistivity zones (1-12 ohm-m) can be observed at depths up to 10 m and 23 m, with horizontal lengths extending from 60 m to 108 m and 120 m to 168 m respectively. The low resistivity zones overlaps with the probable solar evaporation pond (B).

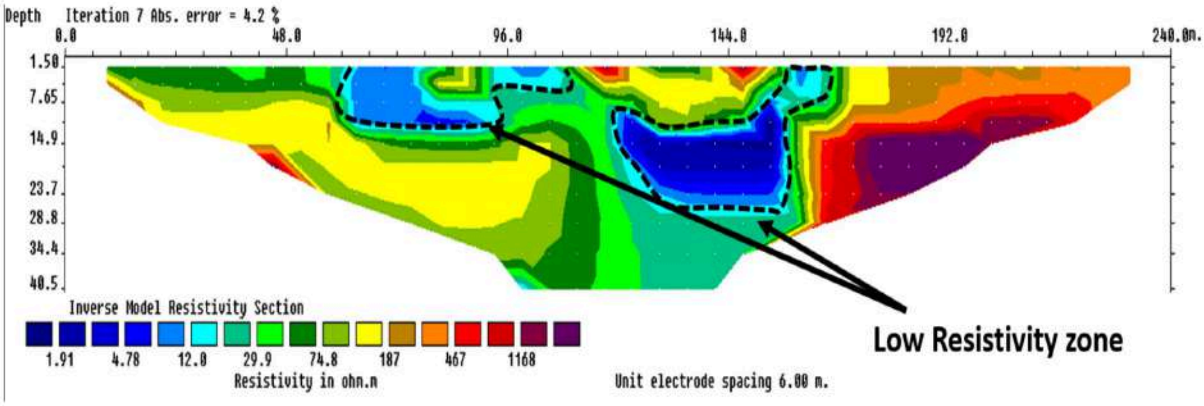


Figure 3.38: Inverted section of ME-21

ME-22 (**Figure 3.39**) was conducted parallel to ME-11, which is located 55 meters away from ME-11. It is outside the premises of M/S Matharu Chemical Industries. The survey profile length of approximately 280 m, reaching a penetration depth of about 47 m. The interpreted resistivity data for the top layer of this profile (up to a depth of 4-5 m) reveals a low resistivity (<179 Ohm-m), suggestive of soil and surface clay. The underlying zone beyond 5 m exhibits high resistivity (>683 ohm-m), which can be attributed to the presence of sand. The resistivity pattern shows higher resistivity as compared to the zones in the top 10-15m as observed in other profiles. It is followed by lesser resistivity going upto <179 ohm-m, which may be linked to the underlying formation of clay/saturated sand. Low resistivity zones observed (<8-10 ohm-m) were absent in this profile.

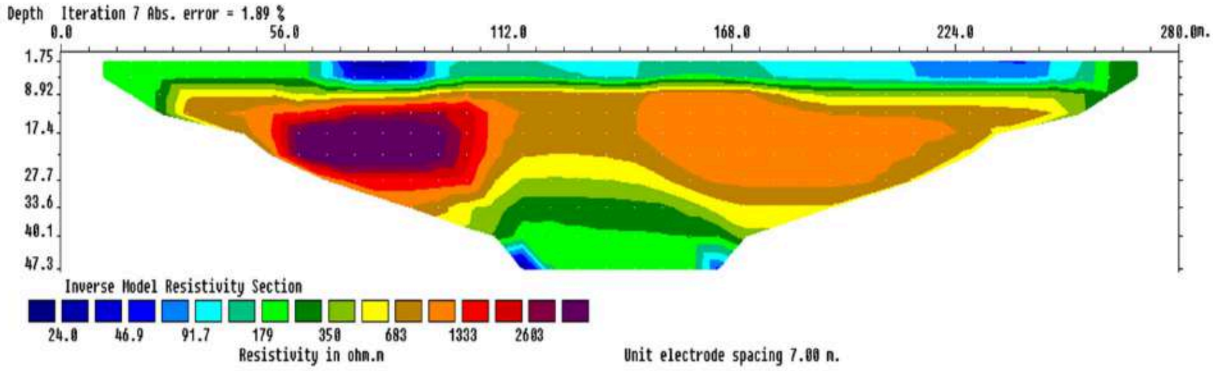


Figure 3.39: Inverted section of ME-22

ME-23 (**Figure 3.40**) was carried out perpendicular the ME-1 to ME-10 and ME-12 to ME-21. The survey profile length of approximately 120 m, reaching a penetration depth of about 20 m. Low resistivity zones (1-9 ohm-m) can be identified at depths of up to 9 m, 3 to 14 m, and upto 9 m. The horizontal lengths of these zones vary from 12 m to 36 m, 42 m to 72 m, and 81 m to 120 m, respectively. These zones are located within the solar evaporation pond (A & B).

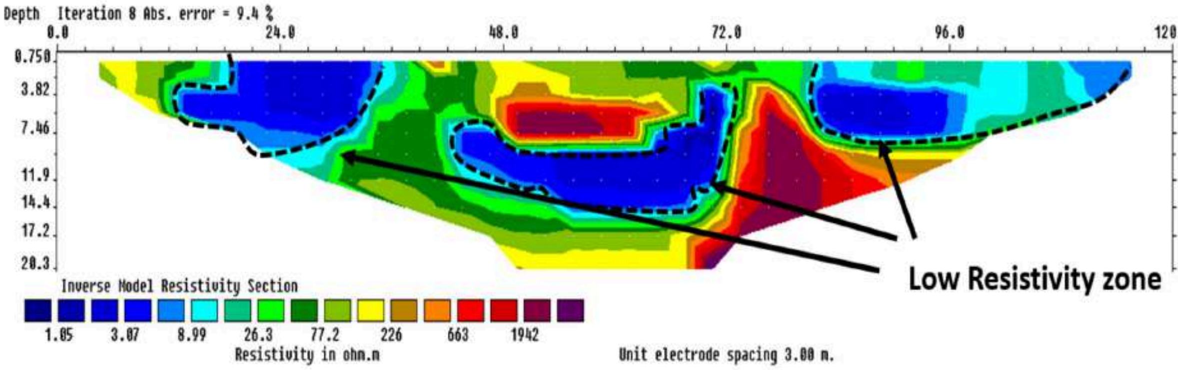


Figure 3.40: Inverted section of ME-23

ME-25 (**Figure 3.41**) was carried out parallel to the profile ME-24 and perpendicular the ME-1 to ME-10. The survey profile length of approximately 240 m, reaching a penetration depth of about 40 m. A Patch of industrial waste dump site (3-7 ohm-m) can be identified at depths up to 7 m and horizontal length from 198 m to 210 m.

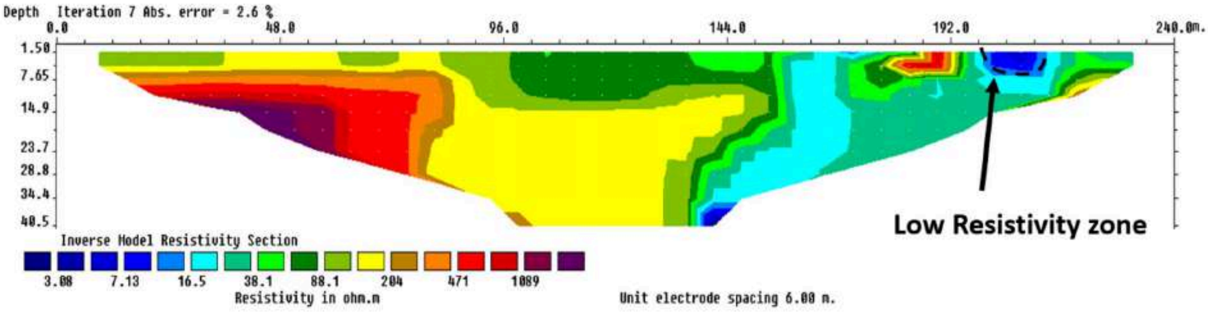


Figure 3.41: Inverted section of ME-25

3.3.1.3 Summary of the inferences from the ERT findings

The use of Geophysical tools in the characterization of contaminated soil and groundwater is attested by numerous papers. In the present work, the Electrical Resistivity Tomography has been used to look for the low anomaly resistivity zones which can be associated with the percolation of the effluent disposed in the Solar

Evaporation Ponds in the premises. As the effluent in the Solar Evaporation Pond had very large TDS (28762-53142 mg/L),it is expected that any leaching of the effluent from the Solar Evaporation pond will lead to conductivity anomalous zones impacted by it. The probable location of the Solar Evaporation Ponds was assumed on the basis of the PPCB old record (**Annexure-I**) and the google images presented in the TCIRD report (2009). The site map was not geo referenced and hence it was not possible to get any georeferenced location of the Solar Evaporation Pond and the Hazardous waste storage shed.

Accordingly, the Electrical Resistivity Tomography was performed at the probable locations of the Solar Evaporation Ponds (A & B) and the Hazardous Storage site as can be deciphered from the PPCB records (**Annexure-I**). The map (Not to scale) and the images from Google Earth formed the basis of designing the laying of the ERT profiles. As expected, low resistivity anomalous zones were observed prominently in the ERT profiles (**Figures 3.17-3.28**) which traversed the Solar Evaporation Pond (A). Similar picture was noted in the ERT profiles (**Figures 3.29-3.38 and Figure 3.40**) which travered the Solar Evaporation Pond (B) or was close to it. It is also to be noted that profile ME11, which was thought to be outside the probable area of the Solar evaporation pond has also anomalous resistivity zones **(Figure 3.27)** like the profiles which traversed the Solar Evaporation Pond (A). It is to mention that the site was levelled and many structures were dismantled by the owner of the Industry. In the process of the levelling of the area, it is also likely that the waste lying inside the Solar Evaporation Pond has also spread to some extent.

Based on the low resistivity anomalous zones observed in the ERT profiles, targetted soil sampling was done at the site during April (28-30, 2024) using mechanical digger and excavator (Make: JCB). During the time of targetted sampling, it was observed that the coloured fluid was present in the Solar Evaporatoin Ponds (A & B) from 0.5m to 2.8m. The fluid collected from the site had very high TDS (approx 70,000 mg/L). The low resistivity anomalies (2-15 ohm-m) observed in the ERT profiles in the top 3-4 m can be linked to the impact of this coloured fluid on the resistivity signature. The drilling by JCB at the SEP indicated the presence of Sheet overlying the brick work surface. However, the drilling was restricted to only three places.   Vertical seepage from the SEP in the event of cracks in the Liner sheet can not be ruled out. In view of the low resistivity signature observed below 4m at the site of SEP, contamination below 4m can not be ruled out. The infiltration during every monsoon will trigger the seepage and eventually contaminating the region.

3.3.2 Ground Penetrating Radar (GPR) Survey

GPR is a subsurface investigation tool that uses pulses of *radio-wave* energy (electromagnetic energy in the MHz region) to image buried features such as pipes, building foundations, land mines, geological layers or even dead bodies. The huge advantage is that it allows the operator to pinpoint the location of buried target without disturbing the ground. It is very good at imaging shallow buried targets (<20m) and works well in complex environments.

