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

जलभृत प्रबंधन योजना
AQUIFER MANAGEMENT PLAN

मुंबई और मुंबई उपनगर जिला, महाराष्ट्र
MUMBAI CITY AND MUMBAI SUBURBAN DISTRICTS, MAHARASHTRA

शहरी संकुलन

URBAN AGGLOMERATE

राज्य इकाई कार्यालय, पुणे

State Unit Office, Pune

2025

जलभृत प्रबंधन योजना
AQUIFER MANAGEMENT PLAN

मुंबई और मुंबई उपनगर जिला, महाराष्ट्र
MUMBAI CITY AND MUMBAI SUBURBAN DISTRICTS, MAHARASHTRA

शहरी संकुलन

URBAN AGGLOMERATE

GOVERNMENT OF INDIA

MINISTRY OF JAL SHAKTI

DEPARTMENT OF WATER RESOURCES

RIVER DEVELOPMENT & GANGA REJUVENATION

CENTRAL GROUND WATER BOARD

STATE UNIT OFFICE, PUNE

2025

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

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

MESSAGE

The **National Aquifer Mapping and Management Programme (NAQUIM)** has been one of the most transformative scientific initiatives undertaken for sustainable groundwater management in India. **NAQUIM 2.0** under the **Annual Action Plan 2024–25**, the programme enters a new and more focused phase - one that seeks to bring **greater precision, deeper insight, and stronger impact** to groundwater governance.

NAQUIM 2.0 builds upon the vast scientific foundation created during the earlier phase, but takes it further by focusing on **finer-scale mapping** in **priority type areas** identified through scientific and management criteria. This new phase aims to provide information at **higher granularity**, supported by an expanded network for **dynamic data collection** on groundwater levels and quality. Such enriched datasets will enable a more nuanced understanding of aquifer systems and facilitate informed decision-making for resource planning and management.

Beyond mapping, NAQUIM 2.0 places strong emphasis on **implementable management strategies**—ensuring that scientific recommendations translate into actionable interventions at the local level. The initiative seeks to strengthen collaboration with **State Governments, District Administrations, and other stakeholders** for effective utilization of aquifer information in water resource planning, demand management, and sustainability initiatives.

I extend my appreciation to all officers, scientists, and technical teams of the Board whose dedicated efforts and field-based innovations continue to drive the success of NAQUIM. Together, we are not only mapping India's aquifers but also charting the course toward a **sustainable and water-secure future**.

SKAmbast

(Dr. Sunil Kumar Ambast)

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

एन. वरदराज

सदस्य (इंजीनियरिंग)

N. VARADARAJ

MEMBER (ENGINEERING)

सत्यमेव जयते

भारत सरकार

जल शक्ति मंत्रालय

जल संसाधन नदी विकास और

गंगा संरक्षण विभाग

केंद्रीय भूमि जल बोर्ड

Government of India

Ministry of Jal Shakti

Department of Water Resources,

River Development and

Ganga Rejuvenation

Central Ground Water Board

MESSAGE

The NAQUIM 2.0 study carried out for the Mumbai Urban Agglomeration is a significant step towards developing a comprehensive and scientific understanding of the Mumbai's groundwater resources. Covering an area of about 603 sq. km across Mumbai City and Suburban areas, this study addresses the challenges of groundwater management in one of the most densely populated and highly urbanized coastal regions of the country.

Through systematic hydrogeological, geophysical and water quality investigations, the study has generated a robust aquifer-wise database that captures the complexity of basaltic aquifers, shallow and deeper groundwater systems, and their interaction with surface water bodies, creeks and the Arabian Sea. The assessment highlights that, while the overall groundwater development stage remains within safe limits, issues such as declining water levels, localized GW quality issues and vulnerability to seawater intrusion along coastal and creek areas require focused attention.

The NAQUIM 2.0 outputs, including aquifer geometry, groundwater quality status, resource estimation and vulnerability mapping, provide a strong scientific foundation for evidence-based decision-making. These findings clearly indicate the need for prudent groundwater abstraction, protection of freshwater aquifers from saline ingress, and enhancement of recharge through rainwater harvesting, especially in areas with deeper post-monsoon water levels. In saline and coastal tracts, non-conventional measures such as rooftop rainwater harvesting and demand-side management assume greater importance.

The Mumbai NAQUIM 2.0 study has immense potential for a robust implementation plan by integrating its recommendations with urban planning, water supply augmentation projects and climate-resilient strategies. Effective use of this aquifer information by line departments, urban local bodies and other stakeholders will help ensure sustainable groundwater management, safeguard potable water resources, and support the long-term water security of Mumbai.

Faridabad

एन वरदराज

(N.Varadaraj)

Bhujal Bhawan, CGO Complex, NH-IV, Faridabad-121001

Tel.: 0129-2477117,0129-2477116, E-mail- meng-cgwb@gov.in

डॉ. उमेश एस. बालपांडे
क्षेत्रीय निदेशक
Dr. Umesh S. Balpande
Regional Director

सत्यमेव जयते

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

PREFACE

The NAQUIM 2.0 study for the Mumbai Urban Agglomeration represents a major advancement in building a scientific and integrated understanding of the city's groundwater systems. Encompassing approximately 603 sq. km across Mumbai City and its suburban areas, the study responds to the pressing challenges of groundwater management in one of India's most densely populated and intensely urbanized coastal regions.

Comprehensive hydrogeological, geophysical, and groundwater quality assessments have resulted in a detailed, aquifer-wise database. This database captures the inherent complexity of Mumbai's basaltic formations, including shallow and deeper aquifers, and their hydraulic connectivity with surface water bodies, tidal creeks, and the Arabian Sea. While the overall stage of groundwater development remains within safe limits, the study identifies emerging concerns such as falling water levels in certain pockets, localized groundwater quality deterioration, and susceptibility to seawater intrusion along coastal and creek-adjacent zones.

Key NAQUIM 2.0 outputs—such as aquifer delineation, groundwater quality appraisal, resource quantification, and vulnerability mapping—offer a strong scientific basis for informed and evidence-driven water management decisions. The findings underscore the importance of regulated groundwater extraction, safeguarding freshwater aquifers from saline ingress, and enhancing recharge through measures like rainwater harvesting, particularly in areas exhibiting deeper post-monsoon water levels. In coastal and saline-prone regions, greater emphasis is required on non-conventional interventions, including rooftop rainwater harvesting and demand management strategies.

Overall, the NAQUIM 2.0 study for Mumbai provides a valuable framework for developing an effective and sustainable groundwater management strategy. Integrating its recommendations with urban planning initiatives, water supply augmentation schemes, and climate-resilient approaches can significantly strengthen long-term water security. Proactive utilization of this aquifer information by urban local bodies, line departments, and other stakeholders will be critical in protecting potable groundwater resources and ensuring Mumbai's future water sustainability

उमेश

Dr. Umesh S. Balpande
Regional Director

LIST OF CONTRIBUTORS

Principal Contributors	
Mrs Parveen Kaur	Scientist-D and Head of Office, CGWB, State Unit Office, Pune (Team Leader, Present)
Dr. J. Davithuraj	Scientist-D and Head of Office CGWB, State Unit Office, Pune (Team Leader, upto May 2025)
Shri Sandeep. D. Waghmare	Scientist-C, CGWB, State Unit Office, Pune
Shri Omkar Kadekar	Young Professional
Shri Upendra V Dhonde	Scientist-D, CGWB, State Unit Office, Pune
Shri Ram Kishor	Assistant Hydrogeologist, CGWB State Unit Office, Pune
Chemical Analysis	
Dr. Devsharan Verma	Scientist-D, CGWB, CR Nagpur
Dr. Rakesh Devangan	Scientist-D, CGWB, CR Nagpur
Dr. Sailee Bhange	Senior Technical Assistant (Chem.) CGWB, CR Nagpur
Shri Vishal Meena	Senior Technical Assistant (Chem.) CGWB, CR Nagpur
Geophysical Investigation	
Shri G.M Londe	Scientist-D (Geophysicist)
Shri Subasridharan S.M	Senior Technical Assistant, (Geophysicist)
Shri Dillip Meena	Senior Technical Assistant, (Geophysicist)

Under overall guidance of
Dr. Umesh S. Balpande, Regional Director, CGWB, CR Nagpur
&
Dr. Pandith Madhnure, Scientist-D, CGWB, CR Nagpur

AQUIFER MANAGEMENT PLAN
MUMBAI CITY AND MUMBAI SUBURBAN DISTRICTS
MAHARASHTRA
(URBAN AGGLOMERATE)

Table of Contents

LIST OF TABLES

कार्यकारी सारांश

मुंबई एवं मुंबई उपनगर जिले को NAQUIM 2.0 (नेशनल एक्विफर मैपिंग एवं प्रबंधन कार्यक्रम) के अंतर्गत अध्ययन हेतु चयनित किया गया, जिसमें लगभग 603 वर्ग किमी क्षेत्र शामिल है। यह अध्ययन चार तालुकों—मुंबई सिटी, कुर्ला, अंधेरी एवं बोरीवली—को कवर करता है। अध्ययन क्षेत्र भारतीय सर्वेक्षण विभाग के टोपोशीट 47A/9 से 47A/16 के अंतर्गत आता है तथा 18°53′–19°19′ उत्तरी अक्षांश और 72°47′–72°59′ पूर्वी देशांतर के बीच स्थित है। इस क्षेत्र को "शहरी समूह (Urban Agglomerate)" प्राथमिकता क्षेत्र के रूप में वर्गीकृत किया गया है।

भौगोलिक दृष्टि से अध्ययन क्षेत्र मुख्यतः समतल तटीय भूभाग से युक्त है, जिसके उत्तर–दक्षिण दिशा में फैली पहाड़ी श्रेणियाँ स्थित हैं। पोवई–कन्हेरी पहाड़ियाँ उत्तर-पूर्वी भाग में प्रमुख उच्च भू-भाग का निर्माण करती हैं और पोवई, विहार एवं तुलसी झीलों के लिए प्रमुख पुनर्भरण क्षेत्र (feeder zone) हैं। क्षेत्र में कई ज्वारीय खाड़ियाँ (creeks) विद्यमान हैं, जिनमें ठाणे खाड़ी सबसे प्रमुख है। माहीम, मीठी, दहिसर एवं ओशिवारा नदियाँ इस क्षेत्र की प्रमुख जल निकासी प्रणालियाँ हैं। भूवैज्ञानिक रूप से यह क्षेत्र ऊपरी क्रिटेशियस से निचले इओसीन काल के डेक्कन ट्रैप बेसाल्टिक लावा प्रवाह से आच्छादित है, जिनके ऊपर स्थानीय रूप से जलोढ़ (Alluvium) जमा है। क्षेत्र में औसत वार्षिक वर्षा 1800 से 2400 मिमी के बीच होती है।

हाइड्रोजियोलॉजिकल अध्ययनों से स्पष्ट होता है कि इस क्षेत्र के प्रमुख जलभृत (aquifers) बेसाल्ट एवं जलोढ़ हैं। भूजल का संचयन मुख्यतः अपक्षयित परतों, दरारों, जोड़ों तथा वेसिकुलर बेसाल्ट क्षेत्रों में होता है। जलस्तर विश्लेषण के अनुसार, 80–85% से अधिक कुओं में 5 मीटर भू-तल से नीचे (mbgl) से कम उथले जलस्तर दर्ज किए गए हैं (पूर्व एवं पश्चात मानसून 2023–2024)। मौसमी उतार-चढ़ाव से अधिकांश कुओं में जलस्तर वृद्धि देखी गई, जबकि दीर्घकालिक प्रवृत्ति विश्लेषण में मुंबई सिटी क्षेत्र में गिरता हुआ तथा मुंबई उपनगर क्षेत्रों में सामान्यतः बढ़ता हुआ जलस्तर पाया गया, हालांकि कुछ स्थानों पर अपवाद स्वरूप गिरावट भी देखी गई।

वर्टिकल इलेक्ट्रिकल साउंडिंग (VES) अध्ययनों से उपसतही संरचना में टॉप सॉइल, अपक्षयित बेसाल्ट, फ्रैक्चर्ड बेसाल्ट तथा मैसिव बेसाल्ट की पहचान हुई, जो लगभग 80 मीटर mbgl तक विस्तृत है। भूजल अन्वेषण आंकड़ों के अनुसार, प्रमुख फ्रैक्चर ज़ोन 60 से 172 मीटर mbgl की गहराई पर पाए गए, जिनकी उपज <1 से 12 लीटर/सेकंड तक रही तथा ट्रांसमिसिविटी 96–141 m^2/दिन पाई गई। हालांकि, फोर्ट, शिवाजी पार्क (दादर), मुलुंड ईस्ट एवं माहीम क्षेत्रों में विभिन्न गहराइयों पर अत्यधिक लवणीय भूजल पाया गया, जो समुद्री जल प्रवेश (seawater intrusion) की संवेदनशीलता को दर्शाता है।

भूजल गुणवत्ता विश्लेषण से ज्ञात हुआ कि सामान्यतः भूजल Ca–Mg–HCO_3 प्रकार का है और अधिकांश स्थानों पर BIS पेयजल मानकों के अनुरूप है, हालांकि कुछ स्थानों पर नाइट्रेट एवं विद्युत चालकता (EC) अधिक पाई गई। GALDIT मॉडल द्वारा किए गए संवेदनशीलता विश्लेषण से यह स्पष्ट हुआ कि तटीय जलभृत विशेषकर पूर्व-मानसून अवधि में मध्यम से उच्च स्तर तक समुद्री जल प्रवेश के प्रति संवेदनशील हैं।

2025 भूजल संसाधन मूल्यांकन के अनुसार, भूजल दोहन की अवस्था (Stage of Extraction) मुंबई सिटी में 46% तथा मुंबई उपनगर में 25.74% है, जिससे सभी चार आकलन इकाइयाँ 'सुरक्षित (Safe)' श्रेणी में आती हैं। भूजल का उपयोग मुख्यतः घरेलू एवं औद्योगिक प्रयोजनों के लिए हो रहा है, जबकि सिंचाई उपयोग नगण्य है।

अध्ययन में अनुशंसा की गई है कि वर्षा जल संचयन, पुनर्भरण कुएँ, परित्यक्त या अल्प उपयोग वाले कुओं को रिचार्ज संरचनाओं में परिवर्तित करना जैसे उपाय विशेष रूप से चिन्हित क्षेत्रों में लागू किए जाएँ। लवणीयता प्रभावित क्षेत्रों में भूजल दोहन को सीमित किया जाए तथा निरंतर जल गुणवत्ता निगरानी सुनिश्चित की जाए। यद्यपि मुंबई वर्तमान में सतही जल स्रोतों के कारण जल अभाव की स्थिति में नहीं है, फिर भी तटीय जलभृतों को समुद्री जल प्रवेश से सुरक्षित रखने हेतु व्यवस्थित भूजल पुनर्भरण एवं संरक्षण अत्यंत आवश्यक है, ताकि दीर्घकालीन जल सुरक्षा सुनिश्चित की जा सके।

EXECUTIVE SUMMARY

Mumbai and Mumbai Suburban districts were covered under the NAQUIM 2.0 (National Aquifer Mapping and Management Programme) study, encompassing an area of approximately 603 km² across four taluks—Mumbai City, Kurla, Andheri, and Borivali. The study area falls within Survey of India Toposheets 47A/9 to 47A/16, extending between 18°53′–19°19′ N latitude and 72°47′–72°59′ E longitude, and has been categorized under the Urban Agglomerate priority area. Physio-graphically, the region is characterized by predominantly flat coastal terrain, flanked by north–south trending hill ranges, with the Powai–Kanheri hills forming a prominent elevated zone in the northeastern part. These hills serve as the recharge and feeder zones for Powai, Vihar, and Tulsi lakes. The area is dissected by several tidal creeks, notably Thane Creek, and drained by the Mithi, Mahim, Dahisar, and Oshiwara rivers. Geologically, the area is underlain by Deccan Trap basaltic lava flows of Upper Cretaceous to Lower Eocene age, overlain locally by alluvium. The region receives high monsoonal rainfall ranging from 1,800 to 2,400 mm annually.

Hydrogeological investigations indicate that the principal aquifers are Basalt and Alluvium, with groundwater occurrence controlled by weathered zones, fractures, joints, and vesicular basalt horizons. Water level data show predominantly shallow groundwater conditions, with more than 80–85% of monitoring wells recording water levels <5 m bgl during both pre- and post-monsoon periods (2023–2024). Seasonal fluctuations indicate a net rising trend in the majority of wells, while long-term trend analysis reveals a declining groundwater trend in Mumbai City and a generally rising trend in Mumbai Suburban districts, except in isolated pockets.

Geophysical investigations using Vertical Electrical Sounding (VES) delineate subsurface layers comprising topsoil, weathered basalt, fractured basalt, and massive basalt up to depths of about 80 m bgl. Groundwater exploration data indicate fracture zones predominantly between 60–172 m bgl, with well yields ranging from <1 to 12 lps and transmissivity values of 96–141 m²/day. However, saline groundwater zones have been encountered at several locations, particularly in Fort, Shivaji Park (Dadar), Mulund East, and Mahim, at variable depths, indicating vulnerability to seawater intrusion.

Groundwater quality assessment shows that groundwater is predominantly of Ca–Mg–HCO_3 type, generally meeting BIS drinking water standards, except for localized nitrate contamination and elevated electrical conductivity in select coastal and urban pockets. GALDIT vulnerability modeling indicates that coastal aquifers are moderately to highly vulnerable to seawater intrusion, particularly during pre-monsoon periods.

As per the 2025 Groundwater Resources Assessment, the Stage of Groundwater Extraction is 46% in Mumbai City and 25.74% in Mumbai Suburban, categorizing all four assessment units as 'Safe'. Groundwater use is predominantly for domestic and industrial purposes, with negligible irrigation demand.

The study recommends strengthening groundwater recharge through rainwater harvesting, recharge wells, and conversion of unused dug wells, particularly in identified recharge-feasible zones. Groundwater abstraction should be regulated in saline-prone areas, with extraction depths restricted and continuous quality monitoring enforced. Although Mumbai is not presently water-scarce due to adequate surface water supply, systematic groundwater recharge and protection are essential to mitigate seawater intrusion risks and ensure long-term aquifer sustainability in this coastal urban agglomeration.

DISTRICT AT A GLANCE

MUMBAI CITY & MUMBAI SUBURBAN DISTRICTS

1	**GENERAL INFORMATION**			
		Geographical Area	:	603 sq. km.
		Administrative Divisions	:	Mumbai City and Mumbai Suburban District
		Co-ordinates	:	N18°53’ & 19°19’ and E 72°47’ & 72°59’.
		Toposheet	:	47A/9, 47A/16, 47A/15
		Taluks	:	Taluka- 4; Mumbai City, Andheri, Kurla, Borivali
		Municipal Corporation	:	1, Brihanmumbai Municipal Corporation (BMC)
		Administrative Wards	:	3, City Ward, Eastern ward & Western Ward
		Population (Census 2011)	:	93,56,962, Projected Population (2024)-1.30 Cr
		Water Supply	:	3975 MLD
		Source for Water Supply	:	7, Vihar and Tulsi within Mumbai and Tansa, Modak Sagar, Upper Vaitarna, Middle Vaitarna and Bhatasa
		Normal rainfall	:	2111 mm to 2420 mm
		Long term rainfall Trend (1901-2023)	:	Rising trend
2	**GEOMORPHOLOGY AND DRAINAGE**			
		Major Physiographic unit	:	3, Bombay Island Salsette Island and Trombay Island.
		Major Drainage	:	4, Mahim, Mithi, Dahisar and Polsar
3	**LAND USE**			
		Brihanmumbai Municipal Corporation is Planning Authority for about 434.55 sq.m (91.24%) excluding the area coming under various Special Planning Authority (SPA)		
4	**SOIL TYPE**		:	The predominant soil types in Mumbai are sandy in the city region and alluvial/loamy in the suburban areas.
		SOIL INFILTRATION	:	**Infiltration Rate (cm/hr): 1.5 to 45.6**
5	**GROUND WATER MONITORING WELLS** (As on May-2025)			
		Dug wells	:	23
		Key Observation Wells	:	37
6	**GEOLOGY**			
		Recent	:	Alluvium
		Upper Cretaceous to Lower Eocene	:	Basalt (Deccan Trap), Rhyolite and Trachyte
7	**GEOPHYSICAL SURVEY**		:	33 VES
8	**HYDROGEOLOGY**			
		Major Water Bearing Formation	:	1. Hard Rock:
				Deccan Traps Basalt- Weathered/Fractured/
				Jointed massive or Amygdaloidal Basalt.
			:	2. Soft Rock:

				Alluvium- beach Sand
		Depth to water level in Shallow Aquifer		
		Pre-monsoon Depth to Water Level (May-2024)	:	0.3 mbgl to 12.81 mbgl
		Post-monsoon Depth to Water Level (Nov -2024)	:	0.00 mbgl to 8.00 mbgl
		Water level Trend (2014-2023)		
		Pre- monsoon Water Level Trend (2014-2023)	:	Rise: 0. 0.146 m/year
				Fall: 0.00 to 0.07 m/year
		Post-monsoon Water Level Trend (2014-2023)	:	Rise: 0. 00 to 0. .48 m/year
				Fall: 0. 00 to 0.63 m/year
9	**GROUND WATER EXPLORATION (**2025)			
		Major Aquifer	:	**Basalt**
		Wells Drilled (CGWB)	:	6 EWs + 1 OW + 2 PZ drilled
		Depth Range	:	37.90 to 202.60 mbgl
		SWL	:	1.08 to 37.27 mbgl
		Discharge	:	< 1 lps to 13 lps
10	**GROUND WATER QUALITY**			

		Constituents		**Pre-Monsoon-2023**		**Pre-Monsoon-2024**	
				Min	Max	Min	Max
		pH		6.86	7.9	3.4	8.73
		EC at 250C (μS/cm)		136	4558	123	6842
		TDS		87	2917	0	4378
		Chloride		11	1375	10.65	905.25
		Sulphate		0	92	0	214
		Nitrate (mg/l)		1	84	0	58
		Fluoride (mg/l)		0.16	1.12	0.02	2
		Calcium		12	491	14	614
		Magnesium		4.86	182	2.4	68
		Total Hardness		70	1530	45	1820
		Sodium		4	529	-	595.4
		Potassium		0	34	-	30
		Iron (mg/l)		0	283	0	0.1

11	**DYNAMIC GROUND WATER RESOURCES (2025)**			
		Annual Extractable Ground Water Resources (MCM)		14.77 MCM (Mumbai) & 72.63 MCM (Mumbai Suburban)
		Total Extraction (MCM)		6.80 MCM (Mumbai) & 18.70 MCM (Mumbai Suburban)
		Net Ground Water Availability for future use (MCM)		7.97 MCM (Mumbai) & 53.93 MCM (Mumbai Suburban)

		Stage of Ground Water Development		46.03% (Mumbai) & 25.74% (Mumbai Suburban)
		Category		**Safe**
12	**MAJOR GROUND WATER PROBLEMS AND ISSUES**			
		Due to urban agglomeration the major challenge is sustainable management of water resources. Urbanization results in an extensive change in land use land cover. This may include loss of vegetation, increase in percentage of impervious surfaces (paved area) and changes in natural flow of storm water runoff directly to stream channels. All these processes result in greater proportion of precipitation going as surface runoff causing low infiltration to the aquifer and poor recharge in the area. The extensive built-up area causes water logging during monsoon season. Ground water quality is also affected due to effluent discharges and anthropogenic activities. There is an additional risk of saline water intrusion along the coastline due to over extraction of Ground water.		
13	**GROUNDWATER MANAGEMENT**			
		For GW management and sustainable use, Rainwater harvesting may be implemented at places with deeper water levels of more than 5 mbgl is observed during post monsoon season. RWH in/and around areas such as Khandoba Mandir, Harmos Ji St, Sion and Mazgaon in Mumbai city, Ranicha Bagh, Borspada, Borivali East, Chandiwali, Sonapur and Vile Parle West in Mumbai Suburban districts can be constructed to enhance GW scenario. Dry or abundant dug wells may be converted into recharge wells with precautions. Further, Integrated Water Management Plan (Plan) with supply and demand side measures, Augmentation of GW and Conjunctive use is planned for efficient management of Water resources		
		The city of Mumbai is an area surrounded by saline water originating from the Arabian Sea and creeks, and saline aquifers are located between the freshwater aquifers, so there is a possibility of saline water rising when groundwater is pumped out of the dug wells and bore wells. it was recommended to take precautionary measures to prevent excessive pumping of groundwater which may lead to saline water rising. Here too, the pumps must be optimally used to prevent the fresh aquifer from being salinized through possible saline water upcoming all along the coast.		

CHAPTER 1
INTRODUCTION

The National Aquifer Mapping and Management Programme (NAQUIM) was launched in 2012 by the Central Ground Water Board (CGWB) as per the recommendations of the report of the Steering Committee on Water Resources and Sanitation in the Twelfth Five Year Plan (2012-2017) of the Planning Commission. NAQUIM (later renamed as NAQUIM 1.0) was launched to delineate and characterize the aquifers and prepare an aquifer management plan at district and block levels. As a follow-up project to NAQUIM, NAQUIM 2.0 was launched in April 2023. NAQUIM 2.0 is designed to provide detailed information to support groundwater management decisions at ground level. Since the issues pertaining to Ground water are area specific, 11 Priority areas were identified based on ground water related issues such as Water Stressed Areas; Urban Agglomerate; Coastal Areas, Industrial Clusters and Mining Areas, Areas with Springs as the principal source, Areas with Deeper Aquifers, Ground Water Contamination, Auto flow zones, Canal Command Areas, Areas with poor ground water quality, Other specific Issues. The present study deals with specific priority area i.e. under “Urban Agglomerate” where emphasis is placed on the effects of urbanization on ground water system in the study area.

1.1 STUDY AREA

Mumbai and Mumbai suburban districts have been taken-up for NAQUIM 2.0 studies covering an area of 603 sq.km containing 4 taluks namely Mumbai city, Kurla, Andheri and Borivali, where total area of Mumbai City is 69 sq. km and Mumbai Suburb is 534 sq. km. The area falls in the Toposheet of 47A/9, 47A/16, 47A/15. between N18°53’ & 19°19’ and E 72°47’ & 72°59’. The total population as per the Census 2011 is 93,56,962. The present study deals with specific priority area i.e. under “Urban Agglomerate” where emphasis is to be placed on the effects of urbanization on ground water system in the study area. Administrative map of the study area is given in **Fig 1.1** and The Salient features of the study area are given in **Table 1.1.**

Mumbai is one of the biggest metropolitan city in India in terms of population size and economy. Located on the western coast facing the Arabian Sea, the city was once made up of seven small islands, which over the centuries got connected through natural and man-made land reclamations. Today, it is a narrow strip of island that abuts the coastal belt of Konkan. (City Profile, BMC DRMMP).

A major part of Mumbai sits on the old island of Salsette which lies at the mouth of Ulhas River. Usually, Mumbai is referred to as three different geographic entities: Mumbai City, Greater Mumbai, and Mumbai Metropolitan Region. Mumbai City is the core of the old port city of Mumbai during the colonial period. Since then, its territory has expanded northward to cover the suburbs and extended suburbs. The Mumbai Island City and the Mumbai Suburban District comprise the Greater Mumbai. The Mumbai Metropolitan Region was formed to create the urban agglomeration consisting of 7 Municipal Corporations and 13 Municipal Councils. In addition to MCGM, it includes the Municipal Corporations of Navi Mumbai, Mira-Bhayandar, Thane, Kalyan-Dombivali, Bhiwandi-Nizampur and Ulhasnagar. (City Profile, BMC DRMMP).

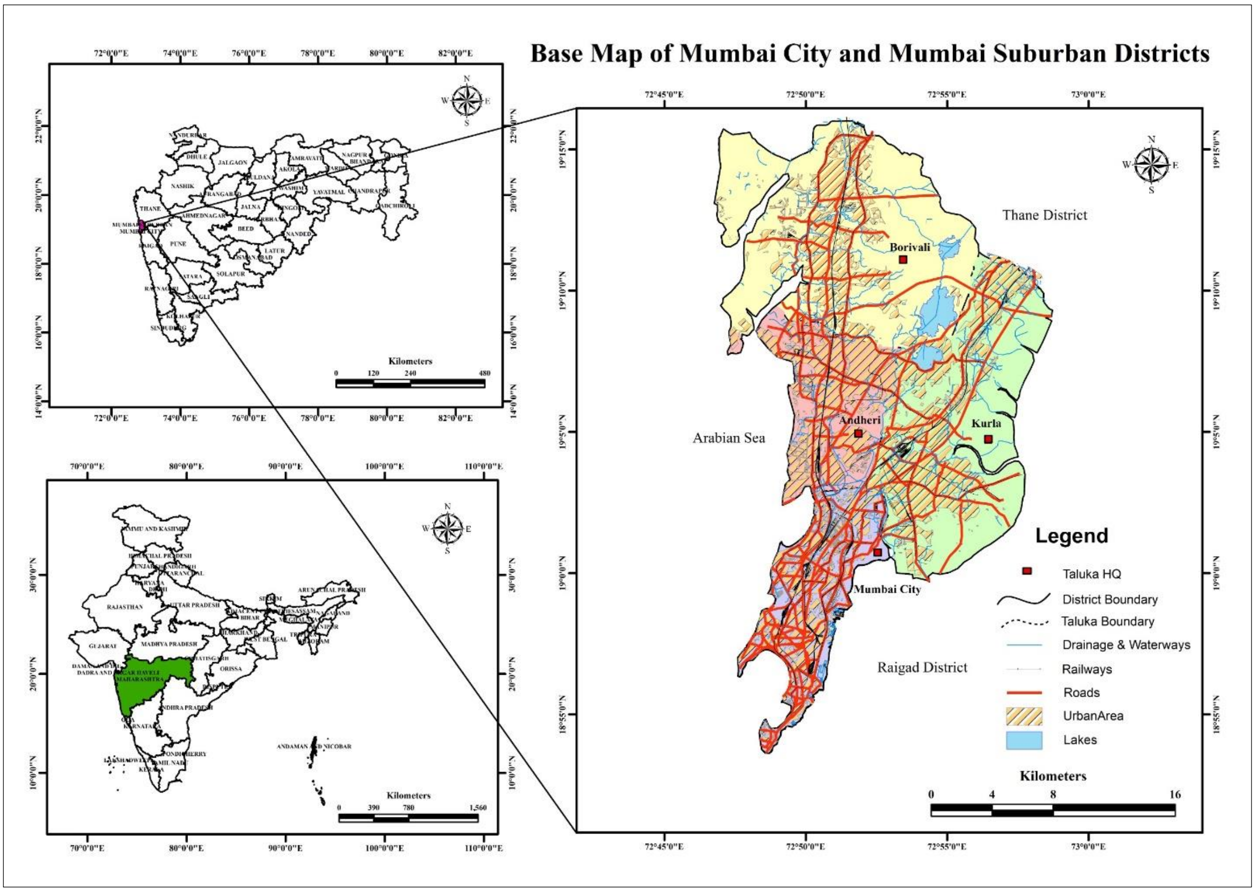


Fig 1.1: Administrative map of Mumbai City & Mumbai Suburban District

Table 1. 1 The Salient features of the study area are given below:

S.No.	Salient Features	Mumbai City and Mumbai suburban District
1.	**Location**	North latitude- 18°53' & 19°19' East Longitude- 72°47' & 72°59'
2.	**Geographical Area**	603 sq. km. (Mumbai City- 69 sq. km.; Mumbai Suburb- 534 sq. km)
3.	**Population (2011)**	93,56,962 13060781 (13.06 Billion) in 2024 (BMC)
4.	**Normal Annual Rainfall**	2111 mm to 2420 mm
5.	**Major Drainage**	Mahim, Mithi, Dahisar and Polsar
6.	**Geology**	Basalt and Alluvium

1.2 DEMOGRAPHY AND POPULATION

Mumbai is one of the densely populated cities. This positions Mumbai as the second most populous city in India, following Delhi. In Mumbai the estimated population of Mumbai is 13.06 million (year 2024) as per data received from Health Department of Brihan Mumbai Municipal Corporation. The population density of 27,029 person per sq.km. This consistent growth underscores Mumbai's significance as a major urban centre in India. Mumbai, India's financial and entertainment capital, is a densely populated and culturally diverse metropolis. There are three Main Administrative

Wards; City Ward, Eastern Ward and Western Ward and population of each is given in the table 1.2

Table 1.2: The ward-wise area and population of Mumbai is shown in table:

Ward-wise area and population of Mumbai (2023 & 2024)							
Administrative Ward	**Area in Sq.km**	**Population**		**Administrative Ward**	**Area in Sq.km**	**Population**	
		2023	**2024**			**2023**	**2024**
A	11.2	193527	194210	P/S	25.19	484833	486544
B	2.65	133147	133616	P/N	46.7	984680	988154
C	1.91	173807	174419	R/S	18.31	723033	725585
D	8.3	362826	364106	R/C	47.95	588028	590102
E	7.27	411382	412833	R/N	14.17	451217	452808
F/S	9.87	377581	378913	**Western Ward**	**232.55**	**5781335**	**5801729**
F/N	12.85	553376	555328	L	15.62	943738	947067
G/S	9.74	395130	396524	M/E	38.19	844885	847865
G/N	8.31	626602	628812	M/W	17.62	430846	432365
City Ward	**72.1**	**3227378**	**3238160**	N	29.68	651512	653810
H/E	12.4	582879	584934	S	32.55	778006	780751
H/W	18.65	321734	322869	T	44.91	357174	358434
K/E	24	861794	864834	**Eastern Ward**	**178.57**	**4006161**	**4020292**
K/W	25.18	783137	785899	**BMC**	**483.22**	**13014874**	**13060781**

Source: Development- Planning and Health Depts of Brihanmumbai Municipal Corporation

Administrative Ward-wise population indicates that 'P/North' ward has maximum population of 9,88,154 persons whereas 'B' ward has minimum population of 1,33,616 persons.

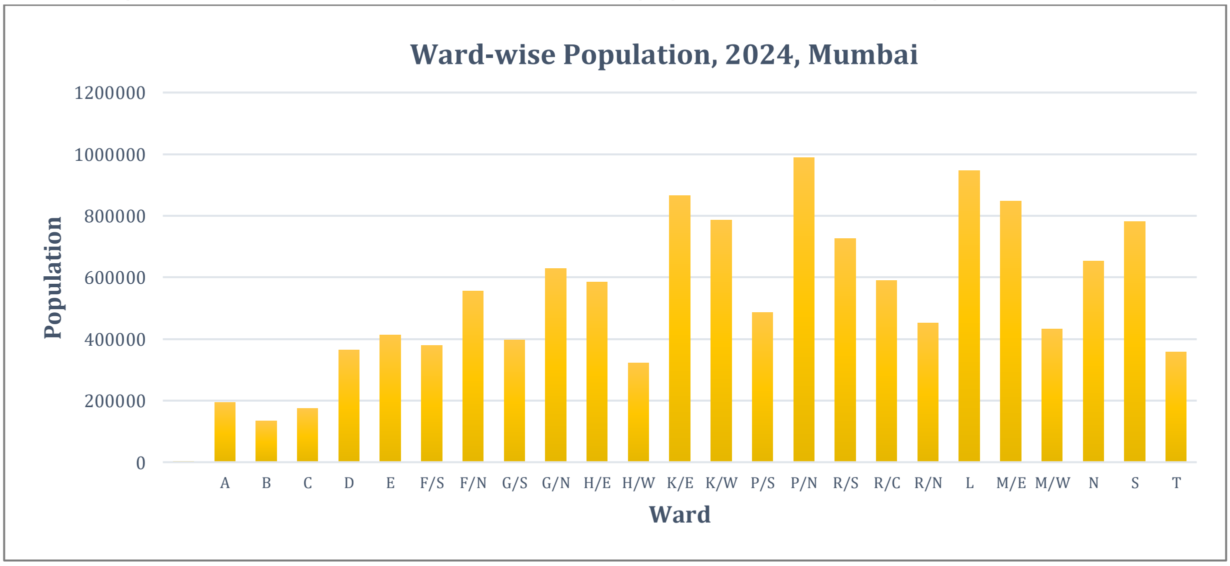
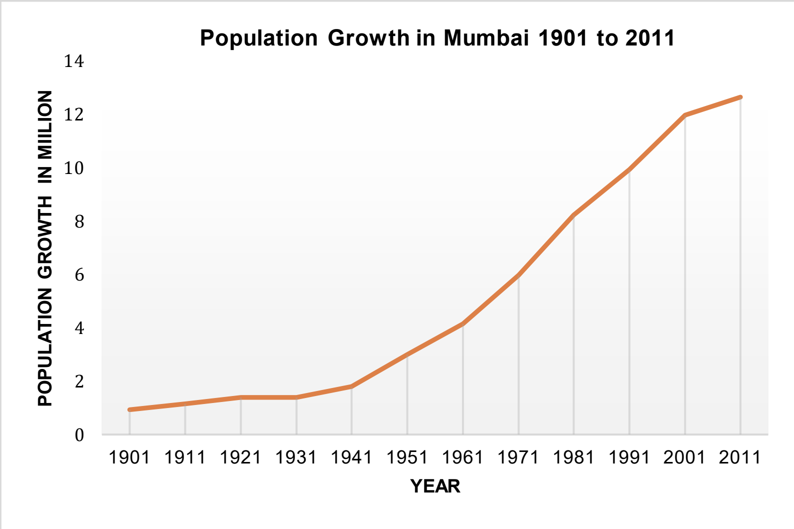


Fig 1.2: Ward-wise Population, 2024, Mumbai

Year	Population in Million	% Growth
1901	0.93	-
1911	1.15	23.7
1921	1.38	20
1931	1.4	11.5
1941	1.8	28.6
1951	2.99	66.1
1961	4.15	38.8
1971	5.97	43.8
1981	8.22	38.0
1991	9.92	21.1
2001	11.97	20.6
2011	12.64	3.8



Source: Census Department of India

Fig 1.3: Population Growth in Mumbai 1901 to 2011

In Mumbai the Growth of Population and rate Increases during year 1901-2011 and district's population grew from 0.93 million in 1901 to 12.64 million in the year 2011. Mumbai's demographic profile underscores its status as a vibrant, diverse, and dynamic city, reflecting a blend of cultures, languages, and traditions.

1.3 WATER RESOURCES AVAILABILITY AND DISTRIBUTION IN THE STUDY AREA

Historical records indicate that the district originally relied on dug wells, lakes, and tanks as sources of water supply. With rapid urbanization and population growth, water demand increased significantly, necessitating the development of a surface water–based piped distribution system by the municipal corporation. At present, the city's water distribution system is extensive and complex, comprising a network of transmission mains and service pipelines that cover the entire urban area. The water supply infrastructure of Greater Mumbai is more than a century old, with the first piped water supply commissioned in 1860. Currently, the city's water supply is sourced from seven surface water reservoirs (lakes). In Mumbai, Ground water is not used for drinking purposes. In order to reduce the illness prevalence in the city, Brihanmumbai Municipal Corporation (BMC) and Government of Maharashtra (GoM) have been discouraged the use of water from wells and ponds. As result, the dug well based water supply was not encouraged. However, being a financial capital of the country, the population growth in the city is very high as compared to other part of country. The supply of water from surface water sources fluctuates depending upon the rainfall during the year. Therefore, there is always the gap between demand and supply. In order to meet the shortfall in water supply, ground water-based supply as a supplementary source of supply has been used for all purposes other than drinking. Ground water is quite vulnerable to contamination from sewage disposal and other human activities. The over pumping may also lead to sea water intrusion.

1.3.1 Status of Water Supply and Demand

Mumbai receives water from seven impounded water resources viz. Vihar and Tulsi within Mumbai and Tansa, Modak Sagar, Upper Vaitarna, Middle Vaitarna and Bhatasa located at a distance of about 100 to 175 Kms from Mumbai. Water available from these sources is conveyed with transmission system ranging from 2235 mm to 5500 mm diameter pipelines and tunnels to the state-of-the-art water treatment facilities at Bhandup Complex (2500 MLD) and Panjrapur (1365 MLD). Water Treatment facilities for Tulsi (14 MLD) and Vihar (100 MLD) are located near to these sources (Table 1.3). At these treatment plants, water is treated with processes such as coagulation, flocculation, settling, rapid sand filtration and post-Chlorination and quality of the effluent water is maintained in accordance with IS 10500: 2012 - Drinking Water Specifications.

Table 1.3: Source of water Supply

Source of Water Supply				
S.No.	**Source**	**Yield in MLD**	**Distance from City**	**Treatment Plant**
1	**Tulsi**	14	City Limit	Tulsi
2	**Vihar**	100	City Limit	Vihar
3	**Tansa**	448	100 km from City	Bhandup Complex
4	**Modak Sagar**	1769	100 km from City	Bhandup Complex
5	**Upper Vaitarna Middle Vaitarna**		173 km from City	Bhandup Complex
6	**Bhatsa**	2039	100 km from City	Bhandup Complex and Panjarapur
	Subtotal	4370	-	-
	Enroute + Losses	-395	-	-
	Total Supply to City	**3975**	**-**	**-**

Source: Hydraulic Engg Dept, BMC, Mumbai

The treated water is stored in the Master Balancing Reservoirs (MBR) located near the treatment plants at Bhandup Complex (within Mumbai) and Yewai (Outside Mumbai). It is further distributed to 27 service reservoirs located throughout Mumbai City with water supply network of about 450 Kms this conveyance system remains charged for 24 hours and eliminates the chances of water contamination because of intrusion of ground water/sewage etc. There is 3975 MLD water supply to Mumbai.

1.3.2 Population Projection, Demand and Augmentation of Water Supply

The population growth trend of Mumbai is rising and the projected population of Mumbai is anticipated to be 17.24 million by the year 2041. The projected water demand for 2041 is 6535 MLD (including enroute supply and transmission losses). The process of developing Government allotted Gargai (440 MLD), Pinjal (865 MLD) and Damanganga-Pinjal River Link Project (1586 MLD) water supply sources to meet the future water demand. On completion of these projects, the water supply will be augmented by 2891 MLD.

1.4. OBJECTIVES OF THE PRESENT STUDY

The NAQUIM 2.0 study Mumbai City and Mumbai Suburban District area has been taken up under the theme 'Urban Agglomerations' and as per the NAQUIM 2.0 Toolkit (CGWB 2024), it was a multidisciplinary study with inputs from the fields of hydrogeology, groundwater geophysics, hydrochemistry and hydrometeorology carried out by a group of scientific collaborators and officials under Annual Action Plan (AAP) 2023-24 and extended to 2024-25. The main objective of the present study is to assess the potential of Groundwater Resources in Mumbai City & Suburban District.

To meet the objective, the following activities were carried out:

1. **Data gap analysis:** The data available regarding the exploratory wells, Geophysical Survey (VES), Ground water level and Ground water quality were compiled and analysed for adequacy of the same in Mumbai city and Mumbai Suburban district.

2. **Establishment of 60 KOW** and monitored in May (Pre-monsoon), August, November (Post monsoon) and January for the years 2023-24 to 2024-2025. Depth to water level maps has been prepared based on water level data collected from KOW for all four seasons.
3. **Collection of GW samples and Chemical Analysis**: 96 sample pre monsoon 2023. Out of which 60 shallow aquifers and 36 are from deeper aquifers and 96 for Pre-monsoon 2024 and post monsoon 2024 and analyzed for 15 parameters and Heavy metals. Ground water quality maps for EC, Cl, F, NO_3 has been prepared for both shallow and deeper aquifers.
4. **Geophysical Investigation: 33** VES carried out in the study area and data has been interpreted for subsurface lithology.
5. **GW Exploration** Under GW exploration **6 EWs, 1 OW and 2 Pz** has been constructed at **8** sites for deciphering aquifer parameters.
6. **Soil Infiltration test:** Soil infiltration studies were carried out at **4** sites in the Mumbai City and Mumbai Suburban area using Double ring infiltrometer. The infiltration tests were conducted for 60 to 80 minutes.
7. **Ground water resources estimation:** GWRE has been carried out in association with GSDA for Mumbai City and Mumbai Sub urban district for the assessment year 2024 and 2025.

The following are the deliverables for the study:

1. Potential of groundwater extraction in the study area
2. Supply and demand gap calculation
3. Demarcation of areas which are highly prone to ground water quality issues due to urbanization and industrialization
4. Demarcation of areas where water level is very shallow (less than 2 mbgl) and suggest conjunctive use of surface water and ground water in systematic and planned way.
5. Possibility of Recycle/Reuse of Grey Water and cost-benefit ratio estimation of installation of artificial recharge structure and treatment of grey water.
6. Vulnerability to seawater ingress.
7. Potential for use of storm runoff for artificial recharge.

1.5 MAJOR CHALLENGES IN THE STUDY AREA

Due to urban agglomeration the major challenge is sustainable management of water resources. Urbanization results in an extensive change in land use land cover. This may include loss of vegetation, increase in percentage of impervious surfaces (paved area) and changes in natural flow of storm water runoff directly to stream channels. All these processes result in greater proportion of precipitation going as surface runoff causing low infiltration to the aquifer and poor recharge in the area. The extensive built-up area causes water logging during monsoon season. Ground water quality is also affected due to effluent discharges and anthropogenic activities. There is an additional risk of saline water intrusion along the coastline due to over extraction of Ground water.

1.6 PREVIOUS STUDIES

There are limited number of scientific studies that have been carried out in the Mumbai area previously, details are given below table 1.4.

Table 1.4 Previous Studies

S.No.	Report	Year
1	Systematic Hydrogeological Survey for Greater Mumbai carried out by Dr. P. K. Naik, Sc-B	1989-90

2	Reappraisal Hydrogeological Studies in Mumbai suburban area by Shri. A.B Kawade, Sc-D	1999-2000
3	District Groundwater Information Brochure, Mumbai district by Shri. Sourabh Gupta, Sc-D	2013
4	Groundwater potential of greater Bombay Area, by R.M. Agashe, Director	1993

CHAPTER 2
PHYSIOGRAPHY, LAND USE & SOIL TYPE

2.1 PHYSIOGRAPHY

The Mumbai City and Mumbai Suburban Districts lie within in the western coast of India and the narrow coastal Konkan tract of Maharashtra sandwiched between Thane District on North and Raigad District on South. Most part of Mumbai area is at sea level and the average elevation ranges from 10 to 15 meters. The northern part of Mumbai is hilly with maximum elevation of 445 m above mean sea level (m amsl) at some of the peaks of hill ranges **(Fig 2.1).** The main physiographic feature of the study area is broad and flat terrain flanked by north – south trending hill ranges. The landforms of each of the islands have been classified into three physiographic terrains namely. Bombay Island Salsette Island and Trombay Island.

- **Bombay island** is divided into six sectors such as 1. Western Ridge comprising of Malabar, Cumballa and Worli Hills, 2. Western coastal low tract,3. The central flat terrain of the island the central including the initial lowlands between the original seven island of Bombay, 4. Eastern ridge comprising of Colaba,5. Dockyard, Cotton green, Sewree, Koliwada and Sion Hills,6. Eastern coastal marshy low lands including the harbour area adjoining Thane Creek which separates Bombay from the main land.
- **Salsette island** is relatively more complex. Its physiography has been divided into seven sectors, viz: a) Outer Western Ridge comprising of Madh, Aksa, Manori, Gorai and Uttan Hills, b) Western Coastal low-lying tract, c) Inner Western Ridge comprising of of Pali, Gilbert and Bondivili hills situated at Bandra, Andheri, and Jogeshwari respectively, d) Flat marshy land between inner and outer western ridge. e) Central hill complex occupying the large tracts of the central, northern and eastern Salsette island. f) Flat land between the western ridge and the central hill complex, g) Amphitheatre type low lands surrounded by hills within the western ridge and the central hill complex. The Powai – Kanheri hills form the largest hilly terrain in the central part of the Salsette island and are the feeder zone for the three lakes viz., Powai, Vihar and Tulsi
- **Trombay Island** is divided into two sectors, Hilly Tract and Low marshy lands surrounding hills. Trombay island has north – south running hills with maximum elevation of 300 m above man sea level (m amsl). Malabar, Colaba, Worli and Pali hills are the isolated small ridges trending north –south in the western part of the district. The hill ranges form almost parallel ridges in the eastern and western part of the area. The Powai – Kanheri hill ranges are the other hill extending in the eastern and central part running NNE – SSW. There are a number of creeks, dissecting the area. Among them, Thane is the longest creek. Other major creeks are Manori, Malad and Mahim which protrudes in the main land and give rise to mud flanges and swamps.

2.2 DRAINAGE

The area is drained by Mahim, Mithi, Dahisar and Polsar rivers. These small rivers near the coast, form small rivulets which inter mingle with each other resulting in swamps and mud flats in the low-lying area **(Fig 2.2).** The drainage pattern of the three islands is described as follows:

Bombay Islands: Formerly Bombay Island was a group of seven islands, which were separated by low marshlands. These marshy tracts were later reclaimed and the islands were joined together artificially as one big island which was separated from the other islands in the north and northeast by Mahim River and the Chembur marshlands. Thus, at present, the original features of land surface except for a few hills, are totally lost. No permanent major features of drainage have been retained in Bombay city except for the main sluice outlets in the form of streams draining westwards into the sea at the northern and southern ends of Worli hill. All the drainages from the hills have been channelized into artificial drains which are connected to the underground sluice system.

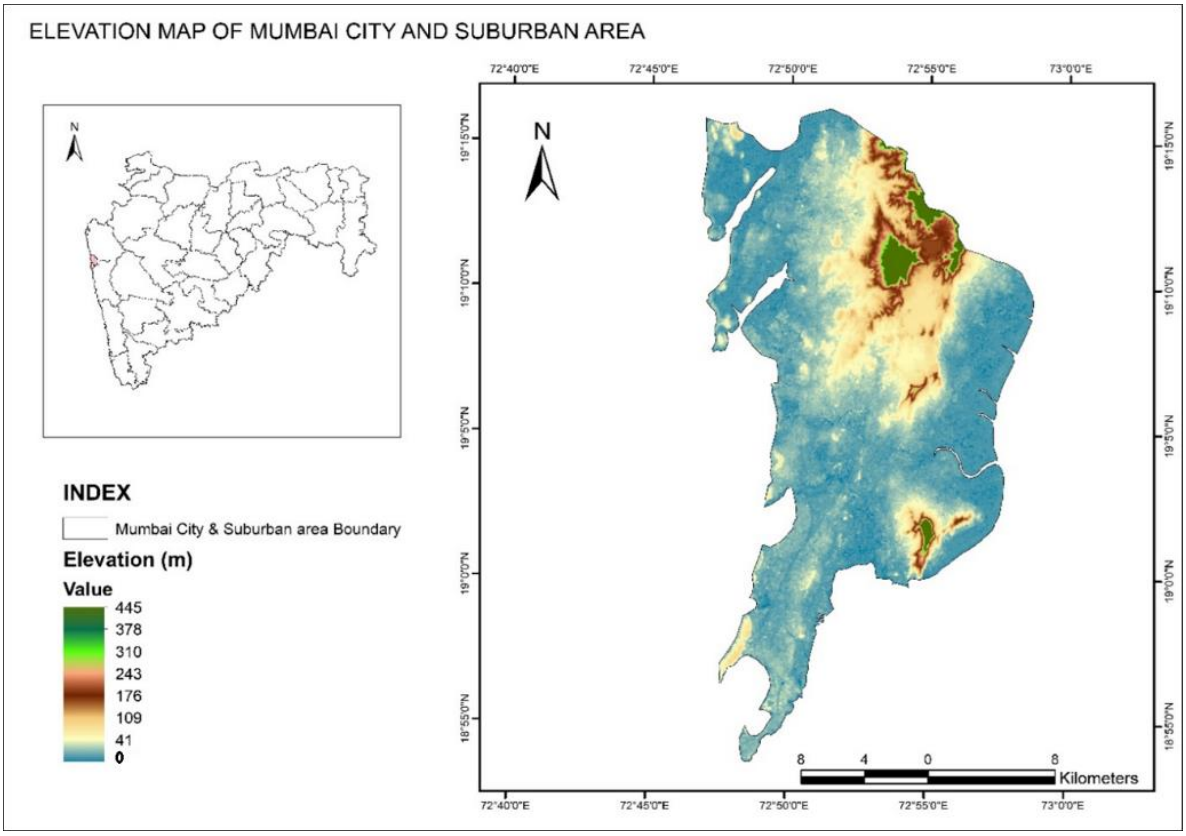


Fig 2.1: Elevation Map Mumbai city and Mumbai Suburban District

Salsette Island: The drainage pattern of the salsette Island is complex. The stream flows occurs in Westward and Eastward direction. Westward direction may be considered as the main direction as there are many more streams in this group. They ultimately constitute three major estuarine river systems, from north to south, i.e 1) Dahisar River 11) Poisar River and iii) Mahim River. The creeks on the eastern coast are in the form of wide water tracts in the coastal marshland, that worth mentioning are situated east of Vikhroli, Kanjur, and Bhandup. All these drains into Thane creek, the southwest flowing arm of Ulhas River.

Trombay Island: The drainage of the Central hill mass of Trombay Island is somewhat radial in pattern. Most of the streams emerge from several spurs of the hills on the northern side and drain into the streams emerging from the eastern flank of the hill complex of Salsette Island, merge into a broad estuarine channel which drains into Thane creek. The, streams emerging from the eastern and western land of the main ridge of Trombay are very short, and drain directly into the marshy tract at the foot of the slope.

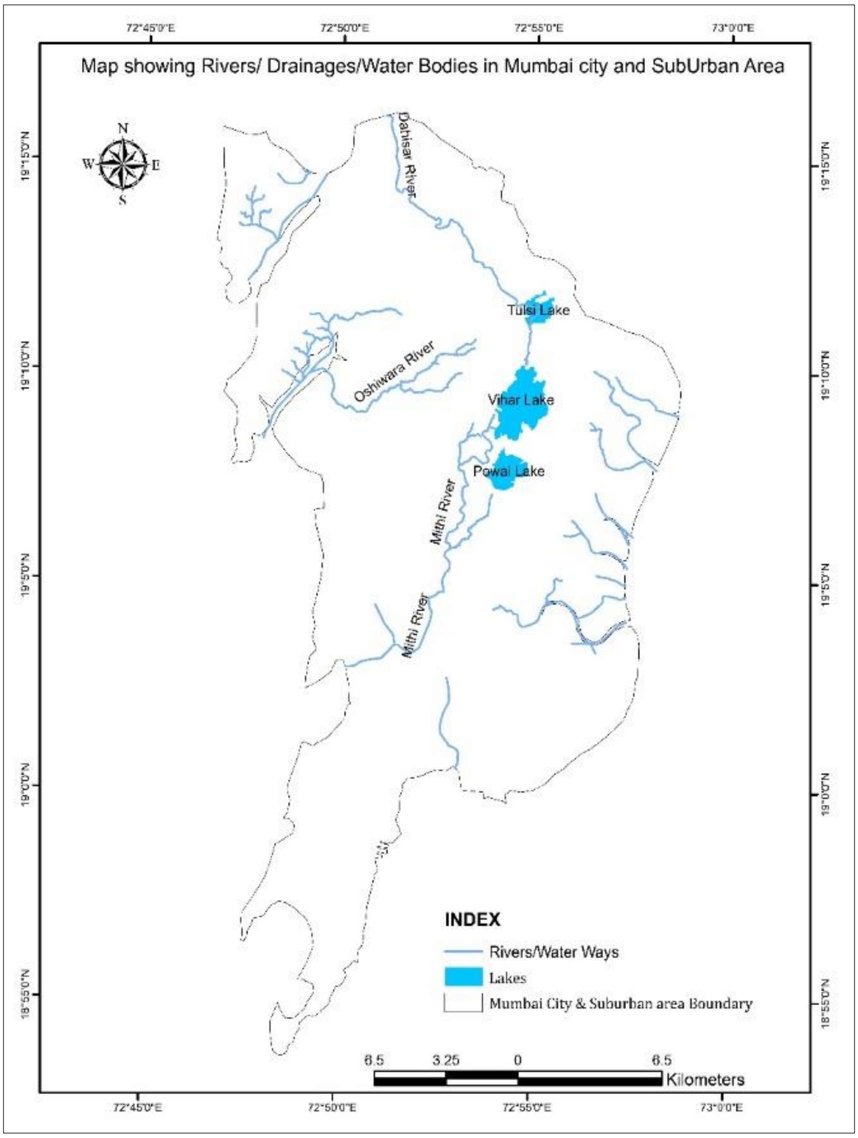


Fig 2.2: Drainage Map of Mumbai

2.3 GEOMORPHOLOGY

The major geomorphological features occurring in the study area includes Linear ridges, Residual Hills, Alluvial Fans, Fluvial Plains, Wetlands and Mudflats and beaches **(Fig.2.3).** Description is given in the Table 2.1

Table 2.1: Major geomorphological features occurring in the study area

S.No.	Geomorphological Feature	Description
1	Linear ridges, residual hill, cuesta and mesa	In Borivali National Park, Pali Hills, Cumbala Hills, Malabar Hills and Mumbra–Belapur Hill ranges comprises of Linear ridges, residual hill, cuesta and mesa are resistant landforms and groundwater prospect in these geomorphic units is poor.
2	Alluvial fans	Occurs near the foot hills
3	Fluvial plains	Fluvial plains are pediments developed when running water deposits material in valleys. Two types of pediments:

		shallow (foothills of the Borivali Hills) and buried pediments (occur between the shallow pediment and creek)
4	Wetlands/mudflats	Marshy or swampy areas that are mainly made up of fine sand and silt and are covered by salt water either permanently or temporarily. Seen beside the creeks. Thane is the longest creek. other major creeks are Manori, Malad and Mahim which protrudes in the main land and give rise to mud flangs and swamps.
5	Salt pans	Observed in some of these wetlands
6	Beach	In the study area, sand and rocky beaches are present along the western coast. Sediment thicknesses in these beaches are not very high.

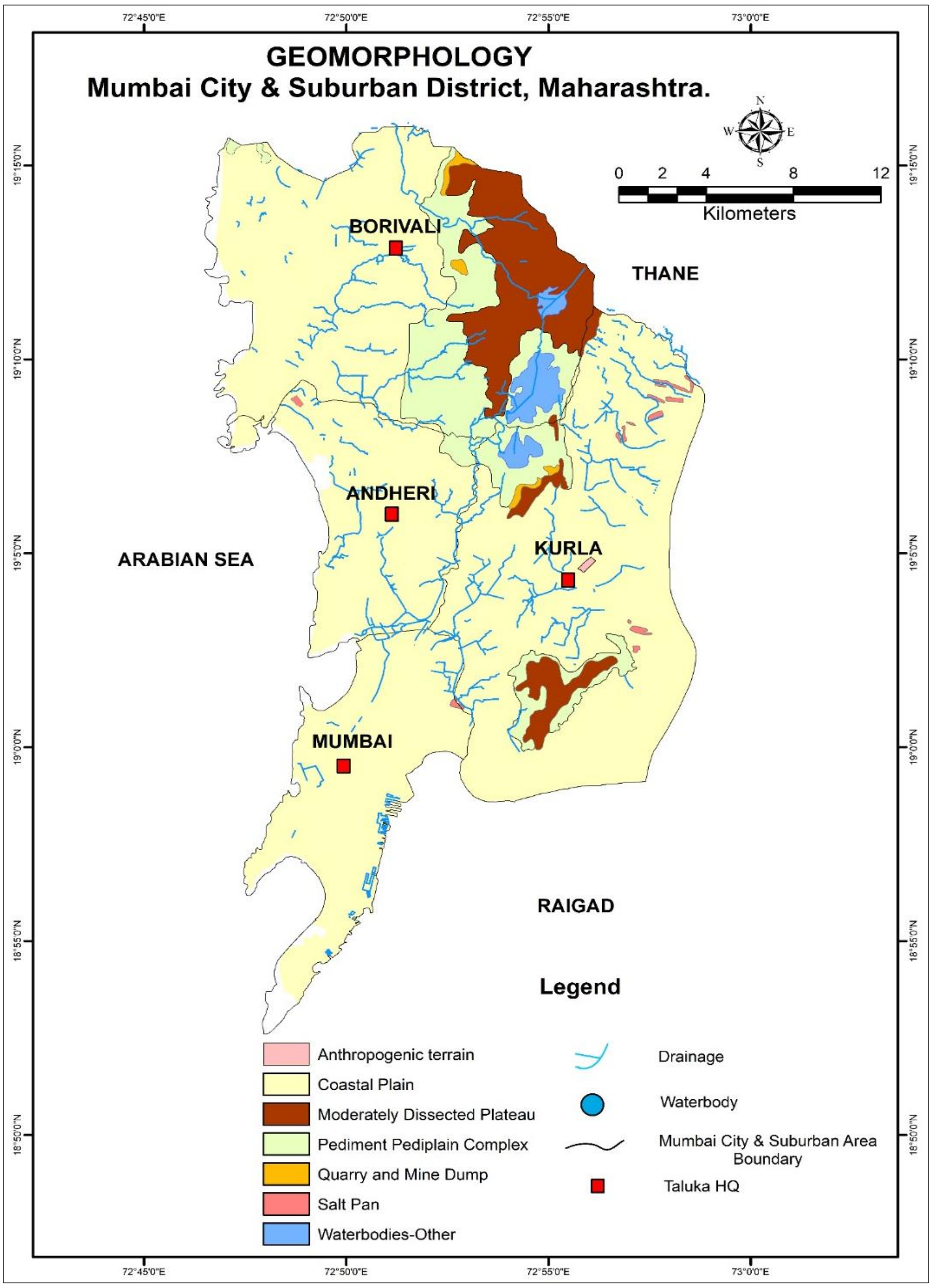


Fig 2.3: Geomorphological Map of the Study Area

2.4 LAND USE

Major part of the Mumbai city and Suburban District is under urbanization or built-up area other than that Forest area as Sanjay Gandhi National Park, open area as Mangroves/ lakes areas are also prevalent **(Fig 2.4).**

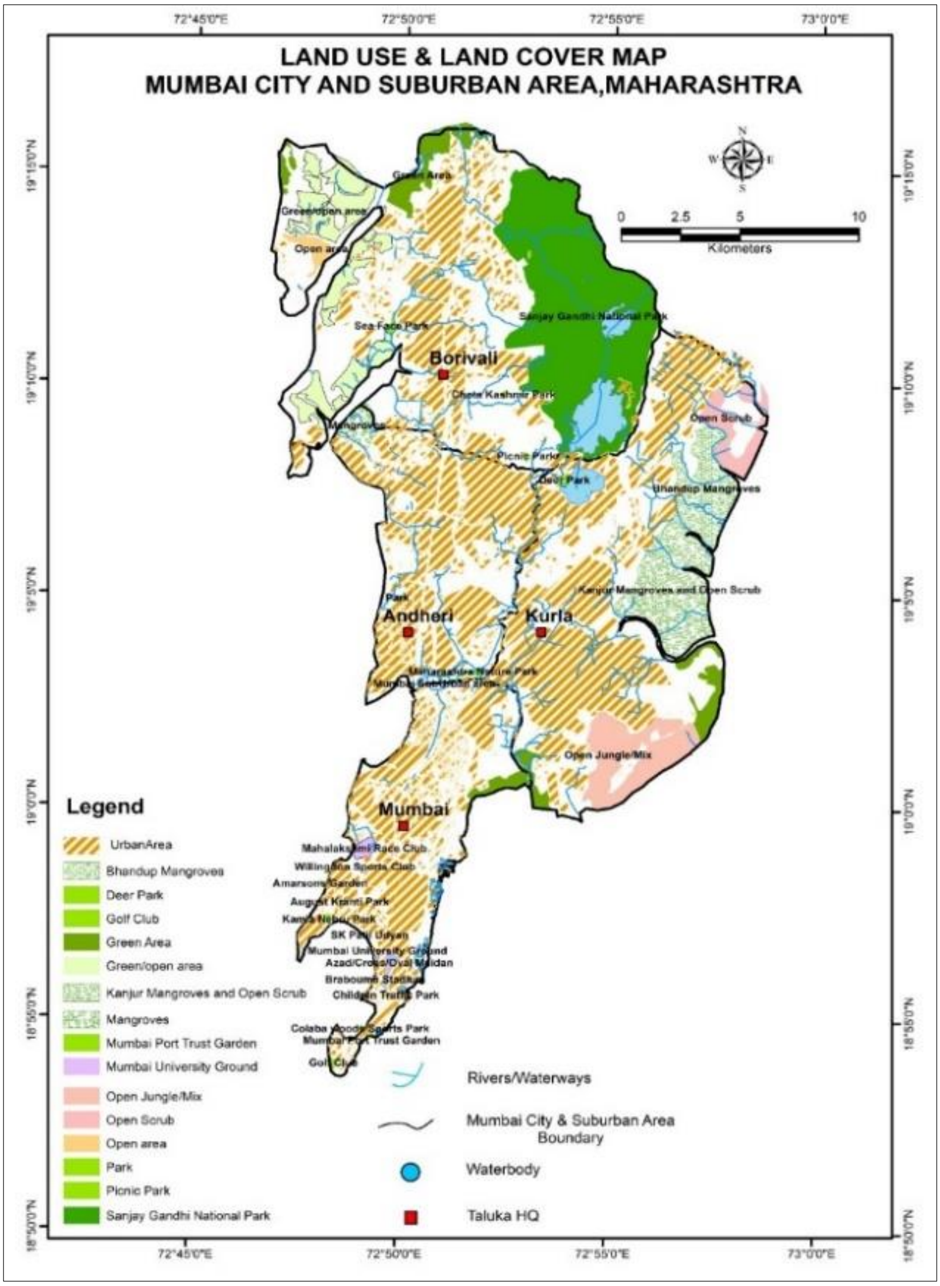


Fig 2.4: Land use pattern in Study Area

2.5 SOIL TYPE

The soil cover in the study area is predominantly sandy due to its proximity to the sea. In the suburbs, the soil cover is largely alluvial and loamy. The underlying rock of the region is composed of black Deccan basalt flows, and their acidic and basic variants dating back to the late Cretaceous and early Eocene eras. Two types of soils have been observed in the district viz., medium to deep black and reddish colored soil. To get a detailed understanding of the soil type, soil infiltration studies were taken up under NAQUIM 2.0 in the study area. The details are given below.

2.6 SOIL INFILTRATION STUDIES

Infiltration in general, may be defined as the phenomenon of movement of water into the soil through the soil surface. The understanding of the phenomenon enables us to estimate more effectively the amount of run-off originating from precipitation and the results thereof can be applied more confidently to resolve various problems. During the present study, soil infiltration studies were carried out at 4 sites in the Mumbai City and Suburban areas using Double ring infiltrometer. The diameter of Inner ring is 30cm and that for the Outer ring is 60cm. The infiltration tests were conducted for 60 to 80 minutes. Summary of the test and results is given in table 2.2.

A perusal of the table shows that the test has been conducted both Park, Open spaces and open land as well. Mumbai is an urban agglomerate and hence finding an open or barren unused land is very difficult. The analysis show that in most places the soil infiltration rates were high indicating the loose well assorted soil that may have been ploughed and/or transported from other places. Fig 2.5, 2.6, 2.7, 2.8

Table 2.2: Summary of soil infiltration test

S.No	Site Name	Taluka	Latitude	Longitude	Land Use	Infiltration Rate (cm/hr)	Soil type
1	Agarwadi-Govandi East	Mumbai City	19.0466468	72.046468	Park	5.6	Loose, well assorted soil
2	St. George Hospital	Mumbai City	18.941355	72.837473	Park	13.5	Loose, well assorted soil
3	CTIRC Training Centre, Kaju pada	Borivali	19.233641	72.867782	Barren land	1.5	Loam
4	Film City, Goregaon	Andheri	19.161241	72.885765	Barren near construction area	45.6	Loose, well assorted soil

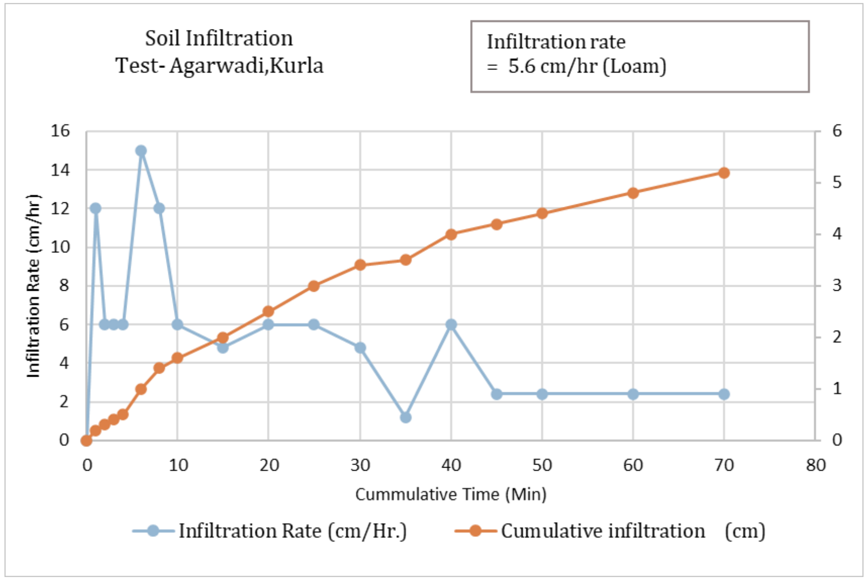


Fig 2.5: Soil Infiltration Test- Agarwadi, Kurla

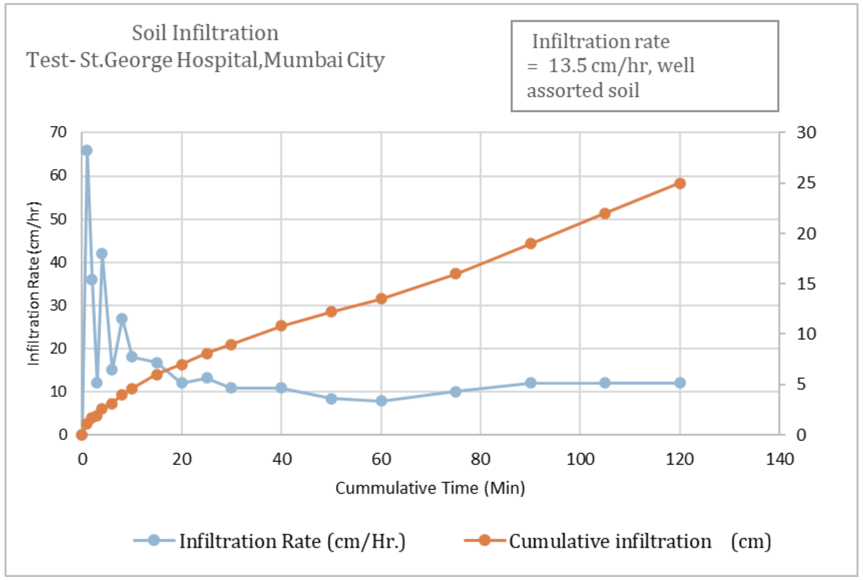


Fig 2.6: Soil Infiltration Test- St. George Hospital, Mumbai City

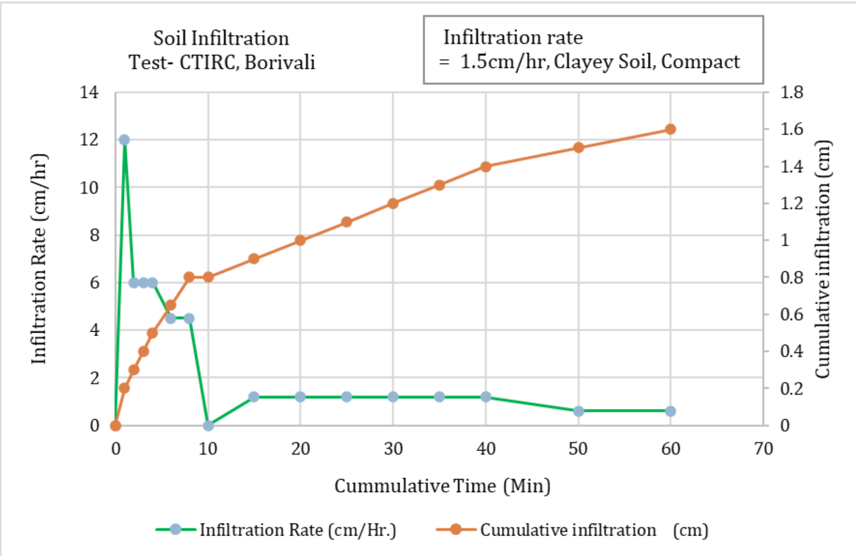


Fig 2.7: Soil Infiltration Test- CTIRC, Borivali

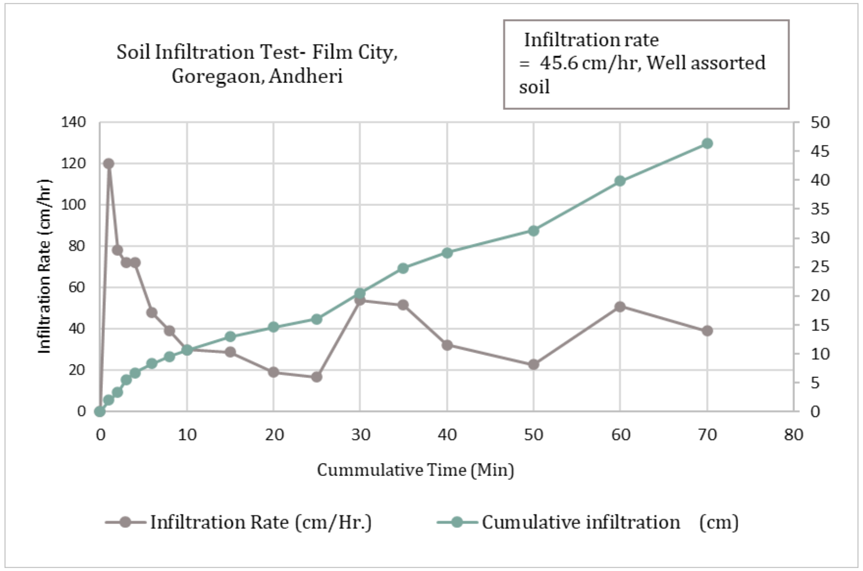
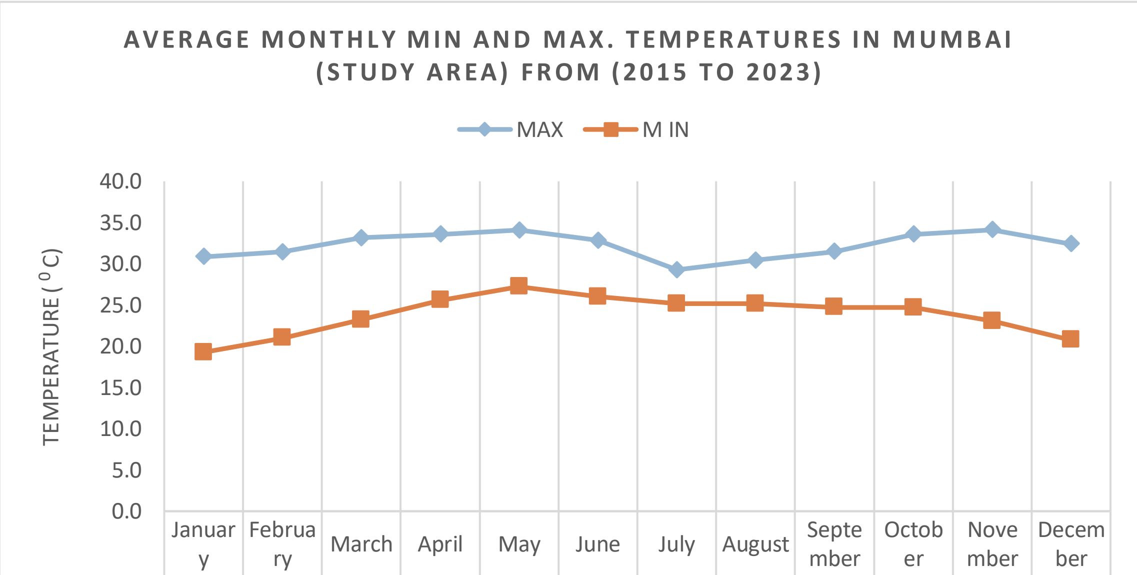


Fig 2.8: Soil Infiltration Test- Film City, Goregaon, Andheri

CHAPTER 3
CLIMATE AND RAINFALL

Geographically, the Mumbai Coast lies within the tropical belt facing the full impact of south-west monsoon with western Ghats to its east. The climate of the area has greatly been influenced, owing to its proximity by the Arabian Sea. The climate of the Mumbai City and Mumbai Suburban districts is characterized by an oppressive summer, dampness in the atmosphere nearly throughout the year and heavy south – west monsoon rainfall from June to September. The climate is tropical, hot all year round, with a long, sunny season from early or mid-October to early June and a rainy season from June to September or early October. The latter is due to the south-west monsoon and is characterized by stuffy weather, cloud cover and frequent rains, which occur almost every day and are sometimes torrential.

During the pre-monsoon period, from March to May, the heat becomes intense, in fact, the temperature can sometimes reach 38-40 °C; this partly happens also in the period after the monsoon, in October and November, when it can reach 36-38 °C. **(Fig 3.1).** The normal rainfall for Mumbai city and Mumbai suburban is 2111 mm and 2420 mm respectively. The rainfall normally occurs during the months of June, July, August, September and October. The maximum rainfall is between June and October and remaining part during the months from November to May is almost dry. The Isohyet Map for the study area has been prepared from 1980 to 2020 for IMD rain gauge stations **(Fig 3.2)**



	January	February	March	April	May	June	July	August	September	October	November	December
MAX	30.9	31.4	33.1	33.6	34.1	32.8	29.3	30.4	31.5	33.6	34.1	32.4
M IN	19.3	21.0	23.2	25.6	27.2	26.0	25.1	25.2	24.7	24.7	23.1	20.8

Fig 3.1: Average Monthly Minimum and Maximum Temperatures in Mumbai City & Suburban area

The normal annual rainfall over the districts is 2111 mm to about 2420 mm for Mumbai City and Mumbai Suburban District respectively. The Monthly variation of rainfall during the last 120 years for Mumbai City and Mumbai Suburban district is shown in **(Fig 3.3a & b).** Throughout these years, Rainfall shows a rising trend. This data is used for the Yearly, Monthly and Seasonal Rainfall-Probability analysis.

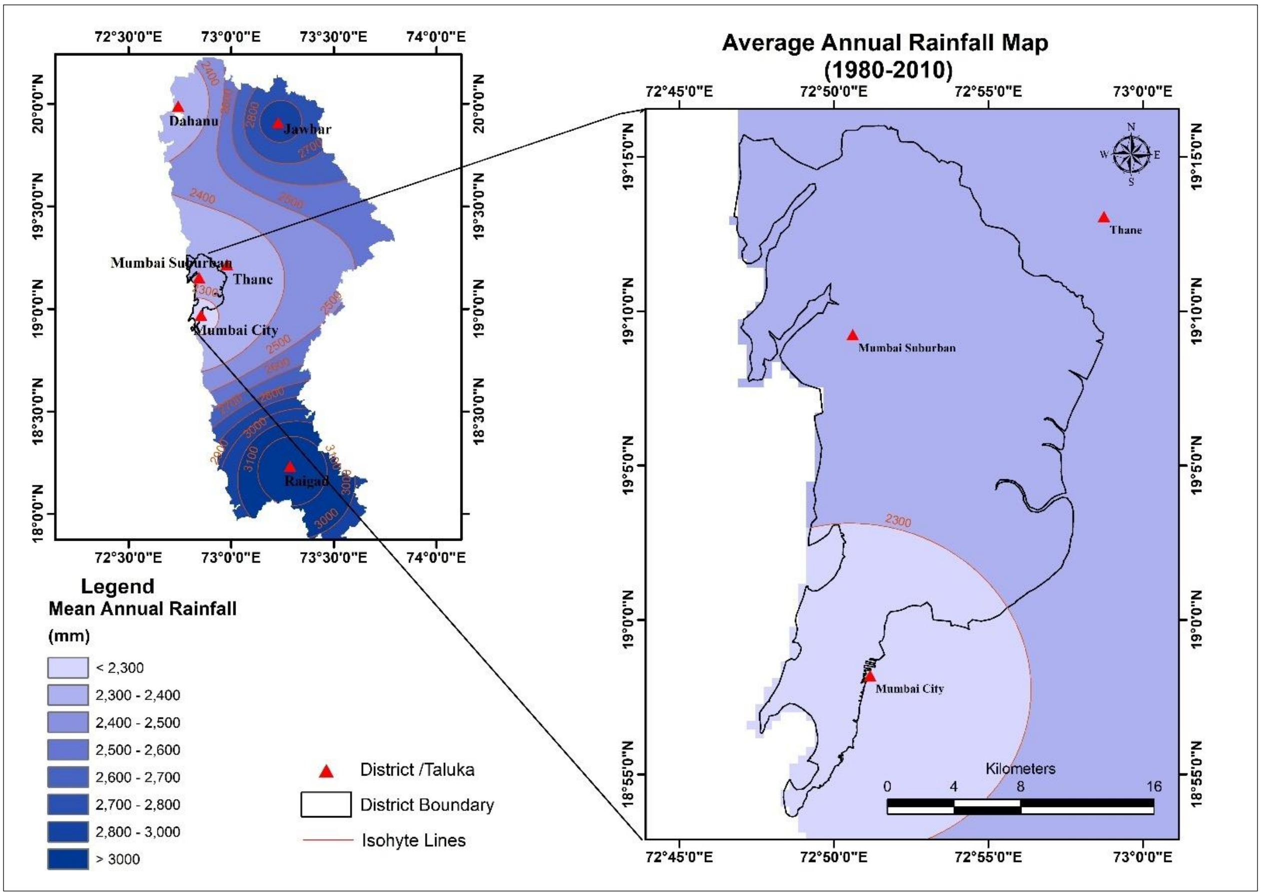


Fig 3.2 Annual Rainfall in Mumbai

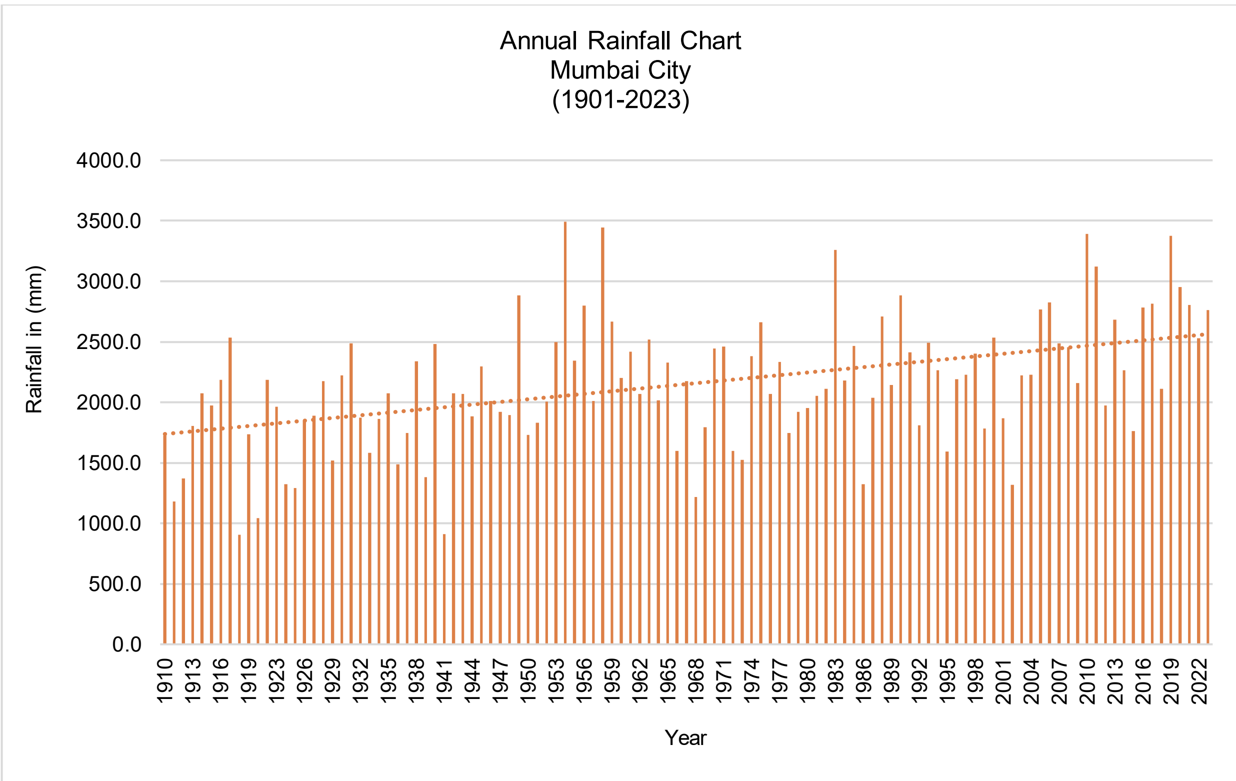


Fig 3.3a: Year wise variation of Seasonal Rainfall during the last 100 years in Mumbai City area

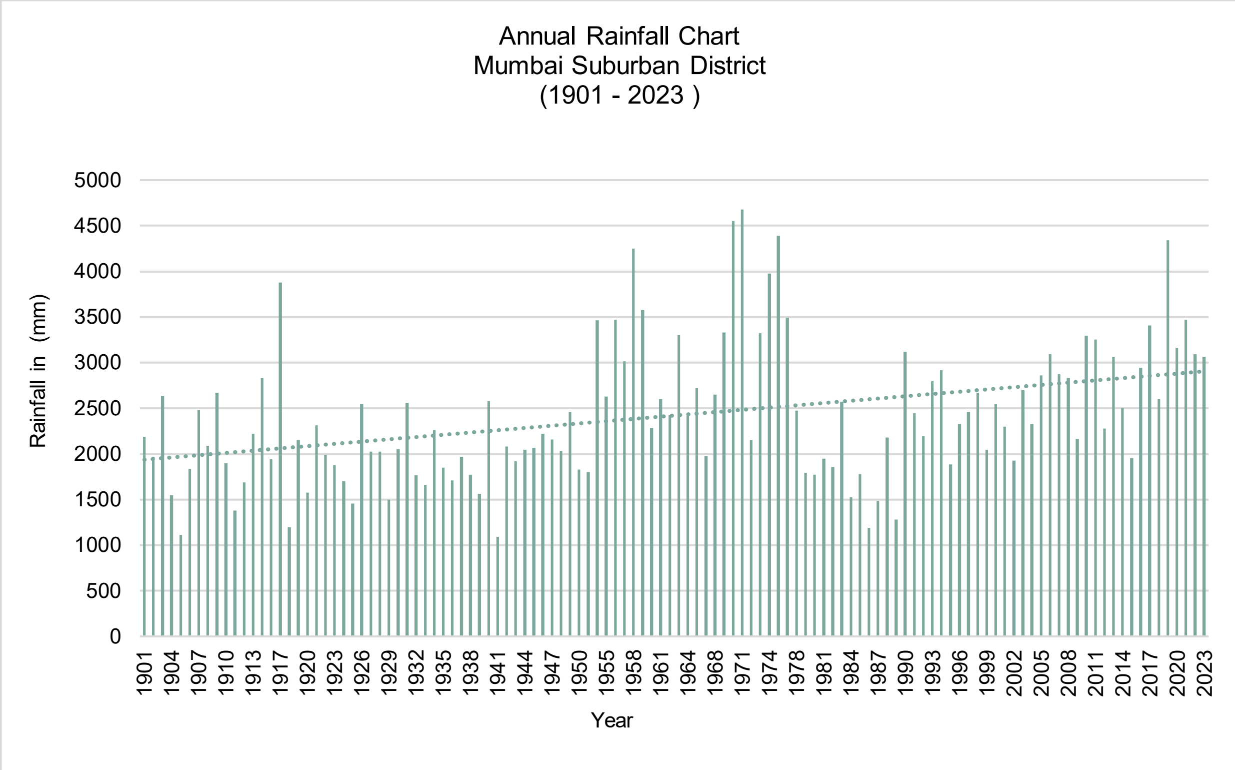


Fig 3.3b: Year wise variation of Seasonal Rainfall during the last 100 years in Mumbai Suburban

Rainfall is the most important natural hydrologic event and is a unique phenomenon varying both in space and time. In the area, basic knowledge of rainfall distribution during individual months, seasons and year is of vital importance for optimum development of water resources and for planning of agriculture operation. Rainfall data of all the rain gauge stations of the area have been collected from available sources and are subjected to various types of analysis to understand the characteristics of the rainfall.

3.1 RAINFALL-PROBABILITY ANALYSIS

The methodology adopted in this study is Rainfall Statistics (Table 3.1), Probability analysis using plotting position and probabilistic methods (Table 3.1). The annual rainfall data is analyzed and the variation in distribution over the area is studied with the statistical parameters i.e Arithmetic Mean. In general, there are various plotting positions and Probabilistic Methods used for analysis (Table). In this study two methods are used for Rainfall probability analysis. One is Weibull Method and second is Chegodayev Method.

1. **Weibull Method** is a continuous probability distribution type where in rainfall amounts are assigned with a rank and the corresponding probabilities are found out using probability density function P(X):

Which is,

$P(X) = m/(N+1)$

Where,

'm' is the Rank of the Data

'N' is equal to Length of the Sample (No. of Years)

Table 3.1: Plotting position and Probabilistic methods

S. No.	Plotting position methods	Probabilistic methods
1.	California = m/N	Normal Distribution
2.	Hazen (m-0.5)/N	Log-Normal Distribution
3.	**Weibull = m / (N + 1)**	Pearson Type-III Distribution
4.	Beard = (m - 0.31) / (N + 0.38)	Log-Pearson Type-III Distribution
5.	**Chegodayev = (m - 0.3) / (N + 0.4)**	Extreme Value Type-I Distribution
6.	Blom (m-3/8)(N+1/4)	
7.	Tukey = (3m-1)/(3N+1)	
8.	Gringorten = (m - 0.44) / (N + 0.12)	
9.	Cunnane = (m - 0.4) / (N + 0.2)	
10.	Adamowski = (m - 1/4) / (N + 1/2)	

where, m is rank of the data and N = length of the sample (no. of years)

The rainfall data are ranked in descending order and Weibull method is utilized to derive the probability of the return period. After arranging the total rainfall in descending order and numbering them from 1 to 24, now we need to find the probability for each rainfall, P= m/ (n+1), n =24, Returning Period (T) = 1/P.

For Example (Table 1, s.no 1):

Total Rainfall = 3393.6 mm, m=1
P= 1/ (24+1), T= 1/P
=0.04, T= 25

That means the chance to rainfall a 3393.6 mm in one year is once each 25 years. The Tables given below show the return periods calculated for both Mumbai city and Mumbai Suburban District for a period of 2 years. Based on the calculated return value period (T), A Return period Curve is prepared shown in fig 3.4 and 3.5

Table 3.2: Frequency and probability Analysis for Rainfall in Mumbai City District (2000-2023, 24 years)

S.No.	Year	Annual Rainfall in (mm)	Rank	Probability (P)	Return Period (T)
1.	2010	3393.6	1	0.04	25
2.	2019	3378.11	2	0.08	12.5
3.	2011	3121.8	3	0.12	8.33
4.	2020	2953.73	4	0.16	6.25
5.	2006	2825.7	5	0.2	5
6.	2017	2815.92	6	0.24	4.17
7.	2021	2803.19	7	0.28	3.57
8.	2016	2781.03	8	0.32	3.13
9.	2005	2769.8	9	0.36	2.78
10.	2023	2762.2	10	0.4	2.5
11.	2013	2681.64	11	0.44	2.27
12.	2000	2532.4	12	0.48	2.08
13.	2022	2528.96	13	0.52	1.92
14.	2007	2488.9	14	0.56	1.79
15.	2008	2455.4	15	0.6	1.67
16.	2014	2266.36	16	0.64	1.56

17.	2004	2227.5	17	0.68	1.47
18.	2003	2224.2	18	0.72	1.39
19.	2009	2157.3	19	0.76	1.32
20.	2018	2113.9	20	0.8	1.25
21.	2012	1974.35	21	0.84	1.19
22.	2001	1867.6	22	0.88	1.14
23.	2015	1764.32	23	0.92	1.09
24.	2002	1318.9	24	0.96	1.04

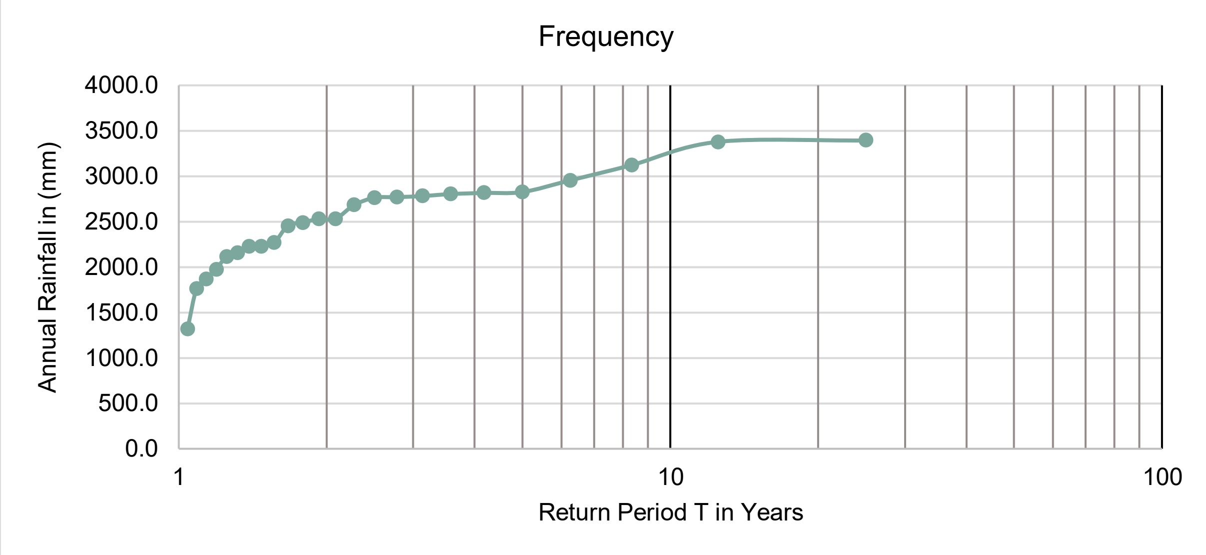


Fig 3.4: Return period curve for Mumbai City District

Table 3.3: Frequency and probability Analysis for Rainfall in Mumbai Suburban District (2000-2023, 24 years)

S. No	Year	Annual Rainfall in (mm)	Rank	Probability (P)	Return Period (T)
1.	2019	4338.72	1	0.04	25
2.	2021	3473.05	2	0.08	12.5
3.	2017	3404.65	3	0.12	8.33
4.	2010	3295.4	4	0.16	6.25
5.	2011	3250.48	5	0.2	5
6.	2020	3159.22	6	0.24	4.17
7.	2022	3093.56	7	0.28	3.57
8.	2006	3089.67	8	0.32	3.13
9.	2023	3065.39	9	0.36	2.78
10.	2013	3062.34	10	0.4	2.5
11.	2016	2945.15	11	0.44	2.27
12.	2007	2873.52	12	0.48	2.08
13.	2005	2860.04	13	0.52	1.92
14.	2008	2834.56	14	0.56	1.79
15.	2003	2698.72	15	0.6	1.67
16.	2018	2599.48	16	0.64	1.56
17.	2000	2543.35	17	0.68	1.47
18.	2014	2504.73	18	0.72	1.39
19.	2004	2324.01	19	0.76	1.32
20.	2001	2301.93	20	0.8	1.25
21.	2012	2274.84	21	0.84	1.19
22.	2009	2165.36	22	0.88	1.14

23.	2015	1951.24	23	0.92	1.09
24.	2002	1927.85	24	0.96	1.04

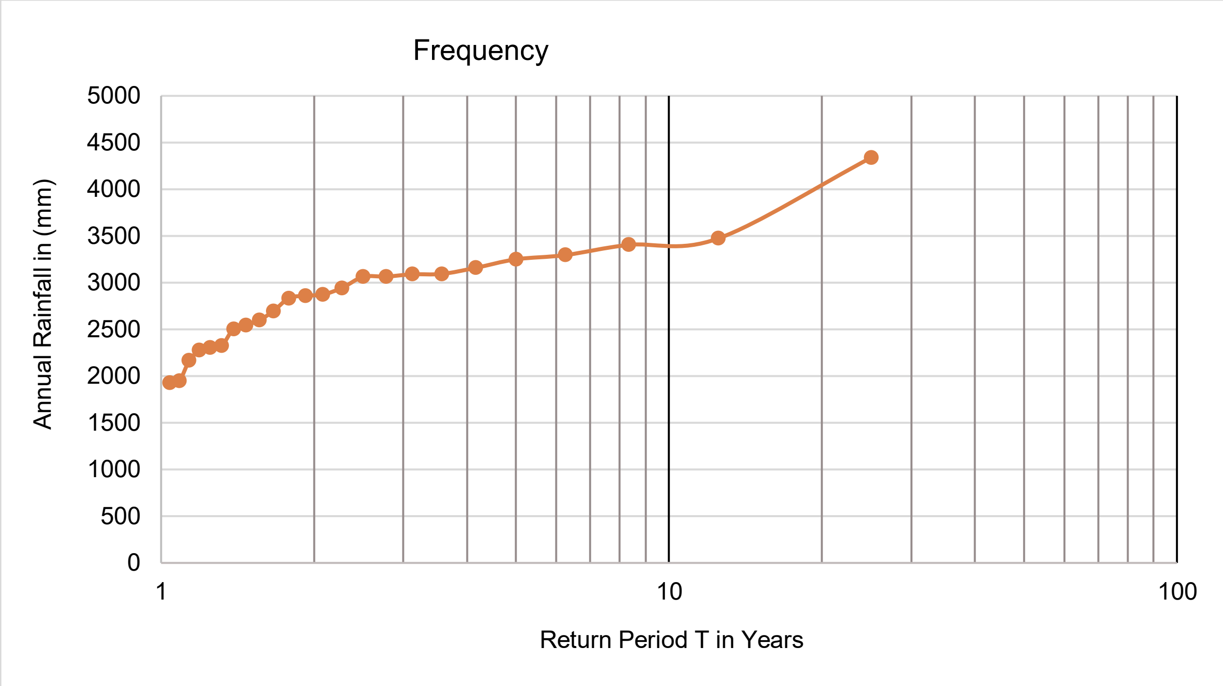


Fig .3.5: Return period curve for Mumbai Suburban District

2. Chegodayev's Method

Occurrence of rainfall for different probability percentages is worked out for all rain gauge stations by using "Chegodayev's formula". It has been worked out by arranging the annual rainfall in descending order and assigning ranks. The probability percentage has been calculated by using following equation

$$P = (m-0.3/n+0.4) \times 100$$

Where,

P = Probability in percentage
m = Rank of variant
n = Total number of variant

From this it can be seen that the first variant has the least probability of occurrence and in the case of last variant the probability of occurrence is the highest. Based on the method, probability percentage (P) has been computed for two rain gauge stations using the rainfall data from 2014 to 2023. Probability curves are drawn by plotting the variants in descending order against probability percentage (P) and are shown in Fig 3.6 a & 3.6 b. From the curves, occurrence of rainfall at particular percentage probability (10, 20...90) are obtained and are given in Table 3.4. From the above Table-3.4, it is revealed that 2400 mm in the Mumbai city and 2700 mm in the Mumbai Suburban district rainfall can be expected to occur in 70% and dependable rainfall for the area can be calculated with the help of probability analysis for the construction of Rainwater Harvesting Structures and recharge structure in the area.