GPR provides images of the subsurface by using the electromagnetic spectrum (EMS) in the microwave range between 10 MHz and 2.6 GHz. It uses energy waves in the microwave band, ranging in frequency from 1 to 1000 MHz. GPR primarily has two main components, – a transmitter and a receiving antenna. The transmitter sends electromagnetic energy into the soil and other material. Ground Penetrating Radar works by emitting a pulse into the ground and recording the echoes that result from subsurface objects. GPR imaging devices also detect variation in the composition of the ground material. If the electromagnetic impulse hits an object, the density of the object reflects, refracts, and scatters the signal. The receiver detects the returning signals and records variations within them. The system has software that translates these signals into images of the objects in the subsurface. GPR is one of the most modern subsurface imaging techniques and has only been a commonplace survey method since the mid-1980s. Of late, it is being used as an effective tool in Environmental Due Diligence studies. Advances in computing power and digital electronics were the key technological driving force for the development of GPR in the 1990s. It is now, arguably, the most versatile and widely used near-surface geophysical imaging tool.

A GPR system sends a pulse of radiating electromagnetic energy into the ground from a *transmitting antenna* at, or just above, the surface. The energy propagates through the sub- surface until it encounters a change in material properties – i.e., the target (a pipe, wall, land mine, geological layer, etc). The energy then bounces off the target (referred to *scattered* or *reflected* signals) and returns back to the surface where it is captured by a *receiving antenna* and recorded in time as a voltage signal, or *trace*. This trace is then displayed on a computer screen and the process repeated at regular intervals along the survey line. This builds up a cross-sectional image of the sub-surface's response in the form of a GPR section (or radargram) that looks a bit like a slice through the ground. The targets can then be visually identified by the nature of their features in the GPR section.

A typical GPR section (**Figure 3.42**) has distance along the top and *two-way travel time* down the side (i.e., the time it takes for the signal to travel down to the target features and back up to the receiver). At each position in the survey, the recorded trace is displayed as a coloured or grey-scale strip of pixels with the whole section being built up from each of these traces. If the *velocity* of the GPR wave through the sub-surface is known, then the depth can be calculated. Layers show up as coloured or black-white-black (or white-black-white) lines (called reflections) and isolated 'blocky' or smaller-scaled features (such as pipes, foundations, etc) produce curved, hyperbolic-shaped features (called diffraction hyperbolae). The GPR section is made up of the traces collected at each incremental point in the section line.

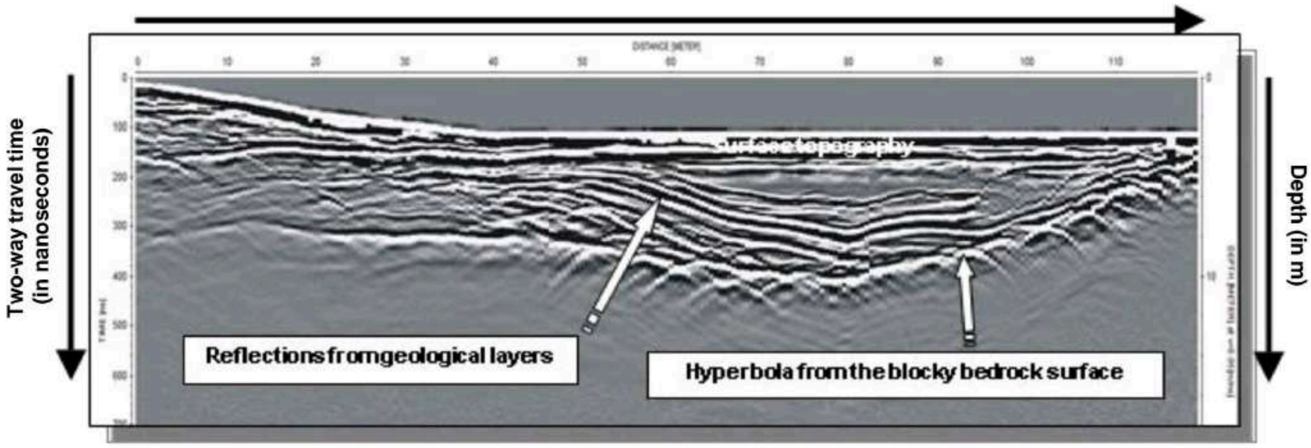


Figure 3.42: Typical GPR profile (Source: GPR 2008 workshop notes)

Instrumentation: In the present study, GSSI-SIR 3000 system has been used for GPR scanning. As the target of the survey was the top 4-8m, 200 MHz. antenna has been used. The data has been collected in the distance mode.

Design of GPR survey: GPR scanning has been done in the distance mode. The GPR profiles are taken in the probable locations of the SEP and HWSS (**Figure 3.43**). The post-processing is done on the RADAN (7.0) software by applying the Time-zero corrections, Back ground removal and applying suitable Gain. GPR profiles have been collected during the period March 29-April 2, 2024. The goal was to look for presence of any buried drums in the probable location of the HWSS/base of the storage area.

Figure 3.43: GPR scanning at the HWSS

GPR scanning in distance mode has been carried out at different locations covering the probable Solar Evaporation Pond area and the Hazarodus Waste Storage Side area (**Figure 3.44**).

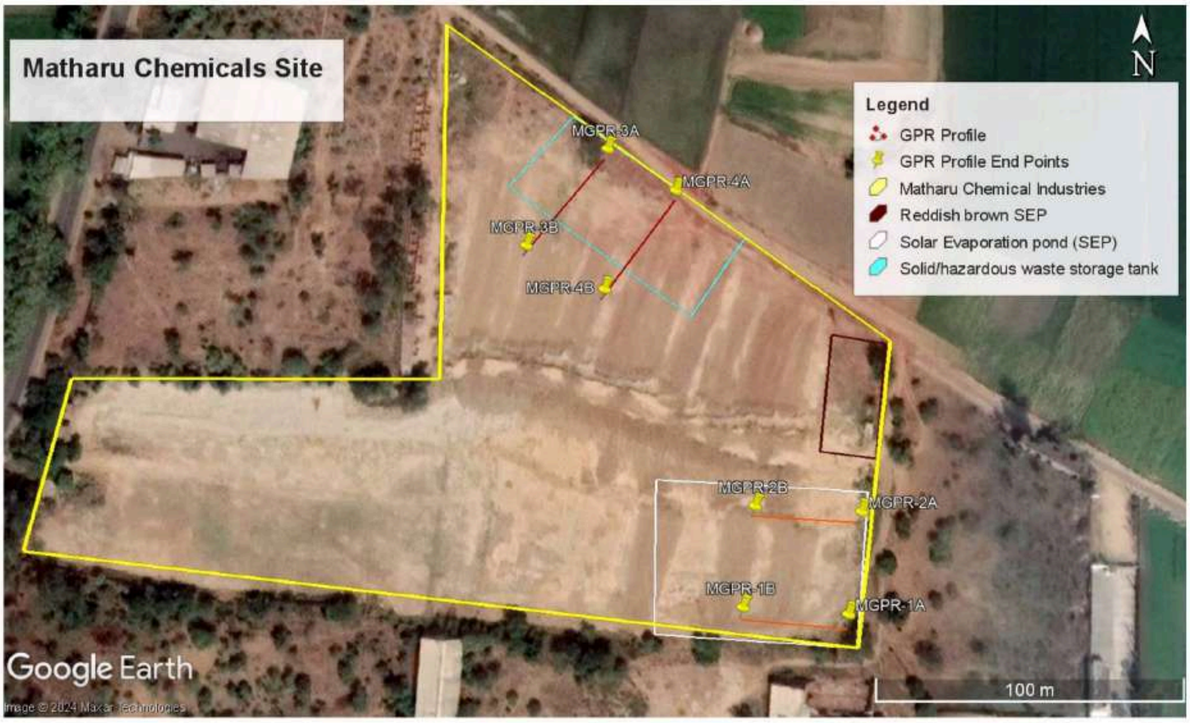
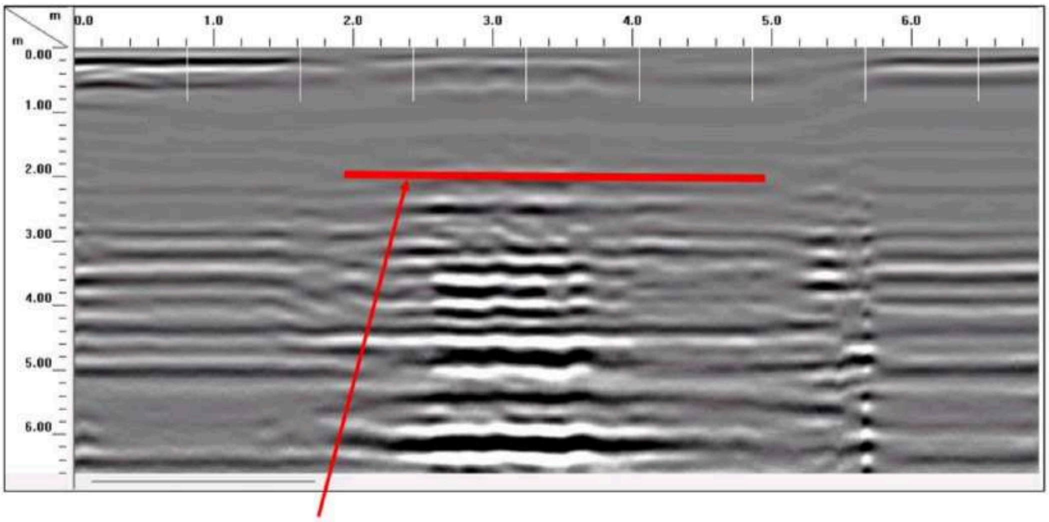


Figure 3.44: GPR profiles in the study area

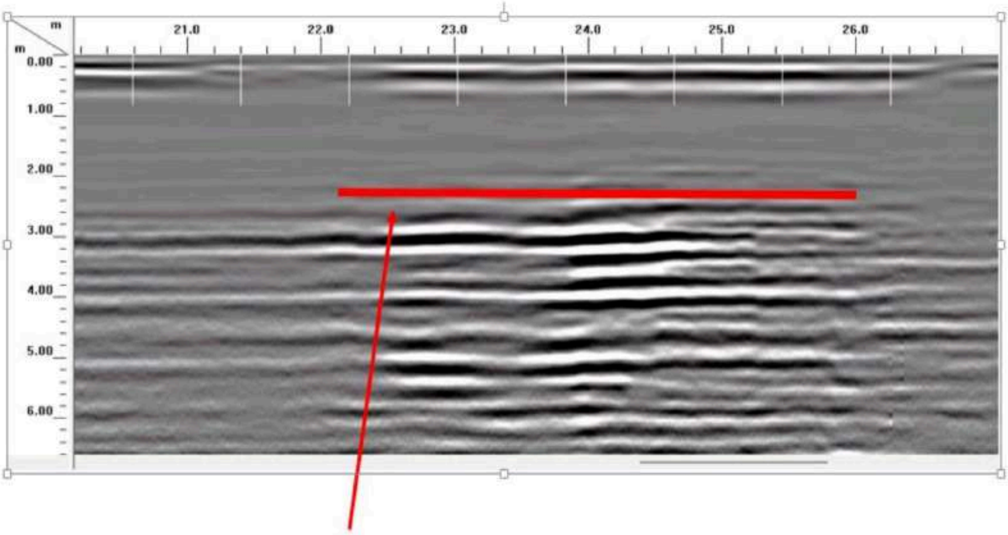
3.3.2.1 GPR Scanning at the SEP

The GPR scans indicate a major reflection at a depth of approximately 2.2m depth (**Figures 3.45-3.46**) at the SEP. Upto 2m, no major reflection could be observed. The loss of any major reflection upto depth of 2m suggests any homoheneous medium/conductive medium.