Table 3.4: Probability Analysis of Occurrence of Annual Rainfall

S. No.	Probability (%)	Rain gauge Station –Rainfall in mm	
		Mumbai city	Mumbai Sub-Urban
1	10	3200	3850
2	20	3100	3700
3	30	2950	3550
4	40	2800	3300
5	50	2700	3100
6	60	2550	2950
7	70	2400	2700
8	80	2250	2550
9	90	2100	2500
10	100	2000	2150

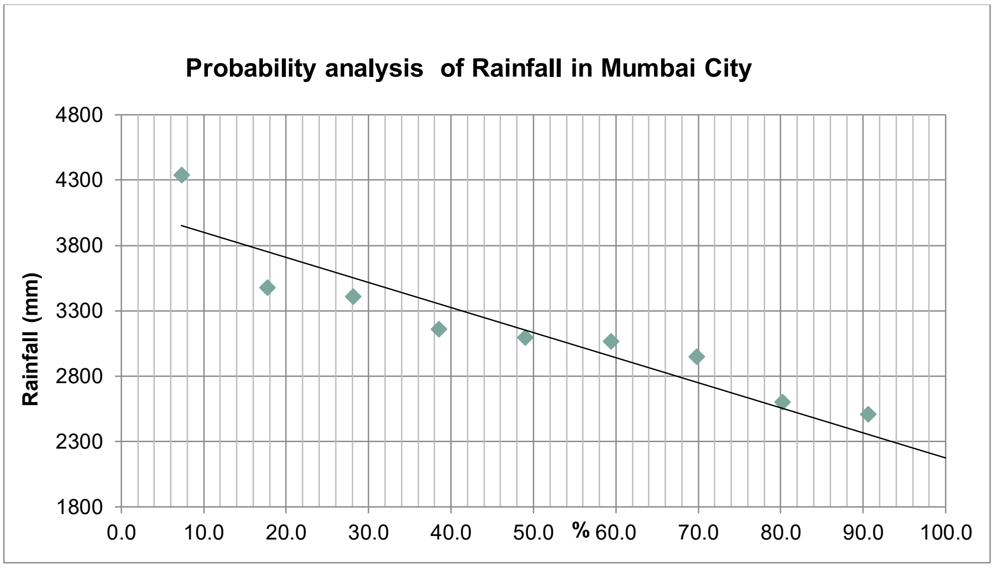


Fig- 3.6a. Probability analysis of Rainfall in Mumbai City

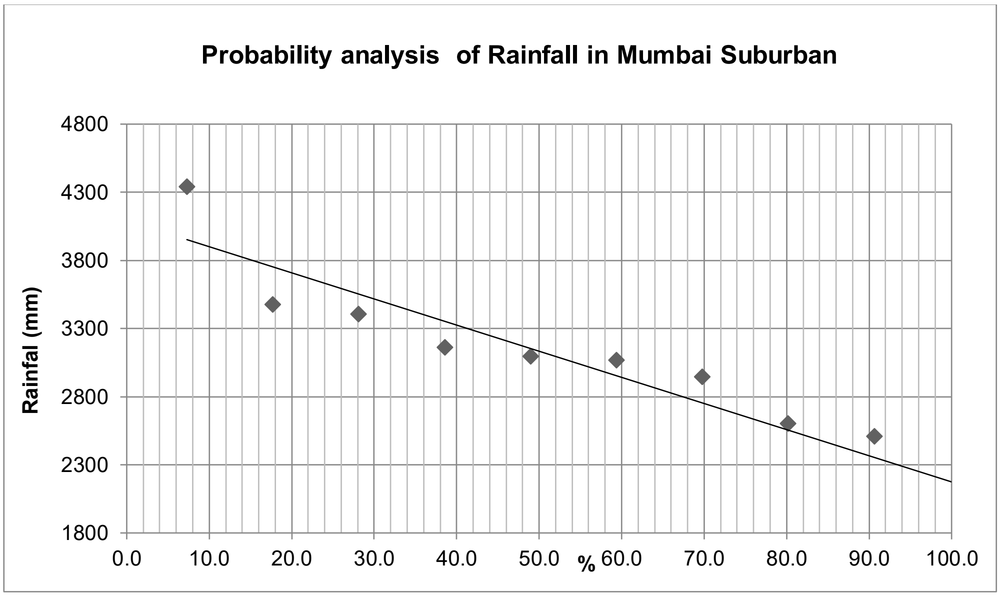


Fig- 3.6b. Probability analysis of Rainfall in Mumbai Suburban

CHAPTER 4
GEOLOGY

4.1 GEOLOGY OF MUMBAI CITY

Mumbai, Gateway to Asia and financial capital of the country, is the capital of Maharashtra is the leading port on the west coast of India. Mumbai is built on group of islands, lying off the Konkan coast. On the western side of the city is the broad sweep of the harbour. In land, the city is formed by the backdrop of the Western Ghat mountain chains. Mumbai city has an area of about 69 sq. kms and falls within latitudes 18˚56' to 19˚17' N and longitude 72 ˚ 47' to 72 ˚ 58' E, in Survey of India Toposheet nos.47 A and B, F. The city is surrounded by Arabian sea to the west and Thane district to the east and north. The city lies on low, flat land a quarter of which is below the sea level. On the either side are low hills. The eastern hills end in the Nariman point. At the end of the western hill is Malabar hill which, at only 55 metres above sea level, is the city's highest point. Land reclamation schemes have brought development of the foreshore, but marshes particularly the Thane creek still covers large area.

Geologically, the entire land is occupied by Deccan Basaltic flows and the associated pyroclastic and the plutonic rocks of upper cretaceous to Palaeogene age. The Deccan basalt of Mumbai Island is considered to be the youngest basalt of Eocene age. Overall, the geology around Mumbai indicates presence of ultrabasic, basics and acid differentiate with intertrappean beds, agglomerates and tuffs. The ultrabasic differentiates are of limited occurrence. Acid rocks include Rhyolite and Quartz Trachyte. The agglomerate and tuff include reworked material as indicated by current bedding and graded bedding. The basalt flows of the area have been grouped into compound flows (i.e. pahoehoe type), simple flows and flows which do not fall in the above categories and hence termed as unclassified flows. The basaltic flows are typically of quartz and hypersthene normative with the minor amount of olivine Theolites. The lava pile of Mumbai is intruded by columnar joined medium grained dolerite dykes.

The Deccan Trap basalt has been classified as Sahyadri Group which has been divided into three formations viz. the lower most Upper Ratangarh Formations followed by Elephanta Formation and topmost Borivali Formation. The upper Ratangarh Formation is restricted to two patches, one from Kurla to Mulund and the other at SE of Kurla. This formation consists of simple 'aa' type of flow. The middle formation i.e. Elephanta formation comprising of simple and compound flows occur as small isolated patches in the SE corner of the city near Thane creek and covers very negligible area. The rest of the area is covered by rocks of Borivali Formation where it is not occupied by alluvium. Normally, alluvium is restricted to the western half of the area. Laterite occurs as small isolated patches in the area north and east of the Mulund. Bauxite occurs within the laterite in irregular shape and is not of any economic importance.

4.2 GEOLOGY OF MUMBAI SUBURBAN

Mumbai Suburban District has an aerial coverage of 386.56 sq. km area and is extended between longitudes 72˚ 45' to 73˚ N and latitudes 18 ˚58'30" to 19 ˚16. E and falls in Survey of India degree sheet no. 47A and 47 F & B. It is bounded by Thane district in North and East, Mumbai City district in the South and Arabian Sea in the West. The district headquarter is in Bandra. Other important localities are Trombay, Kurla, Veswa, Malad, Gorai and Manori. The National Highway no.8 and a broad-gauge line of Western Railway connecting Mumbai and Ahmadabad passes through the area

The area has two distinct physiographic domains viz. (i) coastal plain in the West and (ii) a lower elevated landform in the East. The coastline, trending NNW-SSE, is heavily indented, with a number of creeks, prominent amongst them are Manori, Malad and Thana. The coastline is either rocky or has sandy beaches. Mud flats and saltpans are also present at places. The coastal plain extends as a narrow strip with an average width of 10 km and elevation difference of about 50 m. The highest elevation of the area is 391 m above msl at Mulund while the lowest elevation is 0 m i.e. sea level. The Mithi River is the main river flowing in the district. The river originates from the overflow of Vihar Lake and also receives the overflows from the Powai Lake about 2 Km later. It flows for a total 18 km before it meets the Arabian Sea at Mahim Creek. Many important places have adorned the beauty of this district, including Mount Mary Church, Jogeshwari Caves, Mahakali Caves, Essel World Water Kingdom, Marve Beach, Aksa Beach, Madh Island, Malwani, Sanjay Gandhi National Park, Aarey Colony, Kanheri Caves, Film City, Tulsi Lake, Vihar Lake and Powai Lake.

Geologically, the major part of the district is occupied by the basaltic flows of Elephanta and Borivali formations of the Sahyadri Group, Deccan Trap Supergroup belonging to Upper Cretaceous to Palaeocene age, Laterite of Cenozoic age and alluvium of Quaternary age are also found at places. An arcuate fault originating from Mahim in the North up to Mumbai City in South passes through the district and separates two distinct basaltic flow sequences. The basaltic flows to the North and East of the fault is a sequence mainly of pahoehoe flows. On the basis of marker horizons, lithological characters and geomorphic breaks, the basaltic lava pile to the east of the arcuate Bombay fault has been divided into five different formations viz Salher Formation, Lower Ratangarh Formation, Upper Ratangarh Formation, Karla Formation and Elephanta Formation. The basaltic lava flows exposed to the south and west of the fault have different flow morphologies and associated volcanic and plutonic rocks that have been grouped under Karla and Borivali Formations. The part of district falling towards east of the fault exposes the flow sequences represented by two aa lava flows of Elephanta formation. They are fine grained, very hard and compact. A number of N-S, NNE-SSW and NW-SW trending basalt and dolerite dyke intrude the basalt flows. They range in width from few centimetres to 50 m, and extend for a few km in length, and the part of the district to the west of the arcuate Bombay fault exposes basaltic flows that are interbedded with tuffs, agglomerate and various volcanic and plutonic rocks of Borivali formation.

Laterite has very limited development in the area and it occurs as small residual capping over the Deccan basalt. Laterite capping near Mulund area contains horizons of bauxite. The predominates soil cover in Mumbai city is sandy, whereas in the suburban district, the soil cover is alluvial and loamy. The tidal rivers of the area carry shallow marine sediments and deposit them on river banks forming vast tidal swamps. The stratigraphic sequence in Mumbai city and Suburban districts is given in **Table 4.1.** The Geological Map of the Mumbai City and Mumbai Suburban districts are shown in the **Fig 4.1.** The ground water in the area is confined to inter-trappean sediments. The interbedding planes, joints, vesicles, fissures and weathered mantle facilitate the circulation of ground water.

Table 4.1: Stratigraphic Sequence in Mumbai City and Suburban District

Age	Supergroup	Group	Formation	Lithology	Description
Quaternary				Alluvium	Thick Patches of fine and loamy sand along the River Banks, Loose fine sand along the beaches, Thick Black Colored Mud Flats along the creeks.
Cenozoic				Laterite	Occurs as small residual cappings over the Deccan Basalt
Upper Cretaceous to Palaeogene	Deccan Trap Supergroup	Sahyadri Group	Borivali Formation	Quartz Reef	
				Gabbro	Coarse Grained, Holocrystalline and has equal proportions o feldspar and Pyroxene. It shows 'Salt & Pepper ' Texture with Plagioclase and Dark Pyroxene Grains.
				Trachyte	The acidic rocks occur as sills or interbedded flow within the basic rocks, fine grained, leucocratic in nature.
				Calc Tuff	
				Agglomerate Tuff	Red to brown color, ill developed graded bedding with angular fragments of basalt varying in size from 1 cm to 5 cm. The angular fragments are in a fine-grained clayey groundmass.
				Basalt Flow	Shows varied flow morphologies. They are dense, dark, grey, fined grained and non-porphyritic.
			Elephanta Formation	Basalt flow	The two are aa' lava flows, fine grained, very hard and compact
			Upper Ratangarh Formation	Mainly Compound Flows	Occur as two patched as dense, dark grey, fined grained and non-porphyritic, compact, hard rock

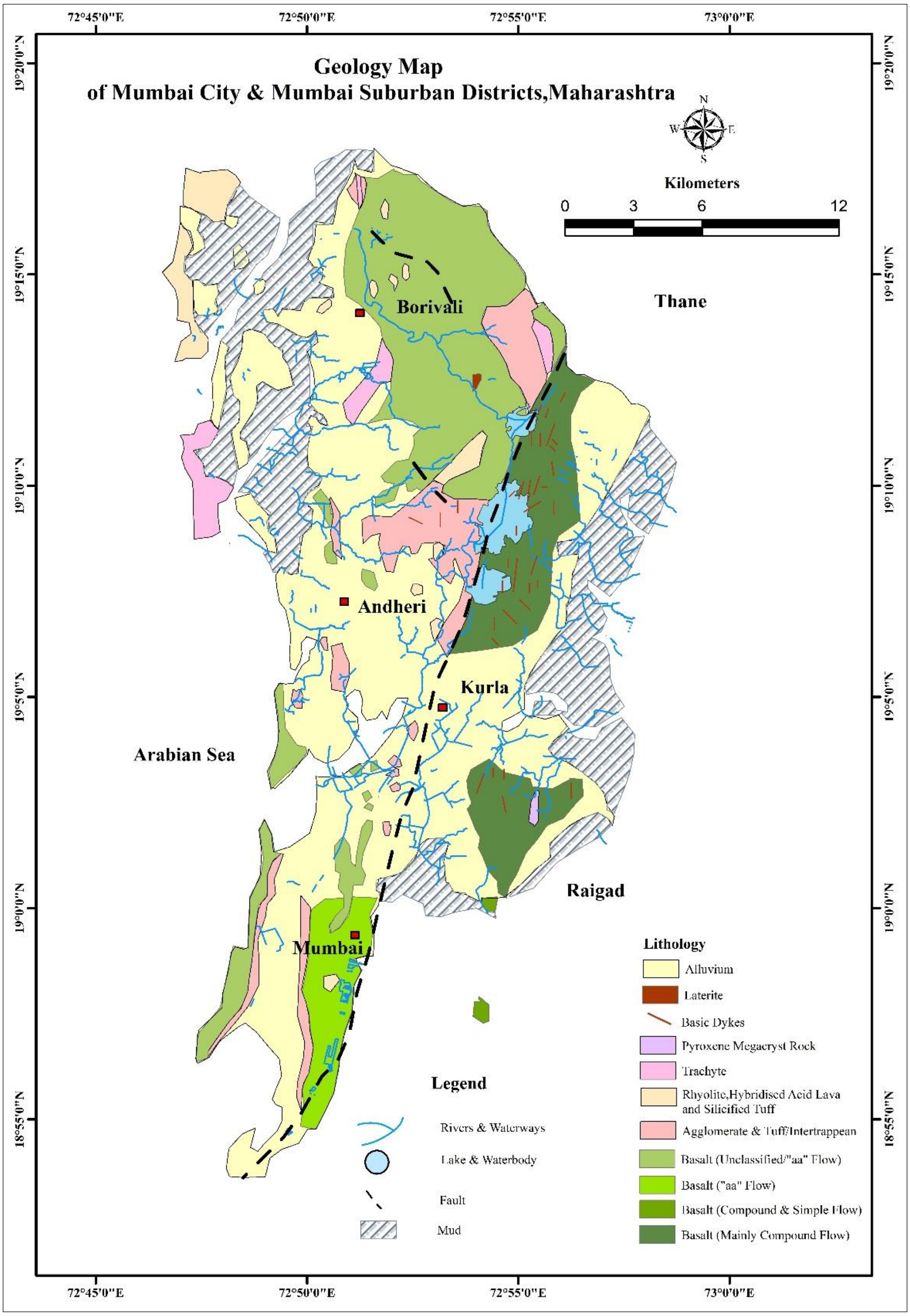


Fig 4.1: Geological Map of the Mumbai City and Mumbai Suburban districts

CHAPTER 5
DATA GAP ANALYSIS AND DATA GENERATION

5.1. DATA GAP ANALYSIS

Data gap analysis was carried out for an area of 600 Sq.kms covering Mumbai city and Mumbai Suburban district. This area covers Toposheet namely 47A/15, 47A/16 and 47B/13 in full or partial covering14 quadrants altogether.
In the context of aquifer mapping, Data Gap Analysis (DGA) has the following major objectives.

- Identification of gaps in the existing data on various aspects of the aquifer being mapped.
- Optimization of additional data requirements for a realistic depiction of the aquifer system and management of its groundwater resources.

Required and Existing Data The data available regarding the exploratory wells, Geophysical Survey (VES), Ground water level and Ground water quality were compiled and analysed for adequacy of the same in Mumbai city and Mumbai Suburban district. The data gap analysis was carried out for each of the quadrant of the Toposheet covering the area of Mumbai city and Mumbai Suburban district. The data pertaining to exploratory wells drilled in the area under Ground Water Exploration programme of CGWB (Toposheet/ quadrant wise). After taking in to consideration the available data of Ground Water exploration, Ground water monitoring, Ground water quality and Geophysical survey the data adequacy is compiled. After analysis of all existing data (Toposheet /quadrant wise) existing data gap is compiled. Considering the existing exploratory wells, Ground water Monitoring, Groundwater Quality and Geophysical survey the data gap i.e. required data is shown in the **Table-5.1** and generated data is furnished in **Table 5.2.**

Table 5.1: Details of Required, existing and data gap of exploratory wells, Geophysical, Ground Water monitoring and Ground water quality stations.

Exploratory Data			Geophysical Data			GW Monitoring Data			GW Quality Data		
Req.	Exist.	Gap	Req	Exist.	Gap	Req.	Exist.	Gap	Req.	Exist.	Gap
9	0	9	33	0	33	60	23	37	60	23	37

5.2. DATA GENERATION

The existing data was plotted on the Toposheet map of the study area to identify suitable locations for data generation **(Fig 5.1).** During the course of the study, location of new key observation wells (37 KOW,), EW sites and sites for VES were identified with the help of Brihanmumbai Municipal Corporation (BMC). The water quality data was analysed in Chemical Laboratory at Central Ground Water Board, Central Region, Nagpur. The summary of data generated is given in **Table 5.2.** The generated data has been utilized to understand aquifer geometry, Aquifer parameters of the deep aquifers in the area and for long term ground water level and quality monitoring for better ground water management.

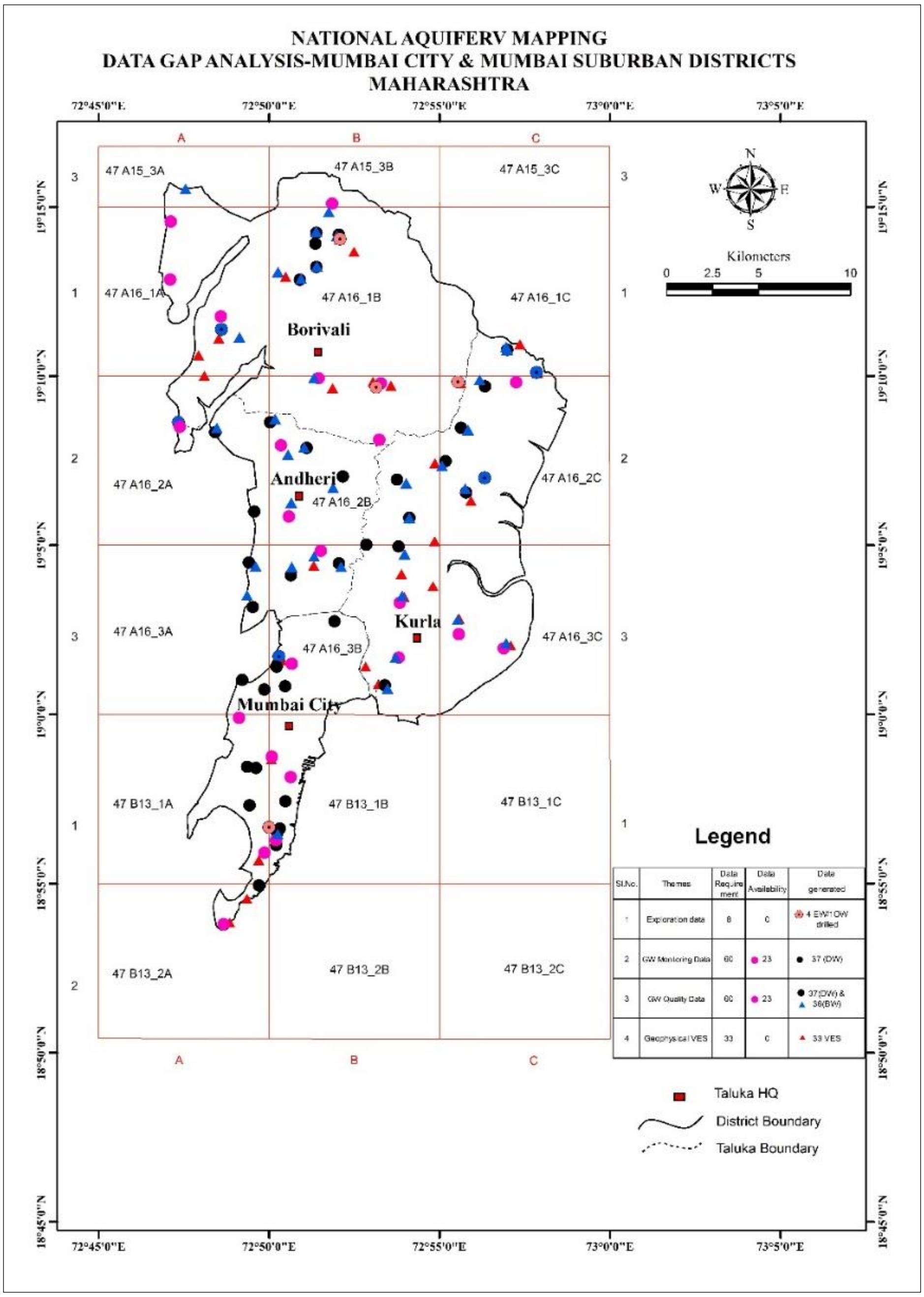


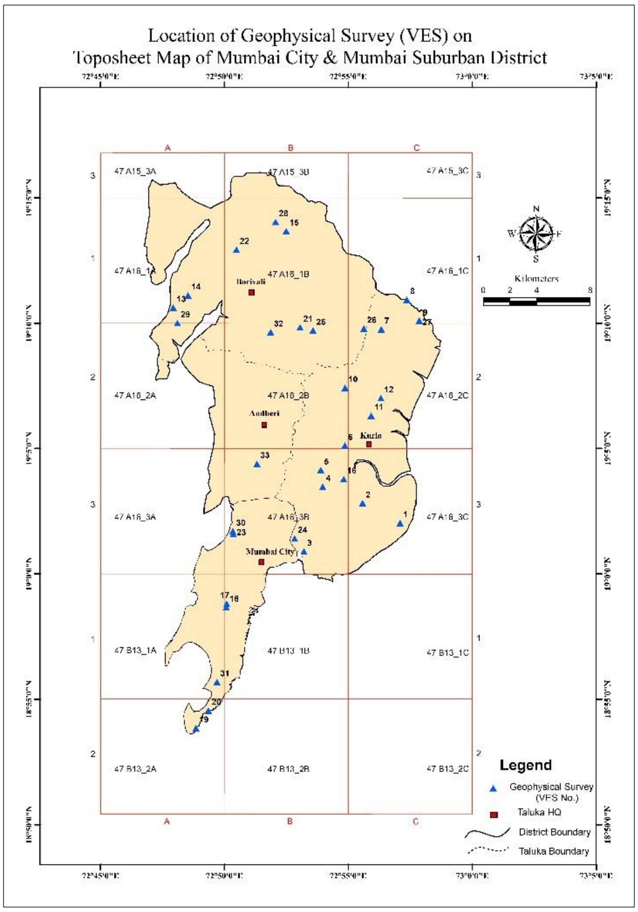
Fig 5.1: Data Gap Analysis and Data Generation in Study Area

Table 5.2: Data Gap Analysis and Data Generation in Study Area

S.No.	Themes	Data Requirement	Data Availability	Data Generated
1	**Exploration data**	9	0	6 EWs + 1 OW + 2 PZ drilled
2	**GW Monitoring Data Water Level (No. of key wells established)**	60	23	37 (DW)
3	**GW Quality Data Water Quality (No. of samples analysed)**	60	23	37 (DW) & 36 (BW)
4	**Geophysical VES**	33	0	33 VES

5.3 GEOPHYSICAL INVESTIGATION

During NAQUIM 2.0, a total of 33 Vertical Electrical Sounding (VES) surveys were conducted in study area. This survey aimed to delineate subsurface lithological variations and identify potential groundwater-bearing zones in the region. Location of Geophysical Investigation studies is shown in **fig 5.2** and List of VES study sites are given in **Table 5.3:**



VES No.	Site Name	Latitude	Longitude
1	Play Ground	19.0339	72.9515
2	Mankhurd campus IIT	19.0471	72.9262
3	Play Ground	19.0150	72.8868
4	Chembur Play Ground	19.0580	72.8994
5	Ground	19.0691	72.8981
6	Gnatkopra	19.0853	72.9143
7	Datta Krita prabadhin	19.1626	72.9388
8	Govind Patil Ground	19.1823	72.9560
9	Sambhij Raja Garden	19.1681	72.9646
10	Telecom Colony, Powai	19.1237	72.9144
11	Godrej Vikroli	19.1052	72.9320
12	Sivaji Garden, Vikholi	19.1169	72.9386
13	Aksa cricket ground	19.1770	72.7989
14	All India Radio	19.1852	72.8088
15	Sanjay Gandhi National Park	19.2279	72.8749
16	Ashok Kante Vdyon	19.0631	72.9135
17	Play Ground	18.9802	72.8348
18	Jijamata udyan	18.9779	72.8345
19	IMD, Colaba	18.8975	72.8141
20	FSI	18.9092	72.8225
21	Goregaon	19.1639	72.8842
22	Kasturba Rane	19.2156	72.8414
23	Shivaji park, Dadar	19.0267	72.8393
24	Bhakti Park	19.0236	72.8805
25	Filmcity, Goregaon	19.1619	72.8929
26	Water filtration plant, Bhandup	19.1631	72.9271
27	BMC ground, Mulund	19.1683	72.9643
28	CTIRC, Borivalli	19.2340	72.8677
29	Malad	19.1668	72.8017
30	BMC ground, Mahim West	19.0284	72.8390
31	Oval ground, Churchgate	18.9282	72.8283
32	Goregaon Road side	19.1607	72.8644
33	Mumbai University, Santacruz	19.0732	72.8552

Fig 5.2: Location of Geophysical Investigation studies Table 5.3 List of VES study sites

The surveys employed the Schlumberger electrode configuration, a widely adopted resistivity method using SSR-MP-ATS, IGIS, India geophysical equipment to investigate the geo-electrical characteristics of the subsurface across varying depths, influenced by local terrain and hydrogeological conditions. The acquired data were interpreted manually and using automated inversion algorithms available in the IPI2W in software. The data acquired provide critical insights into lithological layering, weathering profiles, and groundwater potential, by interpreting variations in electrical resistivity. Through careful interpretation of the VES curves, subsurface formations were classified into distinct geo-electrical layers such as topsoil, weathered/fractured zones, moderately weathered formations, and massive bedrock. Low-resistivity zones were given special attention, as they often signify saturated or clay-rich layers, which could serve as potential aquifers. Importantly, given Mumbai's coastal location, the VES data also served as a tool to identify zones potentially affected by seawater intrusion. This is typically indicated by very low resistivity values, especially in shallow to intermediate depths, which may reflect saline water intrusion into freshwater aquifers. Recognizing these zones is essential for planning protective and remedial groundwater management strategies.

The Geophysical investigation plays a pivotal role in enhancing the understanding of Mumbai's hydrogeological framework and contributes significantly to the identification of viable zones for groundwater development, recharge structures, and aquifer protection, in alignment with NAQUIM's broader vision of ensuring long-term groundwater sustainability and water security.

5.4 RESULTS AND DISCUSSION

1. The interpreted VES results indicate that the top geoelectric layer exhibits resistivity values ranging from 0.4831 to 394 Ohm m, corresponding to topsoil, varying based on its composition and degree of saturation. The thickness of this layer ranges from 1 to 5.818 meters.
2. The second geoelectric layer shows resistivity values between 0.487- and 3188-Ohm m, typically indicating weathered formations. Notably, 14 VES locations revealed very low resistivity values (less than 6 Ohm m), suggesting saline water ingress or highly weathered zones. These zones are predominantly located in the northwestern and northeastern coastal regions of the study area. The thickness of this layer varies between 1 and 25 meters.
3. The third geoelectric layer displays a wider resistivity range of 0.0567 to 18,324 Ohm m. Within this layer:

   - Seven VES points exhibit resistivity values between 18 and 82 Ohm m, indicating fractured/fresh rock formations. The thickness at these points ranges from 8.41 to 37.4 meters, with fracture depths generally between 3.44 and 40.8 meters, particularly in the eastern parts of the area.
   - Eight VES locations detected saline or weathered layers, with resistivity values less than 7 Ohm m and thicknesses ranging from 6.7 to 33.32 meters, extending to depths of up to 40.9 meters, mainly in the northwestern and eastern coastal zones.
   - Massive basaltic formations were also interpreted within this layer, with high resistivity values ranging from 78.9 to 18,324 Ohm m.

4. The fourth geoelectric layer has resistivity values ranging from 0.932 to 2984 Ohm m and thicknesses between 7.194 and 87.8 meters. In this layer:

   - Three VES locations revealed saline water ingress at depths between 15 and 23 meters.
   - Fractured/fresh zones were identified at two locations, with resistivity values around 20 to 22 Ohm m, located in mid-eastern and northwestern isolated pockets.

5. The fifth geoelectric layer was delineated at 10 locations across the study area. Of these:

   - Five sites indicate massive rock formations with high resistivity values ranging from 98 to 3596 Ohm m.
   - Three sites show fractured/fresh formations, with resistivity values between 30- and 35-Ohm m.

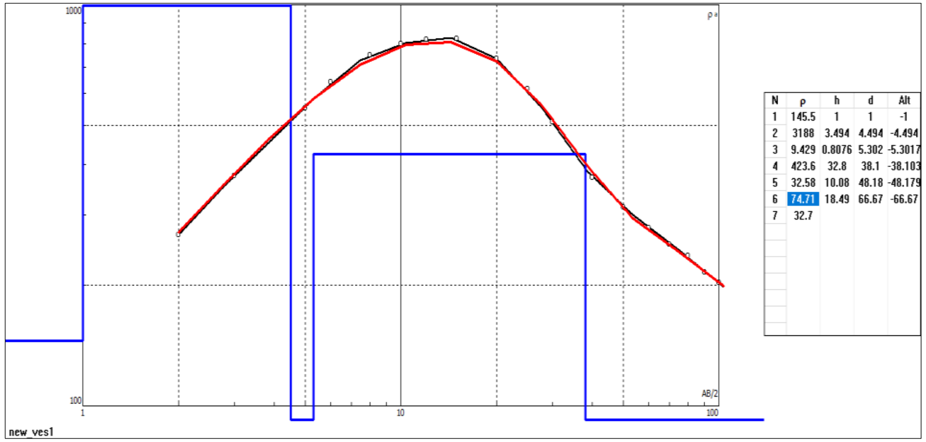
5.5 CONCLUSION

The Vertical Electrical Sounding (VES) survey conducted at 33 locations across Mumbai under the National Aquifer Mapping and Management Programme (NAQUIM) upto a depth of 88 mbgl has provided valuable insights into the subsurface lithology and groundwater potential zones of the region. The geo-electrical interpretation has delineated multiple subsurface layers comprising topsoil, weathered and fractured formations, massive basaltic rock, and zones influenced by seawater ingress. The resistivity variations observed in the survey suggest the presence of potential aquifer zones, particularly in 7 nos of locations within the weathered and fractured basalt layers. These zones, characterized by the resistivity values of 20 to 30 Ohm m which is the indicative of promising groundwater prospects, especially in the North eastern and midland regions of the study area. However, the occurrence of low resistivity zones (<6 Ohm m) in multiple VES points, particularly along the northwestern and eastern coastal belts, points toward the presence of saline water intrusion. This is likely due to proximity to the Arabian Sea. The saline ingress poses a potential risk to the quality and sustainability of groundwater resources in these areas. **Table 5.4**

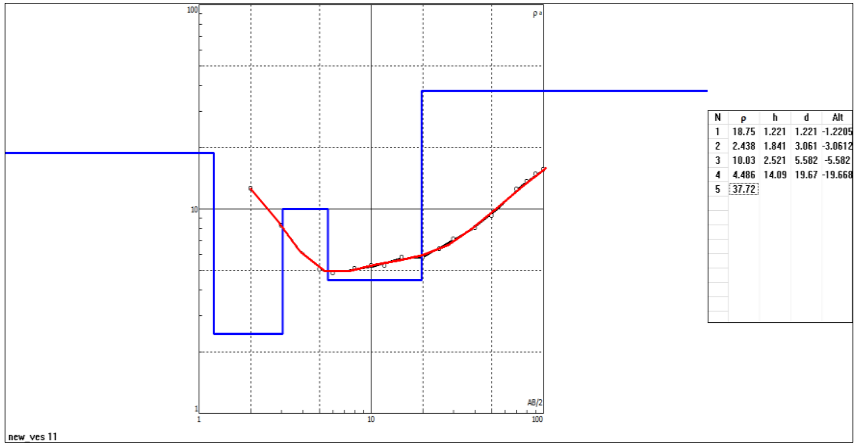
Overall, the VES study underscores the dual reality of groundwater availability and vulnerability in Mumbai. While promising aquifers exist, especially within the basaltic terrain, careful monitoring and management are essential to prevent further seawater intrusion and ensure the long-term viability of groundwater resources. The VES Curve Diagrams for Geophysical Investigation Studies carried out in Study Area are shown in **Fig 5.3** and details are given in **Annexure I.**

Table 5.4 Inferred Lithology, Resistivity and thickness ranges of Mumbai and Mumbai Sub-urban districts:

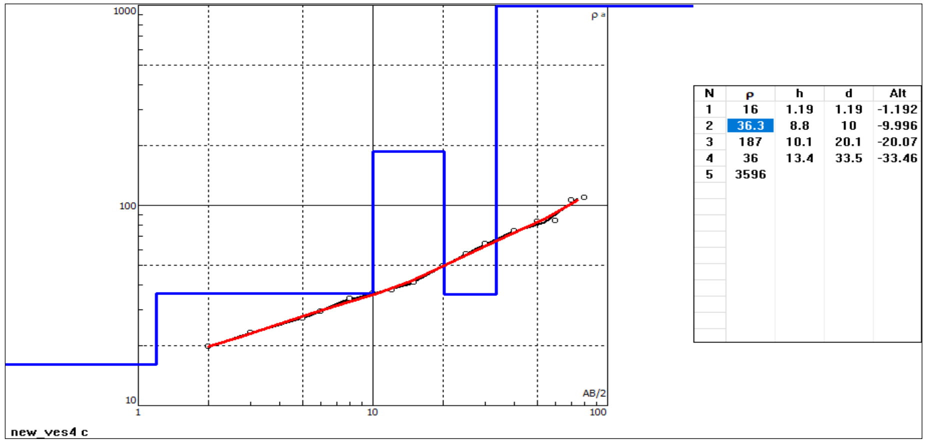
Resistivity Ranges (Ohm m)		Inferred litho Units	Thickness Ranges (m)	
From	To		From	To
0.4831	394	Top Soil	1	5.81
9.18	59.1	Weathered/Moderately Weathered	1	48
10	37	Weathered/Fractures with fresh	2.52	18.91
0.0567	7	Saline Water Ingress	1	33
58	18324	Massive	2.62	88



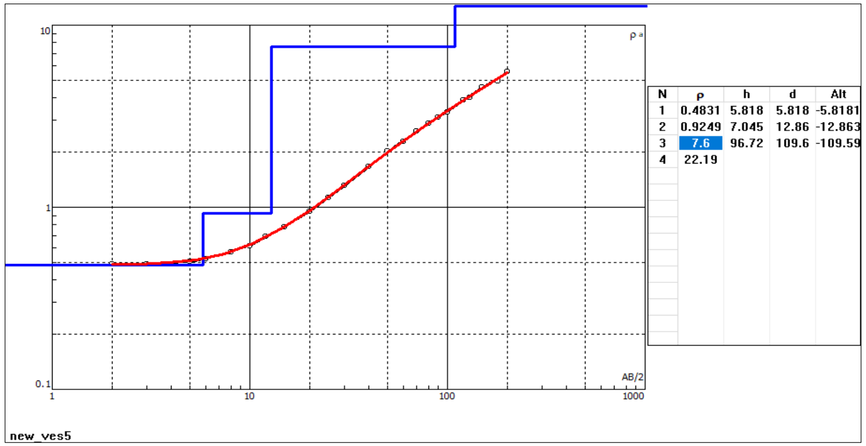
Interpreted VES curve of Film City, Goregaon, Mumbai



Interpreted VES curve of All India Radio, Malad West, Mumbai



Interpreted VES curve of CTIRC, Borivali (East), Mumbai



Interpreted VES curve of Open Ground, Malad, Mumbai

Fig 5.3 VES Curve Diagrams for Geophysical Investigation Studies carried out in Study Area

CHAPTER 6
HYDROGEOLOGY

The major aquifers in the study area comprises of Basalt and Alluvium. The 'Pahoehoe' flows in the district consists of highly vesicular bottom layer having closely spaced horizontal joints but the thickness is generally less. The vesicles are generally filled with secondary minerals and green earths. In such cases, they do not serve as aquifer. However, such vesicular zones are weathered in most part of the area, thus, making them moderately permeable. But if, vesicles are not filled, they act as highly permeable aquifers. The simple and compound "Pahoehoe" flow comprises a basal vesicular zone, middle relatively massive portion followed by a vesicular top. The vesicles of "Pahoehoe" flows are generally not interconnected and thus there is a variation in water holding capacity from the base to the top of the flow. The ground water exists in fractures, joints, vesicles and in weathered zone of Basalt. The occurrence and circulation of ground water is controlled by vesicular unit of lava flows and through secondary porosity and permeability developed due to weathering, jointing, fracturing etc. of Basalt. River Alluvium patches along the course of rivers and Marine Alluvium in the coastal area, are highly potential aquifer but with limited areal extent. The ground water occurs under water table condition in sandy / gritty layers. The alluvial fill of low lying areas underlain by weathered basalt has relatively better ground water potential. The major aquifers in the study area comprises of Basalt and Alluvium.

GW Exploration studies have been carried out in the study area during AAP 2024-2025. A total of 09 wells has been drilled ranging in depth from 37.90 m bgl to 202.60m bgl. The depth of weathering ranges from 11.50 to 23.50 m whereas the static water level ranges from 1.08 to 37.27 m bgl. Most of the fractures are in general encountered at the depths of 60m to 172m in Fractured/Vesicular Basalt. Discharge of these wells ranges from <1 lps to as high as 13 lps (drilling). As per the result of preliminary yield test of Exploratory well and observation well drilled at Film City Goregaon, a high discharge of 5.94 lps was observed with a drawdown of 2.73 m, transmissivity (T) at EW and OW is 96.02 m2/day and 141.45m2/day, specific capacity is 130.54 lpm/m/dd. Other wells with high discharge is drilled at Sambhaji Raje Park, Mulund East with a yield of 13 lps at first Zone encountered at 18-19.5 mbgl, and a high salinity zone was encountered at 131-132.40 mbgl. At Ismail Yusuf College, Andheri, the well has been drilled upto the depth of 200m (EW) and water zones were demarcated at various depths. The high yielding Aquifer zone was encountered at 167-169 mbgl, with the yield of 5.94 lps. The ground water in the area is fresh and potable. Hydrogeologically, the ground water flow direction is towards the sea and is driven by the slope of water table and hydraulic head following the topography of the area.

6.1 GROUNDWATER EXPLORATION IN THE STUDY AREA

Ground Water Exploration by Central Ground Water Board was initiated for the first time in the Mumbai city and Mumbai Suburban districts during AAP-2024-25. The data gap analysis was carried out for each of the quadrant of the Toposheet covering the area of Mumbai city and Mumbai Suburban district. The data pertaining to exploratory wells drilled in the area under Ground Water Exploration program of CGWB (Toposheet/ quadrant wise) has been generated through in-house activity. The data generated in the study area is shown in **Table 6.1 (Annexure II)**

Table 6.1: Data Generated under Ground Water Exploration activity NAQUIM

S.No.	Themes	Data Requirement	Data Availability	Data Generated
1	**Exploration data**	9	0	6 EWs + 1 OW + 2 PZ drilled

The Ground water exploration studies has been taken to decipher the availability and extent of aquifers in the different geological formations; depth wise availability and geometry of the deep-seated aquifers in different geological formations; aquifer parameters of primary and secondary porosity of the aquifer system; the quality of ground water stored in moderately deep aquifers; sustainability of the aquifer water keeping in view the future development and management plan.

Details of wells in drilled in the area is presented in Details of exploratory wells drilled in the Mumbai city and Mumbai Suburban district are presented in **Table 6.2** and Location of exploratory wells is shown in **Fig 6.1**.

Table 6.2: Salient Hydrogeological Data of Exploratory Wells drilled In the Mumbai city and Mumbai Suburban district

S. No	Site	Latitude	Longitude	Well type	Depth drilled (m)	Casing (m) with agl	Zones tapped/ fractures encountered	Discharge (lps)	EC (µS/cm)	SW L (m) bgl	Draw-down (m)	Trans-missivity m2/day	Specific capacity lpm/ m/dd	Forma-tion
1	**Film City, Goregaon**	19.161 480	72.886 020	EW	200	23.50	60 to 62; 105 to 107; 169 to 172 m bgl	Drilling: 12.90 lps PYT: 5.94 lps	1st Zone: 720 3rd Zone: 853	35.90	2.73	96.02	130.54	Basalt
2	**Film City, Goregaon**	19.161 480	72.886 020	OW	178.20	23.50	61 to 62; 84to 86; 168 to 169 m bgl	Drilling; 9.86 lps PYT :2.5lps	1st: 820 2nd: 820	37.27	3.45	141.45	43.47	Basalt
3	**CTIRC Training Centre, Government of Maharashtra, Kajupada**	19.234 134	72.868 124	EW	200	17.50	14 m bgl	0.0371	-	9.75	-	-	-	Basalt
4	**Water Treatment Plant Bhandup Complex**	19.163 217	72.925 956	EW	200	11.50	43 to 44 m bgl	0.0371	1st Zone: 450	22.50	-	-	-	Basalt
5	**Sir J. J.School of Arts, Dhobi**	18.944 813	72.833 075	EW	202.60	17.50	72 to 74 m bgl Saline	0.209		6.38	-	-	-	Basalt

S. No	Site	Latitude	Longitude	Well type	Depth drilled (m)	Casing (m) with agl	Zones tapped/ fractures encountered	Discharge (lps)	EC (µS/cm)	SW L (m) bgl	Draw-down (m)	Trans-missivity m2/day	Specific capacity lpm/ m/dd	Forma-tion
	Talao, Fort													
6	**Sir J. J.School of Arts, Dhobi Talao, Fort**	18.944813	72.833075	PZ	62.30	20.50	15.0 to 19.0	0.037						
7	**Sambhaji Raje Park, Mulund East**	19.168540	72.964120	EW	141.5	21.5	18-19.5; 131-132.40 (saline)	13 lps	1620	1.08	-	-	-	Basalt
8	**Shivaji Park,Dadar**	19.028184	72.837803	PZ	37.9	11.0	18.50-19.0; 36-37 m bgl (saline)	0.43 lps 5.94 lps	1337 19k	7.19	-	-	-	Basalt
9	**Ismail Yusuf College, Andheri**	19.132229	72.852372	EW	200.0	15	13.0-14.0; 102.0-104.0; 167.0-169.0 m bgl	0.037 lps; 3.17 lps; 5.94 lps	568; 676; 788	7.0	-	-	-	Basalt

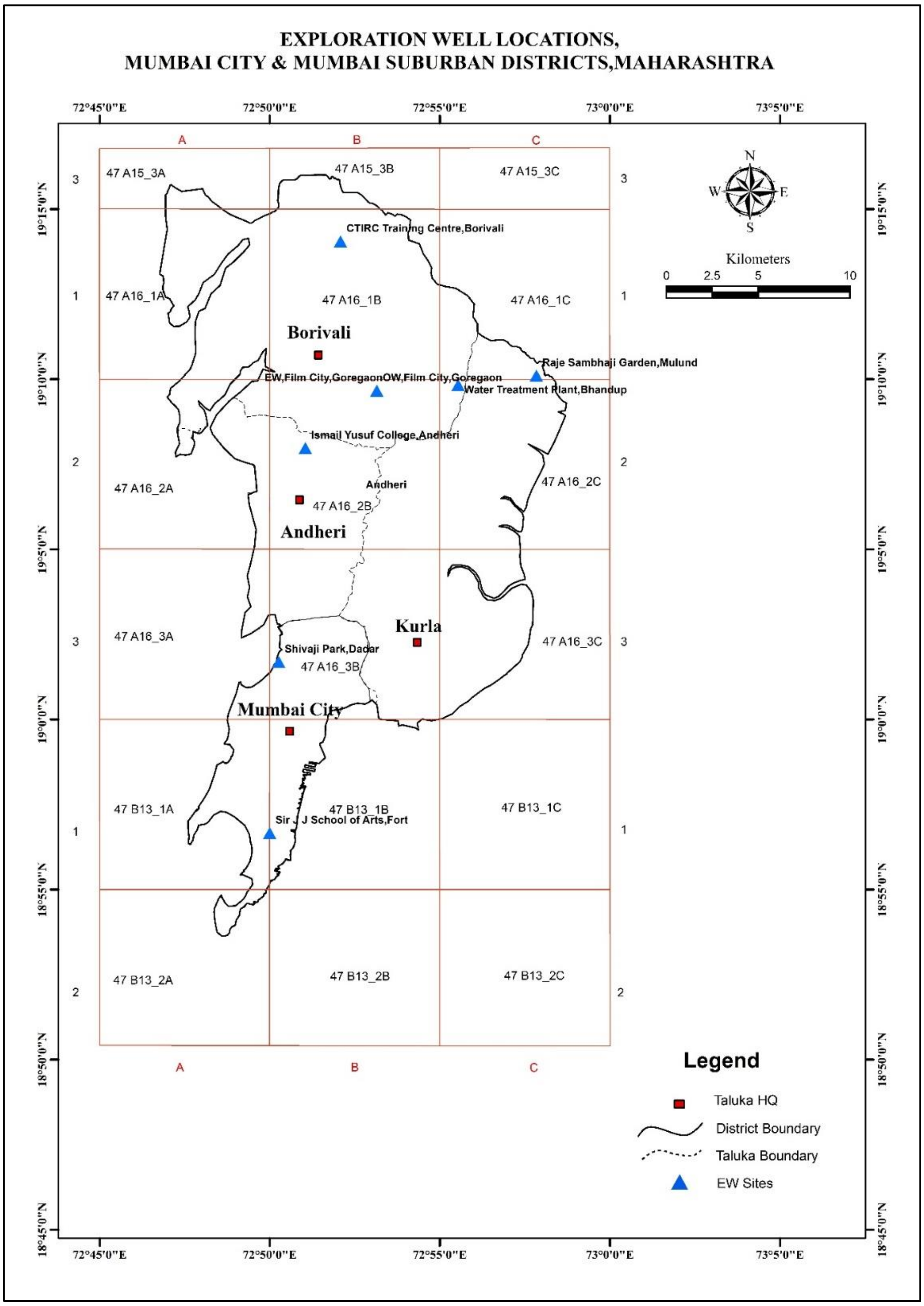


Fig 6.1: Location of Exploratory Wells in Study Area

6.2 3-D HYDROGEOLOGICAL MODEL AND CROSS SECTIONS

On the basis of the data generated from Ground water exploration and Geophysical Studies in the Study area, 2D and 3D models have been prepared to depict different Aquifers present in the area using Rockworks 14. These models can be utilized to determine the aquifer disposition in the sub surface which can be further used for planning and construction of artificial recharge structures. The 3D models and sections prepared for the study area are given in **fig 6.2 & 6.3.** The illustrative diagrams depicts that the major rock types underlying the study area are Basalt. Massive basalt lies deeper beneath the subsurface and overlain by Vesicular and Weathered basalt and followed by Top soil. The Ground water occurs in the fractured massive/ vesicular basalt and /or weathered basalt. At places, Saline water has been identified at relatively shallow depth of 70 m in Colaba

Fort Area, towards the southern part of Mumbai City area, at Sambhaji Raje Park, Mulund east and Shivaji Park, Dadar where high salinity zones have been encountered. Perusal of the 2- cross section NW-SE ~27 kms reveals weathering at shallow depths all along the section with avg. thickness of approx. 8m and ground water occurs in Fractured and vesicular basalt. Deep fractures are encountered at the depth of 90 m at Vikhroli. **(Fig 6.4)** Along the section Section NE-SW (~27 kms) also shallow weathering is observed all along the section with avg. thickness of approx. 10-20m and ground water occurs in Fractured and vesicular basalt and fractures are encountered at the depth of 25-75 m along the section (**fig 6.5)**

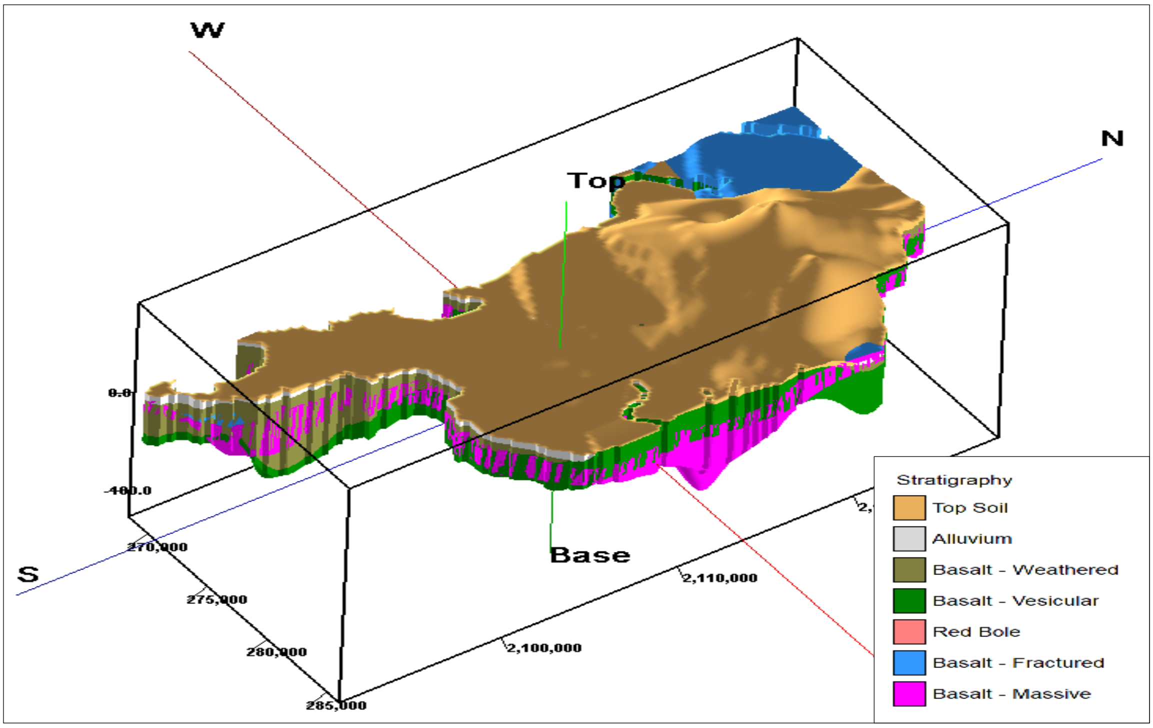


Fig 6.2 : 3-D Lithological Model of Study Area

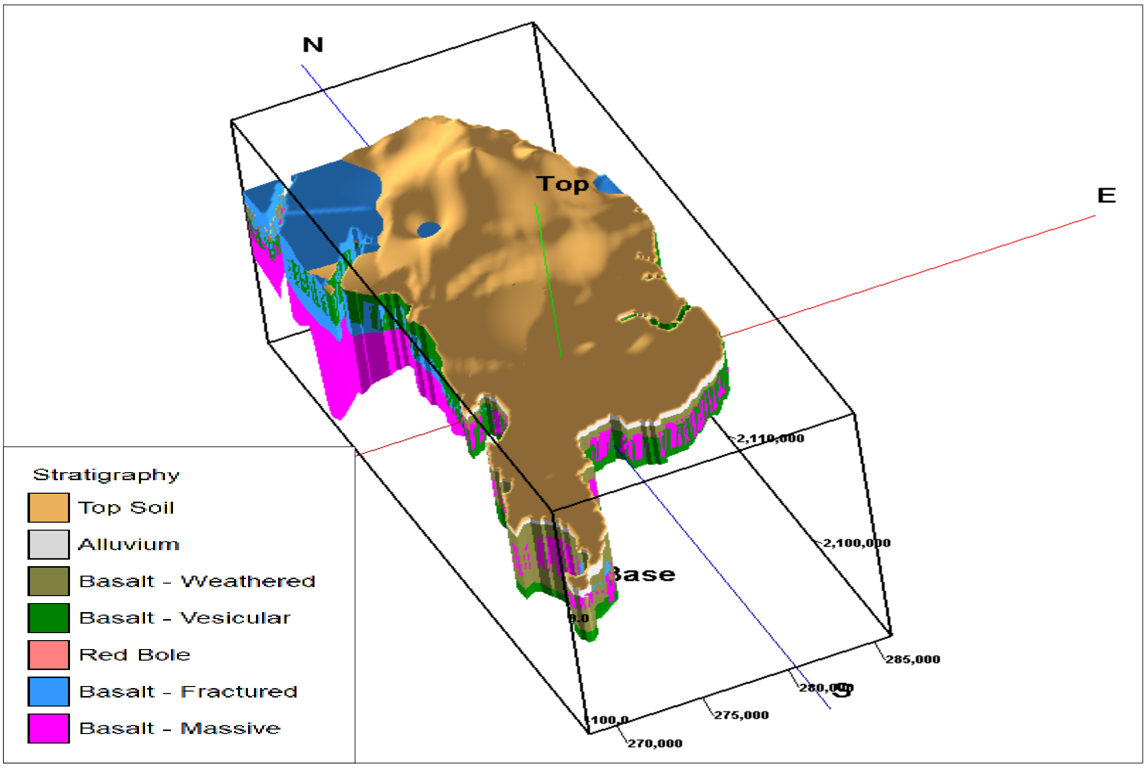


Fig 6.3: 3-D Lithological Model of Study Area

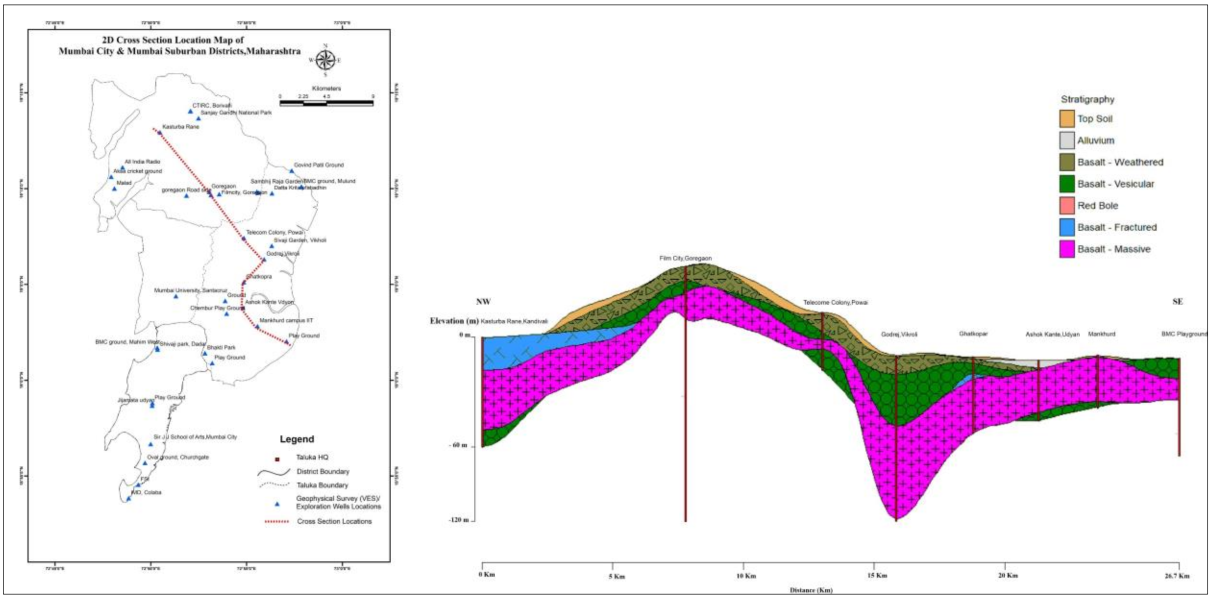


Fig 6.4: 2-D Cross sections from NW-SE of the Study Area

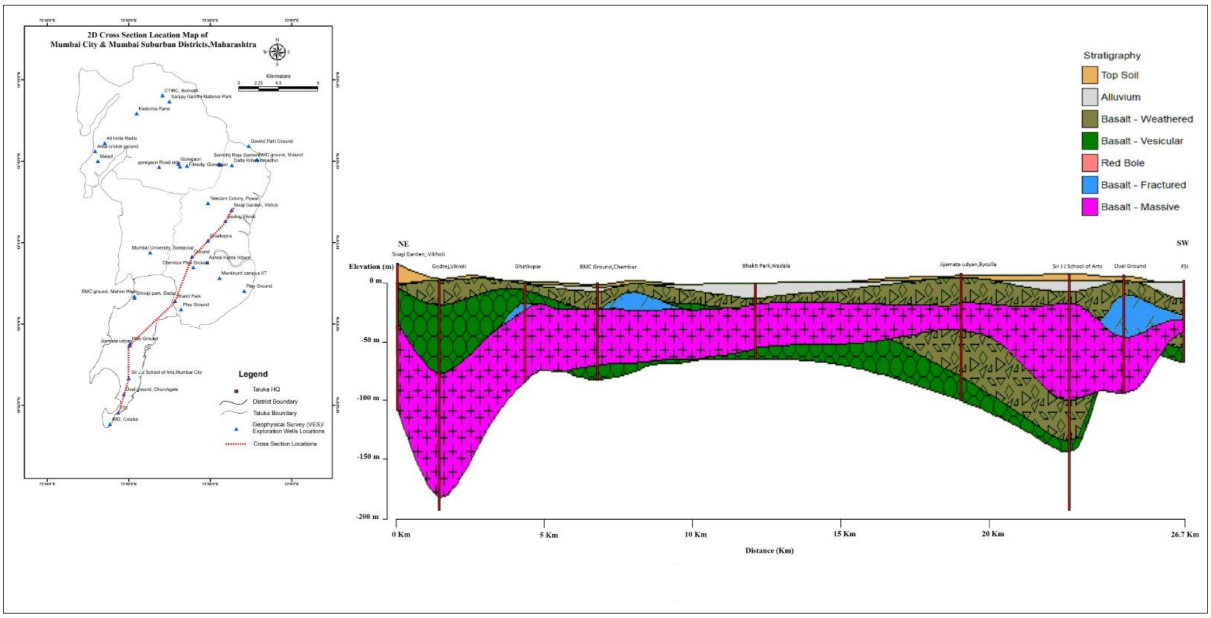


Fig 6.5: 2-D Cross sections NE-SW of the study area

6.3 AQUIFER CHARACTERISTICS

Based on geophysical investigation and exploration studies, the Aqufier systems in the study area can be delineated into two; Shallow and Deeper Aquifers. Table 6.3

Table: 6.3 Aquifer Wise Characteristics

Aquifer Group	Depth Range (m bgl)	Lithology	Aquifer Type	Zones Tapped / Fractures Encountered (m bgl)	Discharge Range (LPS)
Aquifer I	0–30	Basalt (weathered & shallow fractured)	Unconfined to semi-confined	13–14; 14; 15–19; 18–19.5	0.037 – 0.43
Aquifer II	30–172	Basalt (fractured & jointed)	Semi-confined to confined	36–37; 43–44; 60–62; 72–74; 84–86; 102–107; 131–132; 167–172	0.21 – 13.0

Maps depicting depth of occurrence, fractured/granular rock thickness and aquifer-wise yield potential maps are shown in **Figure 6.6a and 6.6b**

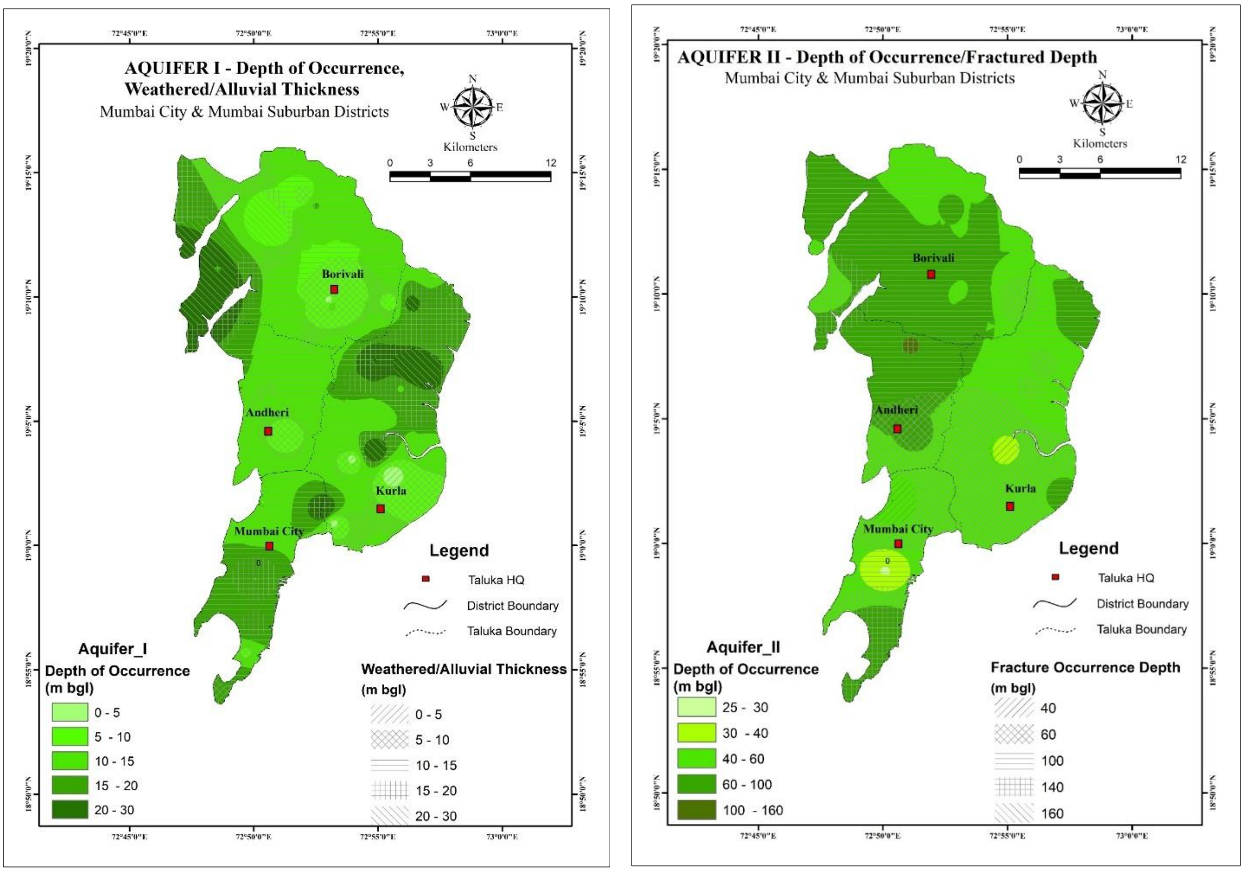


Figure 6.6a & b: Depth of occurrence and fractured rock thickness Aquifer I and Aquifer II

6.4 GROUND WATER LEVEL SCENARIO

Ground water level data is a critical component in understanding and managing ground water resources, offering valuable information about depth and variability of water table in an aquifer. Monitoring changes in ground water levels over a period of time provides insights into the aquifer system and this helps decisions making on sustainable water usage.

The Ground water level data is essential for assessing aquifer recharge and depletion. The fluctuations in ground water levels can be useful in identification of patterns related to natural recharge from precipitation and potential stressors leading to depletion, such as excessive pumping or prolonged droughts. This understanding is crucial for implementing effective ground water management strategies to maintain aquifer sustainability. Ground water level data is also instrumental in delineating ground water flow patterns. By analyzing variations in water table elevations across different locations, the direction and rate of ground water movement within an aquifer can be inferred. This information aids in development of conceptual models for subsurface, contributing to more accurate predictions of ground water behavior and facilitating sustainable water resource planning. The geological structures play a major role in the groundwater flow and quality-related problems. The geologic structures like dykes, lineaments, and fractures act as both carriers as well as barriers for groundwater flow.

For the present study, Central Ground Water Board established 37 Key observation wells in the study area in addition to existing 23 National Hydrograph Stations (NHS). These observation wells (60 nos) were monitored four times a year i.e. January, May (Pre monsoon), August and November

(Post monsoon). The location of Monitoring stations and key observation points for the study area is shown in **fig 6.7**. The water table contour map was prepared to identify the ground water flow direction. The hydrogeological map is shown in **fig 6.8**. Based on the map, it can be concurred that the Ground water flow direction is towards the sea and is driven by the slope of water table and hydraulic head following the topography of the area. Based on the water level data collected from the key observation wells, various depth to water level and ground water level fluctuations maps were prepared. The range wise data for ground water is given in **table 6.4.**

6.5 ANALYSIS OF DATA COLLECTED ON WATER LEVELS

6.5.1 Depth to Water Level – Pre monsoon (May-2023)

The pre monsoon depth to water levels monitored during May 2023 ranges between 0.4 m bgl at Jawaharnagar and 11.7 m bgl at A.M.C. Colony, Borivali. The depth to water levels during pre-monsoon has been depicted in Fig: 6.9. The shallow water levels between 0 and 6 m bgl are observed in most part of the study area and deeper water levels ranging from 7-12 mbgl are seen in isolated patches in Central, Northern and Western part of the study area. (**Fig 6.9)**

6.5.2 Depth to Water Level – August–2023

The depth to water levels during August 2023 ranges between 0.1 m bgl at Film city-Habale Pada to deepest Water level at 8.5 m bgl at Sion Ayurvedic Mahavidyalaya. Spatial variation in post-monsoon depth to water level is shown in Figure-6.10. The water levels in major part of the district range between 0 and 6 m bgl. Deeper water levels of 7 to 10 m bgl are observed in northern and southern part of the study area in isolated patches. **(Fig 6.10)**

6.5.3 Depth to Water Levels - Post-Monsoon Season (November, 2023)

The depth to water levels during November 2023 ranges between 0.21 m bgl at Kalina and Jawaharnagar to deepest Water level at 10.64 m bgl at Mazgaon, Mumbai city. The water levels in major part of the district (88%) range between 0 and 5 m bgl. Deeper water levels of 5 to 10 m bgl are observed in many part of the study area in isolated patches. **(Fig 6.11)**

6.5.4 Depth to Water Levels - January, 2024

The depth to water levels during January 2024 ranges between 0.20 m bgl at Kalina and to deepest Water level at 8.62m bgl at Sion Ayurvedic College. The water levels in major part of the district (92%) range between 0 and 5 m bgl. Deeper water levels of 5 to 10 m bgl are observed in 8 % of the well. **(Fig 6.12)**

6.5.5 Depth to Water Level – Pre monsoon (May-2024)

The pre monsoon depth to water levels monitored during May 2024 ranges between 0.3 m bgl at Jawaharnagar to deepest water level of 12.81 mbgl at Mazgaon. Deeper water levels are observed at A.M.C. Colony, Borivali (11.61 m bgl) and at Sion Ayurvedic Mahavidyalaya water levels is at 9.71mbgl. In general, the Depth to water levels during pre-monsoon, 2024 are observed between the ranges 0-5 mbgl in about 75% of observation wells deeper water levels ranging from 5-10 and >10 mbgl are seen in isolated patches in Central, southern part of the study area. (**Fig 6.13)**

6.5.6 Depth to Water Level – August–2024

A major part of the study area shows depth to water levels in the range 0-5 mbgl during August 2024 monitoring. With the shallow water level of 0-0.3 mbgl at Oshivara, Kalina and Jawaharnagar to deepest water level of 7.25 mbgl at Sion Ayurvedic Mahavidyalaya. Spatial variation in post-monsoon depth to water level is shown in **(Fig 6.14).**

6.5.7 Depth to Water Levels - Post-Monsoon Season (November, 2024)

The depth to water levels during November 2024 ranges between 0 (Ground level) m bgl at Goregaon, Kalina and Jawaharnagar to deepest Water level of >8m bgl at Rani cha Bagh and Sion Ayurvedic Mahavidyalaya. The water levels in major part of the district (88%) range between 0 and 5 m bgl. Deeper water levels of 5 to 10 m bgl are observed in many part of the study area in isolated patches. **(Fig 6.15)**

6.5.8 Depth to Water Levels - January, 2025

The depth to water levels during January 2025 ranges between 0 m bgl at Kalina to deepest Water level at 12.28 m bgl at AMC Colony. The water levels in major part of the district (80%) ranges between 0 and 5 m bgl. Deeper water levels of 5 to 10 m bgl are observed in 11 % of the well. **(Fig 6.16)**

Table 6.4: Data Range of Depth to Water Level for Study Area

Range of DTWL (m bgl)	Total No. of wells	0 to 2	%	2 to 5	%	5 to 10	%	> 10	%
May-23	60	23	38.33	23	38.33	11	18.3	3	5
Aug-23	60	32	53.33	23	38.33	5	8.3	0	0
Nov-23	60	21	35	32	53.33	6	10.0	1	1.67
Jan-24	60	23	38.33	27	45	9	15.0	1	1.67
May-24	60	15	25	30	50	13	21.7	2	3.33
Aug-24	60	37	61.67	19	31.67	4	6.7	0	0
Nov-24	60	20	33.33	32	53.33	8	13.3	0	0
Jan-25	60	21	35	27	45	11	18.3	1	1.67

6.6 WATER LEVEL FLUCTUATIONS

Fluctuation of ground water levels in an area is due to variations in recharge and discharge components in groundwater regime. Recharge components are precipitation; water applied for irrigation and percolation from surface water bodies. Discharge is mainly due to withdrawal of ground water for irrigation, domestic and industrial uses, effluent seepage into drainage courses & evapotranspiration. Fluctuation is also affected by topographic configuration and geological setup of in an area. Seasonal changes are observed because of monsoon rainfall received over an area.

Fluctuations of water levels during post-monsoon season with respect to pre-monsoon season for shallow aquifer for the year 2023 and 2024 have been prepared showing areas with seasonal fluctuations.

During post-monsoon season in shallow aquifers, in ~76.56 % of area water levels have shown a rise in the range of 0-2 m and the maximum rise (4-6 m) is observed in ~0.6% of the area in central part of the study area. Rise within the range of 2 – 4 m is observed in 6.2 % of the area. Fall in groundwater level in is observed in 15.57% of the area, water levels have shown a fall within the range of 0-2m and maximum fall upto 6m is observed in 0.3 % of the area. **(fig 6.17)**

Fluctuations of water levels during post-monsoon season with respect to pre-monsoon season for shallow aquifer for the year 2024 shows that in 81.13% of the area there is rise in ground water levels within the range of 0-2 m. rise in the range of 2-4 m is observed in 6.6% of the area. Fall of >4 m is observed in 1.62 % of the area. Mostly in the northern, central and southern part of the study area. Fall in water level is observed in 9.83 % of the area with in the range of 0-2 m, fall of 2->4 is observed in minor area 0.5% in isolated patches. **(fig 6.18)**

6.7 WATER LEVEL TREND IN THE STUDY AREA

Trend analysis for the last 10 years (2014-2023 has been carried out for 23 hydrograph stations of CGWB. During pre-monsoon season, it is observed that 01 well shows rising trends (0.146 m/yr) and in 3 wells, falling trends are observed (3 wells ranging from 0-0.07 m/yr) **(fig 6.19)**. During post-monsoon season, in 16 wells rising trends are observed (0.0- 0.48 m/yr) and in 6 wells, falling trends ranging from 0-0.63 m/yr are observed. The fall is mostly observed in eastern and north-western part in both seasons. **(fig 6.20)**

6.7.1 HYDROGRAPH ANALYSIS

Variation in short and long-term water level trends, is due to variations in natural recharge, rainfall and withdrawal for various uses and for these 5 hydrograph stations are studied in detail **(Fig.6.21).** Rising limb, shows a natural recharge due to monsoon rainfall and recession limb, indicates continuous increase in extraction. Out of the 6 hydrographs, 4 shows rising trends in both seasons and only one (Mazgaon), shows failing trend in both seasons i.e., 0.25 m/yr during pre and 0.26 m/yr during post monsoon season.

Table 6.5.a: Trend of Water Level - From Year 2014 to Year 2023
DISTRICT: MUMBAI CITY

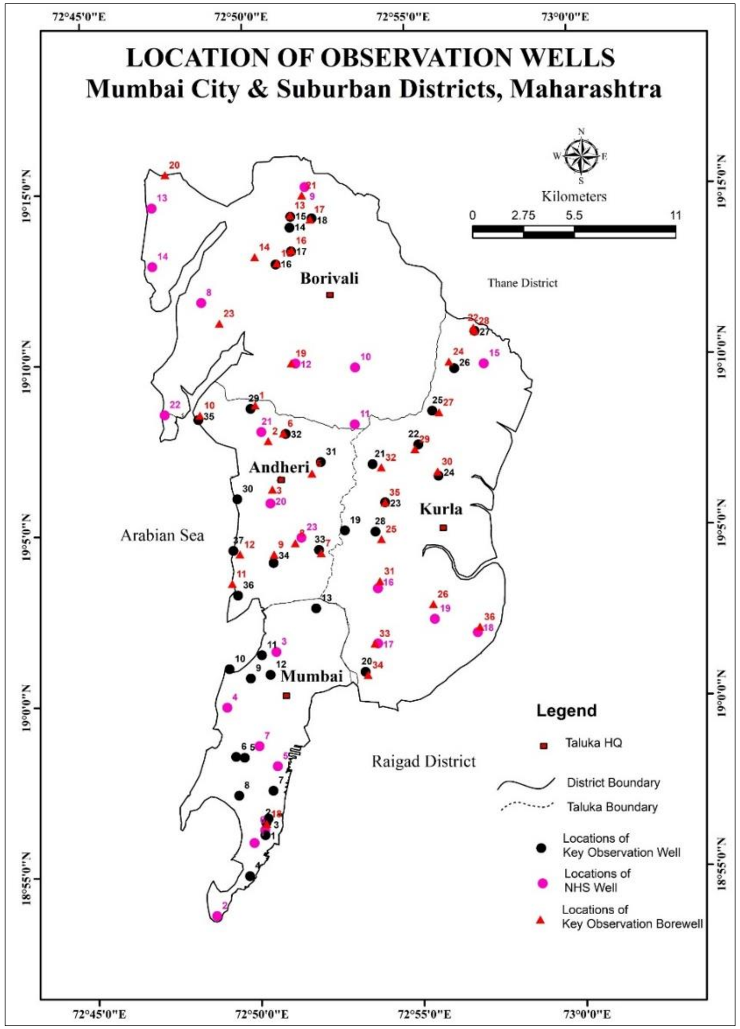
S. No.	Location	Pre-Monsoon			Post-Monsoon			Annual		
		Data Points	Rise (m/year)	Fall (m/year)	Data Points	Rise (m/year)	Fall (m/year)	Data Points	Rise (m/year)	Fall (m/year)
1	Colaba (Dandi)	7		0.0725	9		0.0129	32	0.0455	
2	Bombay (Church Gate)	8		0.0104	10	0.0950		37	0.0388	
3	Colaba-Fort	5			7	0.0115		25	0.0309	
4	Mazgaon	5			7		0.6352	25		0.7176
5	Varli Naka	5			7	0.0571		24		0.0311
6	Mahim	8		0.0342	10	0.0046		37	0.0077	

RODC, CGWB, CR

Table 6.5b: Trend of Water Level - From Year 2014 to Year 2023
DISTRICT: MUMBAI SUBURBAN

S. No.	Location	Pre-Monsoon			Post-Monsoon			Annual		
		Data Points	Rise (m/year)	Fall (m/year)	Data Points	Rise (m/year)	Fall (m/year)	Data Points	Rise (m/year)	Fall (m/year)
1	Rani cha Bagh	5			7	0.0222		25	0.0125	
2	Laxminagar -Mahul	5			7	0.1848		25	0.0402	
3	Trombay-Koliwada	5			7	0.0888		25	0.0304	
4	Agarwadi	5			7		0.0953	25	0.1255	
5	Chembur Gaothan	5			7		0.0156	25		0.0395
6	Khardanda	0			1			3		
7	Vakola.	5			7	0.1422		25	0.0009	
8	Vile Parle West	4			7	0.1269		24	0.1252	
9	Amboli Sarota Pada	4			7	0.0191		24	0.1672	
10	A.M.C. Colony	7	0.1460		10	0.4895		36	0.4687	
11	Varsowa	0			1			3		
12	Madh	3			7	0.2842		23		
13	Film City-Habale Pada	5			7	0.0178		25	0.0381	
14	Mulund East	4			7	0.0417		24	0.1011	
15	Goregaon	5			7		0.0951	25		0.0408
16	Malwani	3			7	0.4215		23		
17	Manori	5			5			20		
18	Gorai Beach	4			7		0.0247	24	0.1151	
19	Dahisar-1	5			7	0.0942		25		0.2440

RODC, CGWB, CR



S.No	District	Taluk	Location Name	Lat	Long
1	Mumbai City	Mumbai City	BMC Ward A Ofice, on Mint Back road	18.93564	72.836837
2	Mumbai City	Mumbai City	St George Hospital Garden	18.941648	72.837381
3	Mumbai City	Mumbai City	CSMT, Indraprastha Bhawan	18.943781	72.838596
4	Mumbai City	Mumbai City	Khandoba Mandir, Harmos Ji St	18.915818	72.828436
5	Mumbai City	Mumbai City	Ward E, BMC Dispensery	18.9736953	72.8270119
6	Mumbai City	Mumbai City	Nair Hospital, Mumbai Central	18.974191	72.822632
7	Mumbai City	Mumbai City	Jaffer Suleiman Masjid, Mazgoan	18.957292	72.841376
8	Mumbai City	Mumbai City	Narayanwadi Mandir	18.955211	72.8238
9	Mumbai City	Mumbai City	Lakshmi Autoworks shop, GS Ward	19.012312	72.831065
10	Mumbai City	Mumbai City	GS Ward , Worli village	19.0170717	72.820241
11	Mumbai City	Mumbai City	Shivaji Park, Dadar	19.0235439	72.8370434
12	Mumbai City	Mumbai City	Dadar East, Sant Gadge Maharaj Trust complex	19.0138956	72.8412072
13	Mumbai City	Mumbai City	Sion Ayurvedic Mahavidyalaya	19.0458556	72.8653381
14	Mumbai City	Mumbai city	Bombay (Church Gate)	18.931944	72.8311389
15	Mumbai City	Mumbai city	Colaba (Dandi)	18.896667	72.8111389
16	Mumbai City	Mumbai city	Mahim	19.025000	72.8444722
17	Mumbai City	Mumbai city	Varli_Naka	18.998333	72.8186389
18	Mumbai City	Mumbai city	Mazgaon	18.969167	72.8439167
19	Mumbai City	Mumbai city	Colaba-Fort	18.938056	72.8366944
20	Mumbai city	Mumbai city	Rani cha Bagh	18.979167	72.8347500
21	Mumbai Suburban	Borveli	Boraveli West (MCO office)	19.231948	72.855978
22	Mumbai Suburban	Borveli	Rokadia (Cross Lane)	19.237290	72.856470
23	Mumbai Suburban	Borveli	Borspada	19.214135	72.848407
24	Mumbai Suburban	Borveli	Boraveli East (Sub Way)	19.220395	72.856461
25	Mumbai Suburban	Borveli	Boraveli East (Kaju Pada)	19.236324	72.867430
26	Mumbai Suburban	Borivali	Malwani	19.196111	72.8097500
27	Mumbai Suburban	Borivali	Dahisar-1	19.251667	72.8641944
28	Mumbai Suburban	Borivali	Film City-Habale Pada	19.163056	72.8880833
29	Mumbai Suburban	Borivali	A.M.C. Colony	19.135278	72.8872500
30	Mumbai Suburban	Borivali	Goregaon	19.165556	72.8575278
31	Mumbai Suburban	Borivali	Gorai Beach	19.242778	72.7853056
32	Mumbai Suburban	Borivali	Manori	19.214167	72.7850278
33	Mumbai Suburban	Kurla	Bail Bazar	19.0836	72.88095
34	Mumbai Suburban	Kurla	Mahul	19.014359	72.889981
35	Mumbai Suburban	Kurla	Chandiwali	19.115624	72.895931
36	Mumbai Suburban	Kurla	Powai	19.124755	72.919646
37	Mumbai Suburban	Kurla	Bhatwadi	19.096838	72.901919
38	Mumbai Suburban	Kurla	Vikhroli	19.10925	72.929677
39	Mumbai Suburban	Kurla	Bhandup	19.14109	72.927201
40	Mumbai Suburban	Kurla	Sonapur	19.161573	72.938935
41	Mumbai Suburban	Kurla	Bhaktimarg	19.179644	72.94978
42	Mumbai Suburban	Kurla	Kirol	19.082688	72.896661
43	Mumbai Suburban	Kurla	Mulund_East	19.163611	72.9541944
44	Mumbai Suburban	Kurla	Chembur_Gaothan	19.055000	72.8972500
45	Mumbai Suburban	Kurla	Laxminagar-Mahul	19.028056	72.8966944
46	Mumbai Suburban	Kurla	Trombay-Koliwada	19.032500	72.9480833
47	Mumbai Suburban	Kurla	Agarwadi	19.039444	72.9261389
48	Mumbai Suburban	Andheri	Oshivara	19.1439	72.8339
49	Mumbai Suburban	Andheri	Theosophical Society (Juhu vile Parle)	19.0999	72.8261
50	Mumbai Suburban	Andheri	Kondvita (Ganeshwadi)	19.1172	72.8694
51	Mumbai Suburban	Andheri	Jogeshwari (E) Natwarnagar	19.1313	72.8517
52	Mumbai Suburban	Andheri	Kalina	19.0744	72.8675
53	Mumbai Suburban	Andheri	Jawaharnagar	19.0685	72.8440
54	Mumbai Suburban	Andheri	Varsowa	19.139	72.8070
55	Mumbai Suburban	Andheri	Bandra (W)	19.0529	72.8254
56	Mumbai Suburban	Andheri	Khardanda	19.0748	72.8235
57	Mumbai Suburban	Andheri	Vile Parle West	19.097500	72.8430833
58	Mumbai Suburban	Andheri	Amboli_Sarota Pada	19.132500	72.8391944
59	Mumbai Suburban	Andheri	Madh	19.141667	72.7897500
60	Mumbai Suburban	Andheri	Vakola	19.080556	72.8586389

Fig 6.7: Location of observation wells in the study area

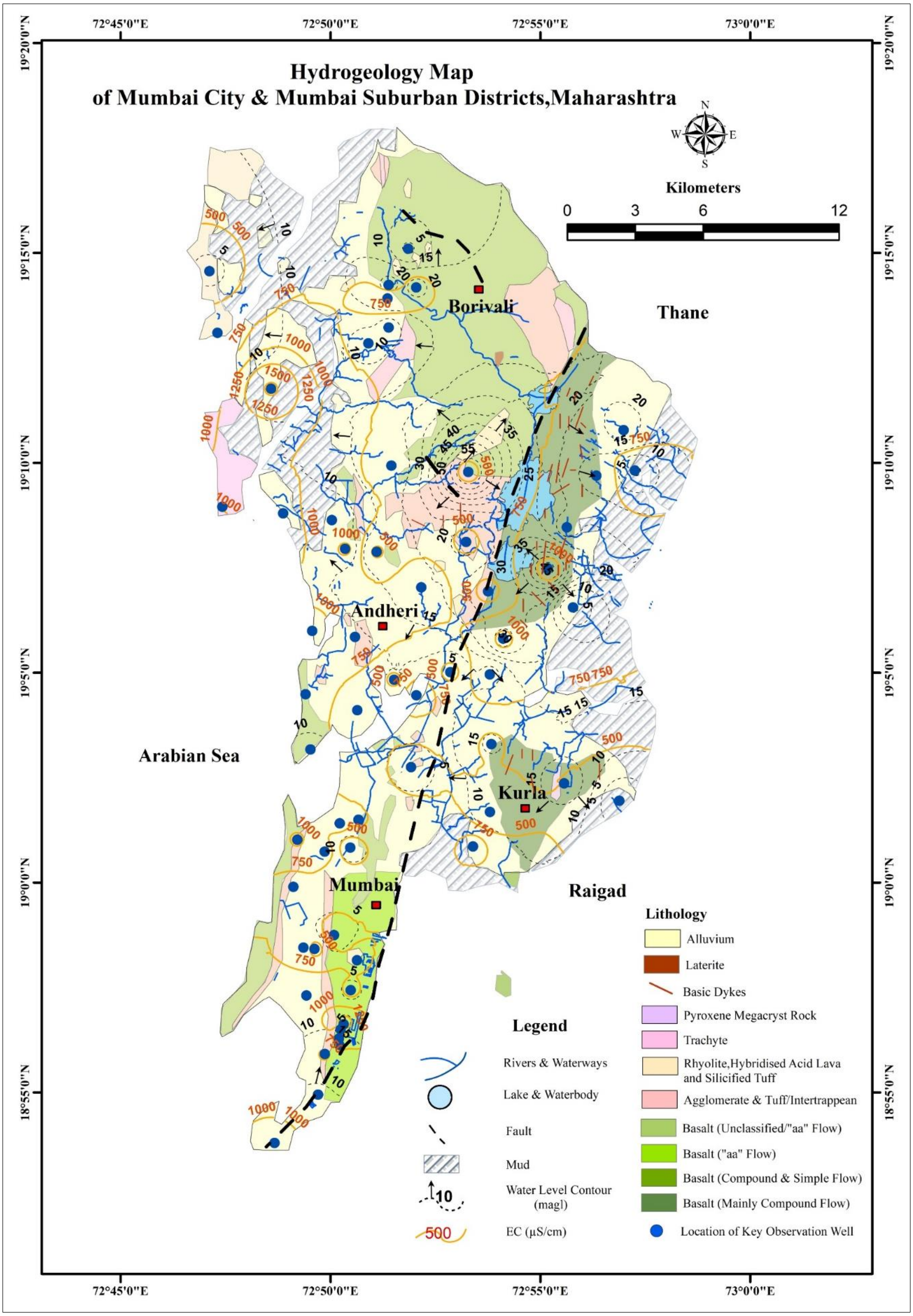


Fig 6.8: Hydrogeological Map of Study Area

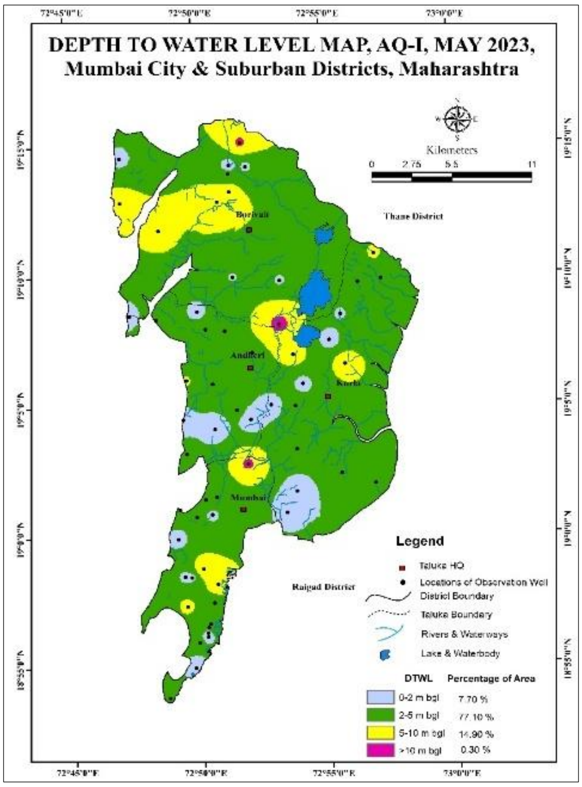


Fig 6.9: Depth to Water level Map May (Pre-Monsoon), 2023

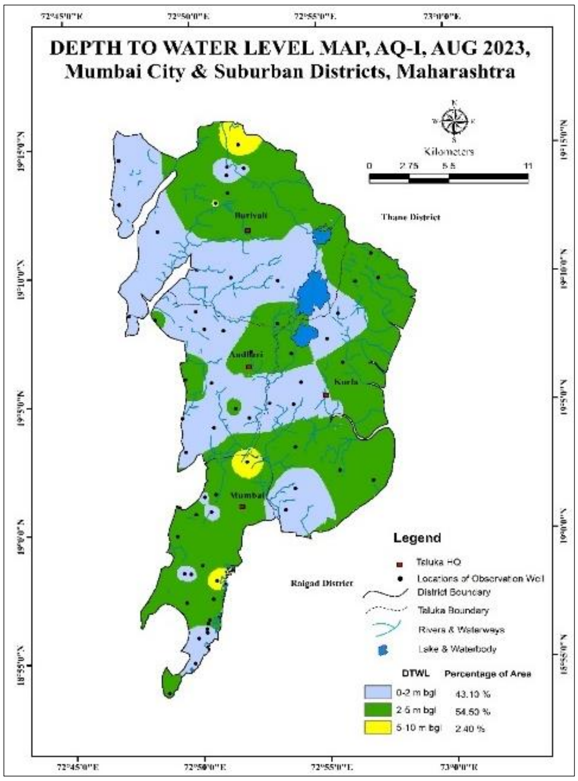


Fig 6.10: Depth to Water level Map Aug, 2023

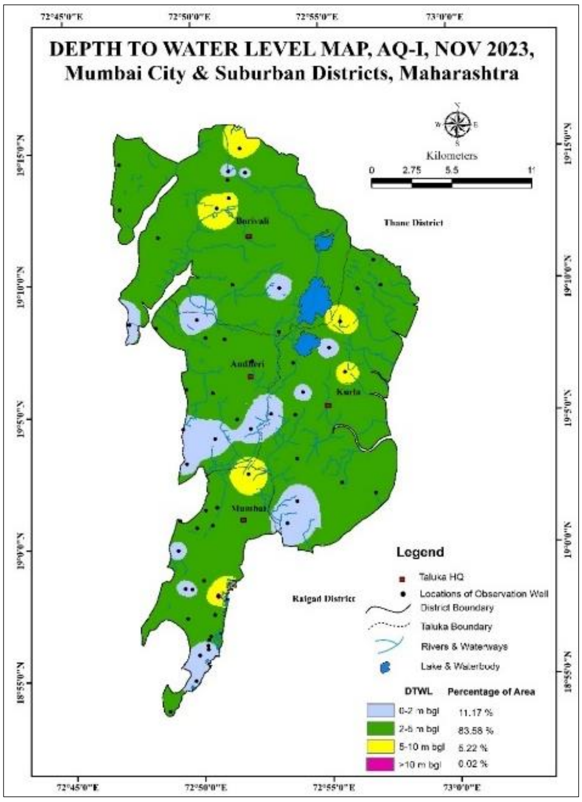


Fig 6.11: Depth to Water level Map, Nov (Post-Monsoon), 2023

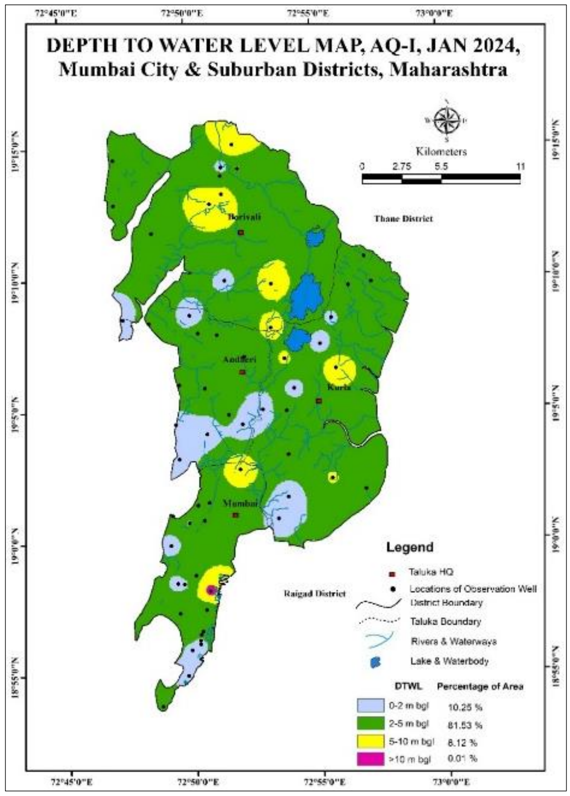


Fig 6.12: Depth to Water level Map Jan 2024

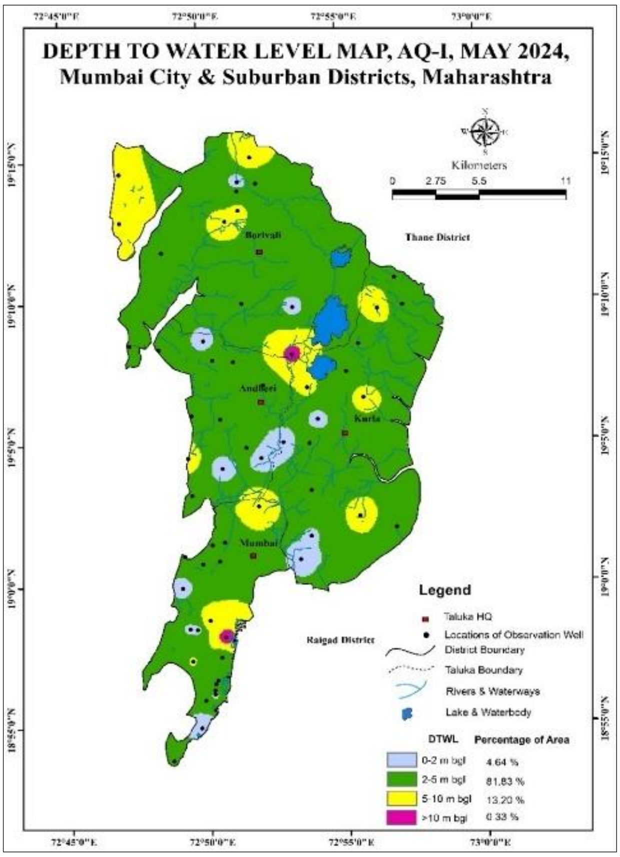


Fig 6.13: Depth to Water level Map May (Pre-Monsoon), 2024

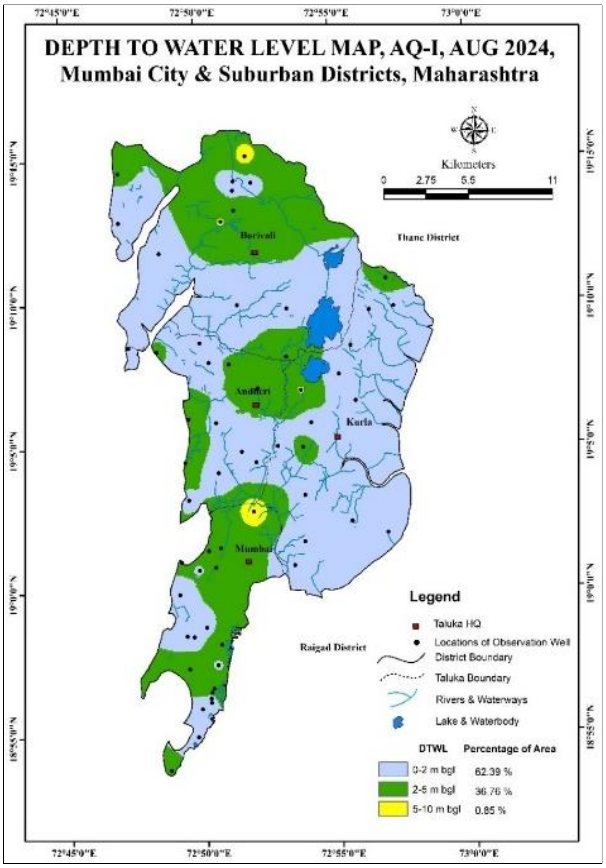


Fig 6.14: Depth to Water level Map Aug, 2024

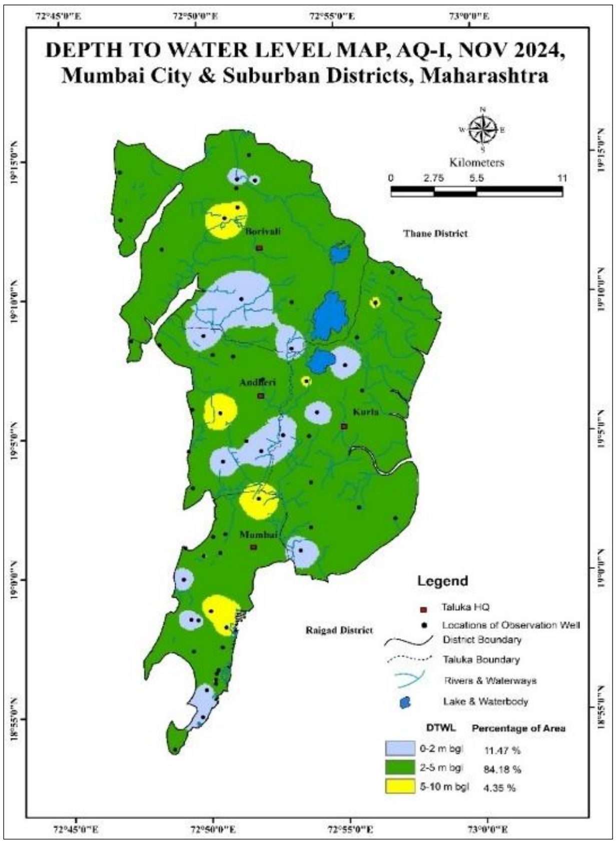


Fig 6.15: Depth to Water level Map, Nov (Post-Monsoon,), 2024

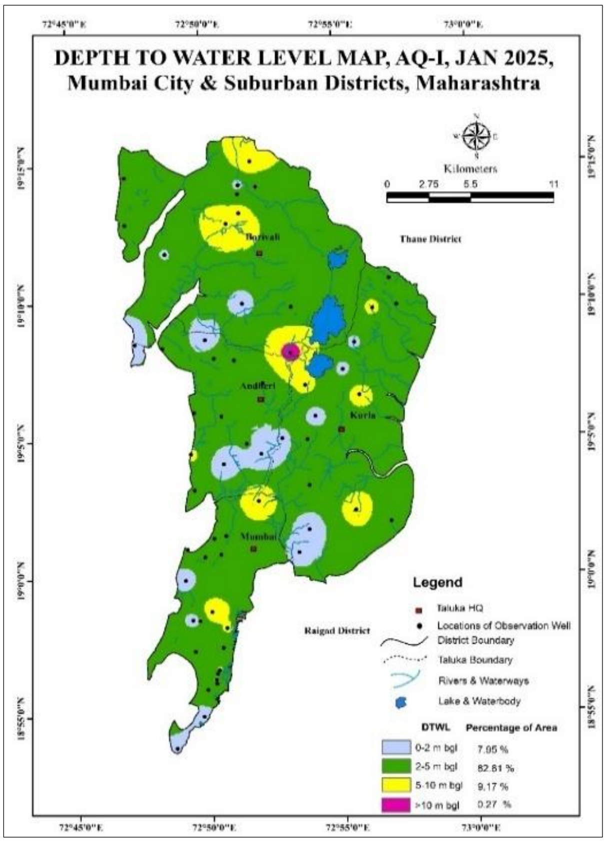


Fig 6.16: Depth to Water level Map, Jan 2025

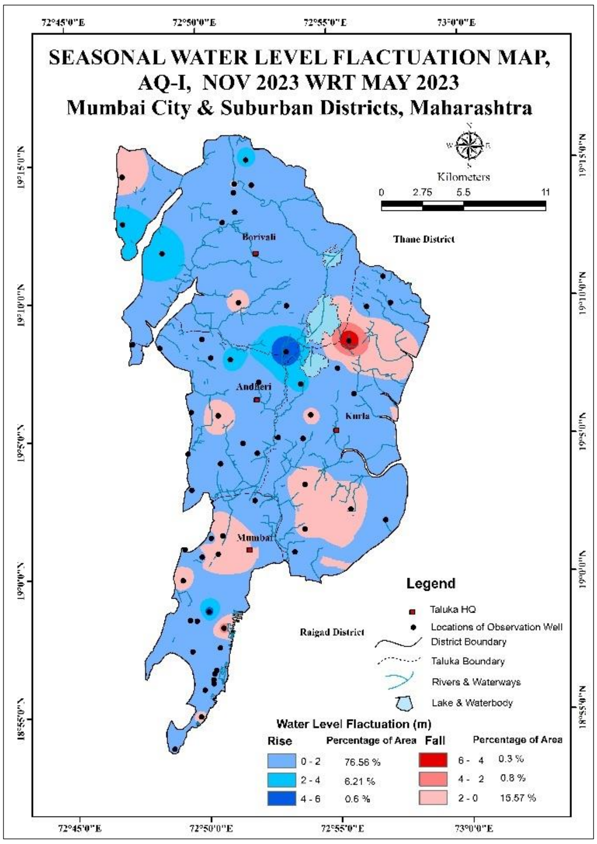


Fig 6.17 **Seasonal Fluctuations Nov. 2023 wrt 2023**

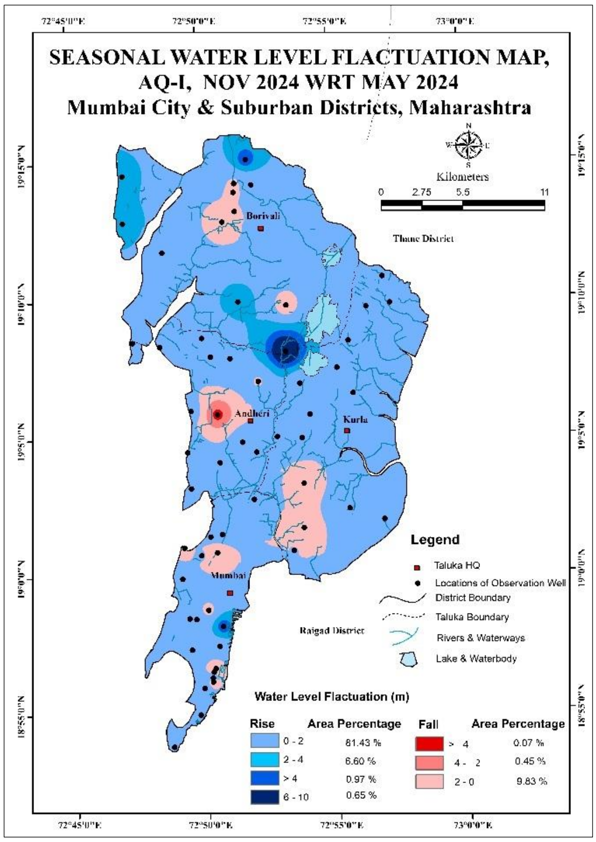
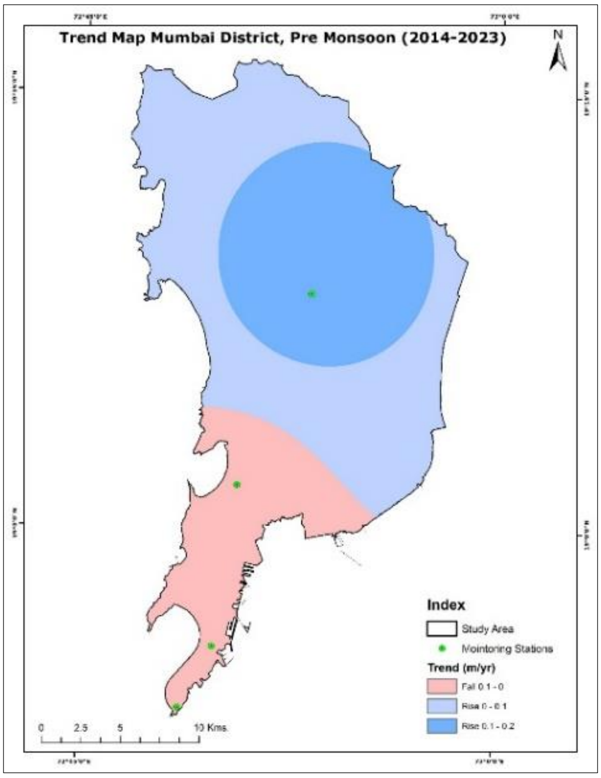