This is likely to be the depth of Bricks Surface/concrete
At Solar Evaporation pond

Figure 3.45: GPR survey (Profile MGPR1 at SEP A)

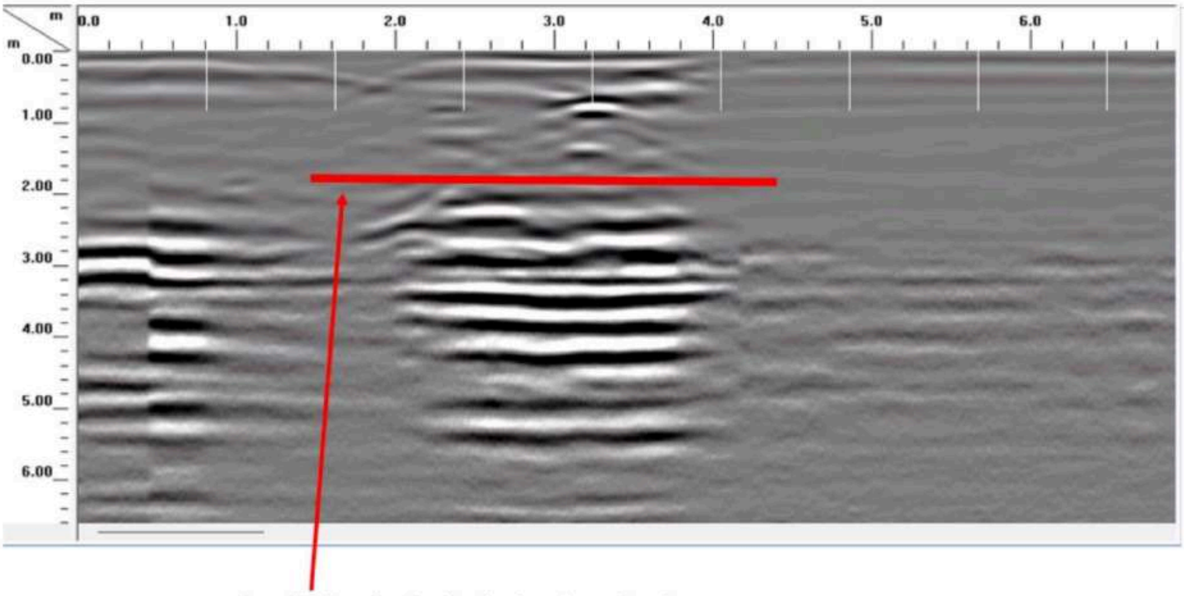


This is likely to be the depth of Bricks Surface/concrete
At Solar Evaporation pond

Figure 3.46: GPR survey (Profile MGPR 2 at SEP-A)

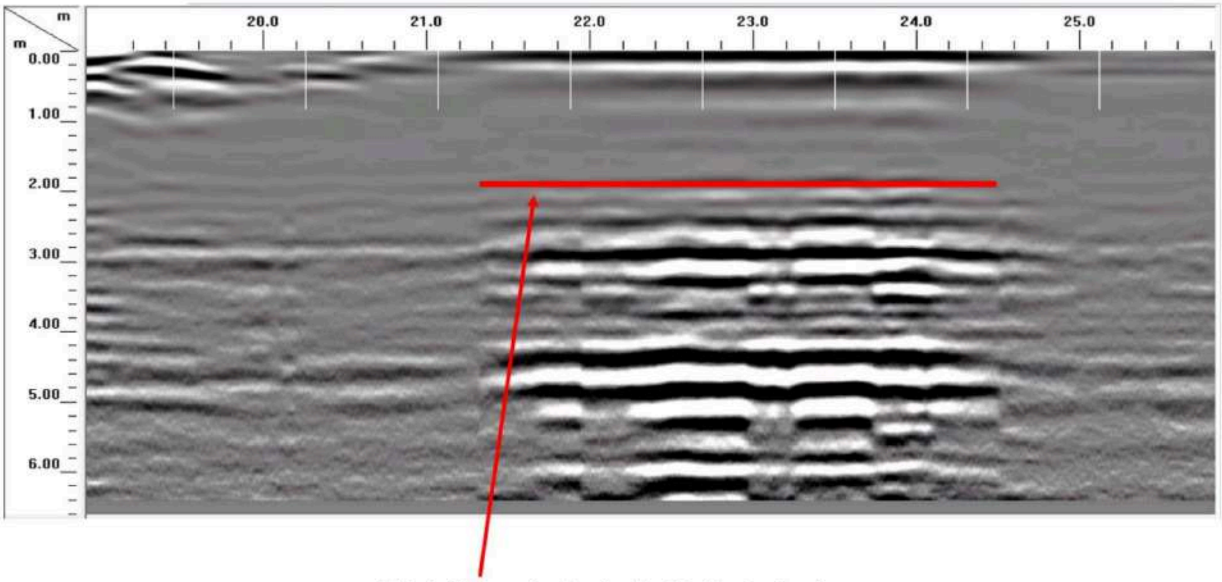
3.3.2.2 GPR scanning at the HWSS

Similar observations are also on other profiles collected at HWSS (**Figures 3.47-3.48**) It is likely that the strong reflection is due to the brick surface at the bottom of the SEP/HWSS.



This is likely to be the depth of Bricks Surface/concrete
At storage Hazardous site

Figure 3.47: GPR survey (Profile MGPR 3 at HWSS)



This is likely to be the depth of Bricks Surface/concrete
At storage Hazardous site

Figure 3.48: GPR survey (Profile MGPR 4 at HWSS)

3.3.2.3 Inferences from the GPR Scanning

The GPR scans do not indicate any major hyperbola in the radargram which can be attributed to presence of buried drums/storage drums at the site. However, the major reflection at 2-2.2m depth can be attributed to the presence of any surface at that depth which is giving reflection. This is also supported during the soil sampling by JCB when the brick surface was encountered at the similar depth at the probable HWSS and SEP sites.

3.4 Soil Sampling

Soil samples have been collected from the study area for analysis (**Table 3.14**). The 1st phase (September 2023) of preliminary sampling (**Table 3.14, Figures 3.49-3.50**) involved collecting the samples close to the contaminated wells, in-side the premises of M/S Matharu Chemical Industries (site of probable Solar Evaporation Pond and Hazardous storage shed). ***Sample (1 no.-MS-14) was collected from the soil which was lying scattered at the site, and which was removed from the site to facilitate the ERT measurements.*** The samples were taken from a 1m x 1m x 1m trench at depths of 30cm, 60cm, and 90cm. To ensure safe laboratory transportation, the samples were packed in airtight sampling bags weighing 1kg each. The samples have been analyzed for various parameters such as pH, EC, Fluoride, Organic Carbon, exchangeable cations, Soil moisture, and heavy metals **(Table 3.15).** The soil sampling was done as per the well-established protocol (Description and Sampling of Contaminated Soils: A Field Guide) by the US EPA (EPA/625/12-91/002).

Table 3.14: Soil sampling Location details

Sr.No	Sample Code	Depths	Latitude	Longitude	Date of sampling	Location
1	MS-1	30 cm (A)	30°17'4"N	76°04'33.4"E	12/09/23	Bhawanigarh village at Mr.Dilbrang singh farm.
		60 cm (B)				
		90 cm (C)				
2	MS-2	30 cm (A)	30°16'54.5"N	76°04'40"E	12/09/23	Bhawanigarh village at Mr Amritpal Singh, paddy field farm
		60 cm (B)				
		90 cm (C)				
3	MS-3	30 cm (A)	30°16'57.1"N	76°04'41"E	12/09/23	Bhawanigarh village at Mr.Kulvinder Singh farm
		60 cm (B)				
		90 cm				

Sr.No	Sample Code	Depths	Latitude	Longitude	Date of sampling	Location
		(C)				
4	MS-4	30 cm (A)	30°17'0.8"N	76°04'48"E	13/09/23	Bhawanigarh village temporary settlement near Matharu chemical plant
		60 cm (B)				
		90 cm (C)				
		120 cm (D)				
5	MS-5	30 cm (A)	30°16'57"N	76°04'53.2"E	13/09/23	Bhawanigarh village, back side of Matharu chemical plant
		60 cm (B)				
		90 cm (C)				
6	MS-6	30 cm (A)	30°19'31"N	76°06'34"E	14/09/23	Ghanurki village, near N.S.Rice mill
		60 cm (B)				
		90 cm (C)				
7	MS-7	30 cm (A)	30°19'31"N	76°04'34"E	09/01/24	Solar Evaporation Pond-A
		60 cm (B)				
		90 cm (C)				
8	MS-8	30 cm (A)	30°16'55.39"N	76°04'52.36"E	09/01/24	Solar Evaporation Pond-B
		60 cm (B)				
		90 cm (C)				
9	MS-9	30 cm (A)	30°16'58.00"N	76°04'52.00"E	09/01/24	Hazardous waste storage shed
		60 cm				

Sr.No	Sample Code	Depths	Latitude	Longitude	Date of sampling	Location
		(B)				
		90 cm (C)				
10	MS-10	30 cm (A)	30°16'58.00"N	76°04'52.00"E	09/01/24	Hazardous waste storage shed
		60 cm (B)				
		90 cm (C)				
11	MS-11	5-10 cm	30°16'56.33"N	76°04'51.80"E	09/01/24	Soil mound 1(ME27)
12	MS-12	5-10 cm	30°16'56.69"N	76°04'50.19"E	09/01/24	Soil mound 2(ME28)
13	MS-13	5-10 cm	30°16'57.25"N	76°04'48.61"E	09/01/24	Soil mound 3(ME29)
14	MS-14	5-10 cm	30°16'17.02"N	76°05'5.44"E	09/01/24	Soil Dump which was lifted from the site by PPCB

Table 3.15: Methodology for analysis of soil physico-chemical characteristics

Parameters	Methodology	Reference
pH and Electrical conductivity	pH and Conductivity meter	Jackson, 1973
Organic carbon	Potassium dichromate oxidation method	Walkley and Black method (1965)
Exchangeable cations (Na, K, Ca and Mg)	Exchangeable calcium and magnesium by versenate method in the ammonium acetate and sodium chloride extract of soil &Flame photometer (Systronic mediflame 127) used to determine the sodium and potassium in ammonium acetate leachate (Jackson, 1973).	(Jackson,1973 and Piper,1966)
Heavy metals (Al, Cr, Mn, Fe, Ni, Cu, Zn & As)	ICP-OES	EPA 3050B method for heavy metal analysis.
Soil Moisture	Weighing balance	.Manual of Soil testing in India, Department of Agriculture & Cooperation Ministry of Agriculture Government of India, Jan 2011.
Soil Texture	Stoke's Law	IS: 2720 (part 4) Hydrometer Method

Figure 3.49: Soil sampling locations in the 0.5 km buffer of the Industry (M/S Matharu Chemical Industry)