Fig 6.18 **Seasonal Fluctuations Nov. 2024 wrt 2024**



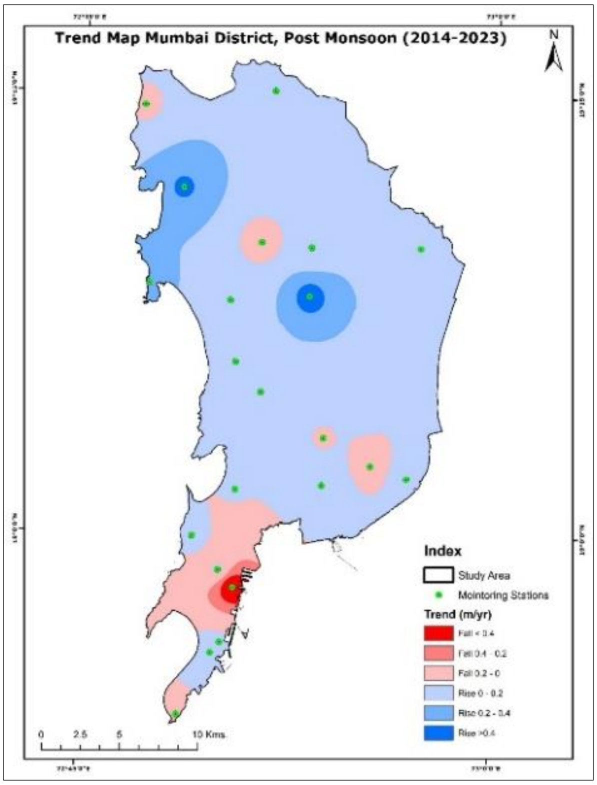
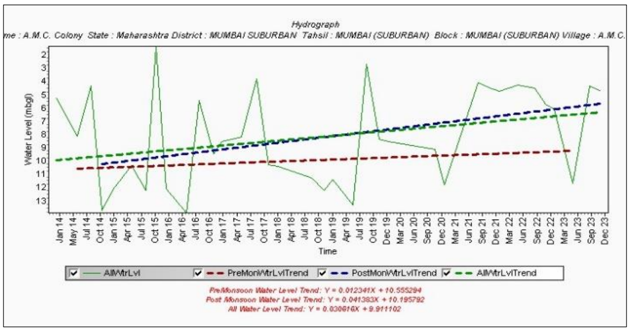
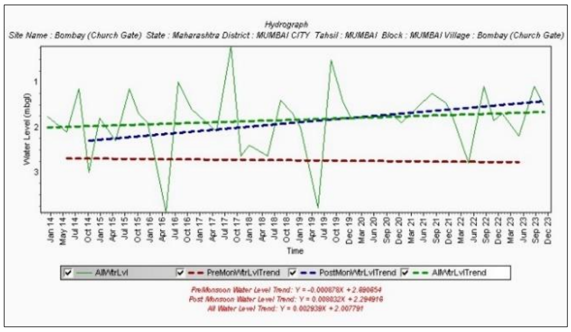


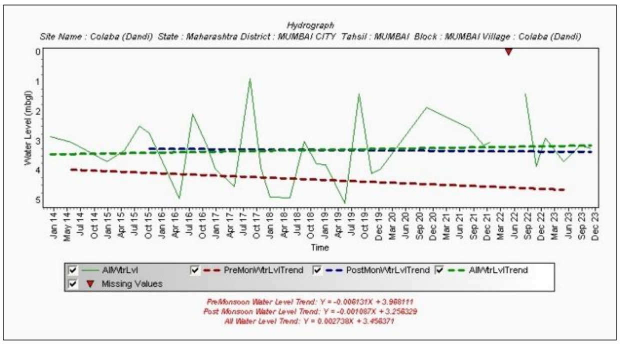
Fig 6.19: Water Level Trend Map Pre-Monsoon (2014- 2023, NHS wells) **Fig 6.20: Water Level Trend Map Post-Monsoon (2014 to 2023, NHS wells)**



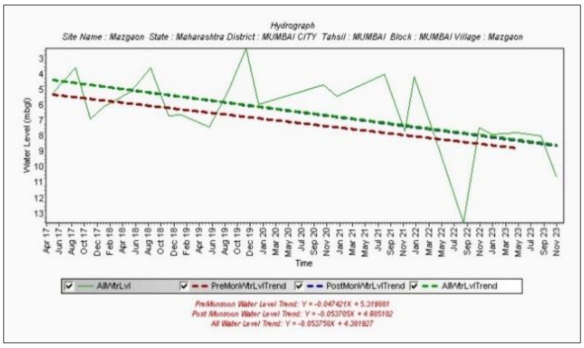
a) Hydrograph: AMC Colony



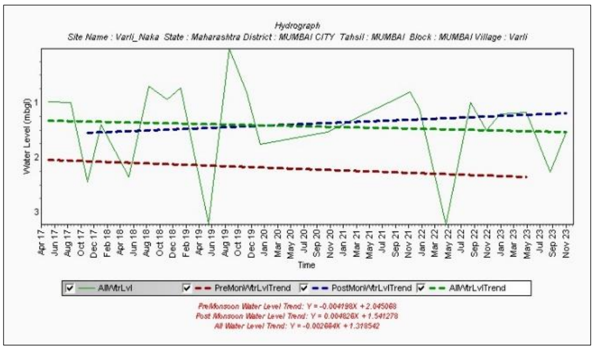
b) Hydrograph: Bombay Churchgate



c) Hydrograph: Colaba Dandi



d) Hydrograph: Mazgaon



e) Hydrograph: Vorli

Fig 6.21: Hydrographs of various locations showing water level trend

CHAPTER 7
HYDROGEOCHEMISTRY

7.1 HYDROGEOCHEMISTRY OF THE STUDY AREA

Evaluation of ground water quality through concentration of its physical, chemical and biological parameters is essential to determine its suitability for the intended use. It helps not only in finding its suitability; it also helps in taking effective remedial measures for its improvement on scientific lines. Central Ground Water Board monitors the ground water quality of the district through analysis of water samples collected from its National Hydrograph Network Stations (NHNS) which represent the shallow aquifer of the district with an objective to understand an overall picture of ground water quality of the study area. During year 2023 and 2024, CGWB has carried out the ground water quality monitoring at all the NHS and KOW. Out of the total 94 samples analyzed, 58 are from BW and 36 are from Dugwells. **Fig 7.1.** The water samples have been analyzed for major cations (Ca, Mg, Na, K) and anions (CO3, HCO3, Cl, NO3, SO4) in addition to pH, EC, F, SiO2, PO4 and TH as CaCO3 and heavy Metals in Regional Chemical Laboratory at CGWB, CR, Nagpur.

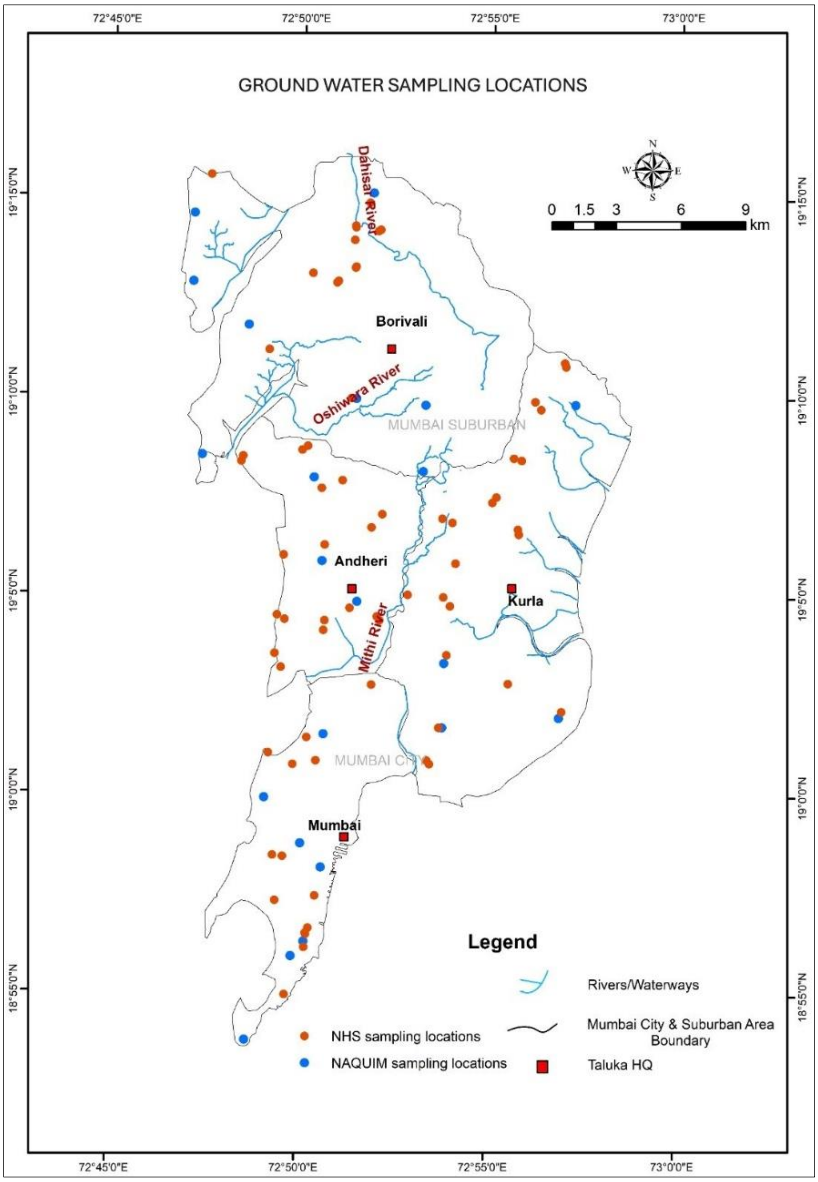


Fig 7.1: Map showing sampling locations for Mumbai city and Mumbai Suburban Districts

7.2 CHARACTERIZATION OF GROUNDWATER QUALITY AND ITS SUITABILITY STUDY

Groundwater is a precious natural resource for several vital functions such as public, industries and agricultural water supply. The quality of the water is equally essential to assess its suitability for different purposes. The quality of the surface water and groundwater depends upon variation in geological formation and soil types. It is impossible to control the dissolution of the constituents in water after they enter the ground water. The analytical data have been considered to assess the chemical quality of ground water and its suitability for drinking, domestic.The result of ground water samples collected during Pre-monsoon 2023 & 2024 have been evaluated in accordance with the standard (BIS (IS-10500-2012)) for drinking purpose and is given in the **Table-7.1 and details are given in Annexure II**

Table: 7.1 Summary of Hydrochemistry in the study area vis-`a-vis BIS Guidelines on Drinking Water (IS 10500:2012) (Pre-Monsoon 2023 & 2024)

Constituents	Pre-monsoon 2023			Pre-monsoon 2024			IS 10500:2012	
	Min	*Max*	*No. of samples beyond permissible limit*	*Min*	*Max*	*No. of samples beyond permissible limit*	*Acceptable limit*	*Permissible limit*
pH	6.86	7.9	Nil	3.4	8.73	3	6.5-8.5	6.5-8.5
EC at 250C (µS/cm)	136	4558	5 (>2000 EC)	123	6842	2 (>2000 EC)	-	-
TDS	87	2917	2	0	4378		500	2000
Chloride	11	1375	1	10.65	905.25	Nil	250	1000
Sulphate	0	92	Nil	0	214	Nil	200	400
Nitrate (mg/l)	1	84	4	0	58	1	45	45
Fluoride (mg/l)	0.16	1.12	Nil	0.02	1.05	Nil	1	1.5
Calcium	12	491	1	14	614	1	75	200
Magnesium	4.86	182	1	2.4	68	Nil	30	100
Total Hardness	70	1530	2	45	1820	2	200	600
Sodium	4	529	-		595.4		-	-
Potassium	0	34	-		30		-	-
Iron (mg/l)	0	283	Nil	0	0.1	Nil	1	-

7.3 RESULTS AND DISCUSSION

1. **pH:** The pH of water is an important indication of its quality and provides important piece of information in many types of geochemical equilibrium or solubility calculations (Hem 1985). The pH of the groundwater in the study area varies from 6.86 to 7.89 in Pre monsoon 2023 and from 7.05 to 8.73 in Pre monsoon 2024. It indicates that all the samples are within the limits of the water quality standards for drinking specified as 6.5 to 8.5. (BIS 2012). Ph is observed to be higher than permissible limit in samples collected from 2 sites during pre-monsoon 2024, namely Mahul dw (Kurla) and Vikhroli (Kurla).
2. **Electrical conductivity (EC):** The conductivity measurement provides an indication of ionic concentrations. It depends upon temperature. The ground water is found to have low to very high salt content as the EC of well water ranges from 136.6 µS/cm at Chandiwali to 4558 *µS/cm* at Laxminagar. High EC with values above 2000 is observed at 4 locations i.e Khardanda 2031 µS/cm, Mahul 2177 µS/cm, Theosophical Society (Juhu vile Parle) 3543

µS/cm and Laxminagar 4558 µS/cm. All these samples with high EC have been collected from BW. The salinity and Chloride maps for both DW and BW are shown in **Fig 7.2 and 7.3**

3. **Uranium:** The analysis for Uranium indicates very low concentration of Uranium in the ground water ranging from BDL to 4.48 ppb at Laxminagar area of Mumbai. There is presence of Uranium in the ground water but in very low concentration and within the permissible limit of 30 ppb as prescribed by BIS and WHO.
4. **Fluoride** is found to be in low concentrations within the permissible limits of BIS. However, fluoride above acceptable limit of 1mg/l (BIS) has been observed in both shallow and deeper aquifers in Pre-Monsoon sample at Borspada, Borivali. **Fig 7.4** Fluoride in aquifers such as Basalt primarily originates from the natural weathering and leaching of fluoride-bearing minerals in ground water.
5. **Nitrate**: Chemical analysis for Nitrate in the GW samples shows presence of NO3 above the permissible limit prescribed by BIS i.e 45 mg/l in 3% of the samples. Fig 7.5. High values of NO3 are observed at Rokadia DW (Cross Lane) 52 mg/l, Varsova GS Ward 70 mg/l and Worli village 84 mg/l could be attributed to anthropogenic activities around the area. **Fig 7.5.**
6. **Heavy metals** I115 acidified samples were collected during pre-monsoon period 2023 & 2024 for heavy metal analysis. The samples were analyzed for Copper, Lead, Zinc, Nickel, Cadmium, Chromium, Manganese and Iron. The concentration of heavy metals like Copper, Lead, Zinc, Cadmium was not detected (ND). As per the analysis heavy metal are either below detectable limit and/or within permissible limits.

7.4 AQUIFER WISE GROUND WATER QUALITY

Groundwater quality in Mumbai exhibits distinct spatial and vertical variations between the shallow and deeper basaltic aquifer systems. The city is underlain by two principal aquifers: a shallow unconfined aquifer (Aquifer-I) and a deeper semi-confined to confined aquifer (Aquifer-II) occurring within jointed and fractured basalt between 30 and 172 m bgl. Aquifer-wise occurrece of major parameters in GW is given in **Table 7.2**

Table 7.2: Aquifer-wise occurrence of major parameters in GW

S.No.	Depth/Chemical Parameter	Aquifer-I	Aquifer-II
1.	**Aquifer disposition**	Shallow	Deeper
2.	**Depth range (m bgl)**	0 to 30m bgl	30 to172 mbgl
3.	**Aquifer type**	Unconfined, weathered basalt	Semi-confined to Confined, Jointed/ fractured basalt
4.	**Electrical Conductivity**	Between 221 to 1572 µs/cm	Between 136 to 4558 µs/cm, (high EC >2000 µs/cm reported at Theosophical Society, Jogeshwari (E), Khardanda, Laxminagar, Mahul
5.	**Chloride**	Within permissible limit	Mostly exceeding within limit (high Cl Values above acceptable limits of BIS reported at Theosophical Society, Jogeshwari (E), Khardanda, Laxminagar, Mahul, Chinchwadi & Agarwadi

6.	**Nitrate**	Within permissible limit, Localized Nitrate >45 mg/l: 03 locations (Rokadia, Varsova & Worli)	Within permissible limit, Localized Nitrate >45 mg/l: 01 (Varsova)
7.	**Salinity / seawater ingress**	Localized	High along coastal Tracts (As per EW data High salinity is observed at JJ school of Arts, Sambhaji Raje Garden (Mulund) Shivaji Park Dadar. High EC suggesting Saline water Intrusion

Aquifer-I: EC values range from 221 to 1572 µS/cm, indicating predominantly fresh to slightly mineralized groundwater. Chloride concentrations generally remain within permissible limits, suggesting minimal influence of saline water. Nitrate concentrations are largely within acceptable limits; however, localized nitrate contamination exceeding 45 mg/L has been observed at a few locations such as Rokadia, Varsova, and Worli, indicating localized anthropogenic influences, such as sewage infiltration. Salinity and seawater ingress in Aquifer-I are limited and occur only in localized pockets.

Aquifer-II : shows comparatively deteriorated groundwater quality. EC values display a wide range from 136 to 4558 µS/cm, with several locations recording values exceeding 2000 µS/cm, notably at Theosophical Society, Jogeshwari (East), Khardanda, Laxminagar, and Mahul. Elevated chloride concentrations, frequently exceeding permissible limits, are reported from multiple locations including Theosophical Society, Jogeshwari (East), Khardanda, Laxminagar, Mahul, Chinchwadi, and Agarwadi, indicating significant saline water influence. Nitrate concentrations in the deeper aquifer are generally within acceptable limits, with only isolated high value reported at Varsova. High salinity observed along coastal tracts—such as at JJ School of Arts, Sambhaji Raje Garden (Mulund), and Shivaji Park (Dadar)—along with high EC values, strongly suggests seawater intrusion in deeper Aquifer.

Conclusion: Overall, the aquifer-wise assessment indicates that while the shallow aquifer in Mumbai retains comparatively fresh groundwater with localized anthropogenic contamination, the deeper aquifer is more vulnerable to sea water intrusion, particularly in coastal areas. The occurrence of high EC and chloride concentrations in Aquifer-II highlights the impact of seawater intrusion, likely exacerbated by groundwater extraction and movement of GW through fractured basalt formations. This emphasizes the need for aquifer-specific groundwater management strategies in Mumbai, with particular emphasis on controlling saline ingress in the deeper aquifer system.

In general, the GW in the study area is suitable for drinking and domestic uses requiring interventions at isolated places. The suitability of groundwater for irrigation purpose was not assessed as the entire area is urban.

7.5 HYDROCHEMICAL FACIES CLASSIFICATION

7.5.1 PIPER DIAGRAM

The piper diagram describes the process responsible for the evolution of the hydro geochemical parameters in Ground water. Based on the major cation and anion content in the water samples and plotting them in the trilinear diagram, Hydrochemical facies could be identified. Hydrochemical facies are very useful in investigating diagnostic chemical character of water in the hydrologic systems. Different types of facies within the same group formations are due to characteristic ground water flow through the aquifer systems and effect of local recharge. The types of facies are interlinked with the geology of the area and distribution of facies with the hydrogeological controls. Hydrochemical facies are delineated by plotting percentage reacting value of major ions on trilinear diagrams known as piper diagram. For demarcating the hydrochemical facies existing in the shallow and deeper aquifer systems Piper Trilinear Diagram were prepared **(Fig. 7.6 a & 7.6 b).** Analysis of the diagram indicates that 92% of groundwater samples from shallow aquifers fall in Ca-Mg-Bicarbonate Type", which is characterized by recent origin of recharge water, which had little interaction with the bedrock. 5% samples fall in the Mixed type category and 3% in Na-K-Cl-SO4 type ".

The samples collected from Deeper aquifers show that 75% of samples fall in the Ca-Mg-Bicarbonate type water whereas 8% samples are in Mixed type category, 12% fall in Na-K-Cl-SO4 type. And 5% fall in Ca-Mg-Cl-Sulphate type of water. Therefore, the Hydrochemical facies classification in Study Area indicates that maximum groundwater samples belong to Ca-Mg-HCO3 type of water. Similar pattern is observed in Samples collected for Pre-Monsoon 2024 as well.

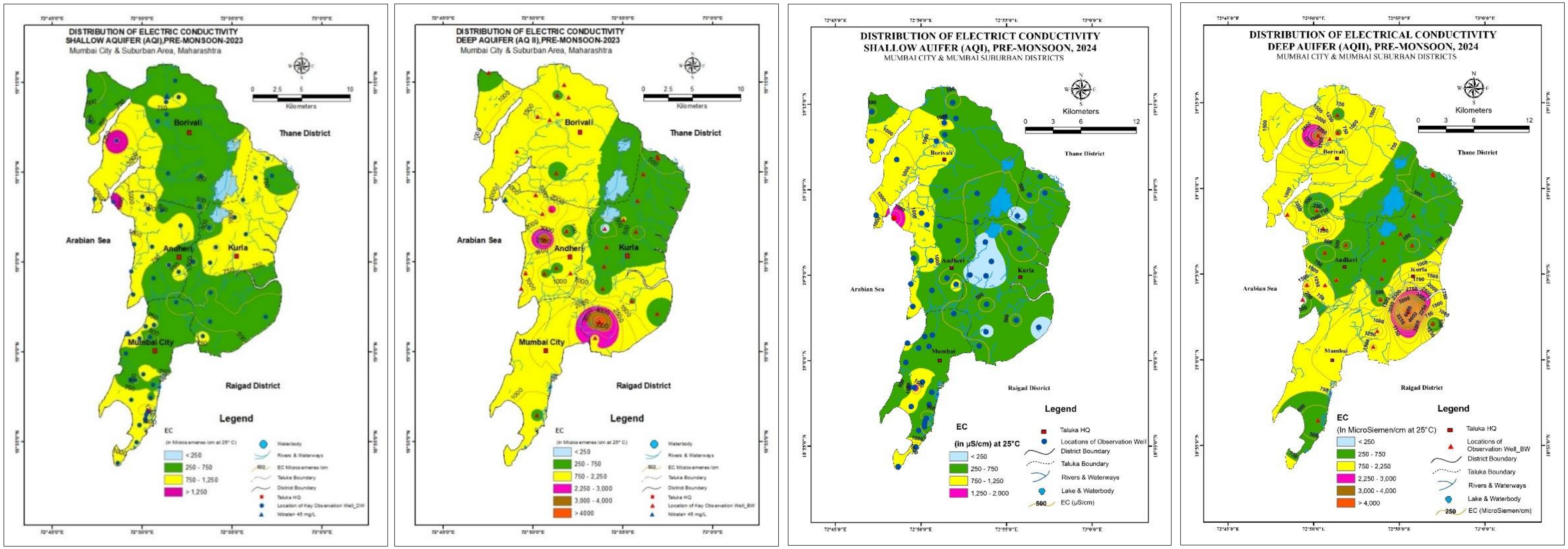
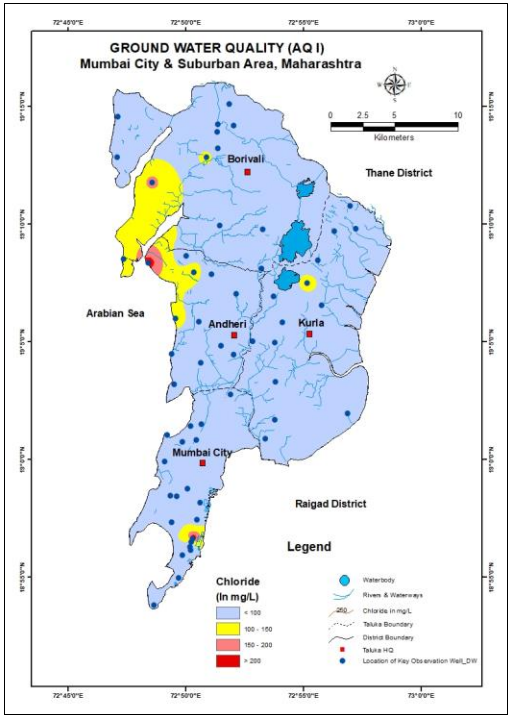
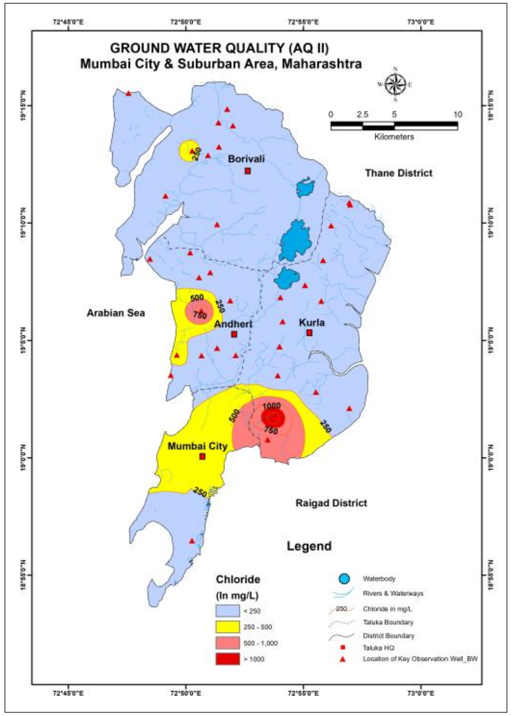


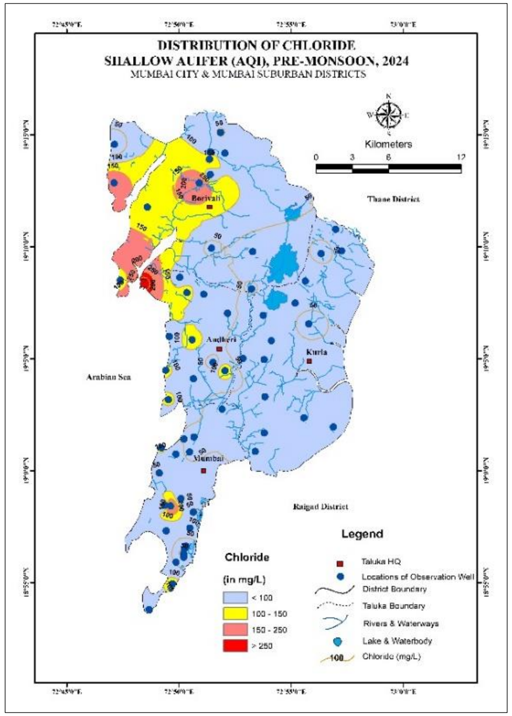
Fig 7.2: Spatial Distribution of Electrical Conductivity



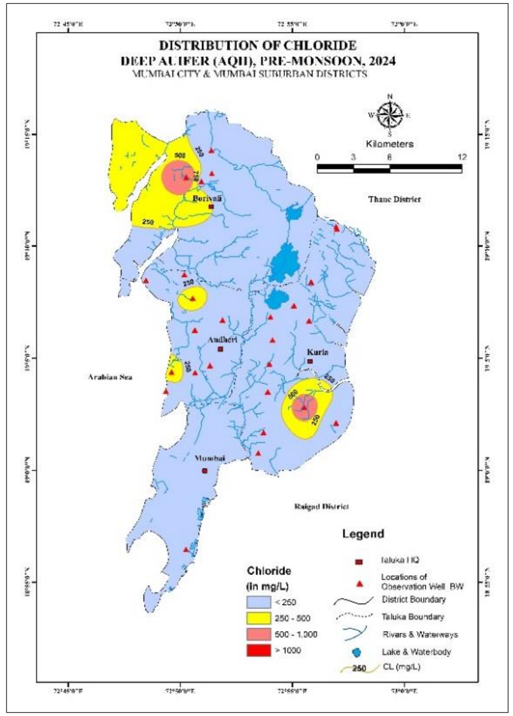
a



b



c



d

Chloride Map (Shallow, Aquifer I (a), Deeper, Aquifer II (b) Pre-Monsoon, 2023

Chloride Map (Shallow, Aquifer I (c), Deeper, Aquifer II (d) Pre-Monsoon, 2024

Fig 7.3: Spatial Distribution of Chloride (2023 & 2024)

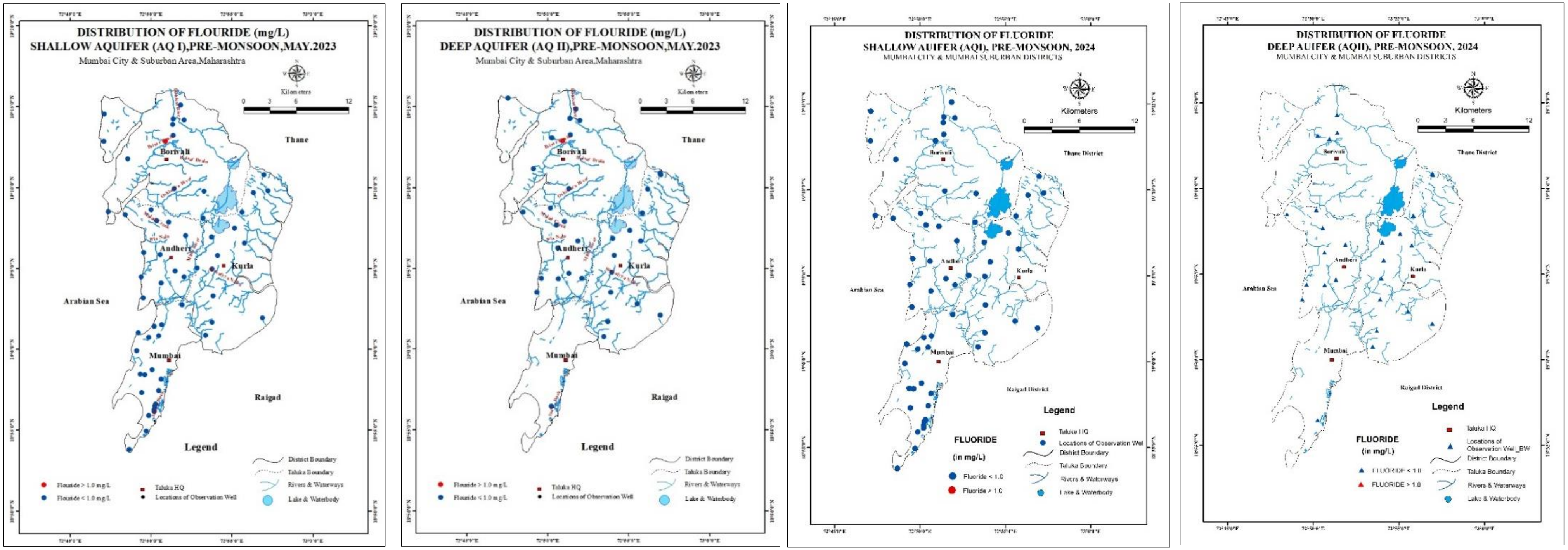


Fig 7.4: Map showing occurrence of Fluoride

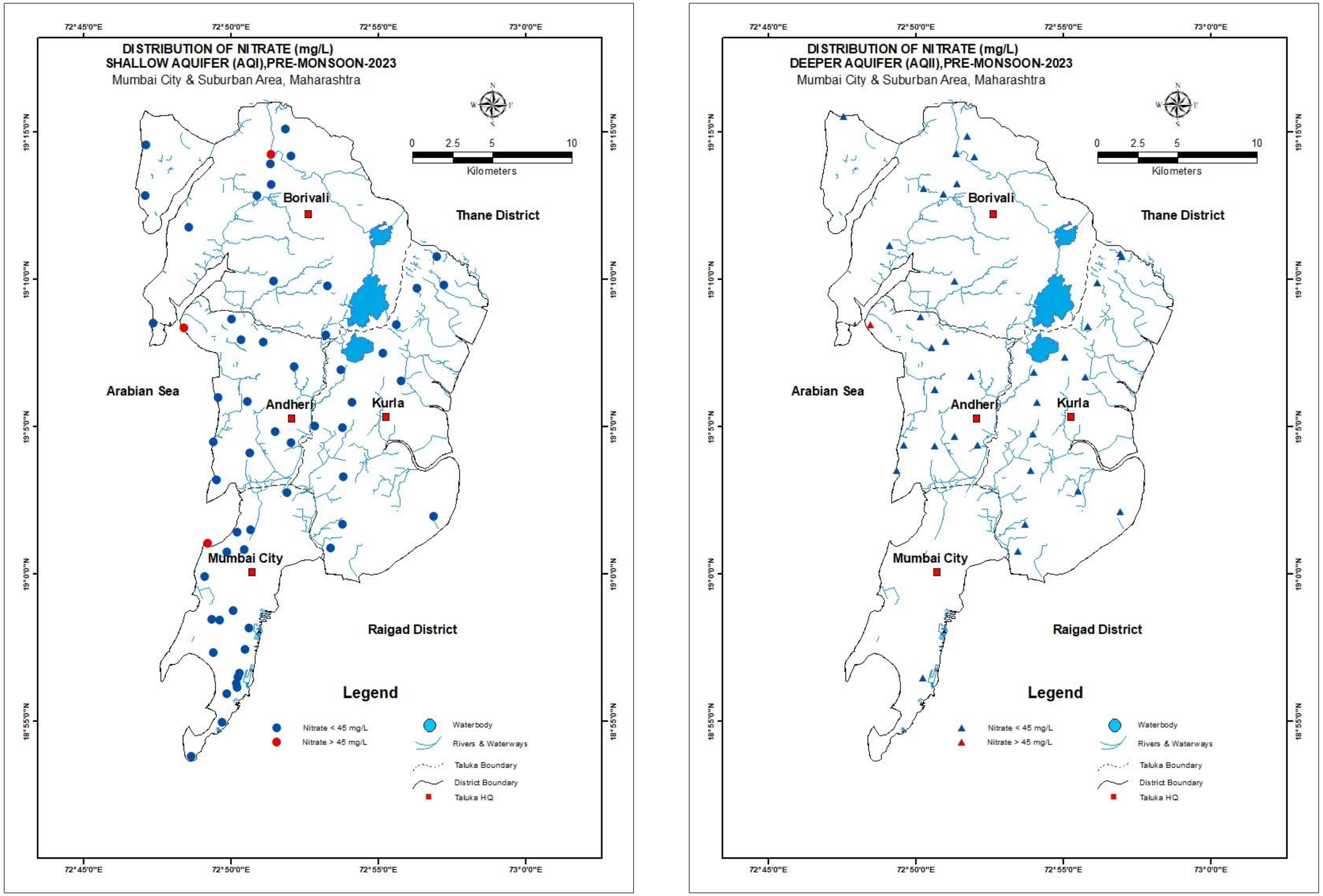


Fig 7.5: Map showing occurrence of Nitrate

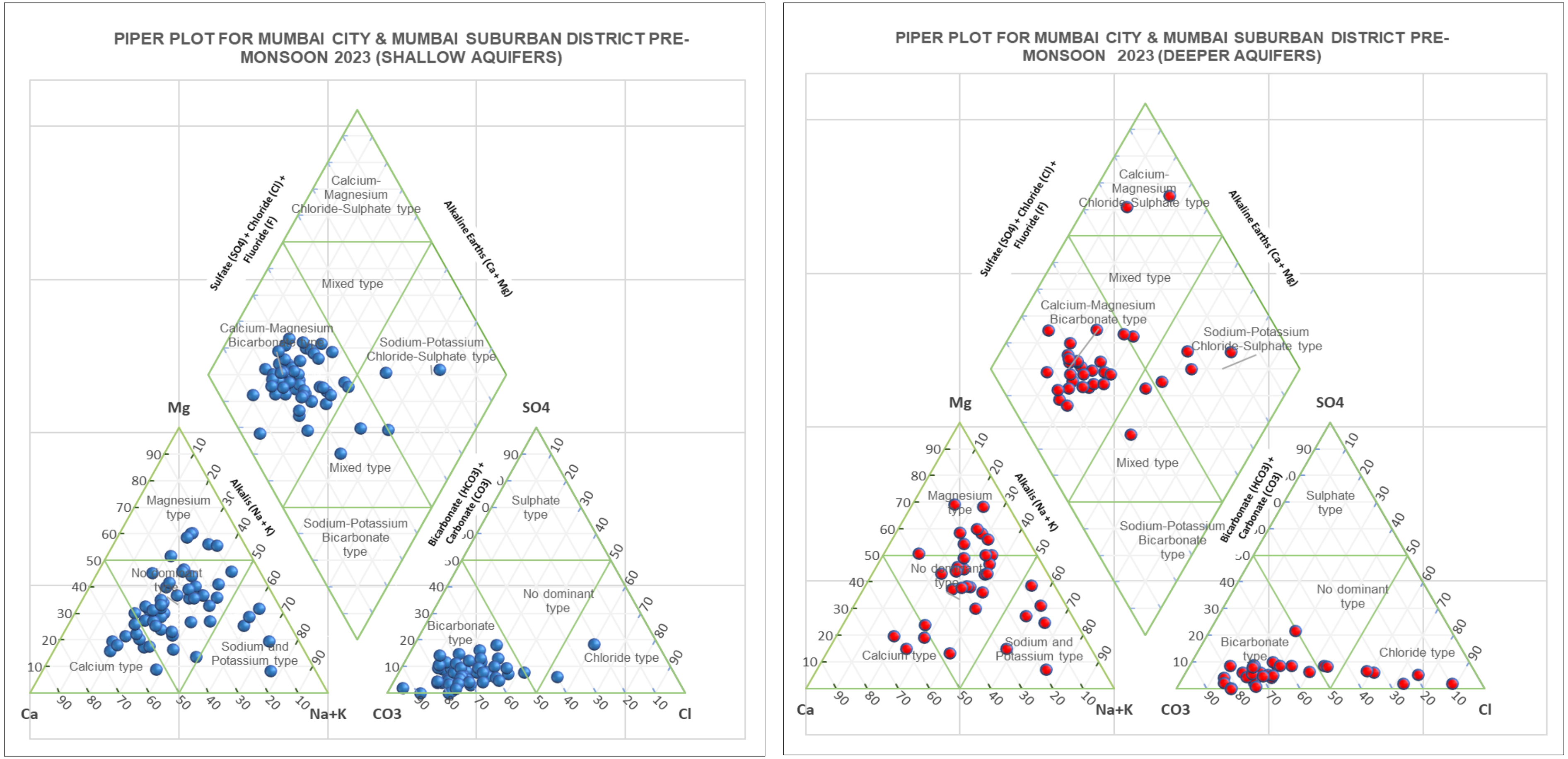
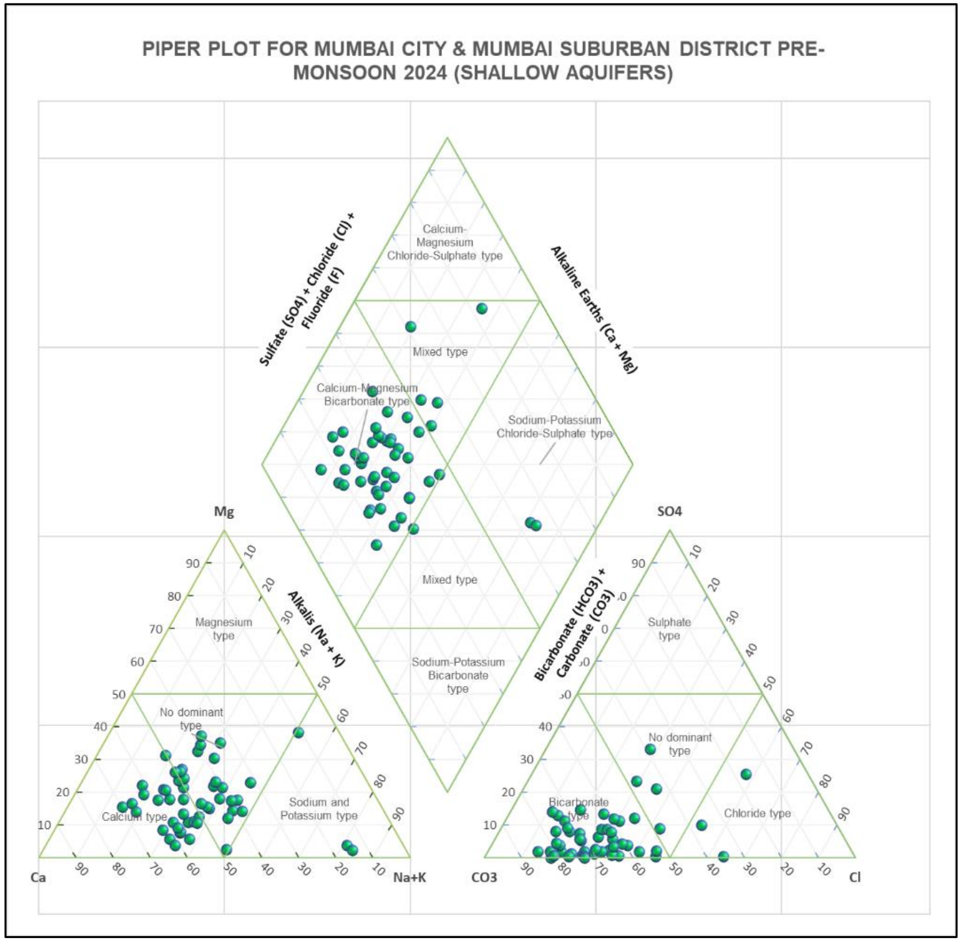


Fig 7.6 a: Piper Trilinear Plot for Shallow and Deeper Aquifer of the Study Area, 2023



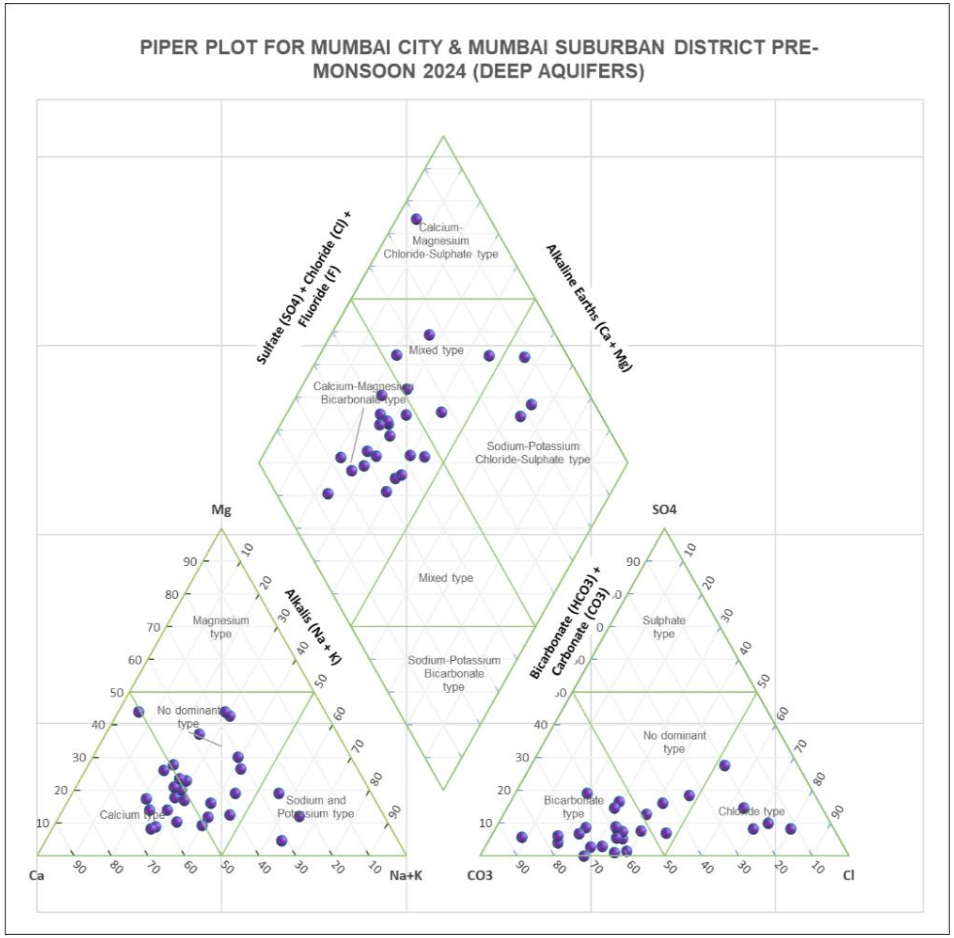


Fig: 7.6 b Piper Trilinear Plot for Shallow and Deeper Aquifer of the Study Area, 2024

7.6 MECHANISM CONTROLLING GROUNDWATER CHEMISTRY

I) GIBB'S DIAGRAM

The dissolved constituents in groundwater and surface water are derived from chemical weathering of rock forming minerals. As rain dissolves the rock components the groundwater becomes concentrated in the most soluble elements of the decomposed rocks i.e.; Na, Ca, Mg, K etc., (Martin, 1988). Tthere is a close relationship between the composition of water and lithology of an aquifer the proposed a classification using ion proportions and total dissolved solids (TDS) and identified three major categories of waters. Rain dominated type Rock dominated type and Evaporatic type.

The ratio of (Na+K)/ (Na+K+Ca) and Cl/Cl+HCO_3 have been plotted against TDS shown as **Fig. 7.7** and **Fig. 7.8** for the samples collected from Shallow and Deeper aquifers. It shows the mechanisms responsible for the groundwater chemistry of the state for both aquifers. The predominant samples from both shallow and deeper aquifers of two years 2023 & 2024 falling in the rock–water interaction dominance field of the Gibbs' diagram. The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolated waters under the subsurface.

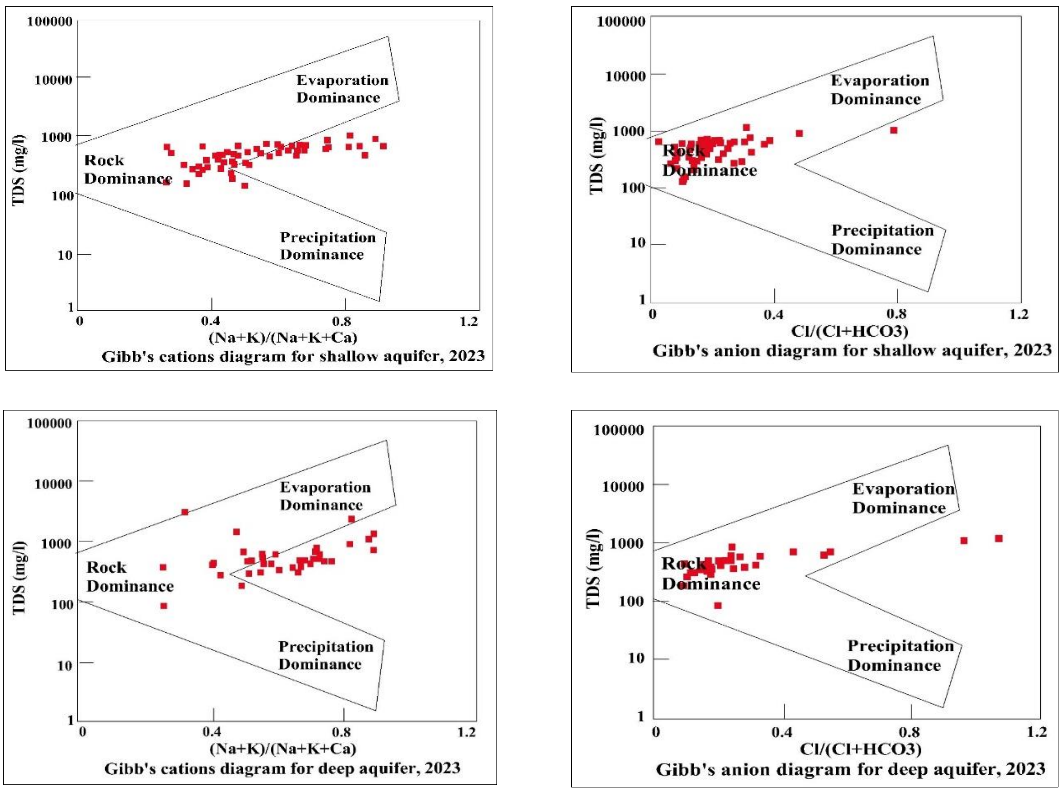


Fig 7.7: Gibbs' Cation and Anion Diagram for shallow and Deeper aquifers, 2023

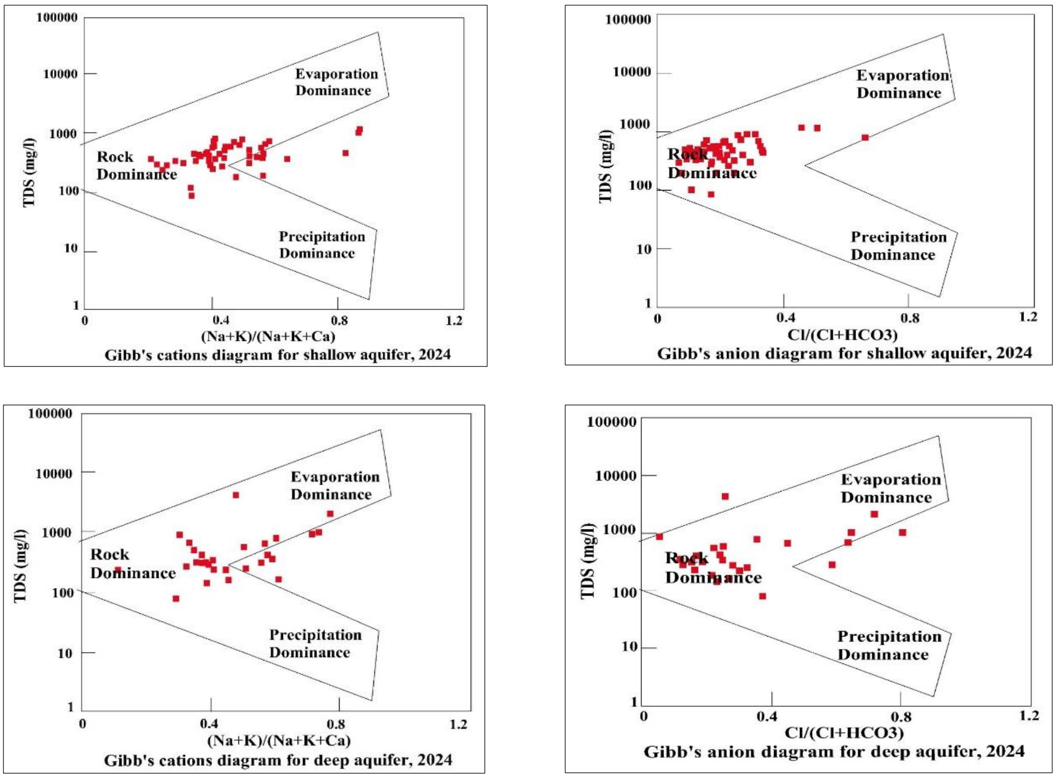


Fig 7.8: Gibbs' Cation and Anion Diagram for shallow and Deeper aquifers, 2024

II) US SALINITY DIAGRAM

The US Salinity Diagram takes into consideration the salinity and sodium hazard of irrigation water. In general, it is observed that the samples fall into the C2S1, C3S1 indicating low sodium hazard which is good for Plantation in the study area. However, some samples fall in the Since it is an urban agglomerate and agricultural practices are not being carried out. The samples that fall into the C3–S4, C4–S4, categories indicate a high salinity and high sodium adsorption hazard. This means the water is generally not suitable for irrigation without specific management practices to address the salinity and sodium issues. The US Salinity Diagram for both deeper and shallow aquifer 2023 and 2024 are shown in **fig 7.9.**

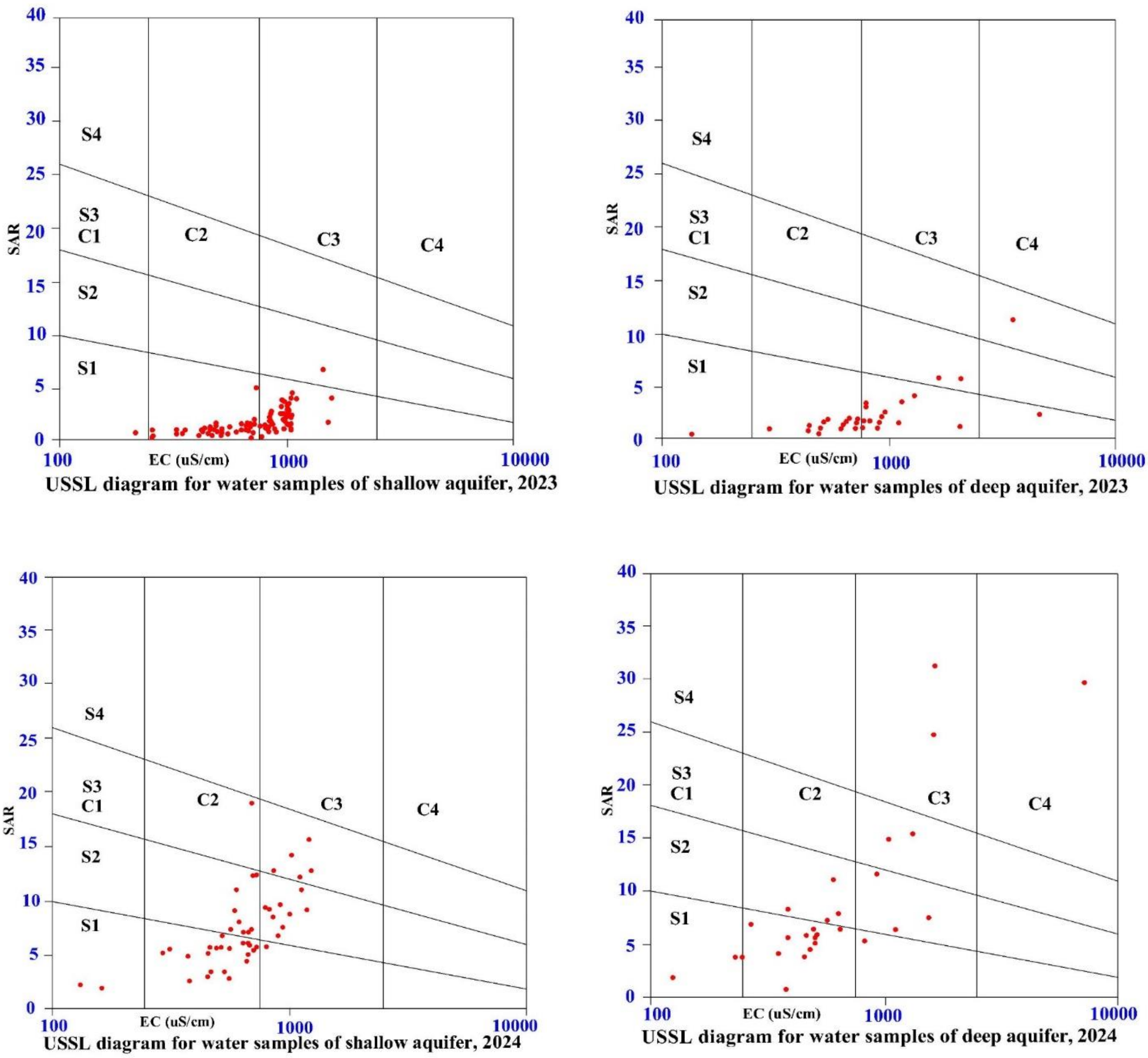


Fig 7.9: US Salinity Diagram for Shallow and Deeper aquifers, 2023-24

III) WILCOX DIAGRAM

EC and Sodium concentrations are very important in classifying irrigation water. The wilcox diagram (Wilcox 1948) relating EC to percentage Sodium shown in **fig 7.10.** shows that all samples are plotted in Excellent to Good and Good to permissible categories indicating their suitability for irrigation with only few samples falling in the unsuitable zone. The study area Mumbai being an urban agglomerate, there are no irrigation practices going on the area. However, it is evident that the ground water is suitable for plantation.

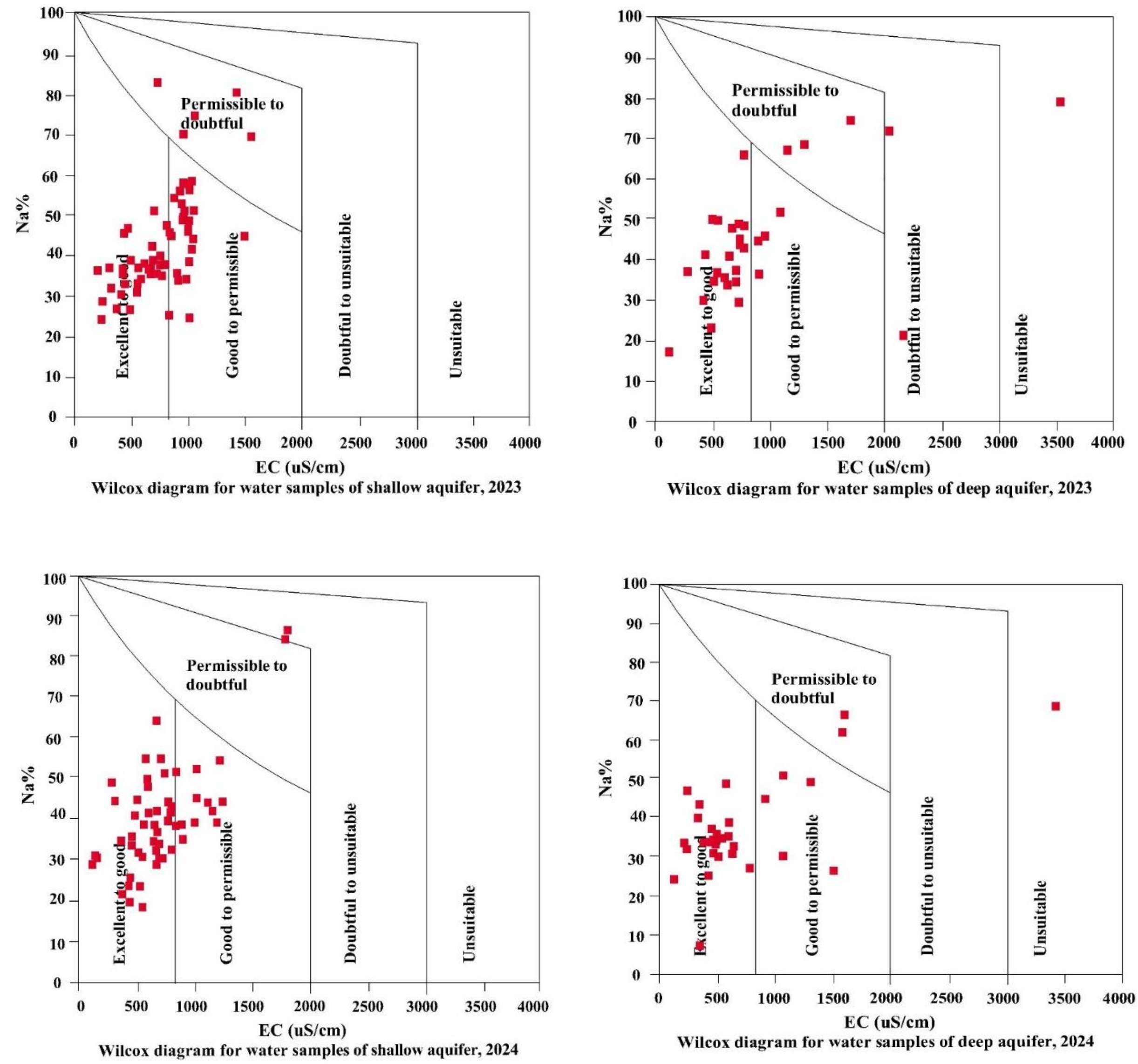


Fig 7.10: Wilcox Diagram for Shallow and Deeper aquifers, 2023-24

CHAPTER 8
GROUND WATER RESOURCES ASSESSMENT

8.1 GROUND WATER RESOURCES ASSESSMENT

One of the deliverables of the NAQUIM Study involved the Assessment of Dynamic Ground Water Resources of Mumbai and Mumbai Suburban district using the GEC -2015 methodology. The Dynamic ground water resources (2024 & 2025) for the entire State of Maharashtra including Mumbai city and Mumbai suburban districts have been assessed jointly by CGWB and State Ground Water Departments under the supervision of the State Level Committee. This exercise has been carried out for the first time in 2024 for Mumbai city and Mumbai Suburban district. The data were collected and entered by GSDA in INGRES a Software/Web-based Application developed by CGWB in collaboration with IIT-Hyderabad (ingres.iith.ac.in). This software is used to estimate, analyze, and access dynamic groundwater resources (i.e recharge and discharge and stage of ground water extraction) Pan India. The Dynamic ground water resources are also known as Annual Ground Water Recharge, since it gets recharged every year from rainfall and other secondary sources such as applied irrigation water, surface water bodies, water conservation structures, etc.

As per the latest Ground Water Resources Assessment (GWRA) for Mumbai and Mumbai Suburban district, i.e 2025, the Annual Extractable Ground Water Resource has been estimated as 14.77 MCM and 72.63 MCM respectively. The Total Annual GW Extraction has been estimated as 6.80 MCM for Mumbai and for Mumbai Suburban it is estimated as 18.70 MCM. Out of which, more than 90% GW extraction is for Domestic Use and remaining is for Industrial purposes in both the districts. Since Mumbai is an urban area and there are no irrigation practices going on, the utilization for irrigation is Nil. The Ground water resources and Utilization is shown graphically in **Fig 8.1 & 8.2** and details are given in **Annexure III**

The Stage of GW extraction which is a measure of Total Annual GW extraction over Total Annual Extractable GW resources expressed in percentage has been estimated as 46 % and 25.74% for Mumbai and Mumbai suburban districts respectively. There are 04 No. of Assessment Units i.e Mumbai, Andheri, Kurla and Borivali and all have been categorized as ‘Safe’. The details of Ground water resources assessment are given in Table given below. The categorization map for the Mumbai is given in **Fig 8.3.** Due to limited available information, the Ground water extraction due to domestic usage in Mumbai Suburban District was calculated for whole of the district and was later averaged out to each Taluka.

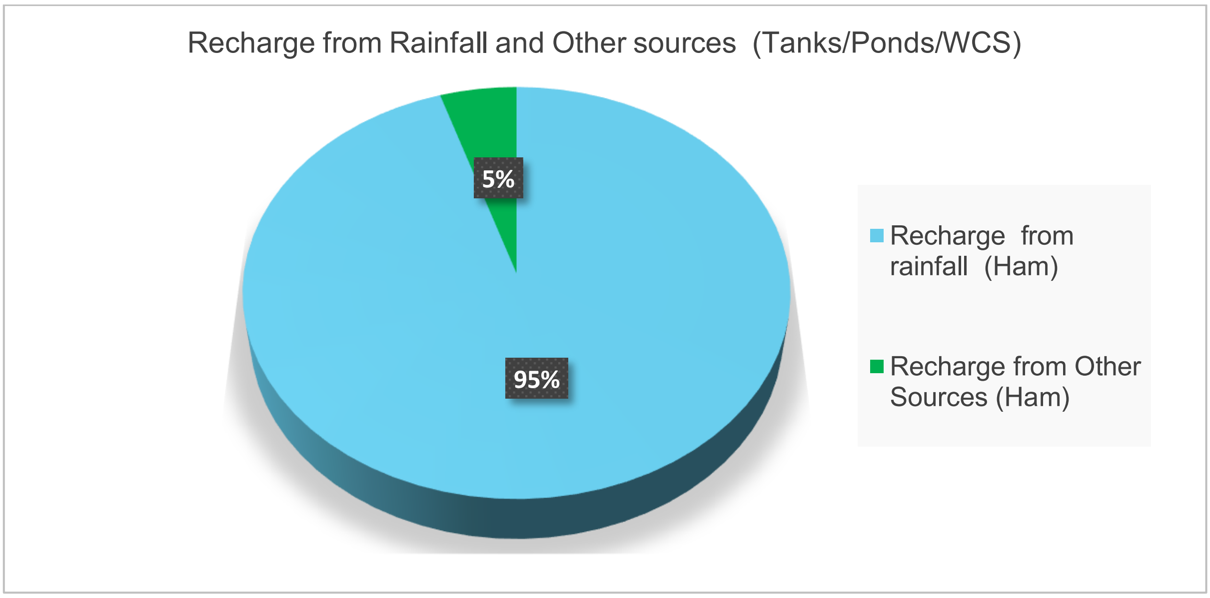


Fig 8.1: Recharge from Rainfall and Other sources (Tanks/Ponds/WCS) in Study Area (GWRE 2025)

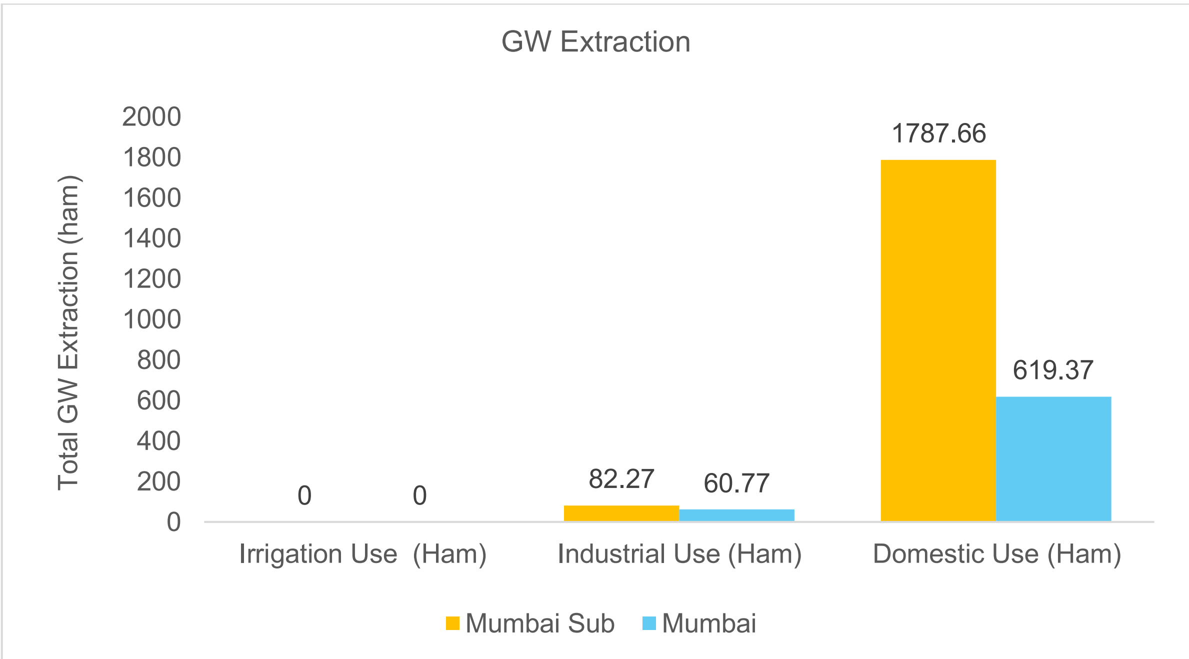


Fig 8.2: Ground water Extraction (GWRE 2025)

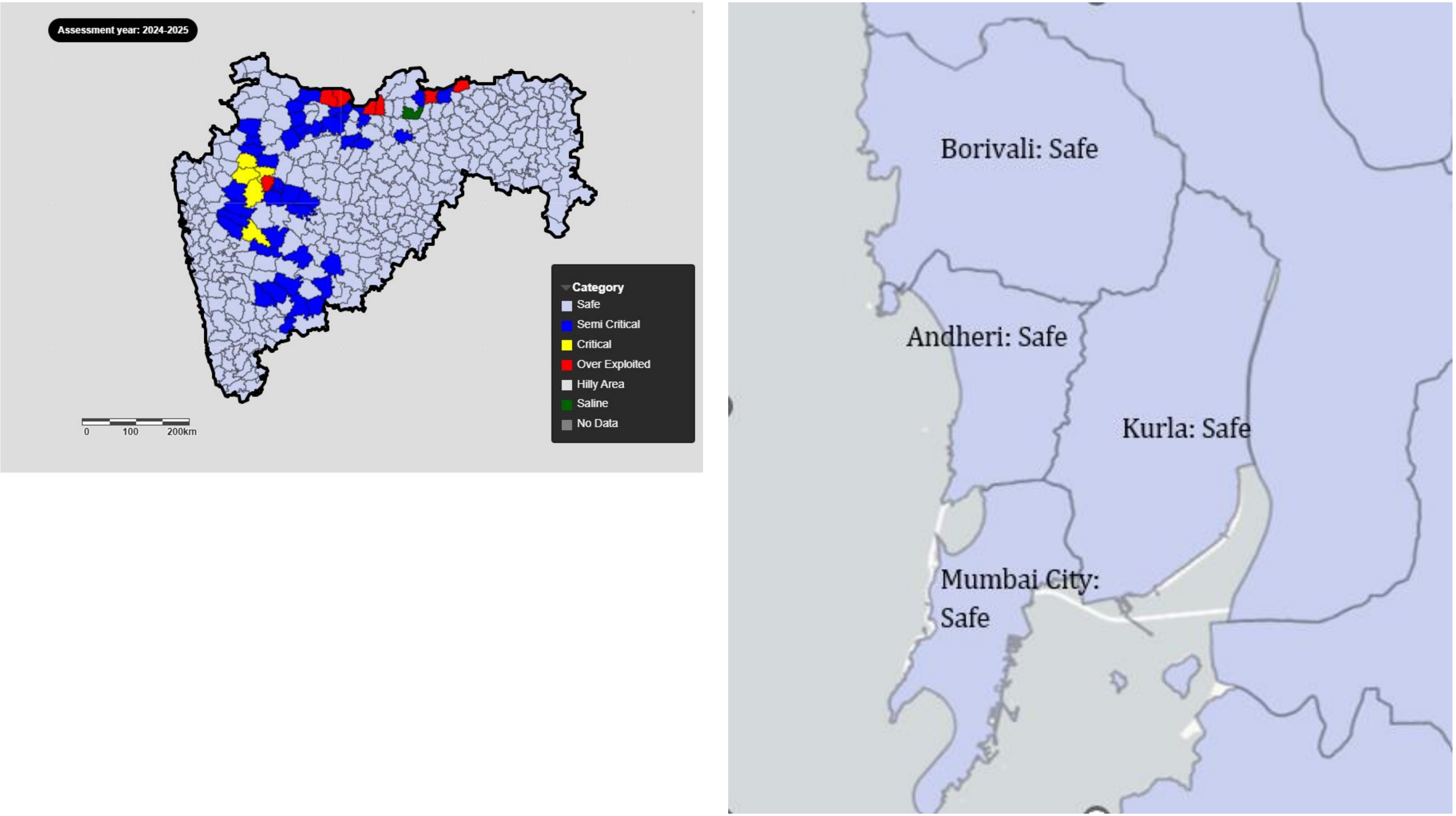


Fig 8.3: Categorization Map of Mumbai City and Mumbai Suburban District, 2025

CHAPTER 9

SEA WATER INTRUSION STUDY IN MUMBAI CITY AND MUMBAI SUBURBAN AREA-USING GALDIT MODEL

9.1 INTRODUCTION GALDIT MODEL

Groundwater vulnerability, defined as susceptibility of groundwater to pollution and contaminant infiltration, is a key topic in hydrogeology and environmental research. It takes into account both how sensitive the groundwater is naturally and how susceptible it is to contamination from certain sources or human activities. There aren't too many suitable methodologies for mapping the spatial distribution of sensitive coastal areas to potential seawater intrusion. A vulnerability index, which is created using hydrogeological, morphological, and other aquifer parameters in a well-defined manner, is one of the systems for evaluating and ranking aquifer vulnerability to pollution. The use of an index has the benefit of eliminating or minimizing subjectivity from the ranking process. Lobo-Ferreira and Cabral (1991) suggested using a vulnerability score to assess the European community maps. The present study area is surrounded by sea from 3 sides and much of the coastal area and islands were re-claimed land sites, it is essential to determine the vulnerability of the of ground water to saline water intrusion. The study has been taken up in accordance to chemical quality data obtained during the pre-Monsoon 2023 and 2024 period.

9.1.1 GALDIT MODEL (An open-ended model)

The approach given here uses an additive model to produce a numerical value for every hydro-geophysical setting. This is an open-ended model in which one or more indicators can be added or removed. The current set of indicators should not be wiped in most cases, and any addition of the indicator would require re-derivation of the weights and classification table, as shown in **Table 9.1.**

Table 9.1: Weights and Ratings given for GALDIT MODEL

<table>
<tr><th rowspan="2">Indicator</th><th rowspan="2">Weight</th><th colspan="2">Indicator Variables</th><th rowspan="2">Importance Rating</th></tr>
<tr><th>Class</th><th>Range</th></tr>
<tr><td rowspan="4">G. Groundwater occurrence/Aquifer type</td><td rowspan="4">1</td><td colspan="2">Confined Aquifer</td><td>10</td></tr>
<tr><td colspan="2">Unconfined Aquifer</td><td>7.5</td></tr>
<tr><td colspan="2">Leaky confined Aquifer</td><td>5</td></tr>
<tr><td colspan="2">Bounded Aquifer (recharge and/or impervious boundary aligned parallel to the coast)</td><td>2.5</td></tr>
<tr><td rowspan="4">A. Aquifer Hydraulic Conductivity (m/day)</td><td rowspan="4">3</td><td>High</td><td>>40</td><td>10</td></tr>
<tr><td>Medium</td><td>10-40</td><td>7.5</td></tr>
<tr><td>Low</td><td>5-10</td><td>5</td></tr>
<tr><td>Very low</td><td><5</td><td>2.5</td></tr>
<tr><td rowspan="4">L. Height of ground water Level above msl (m)</td><td rowspan="4">4</td><td>High</td><td><1.0</td><td>10</td></tr>
<tr><td>Medium</td><td>1.0-1.5</td><td>7.5</td></tr>
<tr><td>Low</td><td>1.5-2.0</td><td>5</td></tr>
<tr><td>Very low</td><td>>2.0</td><td>2.5</td></tr>
<tr><td rowspan="4">D. Distance from shore / High Tide (m)</td><td rowspan="4">4</td><td>Very small</td><td><500</td><td>10</td></tr>
<tr><td>Small</td><td>500-750</td><td>7.5</td></tr>
<tr><td>Medium</td><td>750-1000</td><td>5</td></tr>
<tr><td>Far</td><td>>1000</td><td>2.5</td></tr>
<tr><td rowspan="2">I. Impact status of existing seawater intrusion</td><td rowspan="2">1</td><td>High</td><td>>2</td><td>10</td></tr>
<tr><td>Medium</td><td>1.5-2.0</td><td>7.5</td></tr>
</table>

Indicator	Weight	Indicator Variables		Importance Rating
		Class	Range	
		Low	1-1.5	5
		Very low	<1	2.5
T. Aquifer Thickness (saturated) in meters	2	Large	>10	10
		Medium	7.5-10	7.5
		Small	5-7.5	5
		Very small	<5	2.5

9.2 GALDIT INDEX COMPUTATION

Each of the six indicators is assigned a fixed weight based on how much seawater intrusion it leads. The GALDIT Index is then calculated by adding the individual indicator scores and multiplying them by the formula:

$$\boldsymbol{GALDIT\ Index} = \sum_{i=1}^{6}\{(W_i)R_i\}/\sum_{i=1}^{6} W_i \text{ ………………….…… (4.24)}$$

Where W_i is the i^{th} indicator's weight and R_i is the i^{th} indicator's importance rating. As a result, the user can choose variables that reflect specific conditions in the area of interest, assign significant ratings to those variables, and compute the indicator score using hydrogeological and geological data from the area. Using this additive model, the user can determine a numerical value for any hydro-geographical setting. By substituting the maximum importance ratings of the indicators mentioned below, the "**maximum GALDIT-Index**" is calculated:

$$\boldsymbol{Max} = \{(1)*R_1 + (3)*R_2 + (4)*R_3 + (4)*R_4 + (1)*R_5 + (2)*R_6\}\Big/\sum_{i=1}^{6} W_i$$

$$= \{(1)*10 + (3)*10 + (4)*10 + (4)*10 + (1)*10 + (2)*10\}/15$$

$$= 10$$

Similarly,

By substituting the minimum importance ratings of the indicators as indicated below, the "**minimum GALDIT-Index**" is obtained:

$$\boldsymbol{Min} = \{(1)*R_1 + (3)*R_2 + (4)*R_3 + (4)*R_4 + (1)*R_5 + (2)*R_6\}\Big/\sum_{i=1}^{6} W_i$$

$$= \{(1)*2.5 + (3)*2.5 + (4)*2.5 + (4)*2.5 + (1)*2.5 + (2)*2.5\}/15$$

$$= 2.5$$

The minimum ranking and maximum ranking of the GALDIT index were 2.5 and 10, respectively. The maximum values of the GALDIT index denoted higher vulnerability to SWI. The SWI vulnerability classification index is presented in **Table 9.2.** Based on this classification the vulnerable areas were classified into three classes, namely high vulnerability, moderate vulnerability, and low vulnerability.

9.3 DECISION CRITERIA

After computing the GALDIT-Index, coastal locations can be categorized into three categories of seawater intrusion vulnerability. **Table 9.2** depicts a detailed classification of vulnerability classes based on the range of GALDIT-Index scores between minimum and maximum (2.5 to 10).

Table 9.2: Vulnerability classes

S. No.	GALDIT-Index Range	Vulnerability Classes
1	≥7.5	Highly Vulnerable

2	5-7.5	Moderately Vulnerable
3	<5	Low Vulnerable

9.4 RESULT AND DISCUSSIONS

1. **Groundwater Occurrence (G)**

Groundwater occurrence represents the types of aquifers in the study area. In the present study the aquifer type can be delineated as weathered/fractured Basalt which can be considered as unconfined and shallow in nature. It contains alluvium at the top and highly weathered basalt at some coastal areas. Groundwater occurrence affects the extent of Sea Water Intrusion (SWI) into the groundwater; in natural conditions a confined aquifer is less affected by SWI than an unconfined aquifer. Unconfined aquifers are under atmospheric pressure while confined aquifers are situated under aquitards and the pressure is higher than the atmospheric pressure. Hence, ranking of groundwater occurrence corresponds to the value 7.5 in the entire study area according to the GALDIT modeling index. **Fig. 9.1.**

2. **Aquifer Hydraulic Conductivity (m/day) (A)**

Aquifer hydraulic conductivity (A) is the measure of the rate of flow of water in the aquifer. By definition, aquifer hydraulic conductivity is the ability of the aquifer to transmit water under the effect of a hydraulic gradient (Lobo Ferreira et al., 2005). Higher hydraulic conductivity results in a wider cone of depression and a larger extent of SWI. In the present study the hydraulic conductivity rating varied between 5 and 7.5, which indicates that the hydraulic conductivity of the study area varies between 5 and 40m/day.

3. **Height of ground water Level above msl (m) (L)**

The groundwater level used in the model has been obtained by CGWB during ground water monitoring exercise in 2023-2024. This value was considered as the parameter of height of the groundwater level above sea level (L). This is a critical factor in the evaluation for determining the vulnerability in coastal areas as the height of the groundwater determines the hydraulic pressure which can in turn push back the sea water back. Groundwater levels below the mean sea level increases the vulnerability to SWI. The ranking assigned in the groundwater level parameter was between 2.5 and 7.5. The water level varied from 2 to 5m in the study area. The isolated patches in the central part of the study area has deeper water levels of >5-10mbgl during pre-monsoon period.

3. **Distance from shore / High Tide (m) (D)**

The impact of SWI decreases when moving perpendicularly from shore towards the land. The magnitude of SWI is directly related to the perpendicular distance from the coast. Mumbai being surrounded by sea from three sides the maximum distance from the coast is 10.46 km. Most of the locations showed a minimum distance from 0-2 km from the coast.

4. **Impact status of existing seawater intrusion (I)**

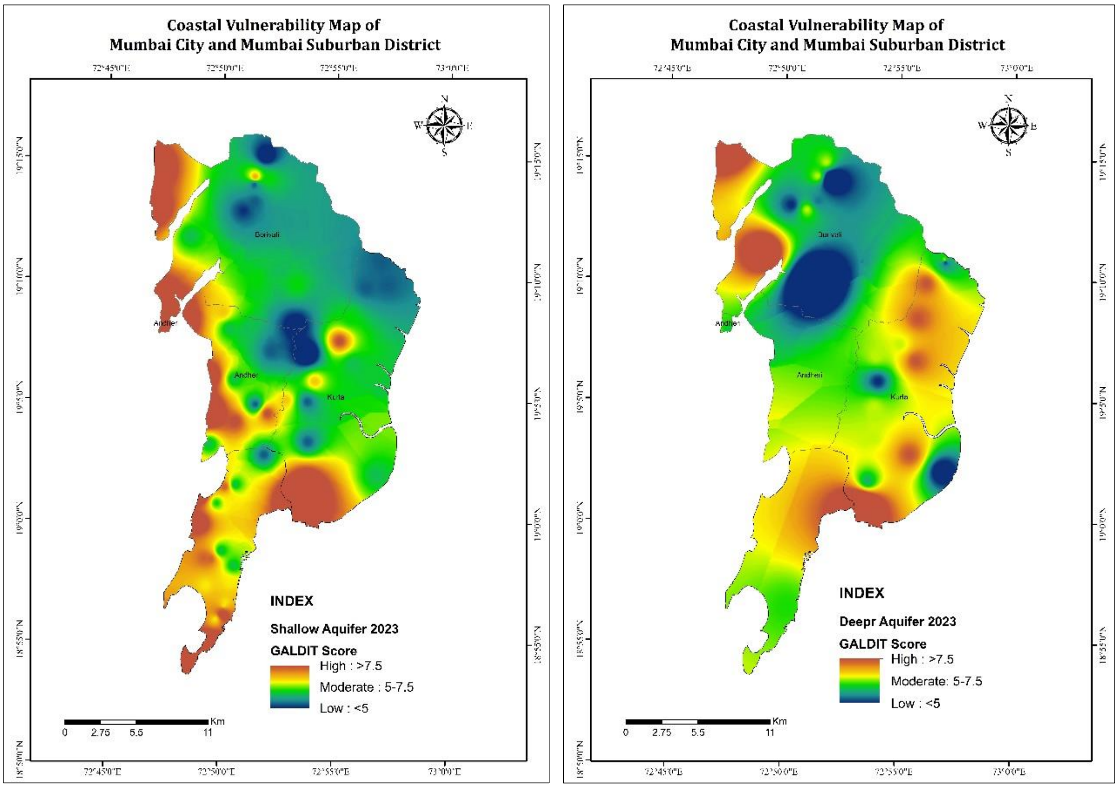
Cl/HCO3 ratio was used to determine SWI into the coastal aquifer. Few areas with higher ratio of more than 1.5 mg/l has been observed in study area.

5. **Aquifer Thickness (saturated) in meters (T)** The higher the aquifer thickness, the greater the extent of the SWI.

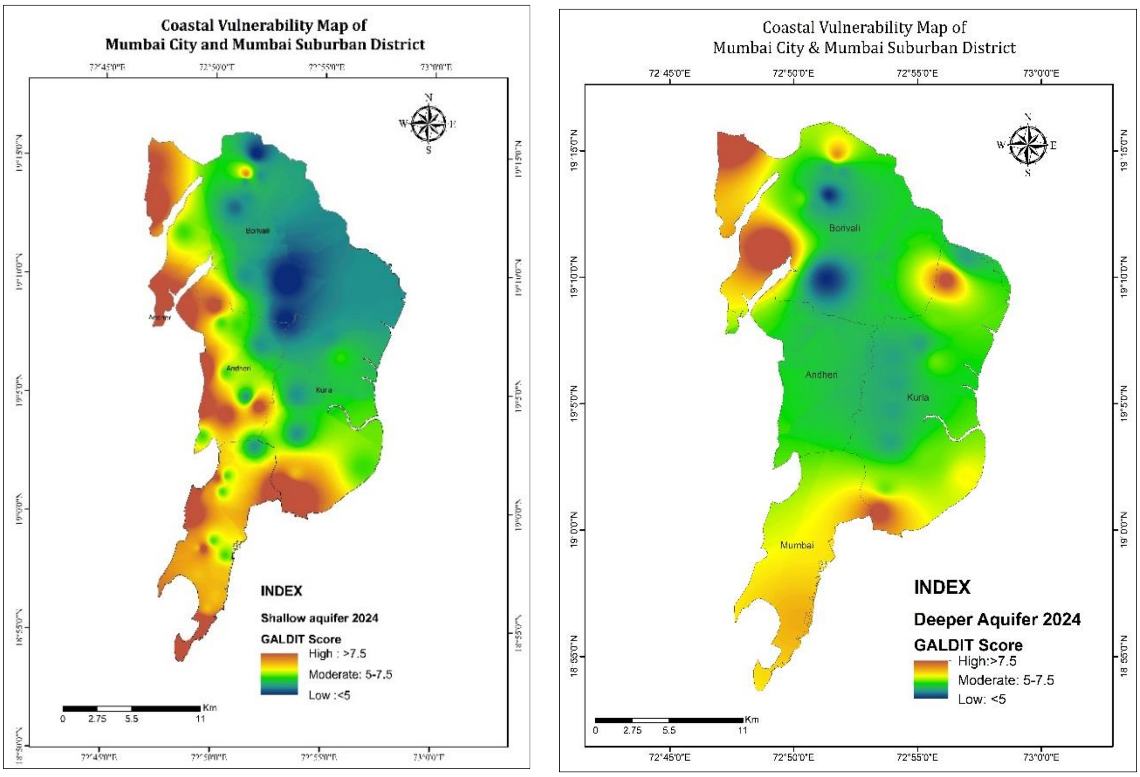
Based on the GALDIT scores between 2.5 to 10, coastal vulnerability maps have been prepared. Shown in **fig 9.1**

9.5 CONCLUSION OF THE GALDIT STUDY

The results of GALDIT MODEL indicates that the aquifer in the study area within has a high-to-moderate vulnerability for sea water intrusion. The GALDIT coastal vulnerability map as shown in the **fig 9.1** shows that shallow aquifers along the Western and southern coast has high vulnerability whereas the North eastern part of the study area has moderate to low vulnerability. Further the deeper aquifer has high vulnerability in the Eastern and south eastern parts of the area especially in the creek areas. From the maps, it can be inferred that around 35% of the total Study area has high vulnerability to sea water intrusion. These vulnerability maps can be used as a tool for the management of the groundwater resources in the study area along the coast and prevention /remediation of salt water intrusion.



(a) Shallow Aquifer, 2023 & (b) Deeper Aquifer, 2023



(c) Shallow Aquifer, 2024 & (d) Deeper Aquifer, 2024

Fig: 9.1: Vulnerability Maps for (a) Shallow, 2023 and (b) Deeper Aquifers, 2023 and (c) Shallow, 2024 & (d) Deeper Aquifers, 2024 in Mumbai City Mumbai Suburban District

CHAPTER 10
GROUND WATER MANAGEMENT IN MUMBAI CITY AND MUMBAI SUBURBAN DISTRICT

10.1 INTRODUCTION

Water conservation is a critical priority for Mumbai due to its rapidly growing population, limited freshwater resources, and the increasing impacts of climate change. The city's water demand is projected to rise from 3,800 million liters per day (MLD) to over 6,426 MLD by 2041, while groundwater and lake levels have already declined to critical levels as observed in May 2024. Additionally, much of Mumbai's water supply infrastructure is over 50 years old, resulting in significant water losses due to leakages and illegal connections. These challenges make water conservation essential to ensure sustainable and reliable water availability in the future. The Municipal Corporation of Greater Mumbai (MCGM) presently supplies approximately 3,850 million litres per day (MLD) of treated potable water against an estimated demand of 4,505 MLD within Mumbai, the economic hub of the country. The potable water supplied conforms to internationally accepted quality standards and entails significant capital and operational expenditure towards treatment, purification, and distribution.

Despite the high level of treatment, this potable water is extensively utilized for non-potable and secondary applications, including toilet flushing, landscaping, vehicle washing, swimming pools, and heating, ventilation and air-conditioning systems. In the context of rapid urbanization, population growth, and finite freshwater resources, such usage results in suboptimal allocation of treated potable water.

Given the existing supply–demand deficit and limitations in augmenting water sources, it may not be sustainable to supply of potable water for secondary uses in the future. Accordingly, it is essential to reduce dependence on municipal potable water for non-potable applications by mandating the adoption of rainwater harvesting systems and recycling/reuse of treated wastewater. Implementation of these measures will enhance water-use efficiency, alleviate stress on municipal water infrastructure, and promote sustainable urban water resource management. Few of the methods that can be adopted to conserve water efficiently are:

10.2 ROOF-TOP RAINWATER HARVESTING

The Municipal Corporation of Greater Mumbai (MCGM) is recognized as the first municipal authority in the State of Maharashtra to introduce mandatory provisions for Rainwater Harvesting (RWH) in urban developments. The mandate was initially enforced with effect from 1 October 2002 for all new development proposals on plots measuring 1,000 square meters and above. Subsequently, pursuant to the implementation of the Development Plan (DP) 2034, the applicability of mandatory RWH provisions was expanded, and from 8 May 2018 onwards, the requirement has been made binding on all developments having a plot area of 500 square meters and above. In compliance with the prevailing Development Control and Promotion Regulations, rainwater harvesting systems are presently being incorporated in all new developments within the jurisdiction of MCGM where such provisions are applicable.

As per data published by the Municipal Corporation, a total of 18,911 groundwater abstraction structures has been identified within the city of Mumbai, comprising 4,638 dug wells, 12,561 tube wells, and 1,712 ring wells. Considering an average daily groundwater withdrawal of approximately 20,000 liters per structure (equivalent to two tanker loads), the aggregate groundwater availability within Mumbai may be conservatively estimated at approximately 378 million liters per day (MLD). This assessment is based on information reported in the Environmental Status Report of BMC for the year 2020–2021. A typical RWH plan for 1000 buildings with roof top area > 500 sqm in Mumbai with average rainfall of 2.2 m is given IN Table 10.1:

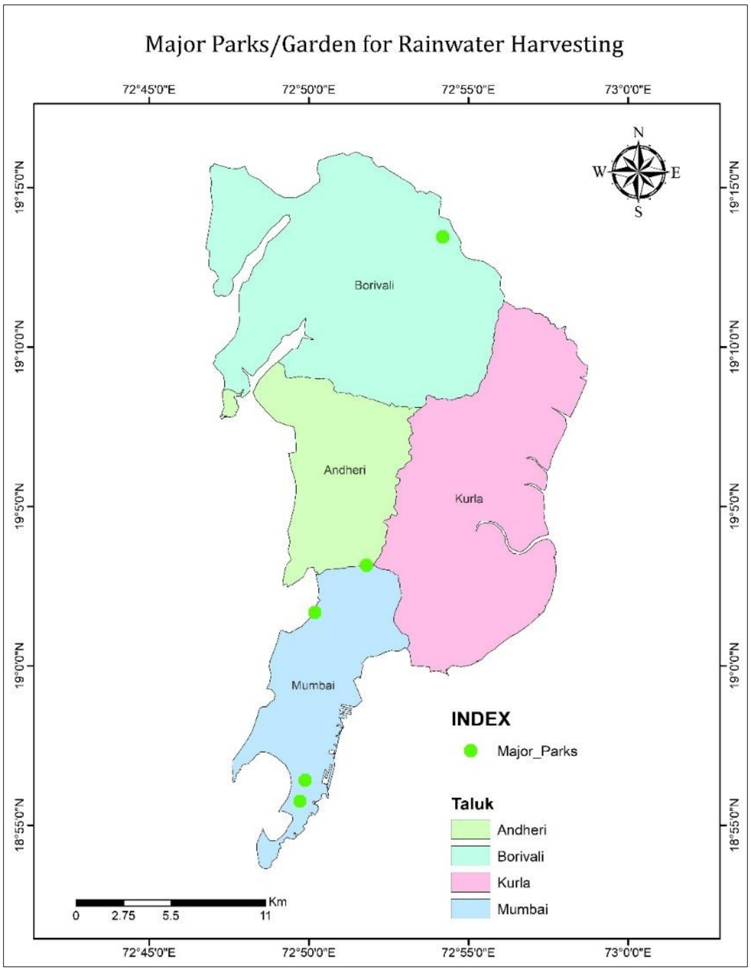
Table 10.1 Roof top RWH Model

Parameter / Scenario	Total Area Source	Run-off Coeff.	Rainfall (m)	Quantum of Run off available (m^3/yr) per Building (2*3*4)	Quantum of Run off available (m^3 for 1,000 buildings) (5*1000)
1	2	3	4	5	6
Rooftop	500 m^2	0.85	2.2	**935 m^3**	**935,000 m^3**
Open Area – 5% of plot	25 m^2	0.2	2.2	**11 m^3**	**11,000 m^3**
Green area – 5% of plot	25 m^2	0.15	2.2	**8.25 m^3**	**8,250 m^3**
Total				954	954000
					~0.95 MCM

10.3 RAINWATER HARVESTING IN PARKS AND GARDENS

Rain-water harvesting methods in parks and open spaces involve micro-watershed management methods that allow rainwater infiltration and percolation into the ground **(Fig 10.1).** The runoff has to be minimized by providing adequate number of percolation pits and dispersion trenches. In large parks, storage of rainwater in small ponds is also possible since the ponds can be integrated with the landscape of the park. In Mumbai there are 480 Recreational Grounds, 325 Parks/Gardens and 369 Play grounds (Environment Status Report 2024-25 BMC). Out of which major parks/grounds include Oval Maidan (Churchgate), 22-acre, Shivaji Park (Dadar) 27 acres, Azad Maidan (Fort) 25 acres, Maharashtra Nature Park (Dharavi) 32 acres and SGNP with 10981 acres area in Mumbai Suburban district **(Fig 10.2).** A typical Model for recharge in parks/gardens has been prepared and shown in **Table 10.2**. It is observed that by construction of Recharge pits in these parks/gardens nearly 10.77 MCM of run-off is available yearly. However, to catch all of the run-off a large number of recharge pit structures are required. Hence, even if 01 recharge pit structures is constructed per 1000 sqm, 0.2 MCM can be conserved. This plan is cost effective and can be implemented conveniently in smaller parks as well. Further, to enhance RWH, and if large areas are available, Ponds can also constructed which have larger storage capacity.