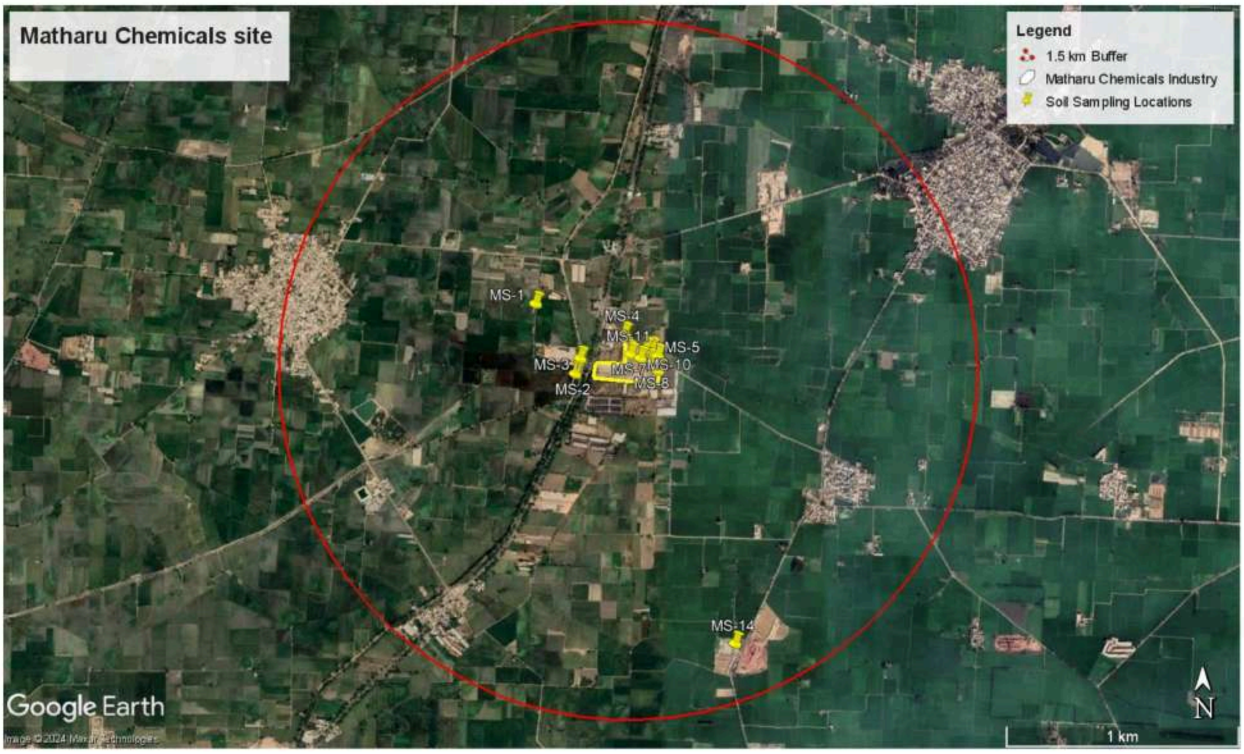


Figure 3.50: Soil sampling locations in the 0.5 km buffer of he Industry (M/S Matharu Chemical Industry)

Based on the inferences from the ERT and GPR survey performed at the site, a targeted soil sampling was done at the site (**Table 3.16, Figures 3.51-3.54**) during April 2024.

Table 3.16: Details of targeted Sampling at the site (April 2024)

Sr. No.	Sample Code	Latitude	Longitude	Depth (m)	Sampling Frequency	No. of samples	Location details	Observation
1	SS-1	30°16'53.00"N	76°5'1.18"E	1	1ft	3	Control site (Upstream of site)	Natural soil
2	SS-2	30°16'57.80"N	76° 4'50.50"E	3	1ft	9	Near hazard waste storage side (Area-II)	Top soil - 0-0.4m Liner sheet, Contaminated (Black colour Solid & Liquid) - 0.4-1.7m Brick layer-1.7-1.9m Below 1.9m natural soil present
3	SS-3	30°16'59.06"N	76°4'51.23"E	3	1ft	9	Hazard waste storage side (Area-II)	Top soil - 0-0.2m HWS red colour sludge-0.2-1.7m Brick layer-1.7-1.9m Below 1.9m natural soil present
4	SS-4	30°16'55.94"N	76° 4'52.35"E	3	1ft	9	Solar evaporation pond	Top soil - 0-0.4m Liner sheet Contaminated (black colour solid & liquid) - 0.4-2.6m Brick layer - 2.6-2.8 m Liner sheet Below 2.8 m Natural soil present
5	SS-5	30°16'55.55"N	76° 4'52.99"E	3	1ft	9	Solar evaporation	Top soil (0-0.4m) Liner sheet

Sr. No.	Sample Code	Latitude	Longitude	Depth (m)	Sampling Frequency	No. of samples	Location details	Observation
							pond	Contaminated (Black colour solid) - 0.4-1.8 m Below 1.8 m Natural soil present
6	SS-6	30°16'54.98"N	76° 4'52.37"E	3	1ft	9	Solar evaporation pond	Top soil - 0-0.4m Liner sheet Contaminated (black colour solid & liquid) - 0.4-2.6m Brick layer - 2.6-2.8 m MG-3, MG-4, MG-5, MG-6, MG-8 Liner sheet Below 2.8 m Natural soil present
7	SS-7	30°16'55.82"N	76° 4'44.41"E	3	1m	3	Near front gate Matharu chemical	Natural soil (No contamination)
8	SS-8	30°16'56.76"N	76° 4'40.81"E	1	1ft	3	Near MG-3, Kulvinder singh farm	Natural soil (No Contamination)
9	SS-9	30°16'59.16"N	76° 4'27.12"E	1	1ft	3	Backside of rice mill, downstream side of MG5.	Natural soil (No Contamination)
10	SS-10	30°16'55.68"N	76° 4'50.6"E	3	1m,2m	2	Wheat field	Top soil- 0-0.4m Contaminated black colour soil- 0.4-1.2m Below 1.2m natural soil present
11	SS-11	30°16'55.71"N	76° 4'51.53"E	3	1.8m,3m	2	Wheat field (Solar evaporation	Top soil (0.40m) Contaminated soil (0.4-2.9m) Brick layer (2.9-3m)

Sr. No.	Sample Code	Latitude	Longitude	Depth (m)	Sampling Frequency	No. of samples	Location details	Observation
							pond)	Below 3m natural soil present
12	SS-12	30°16'55.08"N	76° 4'50.04"E	3	1m,2m	2	Wheat field	Top soil- 0-0.4m Contaminated black colour soil- 0.4-1.7m Below 1.7m natural soil present

Figure 3.51: Targeted soil sampling (April 2024)

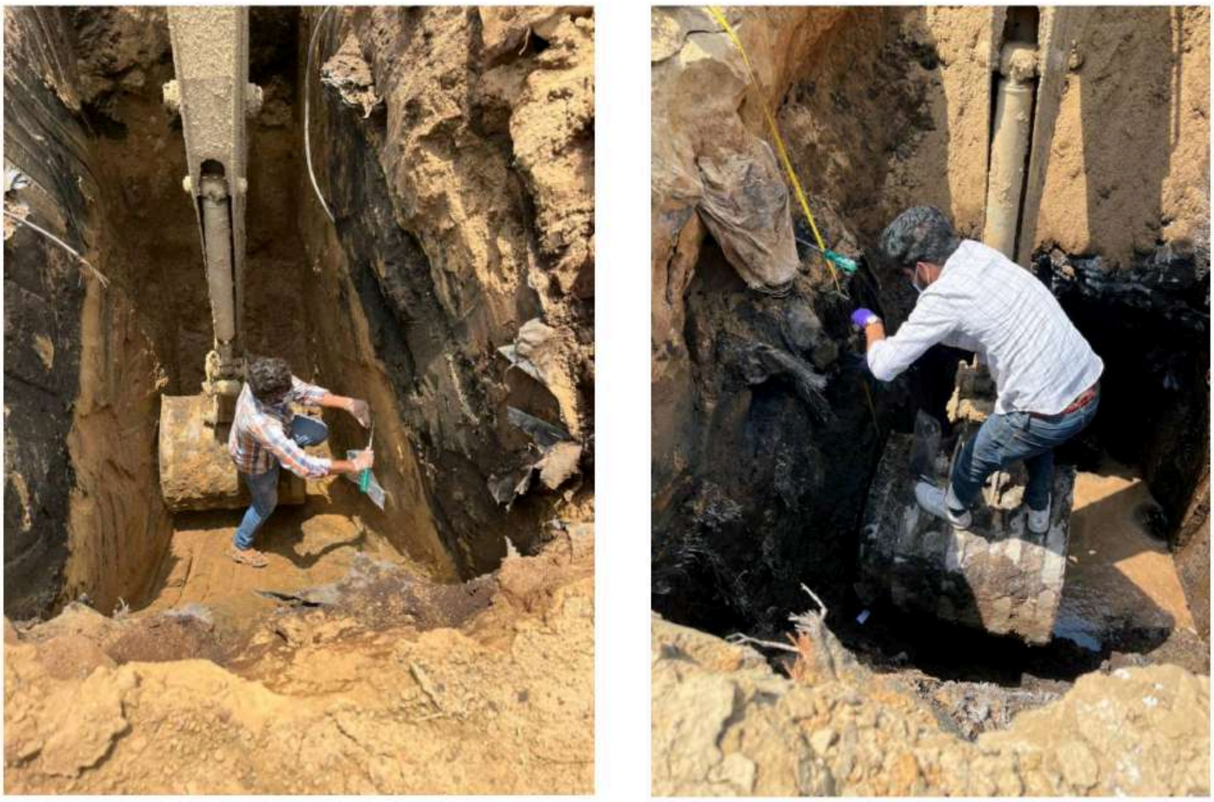


Figure 3.52: Soil sampling at the SEP (April, 2024)

Figure 3.53: Soil sampling at the HWSS (April 2024)

Figure 3.54: Soil sampling at SS-2 near HWSS

3.4.1 Physico-chemical findings

The range of physico-chemical parameters (Table 3.17a) of soil samples detected were pH (7.4 (MS-4A) - 9.0 (MS-6A)), Fluoride (0.061 mg/kg (MS-4A) - 2.7 mg/kg (MS 12)), Sodium ((0.02 gm/kg (MS 11) - 132.5 gm/kg (MS 10C)), Potassium ((0.06 gm/kg (MS-4C & MS 3C) - 0.64 gm/kg (MS-1B), Calcium ((0.02 gm/kg (MS 9C) - 2.1 mg/kg (MS-4C)), Magnesium ((0.01 gm/kg (MS 8A, MS 8C, MS 10B) - 0.14 mg/kg (MS-3A & MS-4D)), Organic Carbon ((0.1% (MS 8A) - 1.26% (MS-3A)) & Moisture content (0.56% (MS 13) - 23.59% (MS-5A)) **(Table 3.17 (a) & (b))** respectively. The majority of samples **(Table 3.17 (b))** had a soil texture of sandy loam followed by sandy clay loam, silt loam, loamy sand, loam and clay. **Samples, namely MS-9 And MS-10 collected from the Hazardous Waste Storage shed had elevated Sodium concentration. Samples, MS-7 and MS-8 collected from the Solar Evaporation Pond have also elevated concentration of Sodium. The sodium concentration in MS-14 (lifted from the site by the PPCB) is not in the same range as that of samples collected from the SEP.**

Table 3.17 (a): Soil Physico-chemical Parameters

Sr No.	Samples	Parameters							
		pH	Flouride (mg/kg)	Exchangeable cations (gm/kg)				Total Organic Carbon (%)	Moisture Content (%)
				Na^+	K^+	Ca^+	Mg^+		
1	MS-1A	8.4	1.6	0.21	0.53	0.18	0.08	1.19	14.19
2	MS-1B	8.1	1.9	0.35	0.64	0.55	0.08	1.10	13.60
3	MS-1C	7.5	1.7	0.30	0.56	0.53	0.08	1.20	18.47
4	MS-2A	7.8	0.6	0.47	0.15	0.43	0.03	1.11	12.62
5	MS-2B	7.9	0.62	0.43	0.14	0.38	0.07	1.08	16.28
6	MS-2C	7.9	0.61	0.24	0.15	0.46	0.04	1.19	16.76
7	MS-3A	8.0	1.6	0.37	0.24	0.27	0.14	1.26	15.26
8	MS-3B	8.1	1.6	0.37	0.18	0.27	0.10	1.14	14.58
9	MS-3C	8.1	0.87	0.33	0.15	0.28	0.08	1.19	14.14
10	MS-4A	7.4	0.061	0.25	0.16	2.05	0.22	1.08	15.50
11	MS-4B	7.7	0.07	0.19	0.09	2.06	0.08	1.07	21.73
12	MS-4C	7.6	0.082	0.18	0.06	2.10	0.07	1.05	18.36
13	MS-4D	7.7	0.11	0.15	0.08	2.06	0.14	1.25	6.78
14	MS-5A	8.4	0.21	0.24	0.19	0.21	0.04	0.84	23.59
15	MS-5B	8.4	0.43	0.17	0.21	0.10	0.04	1.13	14.52
16	MS-5C	8.3	0.38	0.15	0.19	0.10	0.03	1.23	14.51
17	MS-6A (CONTROL)	8.4	0.83	0.44	0.21	0.53	0.06	0.99	16.11
18	MS-6B (CONTROL)	9.0	1.2	0.82	0.36	0.53	0.06	1.05	14.00
19	MS-6C (CONTROL)	8.7	1.3	0.54	0.37	0.60	0.07	1.16	15.82

Table 3.17 (b): Soil Physico-chemical Parameters

Sr No.	Samples	Parameters								
		pH	Flouride (mg/kg)	Exchangeable cations(gm /kg)				Total Organic Carbon (%)	Moisture Content (%)	Soil Texture
				Na⁺	K⁺	Ca⁺	Mg⁺			
1	MS 7A	8.4	0.78	9.4	0.16	0.08	0.03	0.3	4.14	Sandy loam
2	MS 7B	8.7	1.1	20.1	0.16	0.08	0.03	0.5	12.24	Sandy clay loam
3	MS 7C	8.5	1.2	21.7	0.17	0.16	0.02	1.1	16.70	Sandy clay loam
4	MS 8A	8.1	1.7	12.3	0.08	0.03	0.01	0.1	5.24	Sandy clay loam
5	MS 8B	8.2	1.2	16.3	0.07	0.17	0.02	0.4	12.34	Sandy loam
6	MS 8C	8.5	1.8	19.4	0.14	0.15	0.01	0.4	16.06	Sandy clay loam
7	MS 9A	8.4	0.54	0.28	0.2	0.06	0.02	0.4	4.13	Loamy sand
8	MS 9B	8.7	0.62	0.19	0.19	0.06	0.07	0.3	5.62	Sandy loam
9	MS 9C	8.8	0.98	0.16	0.06	0.02	0.02	0.3	9.45	Sandy loam
10	MS 10A	8.4	0.4	0.99	0.3	0.03	0.02	0.4	9.13	Sandy loam
11	MS 10B	8.4	1.1	7.24	0.23	0.12	0.01	0.2	11.80	Sandy loam
12	MS 10C	8.8	2	132.5	0.17	0.08	0.03	1.0	20.61	Clay
13	MS 11	8.1	1.3	0.02	0.12	0.05	0.02	0.3	1.30	Sandy clay loam
14	MS 12	8.6	2.7	0.51	0.23	0.10	0.03	0.4	2.43	Silt loam
15	MS 13	8.4	1.7	0.22	0.12	0.08	0.03	0.2	0.56	Loam
16	MS 14	8.3	1.1	0.45	0.15	0.08	0.02	0.5	2.81	Silt loam

3.4.2 Soil Trace element concentration (September 2023)

Soil samples from the study area were analyzed (**Table 3.18**) using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The analysis revealed a wide range of concentrations for various elements. Aluminium content varied notably, ranging from 578.2 mg/kg (MS 4B) to 12429 mg/kg (MS 12). The concentration of iron exhibited a range from 613.8 mg/kg (MS 4B) to 12767.4 mg/kg (MS 10C). Similarly, chromium levels were observed to fluctuate between 4.0 mg/kg (MS 5A) to 151.5 mg/kg (MS 9B), while manganese concentrations ranged from 14.3 mg/kg (MS 4C) to 355.9 mg/kg (MS 10C). Lead concentrations were within a range of 3.2 mg/kg (MS 4A) to 405.8 mg/kg (MS 11), while nickel concentrations varied between 0.3 mg/kg (MS 4B) to 405.8 mg/kg (MS 11). Copper content ranged from 1.2 mg/kg (MS 4B) to 41.3 mg/kg (MS 9B) and zinc concentrations showed a range from 7.4 mg/kg (MS 4B) to 118 mg/kg (MS 11).

Table 3.18: Soil Trace metals concentration

Sr. No	Sample code	Fe	Mn	Pb	Zn	As	Cd	Ni	Co	Al	B	Cr	Cu	Se
ICP detection Limit (ppm)		0.0004	0.0002	0.0001	0.0003	0.0004	0.0001	0.001	0.001	0.0001	0.0002	0.003	0.001	0.0004
mg/kg														
1	MS-1A	7136.1	137.4	3.5	21.8	2.6	BDL	7.9	3.3	6598.3	8.4	12.8	5.5	63.7
2	MS-1B	10544.1	192.0	4.7	36.4	3.5	BDL	13.7	4.7	11203.5	13.3	17.8	7.7	91.8
3	MS-1C	10885.7	182.3	8.9	42.7	3.6	BDL	13.7	4.8	10513.3	13.5	19.2	18.5	160.5
4	MS-2A	8962.5	177.1	122.1	37.3	2.5	6.3	5.0	3.9	9518.9	141.5	15.2	5.9	92.3
5	MS-2B	8709.3	174.1	5.2	23.4	2.5	BDL	9.3	3.8	8970.9	9.9	13.9	5.6	70.4
6	MS-2C	8931.1	173.1	4.5	28.2	2.5	BDL	9.9	3.9	8796.2	9.7	13.4	6.5	80.5
7	MS-3A	6286.2	127.7	10.7	23.1	1.7	0.3	6.5	2.8	6221.1	8.9	9.7	5.7	64.5
8	MS-3B	3683.4	149.5	30.0	34.4	1.9	0.5	8.6	3.3	4035.3	37.0	12.6	2.9	46.9
9	MS-3C	8315.7	168.1	13.1	27.0	2.7	0.1	7.6	4.9	8121.9	12.6	13.5	6.7	67.5
10	MS-4A	2693.9	55.2	3.2	14.2	0.5	BDL	1.5	1.3	2465.3	5.3	6.8	4.9	42.1
11	MS-4B	613.8	26.9	101.1	7.4	0.2	4.6	0.3	0.7	578.2	48.5	5.9	1.2	9.6
12	MS-4C	1362.0	14.3	10.8	10.8	0.1	0.3	1.5	0.4	1410.2	10.6	5.4	2.3	24.3
13	MS-4D	2759.1	29.2	6.1	10.9	0.5	0.1	1.8	0.9	2391.4	4.9	4.8	2.5	35.8
14	MS-5A	1483.4	34.6	23.9	16.6	0.4	0.2	0.5	4.1	1953.3	4.2	4.0	2.1	49.7
15	MS-5B	2992.6	54.1	12.2	14.6	0.9	BDL	2.5	1.7	3159.3	4.8	6.9	2.1	36.6
16	MS-5C	3403.6	70.0	242.9	24.1	0.9	9.5	3.5	1.9	3411.7	48.4	7.5	2.7	39.2
17	MS-6A (CONTROL)	5290.1	92.1	21.3	24.2	1.2	1.1	4.2	2.3	5350.9	20.7	9.0	4.9	120.5
18	MS-6B (CONTROL)	6155.0	109.6	8.2	23.1	1.7	0.1	9.4	2.8	5904.2	16.7	9.9	5.7	63.4
19	MS-6C (CONTROL)	7080.6	136.1	17.3	28.4	1.9	0.2	4.8	3.2	6980.4	12.0	11.2	5.6	80.5
20	MS 7A	4443.1	97.1	7.0	26.2	BDL	0.2	6.1	2.0	2918.1	7.6	7.5	4.9	BDL

Sr. No	Sample code	Fe	Mn	Pb	Zn	As	Cd	Ni	Co	Al	B	Cr	Cu	Se
ICP detection Limit (ppm)		0.0004	0.0002	0.0001	0.0003	0.0004	0.0001	0.001	0.001	0.0001	0.0002	0.003	0.001	0.0004
21	MS 7B	6876.8	152.0	5.0	33.5	BDL	ND	11.6	2.6	4282.5	12.6	13.8	9.8	BDL
22	MS 7C	7894.8	168.1	196.6	77.7	BDL	3.4	15.8	25.9	4224.5	27.5	20.1	10.5	BDL
23	MS 8A	6965.2	114.0	7.5	29.4	BDL	0.2	8.3	2.3	4583.5	15.0	13.7	8.7	BDL
24	MS 8B	4580.7	115.8	5.2	24.5	BDL	0.6	8.3	1.7	2973.3	62.9	11.3	11.7	BDL
25	MS 8C	6196.8	146.0	12.1	33.5	BDL	0.6	12.4	3.1	4945.9	108.5	16.2	13.2	BDL
26	MS 9A	8639.7	162.7	8.0	39.9	BDL	0.1	13.2	3.8	6221.2	15.9	37.4	16.6	BDL
27	MS 9B	10540.6	194.4	35.6	38.5	BDL	1.1	17.2	3.7	4238.7	24.1	151.5	41.3	BDL
28	MS 9C	8414.1	218.7	8.2	36.8	BDL	0.1	12.4	4.4	7153.0	16.8	56.5	11.4	BDL
29	MS 10A	4203.9	126.0	26.2	25.7	BDL	0.6	5.8	2.0	3479.1	10.5	12.2	4.9	BDL
30	MS 10B	11326.5	259.1	9.8	36.4	BDL	0.1	11.2	3.7	6435.4	27.4	26.1	7.7	BDL
31	MS 10C	12767.4	355.9	7.1	48.7	BDL	ND	9.3	2.5	2706.8	39.5	38.9	7.2	BDL
32	MS 11	9111.3	277.8	405.8	118.0	BDL	7.6	20.4	41.5	10766.5	42.3	34.2	6.7	BDL
33	MS 12	9861.7	282.2	14.6	63.8	BDL	0.3	23.0	7.5	12429.0	28.9	30.2	9.5	BDL
34	MS 13	9164.5	275.1	34.3	49.6	BDL	0.8	19.5	7.2	10855.3	24.0	26.8	7.2	BDL
35	MS 14	8213.2	227.2	11.8	48.8	BDL	0.2	16.6	5.8	8960.7	20.3	21.5	5.7	BDL

BDL= Below Detection Level

ND= Not Detected

It is observed that iron was found more in the **probable area of the HWSS (MS 9 & MS 10). The iron concentration in MS-14 (soil lifted from the site by PPCB (MS 14) is not matching with the concentration in samples collected from HWSS.**

Targetted soil sampling :

The targetted soil sampling **(Table 3.16)** was done at points within the probable locations of the SEP and HWSS and control points.

Inside the probable locations of the SEP: Soil sampling was done upto approximately 3m depth in the probable location of the SEP. It was observed (Figure 3.52) that upto 40cm, one observed soil. However, below 40cm, black effluent of fluid type was present which conntinued upto approximately 2.8m to 3m. Below it, some kind of liner sheet was present which was overlying brick surface, which formed the base of the SEP. The digging was done for 1m below the base of the SEP. Natural soil was found below it. .

Inside the probable locations of HZSS: Soil sampling (SS-3) was also done at the probable location of the HWSS. It was observed **(Figure 3.53)** that upto 20cm. one observed hard soil which had reddish colour. Below 20cm, red colour sludge was present which continued upto approximately 1.8m to 2m. Below it, some kind of liner sheet was present, which was followed by brick surface which formed the base of HWSS. The digging was continued below the base of the HWSS and natural soil was found below it.