Fig 10.1 Recharge structures for RWH in Parks



10.2 Location of Major Garden for Rainwater Harvesting

Table: 10.2 Typical Model for recharge in parks/gardens

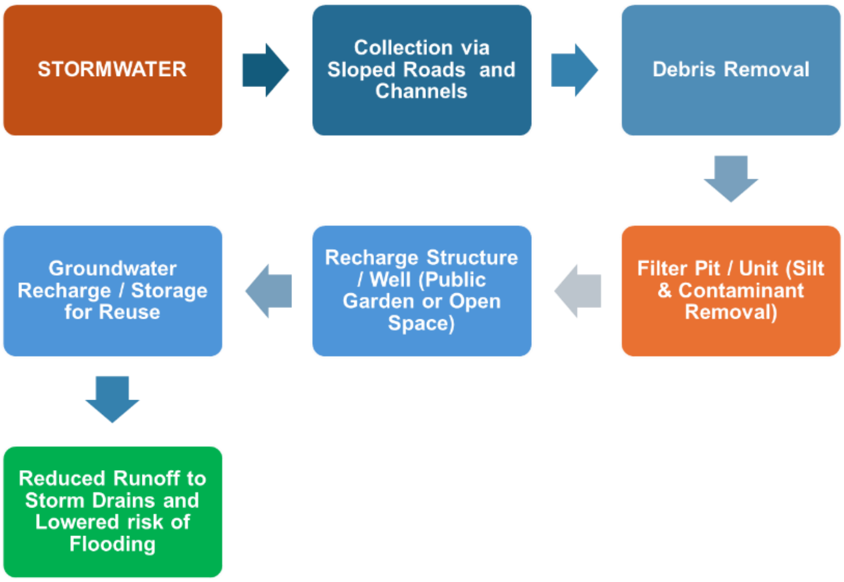
S.No.	Major Parks in Mumbai	Average peak Rainfall (in m)	Area (in Acres)	Area in Sqm	Area (sqm) available for recharge assuming (Only 80 % area can be considered for recharge)	Quantum of Run-off available Cum/Year	Single Recharge Pit Volume (m³)	Effective Recharge Capacity per Pit (m³) (60%)	Required Number of Recharge Pits	Number of Recharge Pits per 1000 sqm	Quantum of recharge feasible Recharge pits in column 11	Cost (@ Rs 15000 per structure)	Cost in Lakhs Rs
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Oval Ground	2	22	89030.92	71224.74	21367.42	4.50	0.60	7913.86	71.22	384.61	1068371	10.68
2	Azad maidan	2	25	101171.5	80937.20	24281.16	4.50	0.60	8993.02	80.94	437.06	1214058	12.14
3	Maharashtra Nature Park (Dharavi) 32 acres	2	32	129499.52	103599.62	31079.88	4.50	0.60	11511.07	103.60	559.44	1553994	15.54
4	Shivaji Park Dadar	2	27	109265.22	87412.18	26223.65	4.50	0.60	9712.46	87.41	472.03	1311183	13.11
5	Sanjay Gandhi National park (Only Mumbai Sub area)	2	10981	44438570	35550855.73	10665256.72	4.50	0.60	3950095.08	35550.86	191974.62	533262836	5332.63
					TOTAL	10768208.84	22.50	3.00	3988225.50	35894.03	193827.76	538410441.84	5384.10
						10.77					0.2		
						IN MCM					IN MCM		

The recharge to ground water through such conservation methods will enhance availability of ground water, arrest decline in ground water levels, sustain drinking water sources, prevent urban flooding, improve ground water quality by dilution and Restrict sea-water ingress.

10.4 RWH FROM STORMWATER RUN-OFF

The rainfall runoff flowing from the roads and open grounds is substantial during rains, which ultimately flows out of the city unutilized. This water if conserved and utilized properly for recharging the ground water reservoir may bring much needed relief to the water scarce areas of the city. Surface run-off rainwater harvesting, also known as storm water harvesting, involves collecting rainwater from impervious urban surfaces such as roads, parks, gardens, parking areas, and footpaths. Rapid urbanization has increased the use of asphalted roads and paved surfaces, resulting in higher surface run-off and reduced groundwater recharge.

1. **Stormwater Harvesting Recharge Structures:** Urban roads are typically constructed with a slope toward the sides, directing rainwater from the crown to roadside drains. The collected run-off flows through side drains and is conveyed to storm water drains or recharge structures. In such systems, storage facilities may be omitted when immediate water use is not required. Depending on run-off quantity and space availability, the filtration unit and recharge structure may be combined. An open unlined channel can be used as a conduit, with a coarse mesh or grill installed at the inlet to remove debris. First-flush devices and storage tanks are optional components of the system. A typical process for storm water harvesting is shown in **fig 10.3**



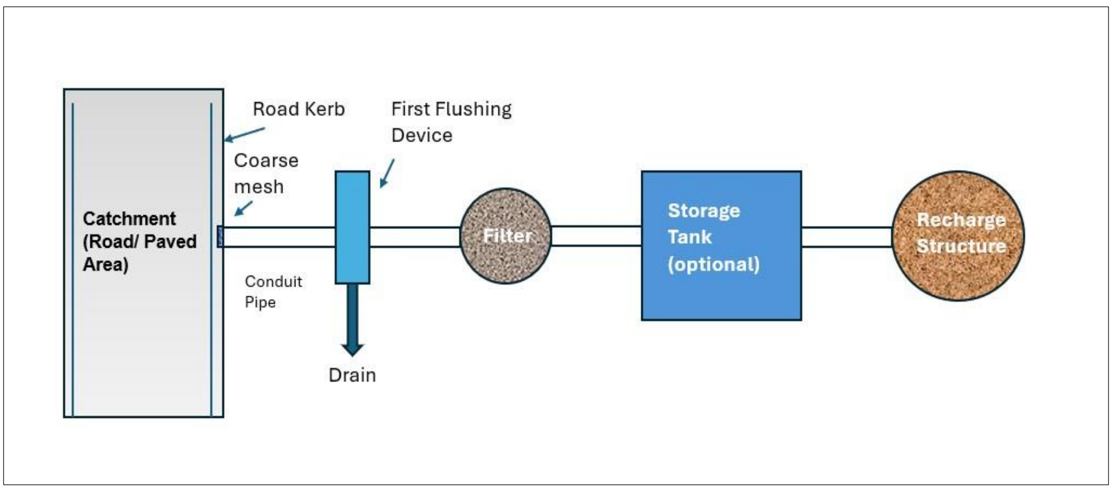


Fig 10.3 Process for Stormwater Harvesting

2. **Infiltration Trenches**: constructed along roads enhance groundwater recharge and reduce storm water flooding. They are typically about 2 feet wide and deep, filled with aggregates and topped with coarse sand. These infiltration trenches may be exposed as walk ways or paved with inter-locking pavers, specially designed with gaps in between for water to flow into the infiltration trenches. The runoff from Roads enters the trench, where water is temporarily stored and percolates into the ground. Excess water during heavy rainfall overflows into storm water drains, and trenches may be paved with permeable pavers. **fig 10.4**

Fig 10.4: Infiltration Trenches along Roadside

10.5 RWH FROM NATURAL FLOW OF WATER

Surface runoff water should be trapped in ponds, tanks and lakes when available, so that it can be used for maintenance during dry periods. This practice is similar to dry land technology of agricultural belts. Low-lying areas and drainage channels are earmarked and convenient micro-watersheds are prepared. Water harvesting is followed based on natural flow and surface accumulation of the runoff water. Water follows the lowest contour gradient available for that area. These structures not only provide water for the park, but also increase groundwater recharge. Providing a bore well in these areas will enhance the availability of water in its vicinity. Rainwater run-off from open space and paved areas can be stored in underground sumps by filtering through sand-bed filters and guiding the filtered water through channels.

For artificial recharge of ground water sites need to be located where the hydrogeological conditions are favorable, i.e., where sufficient thickness of unsaturated/de-saturated aquifer exists and water levels are more than 3 m deep (post monsoon).

The post monsoon depth to water level map and Pre-monsoon/Post monsoon water level trend maps presented in report will gives a good idea of areas suitable for artificial recharge of ground water. Such areas are located in north central part of the district, where water levels are moderately deep and falling water level trends is observed. In other areas where water levels are shallow, ground water development along with augmentation is recommended. In the elevated area roof top rain water harvesting is also feasible by storing rainwater in storage tanks, thereby supplementing the main source of water.

10.6 STORMWATER MANAGEMENT PLAN (SWMP)

10.5.1 Storm Water Management Plan (SWMP) is a technically structured framework designed to regulate the generation, conveyance, treatment, and disposal of storm water runoff in urban and developed environments. Its primary objective is to mitigate hydrological alterations caused by impervious surfaces, thereby reducing the risks of urban flooding, soil erosion, and degradation of surface and groundwater quality. The plan emphasizes both quantitative and qualitative control of runoff by minimizing peak discharge and runoff volume, limiting the transport of sediments and contaminants, and enhancing infiltration to support groundwater recharge. Through the implementation of engineered and nature-based solutions, an SWMP seeks to ensure hydrological stability, environmental protection, and sustainable urban water management.

Mumbai, located on the western coast of India along the Arabian Sea and intersected by multiple creeks, faces significant challenges in storm water management due to tidal variations, which affect the discharge of rainwater and wastewater. The city's existing storm water drainage (SWD) network, approximately 100 years old, includes 274 km of major nallas, 637 km of minor nallas, and 2,181 km of roadside drains, comprising underground drains, lateral connections, and water inlets designed based on local area and weather conditions. The system was originally designed to handle rainfall intensities up to 25 mm/hr at low tide with a runoff coefficient of 0.50; rainfall exceeding this intensity during high tide often results in waterlogging in low-lying areas. Mumbai has 82 major outfalls discharging directly into the Arabian Sea, with additional outfalls along Mahim Creek (9), Mahul Creek (11), Thane Creek (32), and 51 outfalls in western suburban creeks. In suburban and extended suburban areas, open drains are constructed along both sides of roads to facilitate surface runoff.

Table 10.3: Key Features of Storm Water Management

Feature	Description
Flood Risk Mitigation	Reduces the volume and velocity of storm water runoff to prevent flooding.
Pollution Reduction	Treats storm water to remove pollutants before discharge into water bodies.
Groundwater Recharge	Promotes infiltration of storm water to replenish groundwater.
Infrastructure Protection	Protects buildings, roads, and other infrastructure from runoff-related damage.
Environmental Protection	Minimizes impacts of storm water on natural ecosystems and waterways.

Storm water management in Mumbai is a critical concern due to the city's vulnerability to heavy monsoon rains, aging infrastructure, and rapid urbanization. There are certain challenges of storm water management in Mumbai due to following reasons.

1. Aging Drainage Infrastructure: Much of Mumbai's storm water drainage system is over a century old, designed to handle rainfall intensities of approximately 25 mm per hour. However, events like the 2005 flood, which saw nearly 944 mm of rain in a single day, have overwhelmed this system.
2. Tidal Influence: Mumbai's coastal location means that high tides can impede the outflow of storm water, leading to backflow and flooding, especially when heavy rains coincide with high tide periods.
3. Encroachments and Siltation: Unauthorized constructions and accumulation of silt in drains reduce their carrying capacity, exacerbating flooding during heavy rains.
4. Loss of Natural Buffers: Destruction of mangroves and wetlands for urban development has diminished natural water absorption areas, increasing surface runoff and flood risks.

In view of the challenges, some initiatives and solutions initiated by Government in Mumbai City and Suburban districts for the Storm Water Management are as follows:

1. **BRIMSTOWAD Project:** The Brihanmumbai Storm Water Disposal System (BRIMSTOWAD) was initiated to upgrade the city's drainage infrastructure. Proposed in 1993, the project aims to enhance the capacity of drains, construct pumping stations, and implement other measures to mitigate flooding. However, progress has been slow due to funding and implementation challenges.
2. **Pumping Stations:** To combat waterlogging, especially in low-lying areas, the city has constructed several pumping stations that actively remove storm water during heavy rains.
3. **Desilting and Maintenance:** Regular desilting of drains and nullahs is undertaken to ensure unobstructed water flow. However, the effectiveness of these measures is often limited by the scale of the problem and resource constraints.
4. **Federal Investment:** Recognizing the severity of urban flooding, Government has allocated funds to cities like Mumbai for flood mitigation projects, including the expansion of water bodies and construction of new drainage systems.

In the storm water management of Mumbai there are challenges and initiatives and solutions are also given but by means of community-based approach, sustainable management is extremely possible which includes Green Infrastructure, Community engagement and developing robust early warning systems.

1. **Green Infrastructure:** Implementing sustainable drainage solutions, such as permeable pavements and rain gardens (Rain gardens are shallow, planted depressions designed to collect and filter rainwater runoff, preventing flooding and water pollution. They are essentially a form of bio-infiltration basin which includes natural ecosystems by allowing rainwater to soak into the soil after it has been filtered by plants and soil), can help manage storm water at the source, reducing the burden on traditional drainage systems.
2. **Community Engagement:** Educating residents about proper waste disposal and the importance of maintaining clean drains can play a significant role in preventing blockages and subsequent flooding.
3. **Early Warning Systems:** Developing robust early warning systems can provide timely alerts to residents about impending heavy rainfall or flooding

10.5.2 STORM WATER MANAGEMENT PLAN FOR MUMBAI CITY AND SUBURBAN DISTRICTS

Mumbai receives high-intensity monsoon rainfall (~2200–2400 mm/year), most of which mostly goes to sea as runoff resulting in urban flooding and negligible groundwater recharge. At the same time, groundwater resources, particularly deeper Aquifers in are under stress either due to increasing GW abstraction or the quality is deteriorating. One of the methods to reduce surface runoff and flooding, augment GW availability and improve sustainability of deeper aquifers is storm water management in the area. Based on this NAQUIM study, two types aquifer grouping has been done. The table below shows the suitability of recharge measures for the delineated aquifers; and a model plan with cost estimates has been prepared

Aquifer Unit	**Depth Range (m bgl)**	**Recharge Suitability**
Aquifer–I (Shallow)	0–30	Moderate (localized)
Aquifer–II (Deeper)	30–172	High (through recharge shafts / wells)

Table 10.4: A MODEL PLAN FOR ARTIFICIAL RECHARGE AND STORM WATER MANAGEMENT IN THE STUDY AREA:

Structure Type	Target Aquifer	Unit Recharge Capacity (m³/year)	No. of Units	Total Recharge (MCM/year)	Unit Cost (₹ lakh)	Total Cost (₹ lakh)	Suggested Areas for Implementation
Recharge shafts	**Aquifer II**	300	1,200	0.36	1.5	1,800	Recharge shaft 10-15m deep, 1.0 m diameter. into fracture zones. Quality of recharge water should be checked
Recharge wells / abandoned bore conversion	**Aquifer II**	5,000	1,000	5	2	2,000	Minor civil works, storm drain integration
Percolation tanks / basins	**Aquifer I**	50,000	120	6	15	1,800	Open grounds, natural depressions
Recharge trenches	**Aquifer I**	2,000	2,000	4	0.5	1,000	Roadsides, open grounds, integrated with drains
Rooftop recharge	**Aquifer I & II**	1,000	4,000	4	0.25	1,000	Government / institutional buildings/Hotels/Hospitals
Total			10,320	19.36		**7600 lakh**	**(Total : ₹76 crore)**

10.7 INTEGRATED WATER MANAGEMENT PLAN FOR MUMBAI

10.6.1 Introduction to IWMP

Mumbai, a coastal city along the Arabian Sea with a dense urban population, faces water stress due to high seasonal variability and relatively unequitable distribution and availability of water. The city depends primarily on surface water from reservoirs (Vihar, Tulsi, Upper Vaitarna) and limited groundwater resources. Effective water management requires **supply-side augmentation, demand-side optimization, and conjunctive use of surface and groundwater** to enhance resilience, prevent urban flooding, and maintain sustainable water availability. A detailed information on **IWMP is given in Table**

10.6.2 EXPECTED OUTCOMES

- Stabilized groundwater levels and reduced urban water stress.
- Optimized conjunctive use of surface and groundwater for dry and monsoon seasons.
- Mitigated flooding through storm water capture and recharge.
- Reduced dependence on a single source and enhanced water security for domestic, industrial, and municipal use.
- Environmentally sustainable management supporting natural ecosystems and aquifer recharge

TABLE 10.5 INTEGRATED WATER MANAGEMENT PLAN FOR MUMBAI

S.No.	Supply-Side Management	Groundwater Augmentation and Recharge	Conjunctive Use of Surface and Groundwater	Demand Side Management
1	**Optimization of Reservoir Operations:** (SCADA) for real times monitoring of reservoir flows, storage and releases	**Artificial Recharge Structures:** Implement recharge wells, injection wells, percolation tanks, and recharge shafts in open spaces, parks, and low-lying areas.	Prioritize **surface water use during monsoon**; supplement with groundwater during dry months.	**Efficient use of water:** fitting of pipelines with digital flow meters, pressure management valves, and automated leakage detection. Awareness on greywater recycling and dual plumbing in residential and commercial buildings, Encouraging industrial process water reuse and water-efficient technologies.
2	**Enhancement of Capacity** of WTP	**Storm Water Managed Aquifer Recharge (MAR):** Capture runoff from streets, roads, and rooftops; direct it via sedimentation and filtration structures into aquifers.	**Preparation of a Hydrological decision-support system (DSS)** to optimize source allocation.	**Regulatory Measures:** licensing and volumetric-based tariffs for all high-volume groundwater users, incentivize water-efficient appliances and practices via rebates and differential tariffs, prizes and awards by Government in water sector to individuals, society, educational institutes on Taking GW management initiatives
3	**Recharge to the Reservoir** Catchments Areas by constructing Small Check dams, Diversion structures upstream	**Rooftop Rainwater Harvesting:** Mandate rooftop harvesting for residential, commercial, and industrial buildings, with infiltration trenches or recharge pits.	Implementation of **different pumping schedules** for groundwater to avoid localized overdraft and saltwater intrusion in coastal aquifers.	Implementation of GIS-based monitoring of consumption patterns to identify high-loss zones.
4	**Inter-Reservoir Transfers** via pipelines, gravity Channels	**Aquifer Protection Zones:** Delineate recharge zones and restrict impervious construction to maintain natural infiltration.	**Integration of storm water capture** into the conjunctive use system, storing excess runoff for controlled release into reservoirs or aquifers.	**Storm Water Utilization:** Diversion of storm water to recharge ponds, infiltration basins and wetlands. Integrate drainage upgrades with groundwater recharge schemes to mitigate urban flooding.
5	**Maintenance** of supply Pipelines for checks on leakages and breaks	**GW Monitoring and Regulation of GW Extraction:** Install piezometers and groundwater level sensors for continuous monitoring; enforce extraction limits based on sustainable yield.		

10.8 DEMAND-SIDE MANAGEMENT

The main objective of a demand side management plan is to optimize urban water demand through systematic reduction, efficient utilization, recycle and reuse, thereby reducing stress on municipal water supply systems, conserving freshwater resources and ensuring sustainable urban water management. The Demand and Supply statistics in the study area is given in the **Table 10.6**

Table 10.6 Demand and Supply statistics of Mumbai City and Mumbai Suburban district

S.No.	Parameter	Mumbai City	Mumbai Suburban	Remarks
1	**Municipal supply (MLD)**	1,250	2,600	Total MCGM supply = 3,850 MLD
2	**Estimated demand (MLD)**	1,450	3,055	Total demand = 4,505 MLD
3	**Supply-demand gap (MLD)**	200	455	~655 MLD overall deficit (0.65 MCM)
4	**Population (approx.)**	3.0 million	8.5 million	Census 2021
5	**Per capita water use**	135–150 l/day	135–150 l/day	Urban standard per CPHEEO

It is observed that the supply-demand gap is **~14–15%**, higher in suburban areas due to **rapid urbanization** and both regions rely on **MCGM treated surface water**, supplemented by groundwater and limited local storage. This gap can be filled through conjunctive use of surface and ground water, as through various recharge/conservation measures the dependency on surface water can be reduced thereby reducing the deficit between demand and supply.

Other Issues: GW management and Artificial recharge to reduce Land subsidence

- In the recent past many studies have been carried out on land subsidence in Mumbai and Mumbai suburban area. One of the such study has reported land subsidence in Mumbai using InSAR data integrated with groundwater levels, GPS observations, and population growth trends. For the period 2014–2019 (N. V. Sudha Rani Nalakurthi, Manasa Ranjan Behera & Prasad K. Bhaskaran, Volume 32, pages 665–681, (2024) J. Sp Infm Research). Which reveals that an uneven subsidence with rates up to −93 mm/year, especially in Byculla, Colaba, and Andheri East, linked to groundwater extraction. The study also emphasizes the need for integrated management of groundwater, land subsidence, and sea-level rise to reduce coastal risk. In these areas, recharge structures such as recharge pit with filter, recharge shaft, Percolation tanks/ponds must be constructed to keep the aquifers saturated and prevent saline water intrusion.

CHAPTER 11
CONCLUSION

Mumbai and Mumbai suburban districts have been taken-up for NAQUIM 2.0 studies covering an area of 603 sq.km consisting of 4 taluks namely Mumbai city, Kurla, Andheri and Borivali. The area falls in the Toposheet of 47A/9 to 47A/16, between N18°53' & 19°19' and E 72°47' & 72°59'. The present study deals with specific priority area i.e. under "Urban Agglomerate".

The broad physiographic feature of the study area is flat terrain flanked by north – south trending hill ranges. The Powai – Kanheri hills form the largest hilly terrain in the NE part of the area and are the feeder zone for the three lakes viz., Powai, Vihar and Tulsi. There are a number of creeks dissecting the area. The largest creek is Thane creek. The area is drained by Mahim, Mithi, Dahisar and Oshiwara rivers. The entire district is underlain by basaltic lava flows of upper Cretaceous to lower Eocene age. Normal annual rainfall varied from 1800 mm to 2400 mm. Based on the integrated review of the hydrogeological, geophysical, Hydrochemical and climatological studies in the study area the following conclusions and recommendations are made.

1. The major aquifers in the study area Basalt and Alluvium. Ground water exists in fractures, joints, vesicles and in weathered zone of Basalt.
2. Major part of the study area shows shallow water levels of less than 5 mbgl (~85 %). And the in pre monsoon 2024, 75% of wells show water levels of less than 5 mbgl.
3. During the post monsoon for both the years (2023 and 2024) shallow water levels of less than 5 mbgl are observed in more than 80% of wells.
4. Seasonal water level fluctuation between pre and post monsoon 2023 and 2024 indicate that the Water level is rising in 50 no. of wells and falling in 10 no. of wells.
5. The long term water level trend (10 years) indicates that there is a falling water level trend in the Mumbai City area for pre and post monsoon. And the trend is rising in the Mumbai suburban district for both seasons except few places where trend is falling in isolated patches of the area.
6. Vertical Electrical Sounding (VES): Analysis of geo-electrical layers indicate that the study area is covered by Top soil, weathered formation, fractured and Massive formation up to a depth of 80 m bgl.
7. GW Exploration: As per the Exploration data generated for EW and OW varying in depth from 178.20 m bgl to 202.60m bgl, the depth of weathering in the study area ranges from 11.50 to 23.50m. The static water level ranges from 6.38 mbgl to 37.27 m bgl. Most of the fractures are encountered between the depth range of 60m to 172m. Yield of these wells/discharge ranges from <1 lps to a high discharge of 12 lps. As per the result of yield test conducted at EW and OW at Film City Goregaon, the transmissivity (T) of the fractured aquifers is 96.02 m2/day and 141.45m2/day respectively. High saline zones have been encountered at Fort area in Mumbai City at a depth 71 m. Similarly high salinity zones have been encountered at Sambhaji Raje Park, Mulund East, Shivaji Park, Dadar with depth of saline zone at 131mbgl and 18.50 mbgl-37.90 mbgl.
8. Soil infiltration studies: The analysis show that in 3 places the soil infiltration rates were very high indicating the loose well assorted soil that may have been ploughed and/or transported from other places. As per the result of soil infiltration test it is observed that is observed to be loose and well assorted with high infiltration rates. However, the Soil type in CTIRC Training institute Borivali can be classified as Clayey with low final infiltration rate of 1.5cm/hr.
9. As per the latest Ground Water Resources Assessment (GWRA) for Mumbai and Mumbai Suburban district, i.e 2025, the Annual Extractable Ground Water Resource has been

estimated as 14.77 MCM and 72.63 MCM respectively. The Total Annual GW Extraction has been estimated as 6.80 MCM for Mumbai and for Mumbai Suburban it is estimated as 18.70 MCM. Out of which, more than 90% GW extraction is for Domestic Use and remaining is for Industrial purposes in both the districts. Since Mumbai is an urban area and there are no irrigation practices going on, the utilization for irrigation is Nil. The Stage of GW extraction which is a measure of Total Annual GW extraction over Total Annual Extractable GW resources expressed in percentage has been estimated as 46 % and 25.74% for Mumbai and Mumbai suburban districts respectively. There are 04 No. of Assessment Units i.e Mumbai, Andheri, Kurla and Borivali and all have been categorized as 'Safe'

10. GW Quality: The results of chemical analysis through Piper plot show that the ground water in the area is in general, Ca-Mg Bicarbonate Type. All the parameters are with in permissible limit of BIS standards. Except at 3 locations that is Varsova (Shallow and Deeper both), Rokadia cross lane (Shallow) and GS ward Worli (Shallow) where NO3 is above permissible limit of >45 mg/l during pre-Monsoon 2023. NO3 is above permissible limit in 02 locations namely Varsova (deep) and Trombay (Deep) during Pre-monsoon 2024. Electrical Conductivity ranges from 136.6 µS/cm at Chandiwali to 4558 *µS/cm* at Laxminagar Pre-Monsoon 2023. As per various chemical analysis and plots such as Gibbs, Piper, Wilcox and US Salinity, the Ground water in the study area is in general Suitable for drinking, domestic and irrigation purpose.
11. The analysis of GALDIT Model conducted to determine the vulnerability of coastal aquifers in the study area shows that the coastal aquifers are moderate to high vulnerable to sea water intrusion especially during the pre –monsoon period. Hence, it is recommended that GW management measures such as construction of recharge structures may be taken up to push back the saline water back to the sea, and stop or limit the GW extraction to prevent the movement of sea water into the fresh water aquifers. During the construction of Exploratory well in the fort area of Mumbai city, Sambhaji Raje Park, Mulund East and Shivaji Park, Dadar, high saline water zone with EC more than 10000 µS/cm were encountered at variable depths. Hence, GW development may be limited to 60m of depth in fort area of Mumbai city, and completely prohibited at Shivaji Park Dadar due to occurrence of very Saline zones shallow levels as preventive measures in the area with regular checks for GW quality in terms of Electrical conductivity.
12. GW Management Plan: For GW management and sustainable use, Rainwater harvesting may be implemented at places with deeper water levels of more than 5 mbgl is observed during post monsoon season. RWH in/and around areas such as Khandoba Mandir, Harmos Ji St, Sion and Mazgaon in Mumbai city, Ranicha Bagh, Borspada, Borivali East, Chandiwali, Sonapur and Vile Parle West in Mumbai Suburban districts can be constructed to enhance GW scenario. Dry or abundant dug wells may be converted into recharge wells with precautions.
13. As per the information on demand and supply in the area from BMC (Report, Environment status report 2024), it is evident that the city is not dependent on Ground water to meet the domestic and drinking water demands and BMC has prepared plan for future population upto 2040 as well and that it is definitely not under any kind of water scarcity situations. However, since Mumbai being surrounded by sea from three sides, GW recharge must be implemented to reduce the vulnerability of underground aquifers from sea water intrusion.

CHAPTER 12
RECOMENDATIONS

The study area, Mumbai City and Mumbai Suburban districts lies in a coastal, highly urbanized physiographic setting, bounded by the Arabian Sea on three sides. The terrain is generally low-lying with gentle undulations, interspersed with isolated basaltic hillocks. The area experiences a tropical monsoon climate with heavy seasonal rainfall, which constitutes the primary source of groundwater recharge. However, rapid urbanization, extensive paved surfaces and limited open land have significantly reduced natural recharge potential. Hydrogeologically, the area is underlain mainly by Basalt and Alluvium aquifers. Groundwater occurs in the weathered and fractured zones of basalt under unconfined to semi-confined conditions, with storage in joints, fractures and vesicular zones. The depth of weathering ranges from about 11.5 to 23.5 m bgl, while productive fractures are encountered between 60 m and 172 m bgl. Shallow groundwater levels of less than 5 m bgl prevail over most of the area during both pre- and post-monsoon seasons. Long-term trend analysis indicates a declining groundwater level in Mumbai City, whereas Mumbai Suburban district generally shows a stable to rising trend, except in localized patches.

12.1 RECOMMENDATIONS AND SUGGESTIONS

As an output of the NAQUIM study of Mumbai and Mumbai suburban districts following recommendations are suggested for a comprehensive and robust Groundwater Management:

1. **Regulation of Groundwater Extraction**
   - Groundwater extraction should be regulated, especially in coastal and areas vulnerable to sea water intrusion such as Fort area (Mumbai City), Shivaji Park (Dadar), Sambhaji Raje Park (Mulund East) and adjoining locations.
   - Groundwater development beyond 60 m depth should be restricted in Fort area, and completely prohibited in Shivaji Park, Dadar, and creek areas, due to the presence of shallow and highly saline zones. In these areas there are many parks and gardens where recharge structures such as recharge pit with filter, recharge shaft, Percolation tanks/ponds may be constructed to keep the aquifers saturated and prevent saline water intrusion. GW quality Monitoring must be set up around vulnerable areas near coast.
   - New deep borewells tapping fractured zones should be permitted only after detailed hydrogeological and geophysical investigations.
2. **Prevention of Seawater Intrusion**
   - As GALDIT model indicates moderate to high vulnerability to seawater intrusion, particularly during pre-monsoon, controlled pumping schedules should be adopted to avoid excessive drawdown.
   - Artificial recharge measures should be prioritized in coastal stretches to create a freshwater hydraulic barrier and push saline water seaward.
   - Regular monitoring of Electrical Conductivity (EC) in coastal observation wells should be made mandatory.
3. **Artificial Recharge and Rainwater Harvesting (RWH)**
   - Rainwater harvesting structures should be implemented in areas where post-monsoon water levels exceed 5 mbgl, such as:
   - Mumbai City: Khandoba Mandir, Harmos Ji Street, Sion, Mazgaon

- Mumbai Suburban: Ranicha Bagh, Borspada, Borivali East, Chandiwali, Sonapur and Vile Parle West
- Abandoned, dry or under-utilized dug wells should be converted into recharge wells after proper cleaning and installation of filtration systems.
- Recharge structures should be designed considering local soil infiltration characteristics, avoiding clayey zones with low infiltration rates unless supported with recharge shafts.

4. **Identifying Aquifer Protection Zones**
   - Based on hydrogeological conditions, aquifer-wise zoning should be adopted distinguishing shallow weathered zones and deeper fractured aquifers.
   - Sensitive areas showing falling long-term water level trends, particularly in Mumbai City, should be declared as groundwater stress zones for stricter regulation.
   - Land-use controls should be enforced to prevent contamination of recharge areas.
5. **Groundwater Quality Monitoring**
   - Continuous monitoring of groundwater quality is recommended, especially for Nitrate (NO_3^-) and salinity (EC) in locations where exceedance has been observed.
   - Shallow aquifers in urban pockets such as Varsova, Rokadia Cross Lane, Worli and Trombay should be monitored seasonally (pre- and post-monsoon).
   - Measures such as proper sewage management and prevention of leachate infiltration should be strengthened to control nitrate contamination. As a simple measure, in such areas, GW recharge through Roof top rainwater harvesting must be adopted to dilute GW which will eventually reduce Nitrate concentrations.
6. **Sustainable Utilization of Groundwater Resources**
   - Since the Stage of Groundwater Extraction is within 'Safe' limits (46% in Mumbai City and 25.74% in Mumbai Suburban), groundwater may be used as a supplementary resource, not as a primary source.
   - Priority use of groundwater should remain domestic and emergency purposes, avoiding indiscriminate industrial abstraction.
   - Promotion of water-use efficiency and conservation practices should continue, especially in urban residential and commercial sectors.
7. **Monitoring and Data Management**
   - Existing monitoring wells should be strengthened, and additional observation wells may be established in coastal and high-risk areas.
   - Long-term water level and quality data should be systematically collected and analyzed to detect early signs of salinity ingress or declining trends.
   - Integration of monitoring data with GIS-based groundwater information systems is recommended for effective decision-making.
8. **Public Awareness and Institutional Measures**
   - Awareness programs should be conducted to highlight the importance of groundwater recharge and prevention of seawater intrusion.
   - Coordination between BMC, groundwater authorities and urban planners is essential to ensure sustainable groundwater management aligned with future urban growth up to 2040.
9. **Water Audit**
   - A water audit is a systematic process that quantitatively evaluates all water inputs, distributions, and uses within a system to establish a water balance and identify inefficiencies, losses, and opportunities for optimization. It supports demand–supply management by measuring actual consumption against available supply, enabling strategies to reduce waste, improve efficiency, and align water use with demand. A

Case study has been taken up as part of recommendations of NAQUIM Study in Ismail Yusuf College, Jogeshwari. Detailed report is given in following section.

12.2 WATER AUDIT OF ISMAIL YUSUF COLLEGE CAMPUS, JOGESHWARI, MUMBAI: A CASE STUDY

OVERVIEW

Unregulated use of water resources has become common in urban and semi-urban areas, necessitating systematic evaluation of water consumption and management practices. Water auditing provides a structured approach to assess water use efficiency, identify losses, and promote sustainable water management. Recognizing its importance, the National Assessment and Accreditation Council (NAAC) has mandated the submission of an annual Green, Environment and Energy Audit Report for all Higher Educational Institutions from the academic year 2019–20 onwards. Water management forms a key component of this framework.A water audit involves the systematic identification, quantification, analysis, and documentation of water sources, usage patterns, and conservation practices within a campus. In water-stressed regions like India, water audits are essential for reducing wastage, improving efficiency, and ensuring long-term water security. Therefore, water auditing should transition from a voluntary best practice to a mandatory sustainability measure.
The present study focuses on conducting a **Water audit of Ismail Yusuf College campus**, Mumbai with emphasis on existing water resources and consumption patterns. The audit includes primary data collection, site inspections, and review of institutional policies and records. The study provides a structured methodology for campus water auditing and promotes awareness among staff and students regarding responsible water use, serving as a replicable model for urban educational institutions.

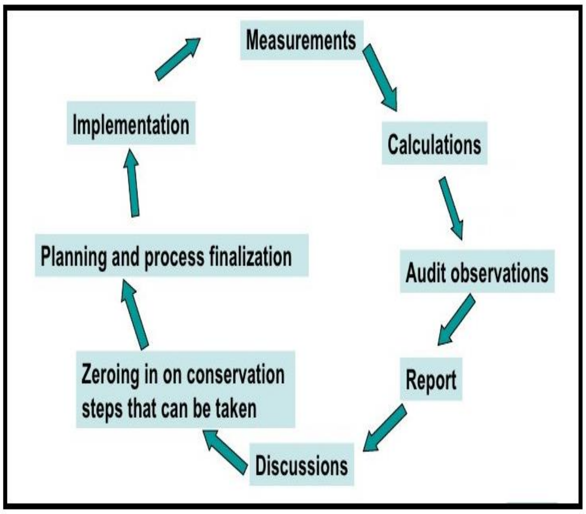
A comprehensive water audit includes resource (supply-side) and consumption (demand-side) assessments, aiming to improve both water-use efficiency and sustainable management of water sources.

- **The broader objectives of the water audit are,**

1. Understanding the water sources in the college campus
2. Identifying the areas where water is consumed
3. Calculating the resource consumption like the land and water.
4. Find out real losses due to pipe leakages, over flow & un-authorized connections.
5. Check unwanted excess usage of water.
6. Identify priorities area which need immediate attention for control and maintenance.
7. Assess the waste water generation of different areas such as laboratories, canteen and toilets.
8. Studying the water consumption pattern
9. Identifying the good practices adapted in the college for water conservation
10. Suggesting viable solutions to improvements
11. Compiling the report with the above-mentioned details

- **The Need of Water audit in campus**

The term campus refers to a physical site and environment where a higher education institution conducts its educational, administrative and social activities. It encompasses a wide range of facilities, including academic buildings, classrooms, laboratories, libraries, residence halls, recreational areas, administrative offices and many more. Developing a green campus is important for educational institutions because it promotes sustainability, enhances student well-being, and reduces operational costs. Sustainable practices, such as energy-efficient buildings and waste reduction, contribute to environmental conservation and can lead to significant cost savings; Additionally, green campuses improve air quality and provide natural spaces that support mental health and academic performance, as studies show that access to green spaces can increase student focus and reduce stress levels, that means positively impacts student well-being and learning by enhancing mental health, promoting physical activity, and improving academic performance.



The essential components of a green campus design include sustainable building materials, energy-efficient systems, water conservation practices, waste reduction strategies, and biodiversity enhancement. Sustainable building materials, such as recycled or locally sourced products, minimize environmental impact. Energy-efficient systems, like solar panels and LED lighting, reduce energy consumption and greenhouse gas emissions. Water conservation practices, including rainwater harvesting and drought-resistant landscaping, help manage water resources effectively. Waste reduction strategies, such as composting and recycling programs, minimize landfill contributions. Finally, biodiversity enhancement through native plant landscaping and green spaces supports local ecosystems. These components collectively contribute to a sustainable and environmentally friendly campus.

Table 12.1: Steps in Water audit

1	**Establish Audit Objectives**	Reducing water consumption, lowering operational costs, or Enhancing sustainability.
2	**Data Collection**	Accurate historical information
3	**Site Inspection**	Inspecting water-related equipment, such as plumbing systems, pumps, cooling towers, and irrigation systems, potential leaks, inefficiencies, or other areas of concern.
4	**Watershed map**	Knowing water flow directions for identifying possibilities of recharge or storages.
5	**Water usage**	Water consumption patterns, peak usage times and anomalies
6	**Leak Detection**	leak detection tests to identify and repair any hidden leaks
7	**Efficiency Assessment**	Evaluating the efficiency of water-using equipment, such as pumps, cooling systems, and water heaters
8	**Water Quality Assessment**	Determine if treatment or filtration systems are required
9	**Recommendations & Solutions**	a comprehensive list of recommendations for improving water efficiency. Prioritize actions, set goals, and estimate potential savings.
10	**Implementation Plan**	Planning timelines and responsibilities to guide the execution of water-saving initiatives.
11	**Monitoring and Reporting**	Establish a monitoring system to track progress and provide regular reports on water consumption and savings. This helps maintain accountability and ensures the effectiveness of implemented measures.
12	**Employee Training and Awareness**	Training employees for water conservation practices can significantly contribute to water conservation

Methodology used:

American Water Works Association (AWWA) method of water audit is used in this study. The method is basically divided into the following tasks:

a. Measuring the supply: The sources of water supply are identified and the water output is measured from each of the sources.
b. Measuring the Authorized metered use: The metered locations are identified and the metered water uses are calculated.
c. Measuring the Authorized Unmetered use: The unmetered consumers are identified and the amount of water used by them is calculated. The uses could be composed of firefighting and training, flushing mains, storm sewers and sanitary sewers.
d. Measure Water losses: The volumes of water that does not fit in the above three categories are the loss in the system. These losses can include accounting errors, unauthorized connections, evaporation of stored water, reservoir overflows, leaks or losses due to malfunctioning of the system.
e. Analyze Audit Results: Audit result comprises of calculation of two quantities, which are potential water system leakage, i.e. difference between total water loss and all measured losses. The second quantity calculated is the recoverable leakage, which is half of all the potential leaks that can be discovered and repaired.

- **About the study Area: Ismail Yusuf College Campus**

Ismail Yusuf College is the fourth oldest college of Mumbai, India. “I Y college”, as it is popularly known, is managed by the Government of Maharashtra. It is the oldest college in North Mumbai. It was established in 1930 with a large donation from Sir Mohammed Yusuf Ismail, K.T. on Jogeshwari Hill. This college is located at Jogeshwari (E) in the western suburb of Mumbai. **(Fig 12.1)** The lush green campus with a beautiful old college building, separate science, vocational course, and humanities buildings, as well as a sports complex, covers 54 acres of land. The scenic beauty and the antique architecture of the college administrative building housed with a spacious library in it, form a heritage structure. The College provides education in arts, science and Commerce streams. Besides these, the college also offers self-finance courses, especially in subjects like Computer science and Biotechnology. There are various courses that are being taught at both UG & PG levels.

Fig 12.1: Ismail Yusuf College Campus

Calculations for water requirement:

The per capita water requirement was calculated with the help of set standards by WHO, for domestic use and using estimated values for irrigation and other purposes. The total water requirements were obtained by multiplying the number of people in the distribution point, with the per capita water requirement for domestic purposes. For irrigation purposes, the total water requirement was obtained by multiplying the area of irrigation with the water requirement per area of the distribution point. The total water requirement gave the ideal amount of water that needed to be pumped into the system and was calculated by following steps,

1. Survey of the distribution points of campus.
2. Finding the number of people contributing to water usage at every distribution point
3. Finding out the areas of irrigated distribution points
4. Finding out the standard values for domestic and other uses
5. Calculation of total water requirements with above data

The standard values were obtained from the prescribed values of World Health Organization (WHO) given in the **table 12.2**

Table 12.2: Prescribed Water Requirement Standard (WHO)

S. No	Usage	Minimum Water Requirement (LPCD)	Maximum Water Requirement (LPCD)	Average Water Requirement (LPCD)
1	Drinking	2	8	5
2	Sanitation	30	50	40
3	Cooking	2	6	4
4	Bathing	8	32	20
5	Washing Clothes	10	30	20
6	Washing Utensils	15	35	25

The average amount of water required for irrigation by drip systems for garden use was taken as 2 liters per sq.m per day. Average water requirement for the college is given in **Table 12.3, Fig 12.2,12.3 and 12.4.**

Table 12.3: Average water requirement for the college

S.No.	Item	No./Area	Average Water requirements in liters per unit	Average water requirement per day
1	Drinking & domestic use for Population (Inmates + floating)	200	114	22800
2	Garden /Lawn area	04 Acres	02 liters per sq.m.	32374
3	Other uses like washing, Play Ground watering etc.	-	Need based	10000
			Total requirement	**65,174**

Thus, the ideal water requirement for the campus was found out and a comparison was made between the actual water usage, ideal water requirement and the amount of water supplied.

Fig 12.2: Ismail Yusuf College Campus: Water Filter plant in Campus

Fig 12.3: Ismail Yusuf College Campus, Common Washrooms in Boys Hostel

Fig 12.4: Ismail Yusuf College Campus: College Canteen

- **Water resources available in Campus**

There are two types of water supplies i.e. Surface water (Corporation water supply) and Ground water (Dug well / Borewell) **Fig 12.5 and 12.6**

1. **Corporation water supply:** The campus has 3 inches Corporation water supply pipe connection supplying 24000 liters per day. The price for this water supply is Rs. 5 - 6 for Non-commercial

use and Rs. 20-50 for Commercial use). The average bill per year for piped water supply for the campus is 03 lakhs rupees.

2. **Ground water supply:** 02 Borewells & 01 Dug well. i.e. need of 41,174 liters is fulfilled by Ground water. The average expenditure for extracting ground water is Rs. 150- 170 per day. The average bill per year for ground water supply for the campus is Rs 50000 to 60000.

For use of above water resources 08 storage tanks are available with capacity of 8000 liters each i.e. total storage capacity in the campus is 24000 liters. The maintenance cost for these tanks is 1.25 lakh per year (Cleaning 2 -3 times with rate Rs. 5000 per tank cleaning). **Fig 12.6**. **Total average expense on water supply is 4.75 lakhs per year i.e. Rs. 7.28 per liter (Total expenses divided by total liters).**

Fig 12.5: Ismail Yusuf College Campus: Borewells & Dugwell in College Campus

Fig 12.6: Ismail Yusuf College Campus: Municipal water supply & underground storage tank

Green Cover: The Department of Botany at Ismail Yusuf College has embarked on a mission to restore the green cover on its campus**. (Fig 12.7).** To achieve this, they have adopted the "Miyawaki

Urban Dense Forest" technique, which aims to quickly revitalize vegetation while preserving biodiversity. The first Miyawaki Forest was implemented through CSR funding form HDFC Life & Keshavshrusti on 22nd August 2019. More than 1250 plants of 32 native tree species were sown in approximately 2000 Sq ft area. The second Miyawaki Urban Dense Forest was developed on 16th February 2022 in association with Forest Creators and ARCON on 3000 sq ft area with 1540 saplings of 41 native varieties Third Miyawaki Urban Dense Forest was developed on 5th June 2022 in association with Forest Creators and Aga Khan Agency for Habitat on 12000 sq ft area with 5630 saplings of 30 native varieties.

Fig 12.7a: Ismail Yusuf College Campus:Green Cover

Dr. Nair from Forest Creators who has successfully carried out one of the biggest Miyawaki plantations in India was actively involved in the activity. Team Forest Creators ensured continuous water supply during the dry season via water tankers.4th Miyawaki Urban Dense Forest was inaugurated on 4th August 2024 in association with Keshav Srushti and Bombay Chartered Accountants' Society (BCAS) on 3000 sq ft area with 1000 saplings of 41 native varieties.

Fig 12.7b: Ismail Yusuf College Campus: Green Cover

Watershed and contour map of the study area is shown in **fig 12.8** and status is given in **Table 12.4**

Table 12.4: Watershed status

Constructed area	13 acres
Botanical Garden	26 Acres
Open ground	08
Garden/Lawn	04 acres
Other Metalled area	03 acres
Total area	**54 acres**

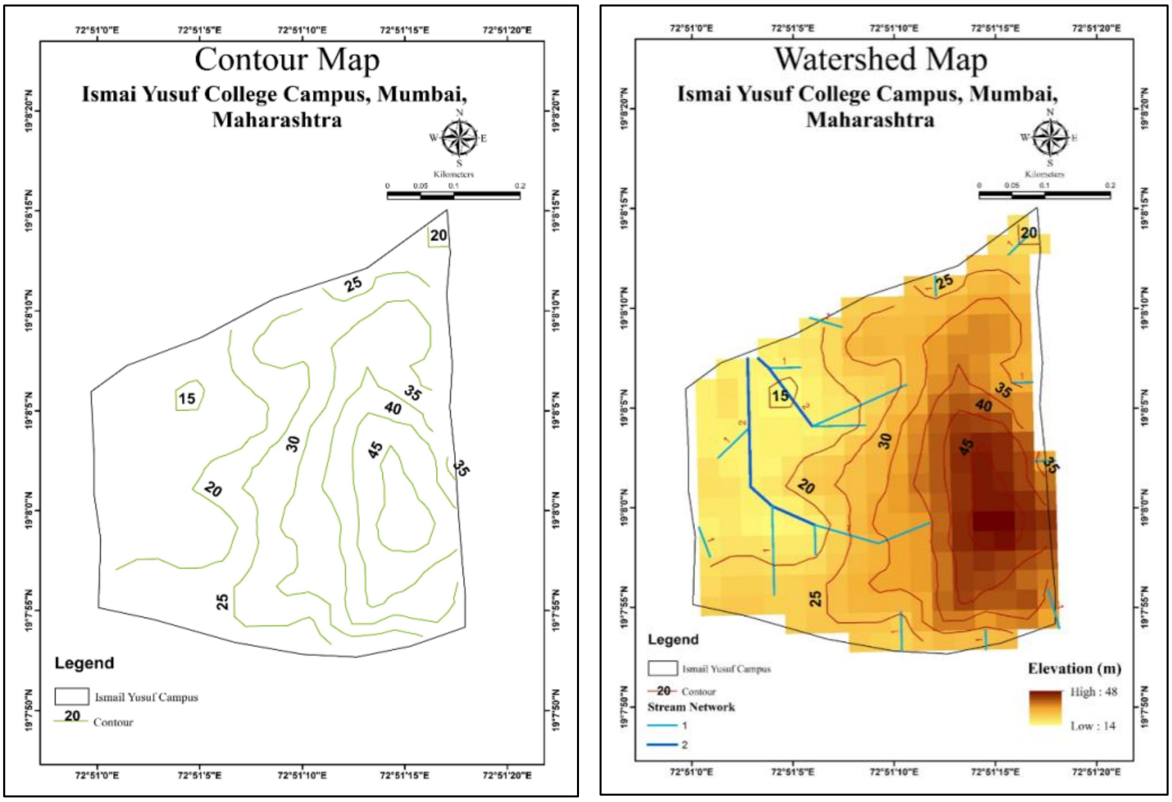


Fig 12.8: Contour Map of college Campus (Left) and Watershed Map (Right)

Roof top rainwater harvesting

The rooftop rainwater harvesting structures are already installed in the campuses and have capacity of recharging around 1.25 lakhs of water. This helps in sustaining the Dug well and borewells in the premises. As the watershed is having undulating shape and also looking in to the baseflow conditions further recharge methods not suggested. **(Fig 12.9)**

Fig 12.9: Rain water harvesting structure in campus

12.2: ANALYSIS & SUGGESTIONS

1. **Inspection of complete water distribution system to detect leakage:** Leakages on main lines calculated by taking the difference between the system supply and the discharge received by the main tank. The amount of effort needed to perform a leak detection survey depends heavily on the information available, such as system aps, inventory of pipes and fittings, and history of repairs.
2. **Replacement of old fittings and joints & corroded pipes:** The fittings and joints in the pipelines are too old, they have to be replaced in order to mitigate losses due to leakage. It is seen that the pipes are corroded, they have to be replaced immediately so that leakage losses are prevented.
3. **Recycling the waste water for further use:** Waste water, for instance the water used for washing the floors of the dairy barn, can be recycled and used again for gardening.
4. **Spreading awareness among workers, staff and students:** Awareness needs to be spread about the loss of water in campus among all the people who are a part of it. Losses due to over-usage of water can be prevented to a great extent. The flow rate of taps should be checked, it should not be more than 2.5 liters/minute. Trainings need to be arranged on environmental management systems and nature conservation. More Messages should be displayed at various locations to aware all about water savings
5. **Construction of Storage Pond:** Construction of Storage Pond with a capacity of 50 lakh liters is suggested. This will fulfill the requirement of gardening and other domestic uses and reduce the pressure on piped water supply as well as save ground water abstraction expenses. With this approximate savings of Rs. 30,000 to 50,000 is expected.
6. College should start drip irrigation for garden & lawn to save water in the campus

Benefits of Water audit

1. Water audit provides decision making tools i.e., knowing where water is being used in a system allows you to make informed decisions about investing resources such as time, and money.
2. Water audit allows to efficiently reduce water losses in the system.
3. Reducing water used at the source may even result in delaying or avoiding capital investments such as a new well, more treatment technology or additional water rights.
4. Creating awareness among water users i.e., customers can see and understand that the utility is taking proactive steps to manage wasted water and save for the future.
5. To counter the depleting water resources and ill usage of water by identification of the problems, leak points, losses, wastage and giving suggestions to minimize the same.
6. The evaluation of water sources which pumped water throughout the campus was the foremost step of the water audit of the campus and then water meters were installed at suitable distribution points to measure the usage. Water meter indicates the measured value of water usage at that particular location.