Soil sampling was performed at SS-2 **(Figure 3.54),** which had the same features as the sampling perfomed inside the probable locations of the Solar Evaporation Pond. As in the case of SS-4, SS-5 and SS-6, coloured fluid was obtained at depth 0.5 to 2.8m, which was followed by some kind of liner sheet and brick surface. Below the brick surface, natural soil was found. This indicated that the point was part of a SEP as well. This is also supported by the low resistivity anomalous zones, which were observed in the ERT profile, ME-22, which traversed very close to the point SS2.

Selected samples from the probable area SEP and control locations (SS1-SS9) were analysed for parameters like Na and SO4, which are linked to the waste generated from the plant operations. The results **(Table 3.17 a & b)** showed that the exchangeable sodium concentrations were much higher at locations SS-4, SS-5, and SS-6 when compared to the control site. Specifically, SS-4 had a concentration of 204 gm/kg, SS-5 had a concentration of 190.5 gm/kg and SS-6 had a concentration of 86 gm/kg. With respect to sulphate, all three locations in the solar evaporation pond (SS-4, SS-5 & SS-6) showed higher concentrations than the natural soil (SS-1).

3.5 Assessment of the Contaminated area due to the waste disposal at the premises of the Industries

Based on the detailed Hydrogeological studies (groundwater level measurement, Pumping test), groundwater analysis of the observation wells, Geophysical studies (Electrical Resistivity Tomography, Ground Penetrating Radar) and the soil sampling, the following inferences can be drawn on the soil and groundwater contamination in the study area.

i) The possible sources to the groundwater pollution are from the improper waste disposal practice at the Solar Evaporations Ponds and the Hazardous waste Storage shed.

ii) The soil sampling performed during September 2023 and December 2023 indicated the elevated concentration of Sodium in samples MS-7 and MS-8 collected at the probable locations of the SEP (A & B) with respect to other samples. Elevated concentration of iron is also observed in sample, MS-10 collected from the probable area of the Hazardous waste storage site.

iii) The Electrical Resistivity Tomography performd at the sites indicates very low resistivity anomalous zones going below 8-10m below the top surface at the region covered by the SEP (A) and SEP (B). Similar resistivity was also observed in ERT profile-ME 20 which did not cover SEP (A) and SEP (B). However, targetted sampling at SS2, close to ME-20 indicated the presence of black coloured soil with coloured fluid, which was also seen during the targetted sampling at SS4, SS5, SS6 and SS-11. Upto 3m, the coloured fluid was obtained and below that some liner sheet was seen, which was overlying the Brick surface which formed the base of the SEP. It is mostly that the contamination has spread outside the SEP due to overflow during the rain fall. The Geophysical measurements attest **contamination beyond the liner sheet, found at approximately 3m. The low resistivity anomalies below the liner sheet upto top 5-10m** can be attributed to contamination in the event of any crack in the liner sheet.

iv) Targetted soil sampling at SS-10 also indicated the presence of black colour material from 0.4 to 1.2 m depth.

v) Based on the inferences from the Electrical Resistivity Tomography and the results of the analysis of soil samples collected from the SEP, HWSS site and the targetted sampling upto 3m at the site, it is evident that sources of contamination like the black fluid (TDS> 70,000 mg/L) and remnants of iron sludge are still present at the site and contamination has spread beyond the SEP and HWSS. Contamination upto 3m depth can be established. Contamination below 3m is not ruled out in case of any cracks in the liner sheet. The contaminated area (CA) covers the probable SEP, HWSS and its vicinity as presented in Figure (3.55). As the contaminated source is at the site for an extended period since the plant was in operation, the gradual infiltration of the leachate and also triggered by the natural recharge during monsoon is adding to the contamination of the unsaturated zone as well as the aquifer.

vi) The hydrogeological investigations and the well development details indicate that the groundwater is being pumped from the deeper aquifer. The contaminated well, MG-3 (Total depth 300 ft) is pumping water at the depth of 250 ft. MG-4 and MG-6 are pumping water at the depth of 180 ft and 220 ft respectively. ***Based on the colour in the groundwater and the well details (slotting provided in the wells), it can be concluded that the groundwater contamination has reached the level of 300 ft below ground level at present. In the absence of any data wherein the pumping is done at a level more than 300 ft, the vertical extent of groundwater contamination beyond 300 ft can not be established at this stage, unless a deep well is drilled and pumping is done from the aquifer at a level more than 300 ft. It is most likely that the contamination of the groundwater at the deeper level (300 ft) is mostly on account of the deep well injection of the mother liquor/effluent.The effluent at the SEP was noticed during the soil sampling. Though some sheet was observed on the base (Brick surface) of the SEP, its integrity may be compromised in the long run as HDPE liner sheets were not in use those days. The contribution to groundwater contamination from the SEP is also possible.***

3.5.1 Delineating the extent of the contaminated Soil

Based on the ERT, GPR and the soil sampling, the soil contaminated is delineated **(Figure 3.55, Table 3.19).** Based on the proximity to the contaminated source (SEP, HWSS and vicinity to the SEP and HWSS), the contaminates zone is shown as three zones. **Zone-I** which is close to the SEP and was found to have dry sludge during the targeted sampling. **The depth from 0.5cm to 3m is considered as active source.**

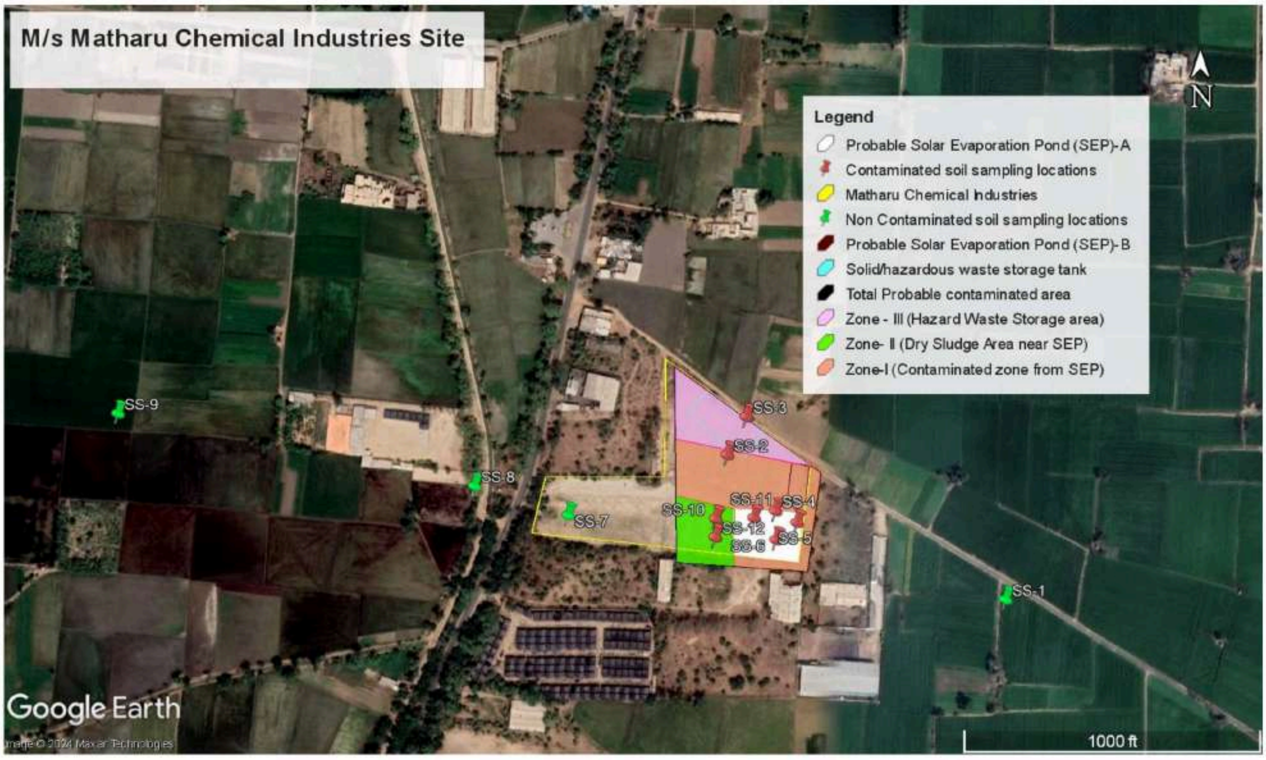


Figure 3.55: Delineation of soil contaminated area inside and close to M/s Matharu Chemical Industries

Table 3.19: Na^+ and SO^{2-}_{4} concentration in targeted samples from SEP

Sr. No.	Sample Code	Depth (feet)	Exchangeable Sodium (gm/kg)	Sulphate (gm/kg)
1	SS-1	1ft	0.2	1.2
		2ft	0.3	2.1
		3ft	0.3	3.0
2	SS-2	3ft	3.5	12.8
		6ft	4.3	19.8
		9ft	4.2	15.5
3	SS-4	3ft	31.5	52.2
		6ft	204	53.6
		9ft	53	76.6
4	SS-5	3ft	190.5	41.1
		6ft	5.8	22.0
		9ft	2.1	3.1
5	SS-6	3ft	86	69.8
		6ft	13	33.1
		9ft	17	37.2
6	SS-9	1ft	0.4	1.2
		1ft	0.1	2.4
		1ft	0.4	1.5
7	SS-11	5.9ft	5	18.3
		9ft	1.1	15.2

Zone-II covers the SEP and also adjoing areas, where targetetd sampling provided dark red fluid whih had high TDS (60,000 to 1,00,000 mg/L). The soil samples had very high Sodium and Sulphate. **The depth from 0.5cm to 3m is considered as active source.**

Zone-III covers the HZSS and area close to it. The targetted sampling indicated the presence of material where iron concentration was found to be high (Table 3.20) **. The depth from 0.5cm to 2m is considered as active source.**

The estimated volume of contaminated Soil is 48064 m^3.

Table 3.20: Details of the different soil contaminated zones

Zone	Zone corner coordinate		Area (Sq.m)	Thickness in meters	Volume in cubic meter
	Latitude	Longitude			
Zone-I (Contaminated zone from SEP). Extends vertically from 0.5m to 3m	A. 30°16'54.44"N B. 30°16'56.34"N C. 30°16'56.76"N D. 30°16'58.65"N E. 30°16'57.55"N F. 30°16'54.27"N	76° 4'50.85"E 76° 4'50.92"E 76° 4'48.66"E 76° 4'48.65"E 76° 4'54.21"E 76° 4'53.70"E	12570	2.5	31425
Zone- II (Dry Sludge Area near SEP). Extends vertically from 0.5m to 3m	A. 30°16'54.59"N B. 30°16'56.76"N C. 30°16'56.34"N D. 30°16'54.44"N	76° 4'48.72"E 76° 4'48.66"E 76° 4'50.92"E 76° 4'50.85"E	3595	2.5	8987.5
Zone - III (Hazard Waste Storage area). Extends vertically from 0.5m to 2m	A. 30°16'58.65"N B. 30°17'1.03"N C. 30°16'57.55"N	76° 4'48.65"E 76° 4'48.60"E 76° 4'54.21"E	5101	1.5	7651.5
Total volume					48064

3.5.2 Delineating the region with contaminated groundwater

The important parameters considered for the assessment of contamination of groundwater include the colour, TOC, COD, TDVS, TDS and sulphate. Out of all the collected sources, the samples from the 5 bore wells (MG-3, MG-4, MG-5, MG-6 and MG-8) show contamination in terms of the reddish-brown colour of the water samples. The colour data is supported by high COD, TOC and TDVS, high TDS and comparably high sulphate in these water sources during both seasons. MG-2 shows slight colour only during the initial 5-60 seconds of pumping.

The high colour, COD and TOC indicate the presence of soluble carbonaceous compounds which are of industrial origin. The high TDVS indicates the majority of organic contamination is volatile in nature at 550 ^{O}C. This indicates the wastewater from the H-Acid manufacturing process is being solubilised in the groundwater of these bore wells. The high TDS and sulphate in these samples indicate that in addition to the organic compounds inorganic salt discharge was also being contributed by the industry in the groundwater within the close vicinity of the industry.

Other than these 5 water sources, other water samples did not show any contamination in terms of colour and other physic-chemical parameters. Most of the water sources are associated with the water supply department used for the municipal water supply. All the water quality parameters for these water sources are within the acceptable/ permissible limits as per drinking water standard BIS-10500.

Based on the colour, COD, TOC, Phenolic compound, Total dissolved Volatile soilds (TDVS), the groundwater contamination zone is delineated. Keeping in mind the dynamic nature of the groundwater, 50m buffer is included around the contaminated wells. The SEP and HWSS continue to be hotspots as well as the near by zones which have been affected during the lavelling of land and the contamination is also evident during the sampling. They continue to be potential sources of groundwater contamination during the monsoon season. Accordingly, the contaminated region is delineated (**Figure 3.56,Table 3.21**).

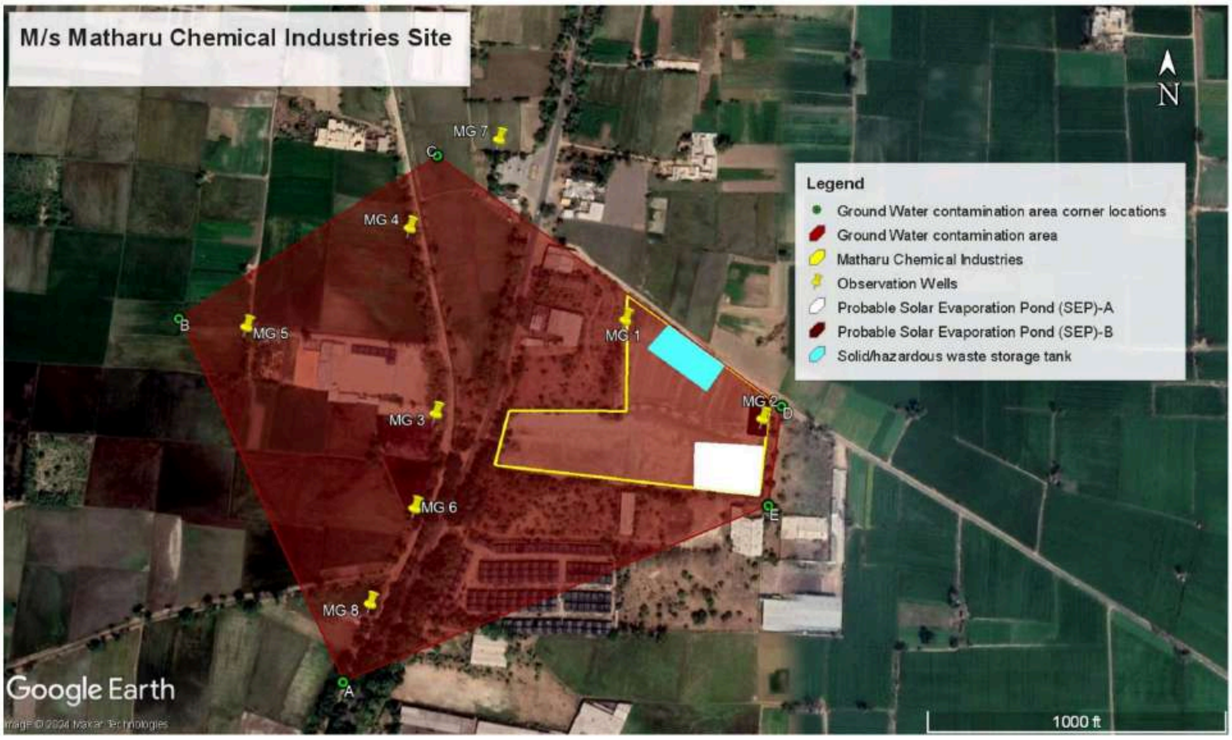


Figure 3.56: Delineation of groundwater contaminated zone

Table 3.21: Details of the Groundwater Contaminated Area Corner locations

Corner code	Corner coordinate		Area (Sq.m)
	Latitude	Longitude	
A	30° 16'48.51"N	76° 4'37.43"E	196211
B	30° 17'0.53"N	76° 4'30.75"E	
C	30° 17'6.12"N	76° 4'40.74"E	
D	30° 16'57.58"N	76° 4'54.26"E	
E	30° 16'54.26"N	76° 4'53.70"E	

3.5.3 Estimating the volume of Contaminated Groundwater

The hydrogeological studies indicate that the water level of most of the wells is in the range of 35m to 45m (below ground level). Approximately, the average water level is 40m (bgl). It is also observed that the contaminated well, MG-3 tapping the aquifer in the zone 83m to 100m. It indicates that the aquifer upto 100m is certainly contaminated. Deep drilling beyond 100m can throw more light on the vertical extent of the contamination. As an approximation, an estimated thickness, 70m is assumed for the contaminated aquifer by considering 10m additional thickness. As the area is alluvial, recommended value, 0.16 for the specific yield of the aquifer is used as per the norms of GEC (2015).

Total volume of estimated contaminated groundwater=

Area contaminated (196211m)×Thickness (70m)× Specifc yield (0.16)

Total volume of estimated contaminated ground water= **2.198 MCM**

Chapter 4

Action Plan for Remediation

4.1 Remediation Options

The uncontrolled disposal of the waste in the premises during the operations of the industry has led to soil and groundwater contaminatiuon. The site is classified as a contaminated site by CPCB (www.cpcb.nic.in). The industry is closed in February 2005 and contamination of the groundwater and soil is evident as attested in Chapter-5. The Geophysical studies supported by the targetted soil sampling indicate the presence of Hazardous substances in side the Solar evapoaration Ponds and the Hazardous waste Storage shed. Borewells in the vicinity are still giving coloured water and the contamination from organic sources is supported by the water chemistry data. The High sulphate content in the contaminated wells and the high SO4 in the soil samples collected from the SEP also establish the linkage. Considering the high solubility of the coloured fluid still present in the SEP and the high rate of groundwater withdrawl in the area and the Transmissivity value in the Intermediate class and very close to the High Class, it is necessary that immediate intervention measaures are taken to minimise and arrest the contamination in the soil and groundwater system.

The overarching goal of the immediate measures is to isolate and contain the dump material inside the premises of M/S Matharuy Chemical Industries so as to prevent the further release of contaminants from the dumpsite to the environment. The goal of the long term measure is to remediate the area below the risk based clean-up levels.

A review of available site remediation technologies was carried out to identify suitable technologies for control the release of the effluent from the site and remediation of contaminated site and the groundwater.

After a detailed assessment of these technologies, the following options are to to be implemented.

4.2 Phase I: Immediate Measures for removal of contaminated source and safe disposal

As evident from the Geophysical measurements and the soil sampling, effluent is still stored in the Solar Evaporation Pond and iron sludge is deposited in the

Hazardous storage site. The area outside the SEP is also contaminated as evident during the soil sampling. It is necessary that upto 3m depth from the surface (Contaminated zone marked in Figure 3.55), the top material (from 05m to 3m depth) need to be lifted and sent to the TSDF site. The material from top to 0.5m is natural soil and can be used to fill up the voids along with the virgin soil. Once the effluent and sludge are removed from the site and sent to TSDF, the contribution to contamination during the monsoon will be minimised over a period time.

4.3 Phase II: Long term measures

The contaminated groundwater is being used for agricultural use since 2006 when the contamination was reported (based on the discussions with the well owners). It is essential to take immediate long term measure for the decontamination of the aquifer. As the groundwater from the contaminated wells have phenolic compunds and indicate that the contamination is due to organic load, one of the well tested remediation technologies will be the Pump and treat based on activated carbon.

At present, the estimated contaminated groundwater is 2.198 MCM and the aquifer has to be decontaminated.

Based on pumping of 8 hours of pumping for 5 abstraction wells (average discharge 15 lps), the pumping rate per year (Q)= 0.788 MCM. As the contaminated volume is 2.198 MCM, the minimum estimated time for the decontamination will be 2.198/0.788 i.e. approx 3 years. The estimated time is based on the assumption and field level data on discharge during the field studies. The contaminated wells, MG-3, MG-4, MG-5, MG-6 and MG-8 can be used as abstraction wells for the purpose.

It need to be mentioned that the detailed project proposal for the Pump-and-treat technology and removal of the waste and transportation to the TSDF can be prepared by an agency to be engaged by the PPCB. A schematic of the Pump and treat based on activated carbon (Figure 4.1) is presented. The implementation of Pump & Treat technology for remediation can be executed by PPCB by engaging a a Remediation Contrator.

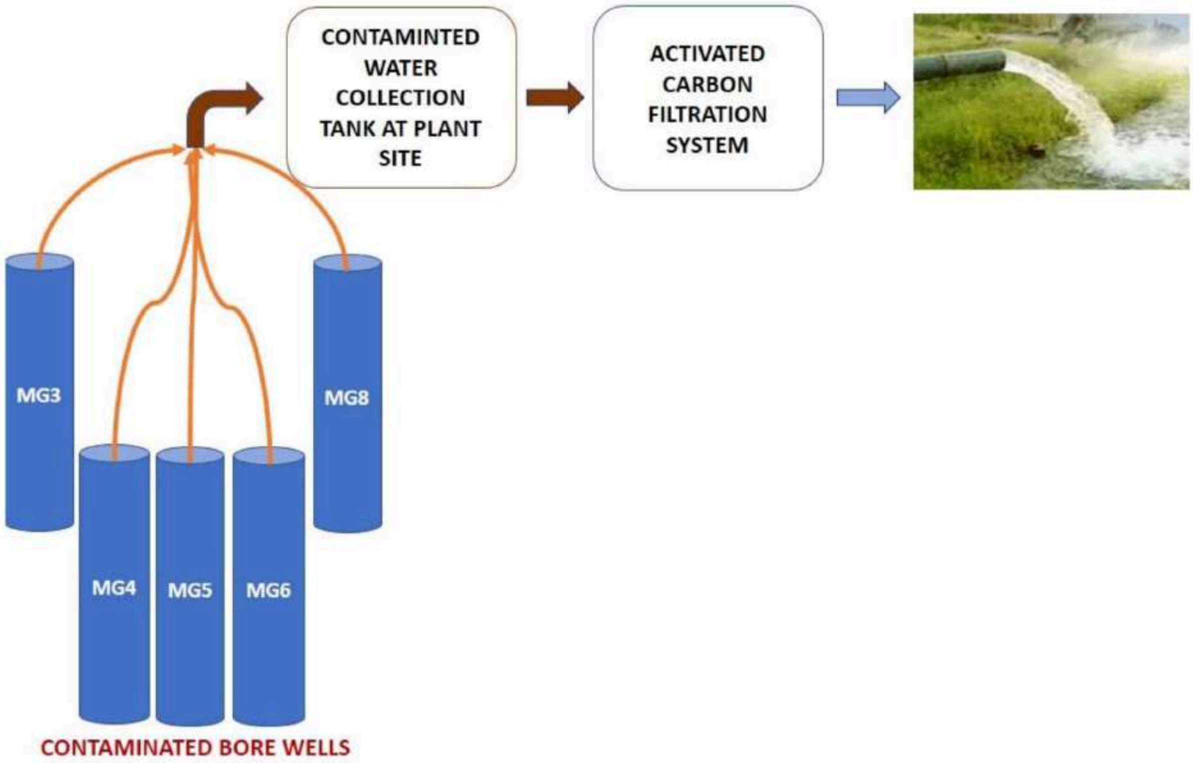


Figure 4.1: Schematic flow chart of pump and treatment method

Chapter 5:

Conclusions and Recommendations

I. M/s Matharu Chemical Industries manufactured H-Acid at its plant located at Bhawanigarh in Sangrur district during the period 1995-2005.

II. During the manufacture of H-Acid, it generated wastes, namely Gypsum sludge, Iron oxide sludge and mother liquor. The mother liquor was disposed in Solar Evaporation Pond and the iron and Gypsum sludge were disposed in specially constructed tanks at the Hazardous waste storage shed.

III. During the reconnaissance site visit, it was observed that wells (3 nos) located approximately 200-250 m away from the site were giving red colour water. During the visit, it was observed that plants and machineries were dismantled and the site did not have any structure. The site is sold out by the owner to a farmer, who uses part of the land for agriculture. Part of the site is leased out to the owner of brick making unit.

IV. Geologically, the study area is part of the Indo-Gangetic plains characterized by alluvial formations. The slope is very gentle and the regional slope is from east to west. There is no natural stream available and the canals of the Bhakra Nangal carry the flood water during the monsoon.

V. The groundwater level data from the observation well network (35 nos) indicates that the water level varied from approximately 35m to 44m (bgl). The well development details provided by the RWSS indicate the presence of Multi aquifer system, which is characterized by multiple aquifers. It is evident that the groundwater is pumped from the semi confined/confined aquifer. The well development details also indicate the presence of clay lenses in the different wells. The groundwater withdrawal in agricultural bore wells is with electric pumps of 15-20 HP capacity. The large scale groundwater withdrawal has led to groundwater stage development of 212% in the Bhabanigarh block. The pumping test indicates Transmissivity of 95.83 m2/day,which is in the intermediate class and very close to the High class (100-1000 m2/day). In view of the Transmissivity value, the contamination from advection is significantly more. The groundwater level (AMSL) contours indicate a general flow direction from east to west.

VI. Comprehensive monitoring of the groundwater sources indicated the presence of Colour, COD, TOC and Phenolics in the wells giving coloured water. The contamination is from the organic load as the H-Acid generates mostly organics in the manufacturing process. The concentration of colour exceeds the permissible limit (IS 10500-2012). Barring the 5 wells, rest of the wells do not indicate issues with color parameter. The wells with elevated color have also elevated SO_4 concentration, which indicates linkage with the waste from the SEP. The color concentration contours indicate movement towards the south west.

VII. The geophysical investigation viz. Electrical Resistivity Tomography and Ground Penetrating Radar in the premises of M/S Matharu Chemicals. Few profiles were collected very close to the site. The overarching goal was to look for signatures of the SEP and HWSS on the Geophysical measurements as they were concealed under the surface.

VIII. The ERT measurements over the probable locations of the SEP indicated the presence of high conductive anomalous zones upto 10-15m in many profiles and the anomalous zones overlapped with the probable SEP locations. This was conspicuous in both SEP (A) and SEP (B). It was also observed that some ERT profiles collected very close to the probable SEP also had very similar features like the one next to it. This indicates that possible overflow of the effluent from the SEP to its immediate surrounding. The GPR scanning at the SEP and HWSS indicated the presence of a strong reflection at approximately 2-3m depth, which can be linked to the presence of the brick surface at the site.

IX. Soil sampling carried out at the SEP indicates elevated concentration of Na and SO4. Sampling carried out at the probable HWSS indicated elevated Iron concentration, which indicates the signature from the iron sludge. It was also observed that the sampling upto 3m at the probable SEP indicated the presence of dark coloured fluid upto 2-3m depth overlying some Liner sheet. Based on the Soil quality at the site, the soil contaminated zone is delineated. The Soil contaminated zone covers approximately 48064 m^2.

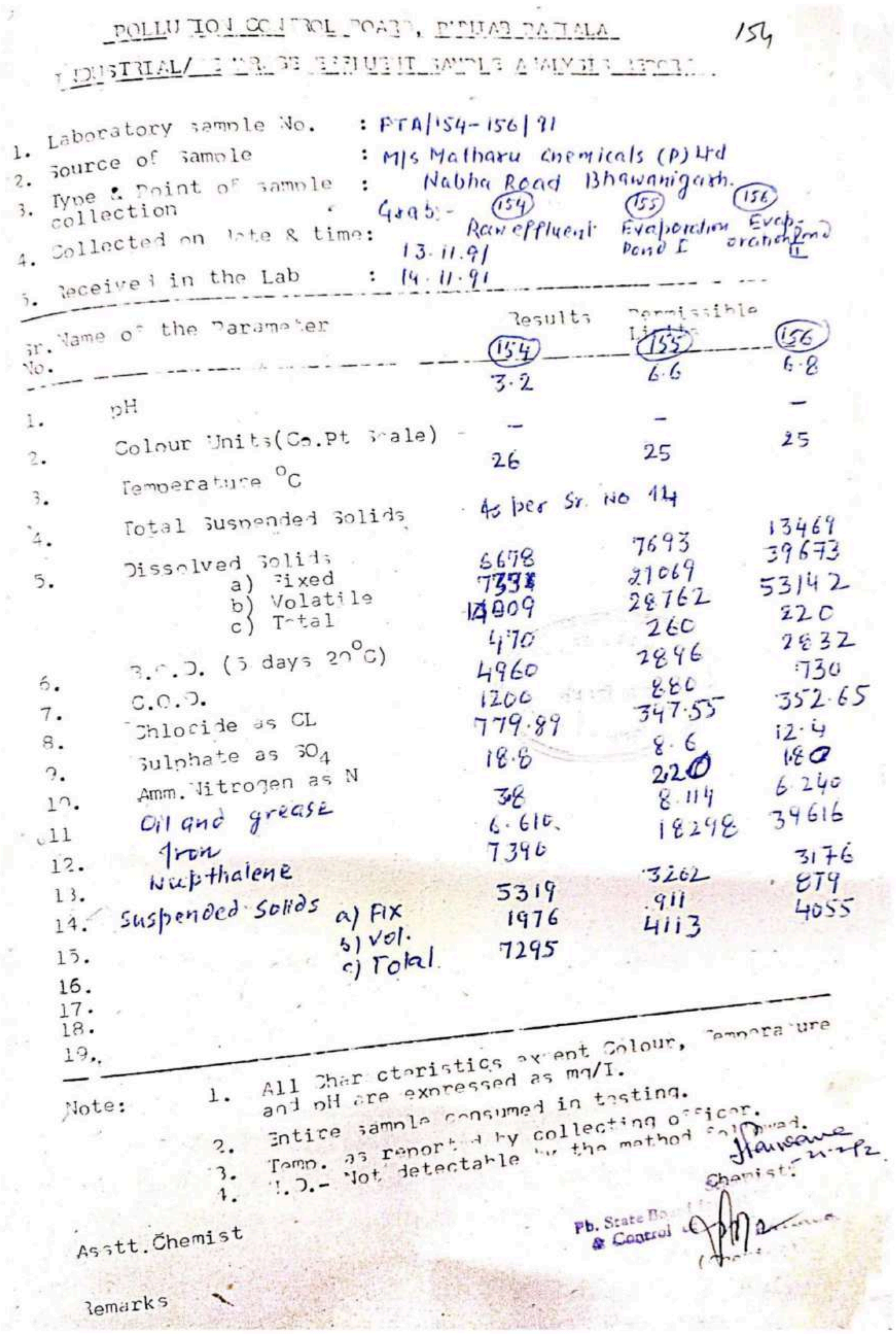
X. Based on the Hydrogeological details (Groundwater level data and along with well development details), groundwater quality studies, the Geophysical studies and the targeted sampling for soil, the zone affected by groundwater contamination is estimated. The zone of contamination is 60 m as per the present available data. As deep well details are not available, 10m buffer is considered to estimated the volume of contaminated aquifer

XI. In view of the high color concentration in the affected wells, high groundwater pumping, and the presence of the effluents in the SEP and sludge at the HWSS, an immediate and well as long term measures for remediation of impacted area have been identified and delineated.

XII. The immediate measure is to lift the contaminated soil from the identified are and transfer it to a TSDF site. The material lying unutilized near the Security room should be disposed off suitably. Once it is transferred to the TSDF site, the void so created need to be filled up by virgin soil. The contaminated groundwater need to be remediated by pump and treat method based on activated carbon. Abstraction wells (5 nos) need to be pumped for approximately 8 hours a day (subject to the necessary permission from the concerned government department). The contaminated wells namely, MG-3, MG-4, MG-5, MG-6, MG-8 can be used as abstraction wells for the purpose. The remediation can be implemented by a competent remediation contractor to be engaged by PPCB through an Expression of Interest. The remediation contractor need to prepare Detailed Project Report (DPR) for the excavation of the material from the identified contaminated zone and transfer it to the TSDF site and remediation of contaminated groundwater.

XIII. The groundwater samples from the contaminated wells (MG-3, MG-4, MG-5, MG-6, MG-8) have sodium absorption ratio (SAR) < 10 and hence it meets the criteria for irrigation water (IS 11624,1986). After treatment, it can be provided to the farmers.

Annexure-I



POLLUTION CONTROL BOARD, PUNJAB PATIALA 154

INDUSTRIAL/DISCHARGE EFFLUENT SAMPLE ANALYSIS REPORT

1. Laboratory sample No. : PTA/154-156/91
2. Source of Sample : M/s Matharu Chemicals (P) Ltd Nabha Road Bhawanigarh.
3. Type & Point of sample collection : Grab:- (154) Raw effluent (155) Evaporation Pond I (156) Evaporation Pond II
4. Collected on Date & time: 13.11.91
5. Received in the Lab : 14.11.91

Sr. No.	Name of the Parameter	Results	Permissible Limits	
		(154)	(155)	(156)
1.	pH	3.2	6.6	6.8
2.	Colour Units (Co.Pt Scale)	—	—	—
3.	Temperature °C	26	25	25
4.	Total Suspended Solids	As per Sr. No 14		
5.	Dissolved Solids			
	a) Fixed	5678	7693	13469
	b) Volatile	7338	21069	39673
	c) Total	14009	28762	53142
6.	B.O.D. (5 days 20°C)	470	260	220
7.	C.O.D.	4960	2846	2832
8.	Chloride as CL	1200	880	730
9.	Sulphate as SO_4	779.89	347.55	352.65
10.	Amm. Nitrogen as N	18.8	8.6	12.4
11	Oil and grease	38	220	180
12.	Iron	6.610.	8.114	6.240
13.	Napthalene	7390	18298	34616
14.	Suspended Solids a) Fix	5319	3262	3176
	b) Vol.	1976	.911	879
	c) Total	7295	4113	4055
15.				
16.				
17.				
18.				
19.				

Note:
1. All Characteristics except Colour, Temperature and pH are expressed as mg/l.
2. Entire sample consumed in testing.
3. Temp. as reported by collecting officer.
4. N.D.- Not detectable by the method followed.

Chemist

Asstt. Chemist

Pb. State Bo & Control

Remarks

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21.5.24

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