12.3 CONCLUSIONS OF THW WATER AUDIT

Water wastage in urban areas is a serious problem caused by rapid urbanization, poor management, and careless human activities. The major causes are leakages in pipelines, overuse in households, lack of water meters, illegal connections, poor drainage systems, and concrete and / or metalled surfaces reducing the ground water recharge. This has caused water scarcity in cities, aquifers in urban areas are emptying, there is continuous increase in water supply costs and last but not the least the environmental damage with stress on rivers and lakes.

This audit involves considerable team discussions and meetings with key staff members on a variety of environmental-related topics. By conducting water audit IY college makes a significant effort to act in an environmentally responsible manner and takes into account the environmental effects of the majority of its activities. Though this case study has less parameters used but still the methodology and recommendations given in this report suggest some more ways in which the college can work to improve its practices and develop into a more sustainable institution. It is very much important to begin with a few things, such as putting water saver taps, initiating drip irrigation, re-using water for gardening and increasing plantation drives.

Annexures

Annexure I

GEOPHYSICAL INVESTIGATIONS CARRIED OUT IN MUMBAI CITY AND MUMBAI SUBURBAN DISTRICTS

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity (Ohm m)	Thickness (m)	Depth (m) From	Depth (m) To	Inferred Lithology
1	Mumbai Suburban	Play Ground	Mumbai	19.0339	72.9515	I	102	2.87	0	2.87	Top Soil
						II	2.4	5.37	2.87	8.25	Weathered/Saline
						III	87.3	15.4	8.25	23.7	Massive
						IV	0.932		23.7		Weathered/Saline
2	Mumbai Suburban	Mankhurd campus IIT	Mumbai	19.0471	72.9262	I	16.48	1	0	1	Top Soil
						II	114.8	33.43	1	34.43	Massive
						III	5.843		34.43		Weathered/Saline
3	Mumbai Suburban	Play Ground	Mumbai	19.0150	72.8868	I	34.2	1	0	1	Top Soil
						II	20.9	2.44	1	3.44	Weathered
						III	36.3	8.41	3.44	11.9	Fractures/Fresh
						IV	47.4		11.9		Moderately Weathered
4	Mumbai Suburban	Chembur Play Ground	Mumbai	19.0580	72.8994	I	44.6	1	0	1	Top Soil
						II	9.18	2.44	1	3.44	Weathered
						III	22.3	37.4	3.44	40.8	Fractures/Fresh
						IV	20.7		40.8		Fractures/Fresh
5	Mumbai Suburban	Ground	Mumbai	19.0691	72.8981	I	17.8	1	0	1	Top Soil
						II	3.47	2.79	1	3.79	Weathered/Saline

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
						III	7.08	10.6	3.79	14.4	Weathered/Saline
						IV	47		14.4		Moderately Weathered
6	Mumbai Suburban	Ghatkopar	Mumbai	19.0853	72.9143	I	9.47	1.44	0	1.44	Top Soil
						II	2.31	9.38	1.44	10.8	Weathered/Saline
						III	18.5		10.8		Fractures/Fresh
7	Mumbai Suburban	Datta Krita prabadhin	Mumbai	19.1626	72.9388	I	29.4	1.85	0	1.85	Top Soil
						II	10.762	21.1	1.85	22.9	Weathered
						III	180		22.9		Massive
8	Mumbai Suburban	Govind Patil Ground	Mumbai	19.1823	72.9560	I	42.6	1.83	0	1.83	Top Soil
						II	9.22	6.98	1.83	8.81	Weathered
						III	547	6.72	8.81	15.5	Massive
						IV	4.59		15.5		Weathered/Saline
9	Mumbai Suburban	Sambahij Raje Garden	Mumbai	19.1681	72.9646	I	15.2	1	0	1	Top Soil
						II	30.2	1.17	1	2.17	Weathered
						III	3.81	6.7	2.17	8.87	Weathered/Saline
						IV	17.3		8.87		Weathered
10	Mumbai Suburban	Telecom Colony, Powai	Mumbai	19.1237	72.9144	I	105	1	0	1	Top Soil
						II	12.7	19.1	1	20.1	Weathered
						III	1174		20.1		Massive
11	Mumbai Suburban	Godrej Vikroli	Mumbai	19.1052	72.9320	I	11.09	1	0	1	Top Soil

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
						II	4.416	13.63	1	14.63	Weathered/Saline
						III	14.04	39.67	14.63	54.3	Weathered
						IV	2984	78.7	54.3	133	Massive
						V	111.5				Fractures/Fresh
12	Mumbai Suburban	Sivaji Garden, Vikholi	Mumbai	19.1169	72.9386	I	7.6	2.12	54.3	2.12	Top Soil
						II	1.88	25.3	2.12	27.4	Weathered/Saline
						III	82.5		27.4		Fractures/Fresh
13	Mumbai Suburban	Aksa cricket ground	Mumbai	19.1770	72.7989	I	10.83	1.093	0	1.093	Top Soil
						II	2.143	1.31	1.093	2.403	Weathered/Saline
						III	0.5703	31.48	2.403	33.89	Weathered/Saline
						IV	57.77		33.89		Massive
14	Mumbai Suburban	All India Radio	Mumbai	19.1852	72.8088	I	18.75	1.221	0	1.221	Top Soil
						II	2.438	1.841	1.221	3.061	Weathered/Saline
						III	10.03	2.521	3.061	5.582	Weathered/Fresh
						IV	4.489	14.09	5.582	19.67	Weathered/Saline
						V	37.72				Fractures/Fresh
15	Mumbai Suburban	Sanjay Gandhi National Park	Mumbai	19.2279	72.8749	I	85	2.33	5.582	2.33	Top Soil
						II	22.3	13.1	2.33	15.4	Weathered/Fresh

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
						III	229		15.4		Massive
16	Mumbai Suburban	Ashok Kante Vdyon	Mumbai	19.0631	72.9135	I	394	3.1	0	3.1	Top Soil
						II	9.34	27.6	3.1	30.7	Weathered
						III	0.0567		30.7		Weathered/Saline
17	Mumbai City	Play Ground	Mumbai	18.9802	72.8348	I	16.15	1	0	1	Top Soil
						II	5.272	16.54	1	17.54	Weathered/Saline
						III	993.9		17.54		Massive
18	Mumbai City	Jijamata udyan	Mumbai	18.9779	72.8345	I	23.3	1.93	0	1.93	Top Soil
						II	9.94	12.8	1.93	14.7	Weathered
						III	78.9		14.7		Massive
19	Mumbai City	IMD, Colaba	Mumbai	18.8975	72.8141	I	85.3	4.12	0	4.12	Top Soil
						II	151	12.9	4.12	17	Massive
						III	658		17		Massive
20	Mumbai City	FSI	Mumbai	18.9092	72.8225	I	209	2.8	0	2.8	Top Soil
						II	45.7	12	2.8	14.8	Moderately Weathered
						III	18324		14.8		Massive
21	Mumbai Suburban	Goregaon	Mumbai	19.1639	72.8842	I	285	1	0	1	Top Soil
						II	77	2.62	1	3.62	Massive
						III	19.1	9.51	3.62	13.1	Fractures/Fresh
						IV	261		13.1		Massive

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
22	Mumbai Suburban	Kasturba Rane	Mumbai	19.2156	72.8414	I	49.81	1.731	0	1.731	Top Soil
						II	12.11	48.27	1.731	50	Weathered
						III	4.003		50		Weathered/Saline
23	Mumbai City	Shivaji park, Dadar	Mumbai	19.0267	72.8393	I	109	5.08	0	5.08	Top Soil
						II	5.99	10.6	5.08	15.7	Weathered/Saline
						III	1381		15.7		Massive
24	Mumbai Suburban	Bhakti Park	Mumbai	19.0236	72.8805	I	78.7	1.78	0	1.78	Top Soil
						II	0.487	18.3	1.78	20.1	Weathered/Saline
						III	27.8		20.1		Fractures/Fresh
25	Mumbai Suburban	Filmcity, Goregaon	Mumbai	19.1619	72.8929	I	145.5	1	0	1	Top Soil
						II	3188	3.494	1	4.494	Massive
						III	9.429	0.8076	4.49	5.302	Weathered
						IV	423.6	32.8	5.3	38.1	Massive
						V	32.58	10.08	38.1	48.18	Moderately Weathered
						VI	74.71				Massive
26	Mumbai Suburban	Water filtration plant, Bhandup	Mumbai	19.1631	72.9271	I	345	1	0	1	Top Soil
						II	2.76	1.02	1	2.82	Weathered/Saline
						III	2660	2.98	2.82	5.8	Massive
						IV	45.1	42.4	5.8	48.2	Moderately Weathered

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
						V	98				Massive
27	Mumbai Suburban	BMC ground, Mulund	Mumbai	19.1683	72.9643	I	23.44	2.643	0	2.643	Top Soil
						II	5.78	2.195	2.64	4.838	Weathered/Saline
						III	10.69	17.48	4.84	22.32	Weathered
						IV	69.83	43.02	22.3	65.34	Massive
						V	3.346				Weathered/Saline
28	Mumbai Suburban	CTIRC, Borivalli	Mumbai	19.2340	72.8677	I	16	1.19	0	1.19	Top Soil
						II	36.3	8.8	1.19	10	Weathered
						III	187	10.1	10	20.1	Massive
						IV	36	13.4	20.1	33.5	Weathered
						V	3596				Massive
29	Mumbai Suburban	Malad	Mumbai	19.1668	72.8017	I	0.4831	5.818	0	5.818	Top Soil
						II	0.9249	7.045	5.82	12.86	Weathered/Saline
						III	7.6	96.72	12.9	109.6	Weathered/Saline
						IV	22.19				Fractures/Fresh
30	Mumbai City	BMC ground, Mahim West	Mumbai	19.0284	72.8390	I	62.7	1.6	0	1.6	Top Soil
						II	0.718	3.48	1.6	5.08	Weathered/Saline
						III	170	10.7	5.08	15.8	Massive

VES No.	District	Location	Taluka	Latitude	Longitude	Layers	Resistivity	Thickness	Depth (m)		Inferred Lithology
							(Ohm m)	(m)	From	To	
						IV	59.1	15.6	15.8	31.4	Moderately Weathered
						V	118				Massive
31	Mumbai City	Oval ground, Churchgate	Mumbai	18.9282	72.8283	I	114.8	2.372	0	2.372	Top Soil
						II	23.42	6.637	2.372	9.009	Weathered
						III	18.97	18.91	9.009	27.92	Fractures/Fresh
						IV	42.6	7.194	27.92	35.11	Moderately Weathered
						V	157.3				Massive
32	Mumbai Suburban	Goregaon Road side	Mumbai	19.1607	72.8644	I	27.1	1	0	1	Top Soil
						II	4.37	1.35	1	2.35	Clay
						III	32.7	7.87	2.35	10.2	Weathered/Fresh
						IV	94.4	87.8	10.2	98.1	Massive
						V	769	30.4	98.1	128	Massive
33	Mumbai Suburban	Mumbai University, Santacruz	Mumbai	19.0732	72.8552	I	28.5	1.02	0	1.02	Top Soil
						II	6.52	6.71	1.02	7.73	Weathered
						III	1.53	33.2	7.73	40.9	Weathered/Saline
						IV	179	25.8	40.9	66.7	Massive
						V	35				Fractures/Fresh

Annexure II

Salient Hydrogeological Data of Exploratory Wells drilled In the Mumbai city and Mumbai Suburban district

S. No	Site	Latitude	Longitude	Well type	Depth drilled (m)	Casing (m) with agl	Zones tapped/ fractures encountered	Discharge (lps)	EC (µS/cm)	SW L (m) bgl	Draw-down (m)	Trans-missivity m2/day	Specific capacity lpm/ m/dd	Forma-tion
1	**Film City, Goregaon**	19.161480	72.886020	EW	200	23.50	60 to 62; 105 to 107; 169 to 172 m bgl	Drilling: 12.90 lps PYT: 5.94 lps	1St Zone:720 3rd Zone: 853	35.90	2.73	96.02	130.54	Basalt
2	**Film City, Goregaon**	19.161480	72.886020	OW	178.20	23.50	61 to 62; 84to 86; 168 to 169 m bgl	Drilling; 9.86 lps PYT :2.5lps	1st: 820 2nd: 820	37.27	3.45	141.45	43.47	Basalt
3	**CTIRC Training Centre, Kajupada**	19.234134	72.868124	EW	200	17.50	14 m bgl	0.0371	-	9.75	-	-	-	Basalt
4	**Water Treatment Plant Bhandup Complex**	19.163217	72.925956	EW	200	11.50	43 to 44 m bgl	0.0371	1st Zone:450	22.50	-	-	-	Basalt

S. No	Site	Latitude	Longitude	Well type	Depth drilled (m)	Casing (m) with agl	Zones tapped/ fractures encountered	Discharge (lps)	EC (µS/cm)	SW L (m) bgl	Draw-down (m)	Trans-missivity m2/day	Specific capacity lpm/ m/dd	Forma-tion
5	**Sir J. J. School of Arts, Dhobi Talao, Fort**	18.944813	72.833075	EW	202.60	17.50	72 to 74 m bgl Saline	0.209		6.38	-	-	-	Basalt
6	**Sir J.J. School of Arts, Dhobi Talao, Fort**	18.944813	72.833075	PZ	62.30	20.50	15.0 to 19.0	0.037						
7	**Sambhaji Raje Park, Mulund East**	19.168540	72.964120	EW	141.5	21.5	18-19.5; 131-132.40 (saline)	13 lps	1620	1.08	-	-	-	Basalt
8	**Shivaji Park,Dadar**	19.028184	72.837803	PZ	37.9	11.0	18.50-19.0; 36-37 m bgl (saline)	0.43 lps 5.94 lps	1337 19k	7.19	-	-	-	Basalt
9	**Ismail Yusuf College, Andheri**	19.132229	72.852372	EW	200.0	15	13.0-14.0; 102.0-104.0;	0.037 lps; 3.17 lps; 5.94 lps	568; 676; 788	7.0	-	-	-	Basalt

S. No	Site	Latitude	Longitude	Well type	Depth drilled (m)	Casing (m) with agl	Zones tapped/ fractures encountered	Discharge (lps)	EC (µS/cm)	SW L (m) bgl	Draw-down (m)	Trans-missivity m2/day	Specific capacity lpm/ m/dd	Forma-tion
							167.0-169.0 m bgl							

Annexure III

Depth to water levels from May 2023 to May 2025

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov -24	Jan-25	May-25
1	DW	18.9356	72.8368	Mumbai City	Mumbai City	BMC Ward A Office, on Mint Back road	47B/13-C2	3.65	1.5	0.8	Basalt	1.56	1.05	1.1	1.6	1.62	1.86	2.2	2.75	1.85
2	DW	18.9416	72.8374	Mumbai City	Mumbai City	St George Hospital Garden	47B/13-C2	3	2	0.6	Basalt	2.23	2.1	2.17	2.23	2.05	2.06	2.05	2.27	2.01
3	DW	18.9438	72.8386	Mumbai City	Mumbai City	CSMT, Indraprastha Bhawan	47B/13-C2	4.3	1.5	GL	Basalt	3.61	3.48	3.58	3.65	4.1	Dry	Dry	Dry	Dry
4	DW	18.9158	72.8284	Mumbai City	Mumbai City	Khandoba Mandir, Harmos Ji St	47B/13-B3	4	2	0.8	Basalt	1.23	0.83	1.32	0.87	0.72	0.58	0.61	0.74	0.52
5	DW	18.9737	72.827	Mumbai City	Mumbai City	Ward E, BMC Dispensery	47B/13-B1	4	1.5	GL	Basalt	1.34	1	1.1	1.6	1.26	1.07	1.1	1.88	NA
6	DW	18.9742	72.8226	Mumbai City	Mumbai City	Nair Hospital, Mumbai Central	47B/13-B1	6	1.5	0.5	Basalt	1.47	1.63	1.45	1.15	1.55	1.11	0.7	1.2	NA
7	DW	18.9573	72.8414	Mumbai City	Mumbai City	Jaffer Suleiman Masjid, Mazgoan	47B/13-C2	7	1.1	1	Basalt	3.65	3.15	2.15	2.76	2.95	1.72	1.9	2.6	1.85
8	DW	18.9552	72.8238	Mumbai City	Mumbai City	Narayanwadi Mandir	47B/13-B2	8	3	0.7	Basalt/Alluvium	6.05	5.08	4.92	4.16	5.22	3.68	4.28	4.37	3.8
9	DW	19.0123	72.8311	Mumbai City	Mumbai City	Lakshmi Autoworks shop, GS Ward	47A/16-B6	5	1	GL	Basalt/Alluvium	2.1	2.35	2.05	1.92	1.98	1.82	1.9	2.1	1.45
10	DW	19.0171	72.8202	Mumbai City	Mumbai City	GS Ward , Worli village	47A/16-B6	4.5	2	0.8	Basalt	2.93	2.65	2.65	2.75	2.23	2.16	2.4	2.4	2.52
11	DW	19.0235	72.837	Mumbai City	Mumbai City	Shivaji Park, Dadar	47A/16-C6	6	6	1	Basalt/Alluvium	2.96	1.7	2.75	3.22	3.55	2.65	3.15	3.37	2.4
12	DW	19.0139	72.8412	Mumbai City	Mumbai City	Dadar East, Sant Gadge	47A/16-C6	6	3	GL	Basalt	1.52	1.5	2.48	2.72	2.52	3.61	4.25	1.9	1.91

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov-24	Jan-25	May-25
						Maharaj Trust complex														
13	DW	19.0459	72.8653	Mumbai City	Mumbai City	Sion Ayurvedic Mahavidyalaya	47A/16-C5	13	10	0.5	Alluvium + Agglomerate & Tuff/Intertrappean	10.75	8.5	9.72	8.62	9.71	7.25	8.7	8.82	7.11
14	DW	18.9319	72.8311	Mumbai City	Mumbai city	Bombay (Church Gate)	47B/13-B2	4.4	3.35	0.75	Basalt	2.2	1.1	1.53	1.7	2.1	0.9	1.5	3.92	1.87
15	DW	18.8967	72.8111	Mumbai City	Mumbai city	Colaba (Dandi)	47B/13-B3	5.4	1	0.85	Alluvium	3.7	3.16	3.26	3.8	4.21	2.6	3.1	1.8	3.31
16	DW	19.025	72.8445	Mumbai City	Mumbai city	Mahim	47A/16-C6	5.8	3	1.05	Basalt/Alluvium	3.5	3.06	4.24	4.19	4.61	2.8	3.32	4.4	4.56
17	DW	18.9983	72.8186	Mumbai City	Mumbai city	Varli_Naka	47B/13-B1	6.9	1.5	0.7	Alluvium	1.18	2.26	1.54	1.2	1.16	1.2	1.16	1.15	1.56
18	DW	18.9692	72.8439	Mumbai City	Mumbai city	Mazgaon	47B/13-C1	13.6	0.85	3	Basalt	7.8	8.3	10.64	12.1	12.81	5	7.4	5.28	4.62
19	DW	18.9381	72.8367	Mumbai City	Mumbai city	Colaba-Fort	47B/13-C2	3.8	2	0.75	Basalt	1.67	1.68	1.39	1.73	2.5	1.53	1.8	1.56	2.44
20	DW	18.9792	72.8348	Mumbai city	Mumbai city	Rani cha Bagh	47B/13-C1	10.6	5.5	0.4	Basalt	9.2	3.85	4.24	4.8	8.35	1.4	8.82	8.35	1.19
21	DW	19.2319	72.856	Mumbai Suburban	Borvali	Boraveli West (MCO office)	47A/16-C1				Basalt	2.44	1.67	2.32	2.56	2.42	1.78	2.62	2.5	1.72
22	DW	19.2373	72.8565	Mumbai Suburban	Borvali	Rokadia (Cross Lane)	47A/16-C1				Basalt	0.73	0.48	0.85	0.98	0.68	0.65	0.91	1.31	0.45
23	DW	19.2141	72.8484	Mumbai Suburban	Borvali	Borspada	47A/16-C1				Basalt	7.62	5.26	7.1	7.71	6.1	NA	NA	NA	NA
24	DW	19.2204	72.8565	Mumbai Suburban	Borvali	Boraveli East (Sub Way)	47A/16-C1				Alluvium	7.37	2.16	5.95	6.42	5.95	2.87	5.98	7.01	2.25
25	DW	19.2363	72.8674	Mumbai Suburban	Borvali	Boraveli East (Kaju Pada)	47A/16-C1				Basalt	1.52	1.75	1.58	1.92	2.12	1.42	1.85	1.9	NA

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov-24	Jan-25	May-25
26	DW	19.1961	72.8098	Mumbai Suburban	Borivali	Malwani	47A/16-B2	9.4	4	1	Alluvium	5.9	0.8	2.54	3.3	3.8	0.8	2.01	1.94	1.81
27	DW	19.2517	72.8642	Mumbai Suburban	Borivali	Dahisar-1	47A/16-C1	11.65	5.5	0.6	Basalt	10.7	9.95	8.03	9.3	8.34	6.2	3.24	9.1	8.93
28	DW	19.1631	72.8881	Mumbai Suburban	Borivali	Film City-Habale Pada	47A/16-D3	4	2.9	0.5	Basalt	1.85	0	1.34	6.1	1.41	0.7	2.31	2.65	1.35
29	DW	19.1353	72.8873	Mumbai Suburban	Borivali	A.M.C. Colony	47A/16-D3	14	3.8	0.95	Agglomerate & Tuff/Intertrappean	11.7	4.32	4.78	6.1	11.61	4.8	1.32	12.28	4.86
30	DW	19.1656	72.8575	Mumbai Suburban	Borivali	Goregaon	47A/16-C3	6.6	4	0.7	Alluvium	1.9	0.65	2.43	1.4	2.76	0.2	0	1.23	2.11
31	DW	19.2428	72.7853	Mumbai Suburban	Borivali	Gorai Beach	47A/16-A1	5.9	3.9	0.7	Rhyolite, Hybridised Acid Lava & Silicified Tuff	1.55	0.45	3.06	3.4	5.24	2.2	2.95	3.15	6.96
32	DW	19.2142	72.785	Mumbai Suburban	Borivali	Manori	47A/16-A1	10	8	0.6	Rhyolite, Hybridised Acid Lava & Silicified Tuff	6.22	0.78	2.82	2.96	7.3	0.1	4.67	3.48	4.79
33	DW	19.0836	72.881	Mumbai Suburban	Kurla	Bail Bazar	47A/16-D4	8	5.2	0.85	Alluvium	1.1	0.95	0.92	0.95	0.9	0.82	0.86	1.7	NA
34	DW	19.0144	72.89	Mumbai Suburban	Kurla	Mahul	47A/16-D6	4.6	6	0.75	Alluvium	0.85	0.7	0.62	0.8	0.72	0.4	0.71	1.4	NA
35	DW	19.1156	72.8959	Mumbai Suburban	Kurla	Chandiwali	47A/16-D4	9.4	7.5	0.6	Basalt	6.71	2.95	4.31	5.4	5.55	NA	NA	NA	NA

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov-24	Jan-25	May-25
36	DW	19.1248	72.9196	Mumbai Suburban	Kurla	Powai	47A/16-E4	3.1	3.5	0.65	Basalt	0.66	0.7	0.35	0.76	2.15	0.61	0.54	1.52	NA
37	DW	19.0968	72.9019	Mumbai Suburban	Kurla	Bhatwadi	47A/16-D4	7.1	2.5	0.7	Basalt	1.25	1.1	1.52	1.3	1.25	1.05	1.23	1.2	0.72
38	DW	19.1093	72.9297	Mumbai Suburban	Kurla	Vikhroli	47A/16-E4	9	20	0.2	Fractured Basalt/Alluvium	6.85	3.35	5.98	7.1	5.96	0.4	4.54	5.8	0.3
39	DW	19.1411	72.9272	Mumbai Suburban	Kurla	Bhandup	47A/16-E3	5	4.8	0.74	Basalt	1.81	1.4	7.52	1.69	2.15	1.71	2.11	1.71	1.87
40	DW	19.1616	72.9389	Mumbai Suburban	Kurla	Sonapur	47A/16-E3	5.8	1.5	0.6	Weathered Basalt	2.9	2.3	2.42	NA	6.4	0.9	5.26	5.26	3.15
41	DW	19.1796	72.9498	Mumbai Suburban	Kurla	Bhaktimarg	47A/16-E2	7.5	12	0.7	Alluvium	5.21	3.1	4.12	4.55	4.95	2.6	3.8	4	NA
42	DW	19.0827	72.8967	Mumbai Suburban	Kurla	Kirol	47A/16-D5	5.95	2.55	0.87	Alluvium	2.88	1.76	2.81	3.05	3.3	2.51	2.77	2.7	1.2
43	DW	19.1636	72.9542	Mumbai Suburban	Kurla	Mulund_East	47A/16-E3	9.4	4.2	1	Alluvium	3.75	2.23	3.54	3.5	3.37	1.8	2.51	4.37	3.07
44	DW	19.055	72.8973	Mumbai Suburban	Kurla	Chembur_Gaothan	47A/16-D5	6.9	3.7	0.5	Alluvium	3.1	2.92	3.4	3.2	2.68	1.8	3.7	2.34	3.27
45	DW	19.0281	72.8967	Mumbai Suburban	Kurla	Laxminagar-Mahul	47A/16-D6	6.9	7	0.9	Basalt/Alluvium	0.45	0.38	0.5	0.7	1.8	0	2.64	0.65	1.32
46	DW	19.0325	72.9481	Mumbai Suburban	Kurla	Trombay-Koliwada	47A/16-E6	6.8	2.7	0.7	Alluvium	3.55	3.07	2.8	3.2	3.8	1.9	2.3	3.7	4.11

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov-24	Jan-25	May-25
47	DW	19.0394	72.9261	Mumbai Suburban	Kurla	Agarwadi	47A/16-E6	6.25	3	0.7	Basalt	3.65	2.43	4.1	5.2	6.33	1.3	4.93	6.47	3.22
48	DW	19.1439	72.8339	Mumbai Suburban	Andheri	Oshivara	47A/16-C3				Alluvium	1.2	0.65	0.45	1.2	0.81	0	0.64	0.6	0.62
49	DW	19.0999	72.8261	Mumbai Suburban	Andheri	Theosophical Society (Juhu vile Parle)	47A/16-B4				Alluvium	5.2	4.18	4.72	4.9	4.93	4	3.93	4.55	3.42
50	DW	19.1172	72.8694	Mumbai Suburban	Andheri	Kondvita (Ganeshwadi)	47A/16-C4				Alluvium	3.75	3.05	2.95	2.9	2.8	2.7	2.93	2.92	2.88
51	DW	19.1313	72.8517	Mumbai Suburban	Andheri	Jogeshwari (E) Natwarnagar	47A/16-C3				Basalt/Alluvium	4.85	0.76	2.05	2.16	4.81	2.2	3.11	2.85	2.19
52	DW	19.0744	72.8675	Mumbai Suburban	Andheri	Kalina	47A/16-C5				Alluvium	0.5	0.3	0.21	0.2	0.32	0	0	0	0.2
53	DW	19.0685	72.844	Mumbai Suburban	Andheri	Jawaharnagar	47A/16-C5				Alluvium	0.4	0.68	0.21	0.8	0.3	0.1	0	0.2	0.6
54	DW	19.139	72.807	Mumbai Suburban	Andheri	Varsowa	47A/16-B3	5.8	2.6	0.5	Alluvium	4.74	2.3	4.22	4.2	4.98	2.31	3.98	4.57	3.43
55	DW	19.0529	72.8254	Mumbai Suburban	Andheri	Bandra (W)	47A/16-B5				Basalt	2.4	1.73	1.75	0.6	3.62	1.7	3.1	2.42	1.75
56	DW	19.0748	72.8235	Mumbai Suburban	Andheri	Khardanda	47A/16-B5	7.3	4.3	1.35	Basalt	1	0.78	0.73	0.9	6.83	3.92	4.93	5.53	0.7
57	DW	19.0975	72.8431	Mumbai Suburban	Andheri	Vile Parle West	47A/16-C4	6.15	6	0.9	Agglomerate & Tuff/Intertrappean	3	1.75	3.92	3.2	4.21	1.5	8.82	2.58	2.52

S.No.	Type	LAT	LONG	District	Taluk	Location Name	Toposheet No & Quadrant	Depth (m bgl)	Dia (m)	MP (m)	Formation	May-23	Aug-23	Nov-23	Jan. 2024	May-24	Aug-24	Nov-24	Jan-25	May-25
58	DW	19.1325	72.8392	Mumbai Suburban	Andheri	Amboli_Sarota Pada	47A/16-C3	5.6	7.5	0.2	Alluvium	3.1	1.38	2.52	2.3	3.24	1.2	2.21	2.95	1.02
59	DW	19.1417	72.7898	Mumbai Suburban	Andheri	Madh	47A/16-B1	5.9	4.5	0.6	Trachyte	1	0.45	0.77	0.3	4.56	0.3	2.63	0.35	0.81
60	DW	19.0806	72.8586	Mumbai Suburban	Andheri	Vakola	47A/16-C5	9	4	0.2	Alluvium	2.95	2.32	2.62	2.7	3.3	1.7	2	2.15	1.91

Annexure IV

Ground water Quality of Mumbai City and Mumbai Suburban District, Pre-Monsoon 2023

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/ BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
							µS/cm	……………………………………….mg/L…..…………………………………….……….												ppb		
1	Mumbai	Oshiwara	19.1439	72.8339	DW	7.62	866	554	275	70	24	67	7	0	397	74	26	7	0.26	1.76	1.76	1.00
2	Mumbai	Oshiwara	19.1456	72.8363	BW	7.52	954	611	270	84	15	80	4	0	275	145	38	5	0.29	0.61	2.12	-0.90
3	Mumbai	Amboli (Mahalakshmi Tower)	19.128	72.8426	BW	7.75	1310	838	255	36	40	156	7	0	366	202	52	5	0.73	0.71	4.24	0.90
4	Mumbai	Theosophical Society (Juhu vile Parle)	19.0999	72.8261	DW	7.45	1071	685	190	14	38	131	10	0	378	113	50	12	0.30	1.42	4.12	2.40
5	Mumbai	Theosophical Society (Juhu vile Parle)	19.1043	72.8442	BW	7.36	3543	2268	400	116	27	529	10	0	391	908	84	2	0.25	3.48	11.51	-1.60
6	Mumbai	Vileparle	19.1043	72.8442	BW	7.60	734	470	230	34	35	42	1	0	299	50	30	5	0.54	0.79	1.19	0.30
7	Mumbai	Kondvita (Ganeshwadi)	19.1172	72.8694	DW	7.50	1004	643	360	104	24	52	13	0	439	71	46	23	0.36	2.28	1.19	0.00
8	Mumbai	Kondvita (Ganeshwadi)	19.1117	72.8647	BW	7.66	440	281	180	32	24	23	1	0	214	35	15	7	0.39	0.00	0.74	-0.10
9	Mumbai	Jogeshwari (E) Natwarnagar	19.1313	72.8517	DW	7.45	468	299	190	44	19	25	1	0	232	32	29	2	0.34	0.00	0.79	0.00

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/ BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
10	Mumbai	Jogeshwari (E) Natwarnagar	19.1316	72.8505	BW	2.70	2501	**Acidified Sample**														
11	Mumbai	Kalina	19.0744	72.8675	DW	7.42	951	608	255	74	17	63	24	0	378	82	13	32	0.26	0.62	1.71	1.10
12	Mumbai	Kalina	19.0728	72.8686	BW	7.34	799	511	170	44	15	93	22	0	342	85	16	27	0.25	0.00	3.09	2.20
13	Mumbai	Vakola	19.0779	72.8554	BW	7.36	620	397	215	58	17	31	8	0	238	46	14	26	0.25	0.01	0.91	-0.40
14	Mumbai	Jawaharnagar	19.0685	72.844	DW	7.46	553	354	200	50	18	29	11	0	244	39	25	20	0.21	0.00	0.89	0.00
15	Mumbai	Jawaharnagar	19.0726	72.8444	BW	7.49	638	409	205	60	13	35	5	0	281	39	18	11	0.32	0.08	1.06	0.50
16	Mumbai	Varsova	19.139	72.807	DW	7.70	1436	919	205	28	33	213	22	0	439	213	53	45	0.32	0.58	6.47	3.10
17	Mumbai	Varsova	19.1412	72.8078	BW	7.29	910	583	250	42	35	55	7	0	275	71	30	70	0.27	1.60	1.52	-0.50
18	Mumbai	Bandra (W)	19.0529	72.8254	DW	7.53	805	515	270	60	29	44	7	0	311	57	45	35	0.38	1.02	1.17	-0.30
19	Mumbai	Bandra (W)	19.0587	72.8226	BW	7.73	835	534	245	22	46	60	2	0	360	60	28	2	0.79	0.68	1.67	1.00
20	Mumbai	Khardanda	19.0748	72.8235	DW	7.72	957	612	230	26	40	72	12	0	336	92	27	8	0.44	0.36	2.07	0.90
21	Mumbai	Khardanda	19.073	72.8268	BW	7.66	2031	1300	355	30	68	245	6	0	391	418	57	3	0.46	0.00	5.65	-0.70
22	Mumbai Suburban	Boraveli West (MCO office)	19.23195	72.856	DW	7.71	1052	673	265	18	53	96	5	0	397	92	59	7	0.61	0.80	2.55	1.20
23	Mumbai Suburban	Rokadia (Cross Lane)	19.23798	72.8564	BW	7.36	674	431	200	26	33	51	2	0	201	64	68	21	0.38	0.00	1.57	-0.70

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
24	Mumbai Suburban	Rokadia (Cross Lane)	19.237290	72.856470	DW	7.08	612	391	215	50	22	30	7	0	201	46	34	52	0.21	0.00	0.88	-1.00
25	Mumbai Suburban	Chichwadi	19.21797	72.8377	BW	7.68	1703	1090	270	32	46	221	14	0	360	347	53	5	0.48	0.58	5.85	0.50
26	Mumbai Suburban	Borspada	19.21414	72.8484	DW	7.89	749	479	70	18	6	96	16	0	73	117	49	40	1.12	0.00	4.98	-0.20
27	Mumbai Suburban	Borspada	19.21475	72.849	BW	7.67	1157	740	245	16	50	129	2	0	372	160	34	3	1.05	0.00	3.58	1.20
28	Mumbai Suburban	Boraveli East (Sub Way)	19.2204	72.8565	DW	7.43	527	337	190	26	30	20	7	0	244	21	23	8	0.49	0.00	0.62	0.20
29	Mumbai Suburban	Boraveli East (Sub Way)	19.22082	72.8568	BW	7.73	765	489	225	24	40	58	1	0	323	64	22	1	0.98	0.00	1.68	0.80
30	Mumbai Suburban	Boraveli East (Kaju Pada)	19.236324	72.867430	DW	7.14	784	502	250	64	22	43	8	0	342	53	3	31	0.36	0.00	1.18	0.60
31	Mumbai Suburban	Boraveli East (Kaju Pada)	19.235800	72.8665	BW	7.73	753	482	220	22	40	49	1	0	317	60	8	2	0.28	0.00	1.44	0.80
32	Mumbai City	BMC Ward A Ofice, on Mint Back road	18.93564	72.8368	DW	7.80	1021	653	330	46	52	57	26	0	458	82	33	10	0.52	0.31	1.36	0.90
33	Mumbai City	St George Hospital Garden	18.94165	72.8374	DW	7.63	776	496	245	34	39	42	5	0	336	57	13	6	0.21	0.38	1.16	0.60
34	Mumbai City	St George Hospital Garden	18.94115	72.83758	BW	7.69	732	468	235	40	33	48	9	0	305	71	18	12	0.20	0.00	1.35	0.30

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/ BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
35	Mumbai City	CSMT, Indraprastha Bhawan	18.94378	72.8386	DW	7.57	1572	1006	275	42	41	176	12	0	348	273	41	13	0.24	0.28	4.61	0.20
36	Mumbai City	Khandoba Mandir, Harmos Ji St	18.91582	72.8284	DW	7.47	966	618	270	42	40	71	18	0	372	85	42	22	0.23	0.59	1.88	0.70
37	Mumbai City	Ward E, BMC Dispensery	18.9737	72.827	DW	7.42	361	231	135	38	10	17	5	0	177	25	6	11	0.19	0.00	0.64	0.20
38	Mumbai City	Nair Hospital, Mumbai Central	18.97419	72.8226	DW	7.69	741	474	200	44	22	57	10	0	281	71	27	10	0.37	0.55	1.75	0.60
39	Mumbai City	Jaffer Suleiman Masjid, Mazgoan	18.95729	72.8414	DW	7.31	688	441	225	42	29	41	10	0	256	82	19	10	0.26	0.00	1.17	-0.30
40	Mumbai City	Narayanwadi Mandir	18.95521	72.8238	DW	7.59	981	628	270	16	56	60	11	0	366	71	21	40	0.26	1.13	1.59	0.60
41	Mumbai City	Lakshmi Autoworks shop, GS Ward	19.01231	72.8311	DW	7.46	823	527	225	40	30	51	10	0	323	57	20	23	0.33	0.42	1.48	0.80
42	Mumbai City	GS Ward , Worli village	19.01707	72.8202	DW	7.55	1040	666	410	132	19	38	11	0	415	71	29	84	0.30	1.24	0.81	-1.40
43	Mumbai City	Shivaji Park, Dadar	19.02354	72.837	DW	7.58	850	544	330	102	18	35	5	0	299	78	15	15	0.25	0.00	0.84	-1.70
44	Mumbai City	Dadar East, Sant Gadge Maharaj	19.0139	72.8412	DW	7.63	221	141	80	14	11	11	3	0	104	11	4	11	0.22	0.00	0.55	0.10

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/ BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
		Trust complex																				
45	Mumbai City	Sion Ayurvedic Mahavidyalaya	19.04586	72.8653	DW	7.45	333	213	120	26	13	18	5	0	165	14	18	4	0.29	0.00	0.70	0.30
46	Mumbai	Bail Bazar	19.0836	72.881	DW	7.68	438	280	165	44	13	18	5	0	220	32	0	8	0.55	0.82	0.62	0.30
47	Mumbai	Mahul	19.01436	72.89	DW	7.73	843	540	265	40	40	63	6	0	397	67	23	9	0.44	0.89	1.68	1.20
48	Mumbai	Chandiwali	19.11562	72.8959	DW	7.36	418	267	180	32	24	17	3	0	256	18	0	7	0.39	0.64	0.55	0.60
49	Mumbai	Powai	19.12476	72.9196	DW	7.49	1053	674	340	56	49	71	14	0	360	121	22	40	0.35	1.02	1.67	-0.90
50	Mumbai	Bhatwadi	19.09684	72.9019	DW	7.65	1037	664	375	54	58	66	3	0	574	14	9	19	0.39	1.00	1.48	1.90
51	Mumbai	Vikhroli	19.10925	72.9297	DW	7.68	981	628	185	22	32	120	5	0	427	89	19	2	0.34	0.45	3.84	3.30
52	Mumbai	Bhandup	19.14109	72.9272	DW	7.61	762	488	270	22	52	37	4	0	336	57	13	16	0.33	0.52	0.99	0.10
53	Mumbai	Sonapur	19.16157	72.9389	DW	7.63	880	563	310	26	60	44	1	0	403	32	59	7	0.32	0.96	1.09	0.40
54	Mumbai	Bhaktimarg	19.17964	72.9498	DW	7.73	925	592	300	28	56	39	6	0	415	43	18	10	0.36	1.26	0.97	0.80
55	Mumbai	Kirol	19.08269	72.8967	DW	7.70	1010	646	290	50	40	77	3	0	470	78	8	5	0.58	0.74	1.96	1.90
56	Mumbai	Goregaon	19.16571	72.8553	BW	7.36	524	335	185	28	28	30	0	0	232	39	22	6	0.43	0.44	0.96	0.10
57	Mumbai	Goraigaon	19.25898	72.7925	BW	7.29	561	359	160	26	23	47	2	0	232	57	13	6	0.86	2.19	1.60	0.60
58	Mumbai	Dahisar	19.2476	72.8626	BW	7.44	898	575	300	40	49	49	1	0	317	103	37	1	0.56	1.42	1.23	-0.80
59	Mumbai	Mulund East	19.18119	72.9492	BW	7.64	506	324	205	62	12	21	1	0	268	25	10	9	0.47	0.58	0.64	0.30
60	Mumbai	Malwani	19.18588	72.8189	BW	7.58	1087	696	320	40	53	67	34	0	403	96	49	43	0.41	1.86	1.62	0.20

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/ BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
61	Mumbai	Sonapur	19.16488	72.9363	BW	7.79	643	411	245	28	43	35	0	0	305	53	14	1	0.40	0.45	0.98	0.10
62	Mumbai	Rajawadi	19.07898	72.8997	BW	7.88	656	420	235	18	46	41	1	0	360	35	7	6	0.51	0.42	1.16	1.20
63	Mumbai	Agarwadi	19.04667	72.9256	BW	7.93	727	466	250	40	36	41	1	0	342	53	16	1	0.38	0.45	1.13	0.60
64	Mumbai	Bhandup	19.14018	72.9306	BW	7.70	748	479	270	12	58	37	0	0	330	57	19	9	0.36	0.67	0.99	0.00
65	Mumbai	Bhaktimarg	19.17964	72.9498	BW	7.65	299	191	105	20	13	19	0	0	153	14	13	1	0.33	0.31	0.82	0.40
66	Mumbai	Powai	19.12248	72.9179	BW	7.80	765	489	240	18	47	48	2	0	317	53	29	17	0.42	0.67	1.35	0.40
67	Mumbai	Vikhroli	19.11129	72.9292	BW	7.64	450	288	145	26	19	29	3	0	232	28	0	1	0.34	0.29	1.04	0.90
68	Mumbai	Chembur	19.05844	72.8984	BW	7.70	507	324	180	14	35	28	0	0	262	32	0	4	0.37	0.41	0.91	0.70
69	Mumbai	Chandiwali	19.11396	72.9004	BW	7.70	136	87	70	12	10	4	1	0	73	14	1	4	0.20	0.44	0.20	-0.20
70	Mumbai	Laxminagar	19.02808	72.8952	BW	7.09	4558	2917	1530	491	74	235	1	0	256	1375	40	4	0.20	4.48	2.61	-26.40
71	Mumbai	Mahul	19.01278	72.8913	BW	7.13	2177	1393	935	74	182	67	1	0	342	567	21	3	0.23	3.64	0.95	-13.10
72	Mumbai	Bhatwadi	19.09684	72.9019	BW	7.68	741	474	265	28	47	31	1	0	299	64	16	17	0.27	0.81	0.83	-0.40
73	Mumbai	Trombay	19.03514	72.9492	BW	7.37	524	335	140	28	17	41	3	0	183	50	20	12	0.25	0.81	1.50	0.20
74	Mumbai	Bombay (Church Gate)	18.93194	72.8311	DW	7.22	688	440	260	48	34	36	9.5	0	354	35	32.5	4.6	0.89	0.84	0.97	0.6
75	Mumbai	Colaba (Dandi)	18.89667	72.8111	DW	7.06	1055	675	305	48	45	87	7	0	452	89	28	22	0.28	0.24	2.167	1.3
76	Mumbai	Mahim	19.025	72.8444	DW	7.13	783	501	265	56	30	42	9	0	342	53	17	33	0.16	0.56	1.109	0.3

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F	U	SAR	RSC
77	Mumbai	Varli_Naka	18.99833	72.8186	DW	7.32	699	447.4	245	74.15	14.58	39.81	12.87	0	335.6	42.54	33	13	0.24	0.681	1.106	0.6
78	Mumbai	Mazgaon	18.96917	72.8439	DW	7.18	708	453.4	235	70.14	14.58	45.24	6.69	0	317.3	60.27	21	4	0.303	0.368	1.283	0.5
79	Mumbai	Colaba-Fort	18.93806	72.8367	DW	7.64	1033	661.1	340	88.18	29.16	57.91	25.83	0	488.2	81.54	27	5	0.185	0.591	1.365	1.2
80	Mumbai Sub-urban	A.M.C. Colony	19.13528	72.8872	DW	7.39	449	287.6	155	38.08	14.58	24.63	4.11	0	170.9	46.09	18	10	0.29	0.163	0.86	-0.3
81	Mumbai Sub-urban	Vile Parle West	19.0975	72.8431	DW	7.49	1003	641.9	260	36.07	41.31	87.89	15.05	0	408.8	92.17	38	10	0.54	0.71	2.37	1.5
82	Mumbai Sub-urban	Amboli_Sarota Pada	19.1325	72.8392	DW	7.28	1026	656.6	255	50.1	31.59	97.73	10.74	0	353.9	134.7	36	10	0.52	0.546	2.661	0.7
83	Mumbai Sub-urban	Madh	19.14167	72.7897	DW	7.33	958	613.3	225	66.13	14.58	86.35	22.91	0	299	109.9	40	43	0.32	0.609	2.503	0.4
84	Mumbai Sub-urban	Malwani	19.19611	72.8097	DW	7.56	1522	974.1	455	32.06	91.13	96.59	2.35	0	500.4	156	92	9	0.84	1.801	1.969	-0.9
85	Mumbai Sub-urban	Dahisar-1	19.25167	72.8642	DW	7.31	494	316.2	145	38.08	12.15	35.91	5.49	0	158.7	46.09	42	12	0.4	0.162	1.297	-0.3
86	Mumbai Sub-urban	Film City-Habale Pada	19.16306	72.8881	DW	7.38	482	308.4	185	46.09	17.01	20.92	0.59	0	207.5	28.36	35	4	0.35	BDL	0.669	-0.3
87	Mumbai Sub-urban	Goregaon	19.16556	72.8575	DW	7.31	654	418.6	210	48.1	21.87	39.43	3.09	0	274.6	49.63	26	8	0.37	0.029	1.183	0.3
88	Mumbai Sub-urban	Mulund_East	19.16361	72.9542	DW	7.56	559	357.8	205	48.1	20.66	29.61	1.54	0	250.2	42.54	20	5	0.26	BDL	0.899	0

S. No	DISTRICT	SITE NAME	Latitude (N)	Longitude (E)	Source (DW/BW)	pH	EC	TDS	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F	U	SAR	RSC
89	Mumbai Sub-urban	Chembur_ Gaothan	19.055	72.8972	DW	7.18	475	304.2	140	48.1	4.86	32.74	11.53	0	219.7	28.36	12	9	0.26	BDL	1.203	0.8
90	Mumbai Sub-urban	Laxminagar-Mahul	19.02806	72.8967	DW	6.86	254	162.8	105	32.06	6.075	8.29	3.82	0	122	14.18	5	14	0.19	BDL	0.352	-0.1
91	Mumbai Sub-urban	Trombay-Koliwada	19.0325	72.9481	DW	7.21	264	168.8	110	32.06	7.29	10.89	4.97	0	134.2	14.18	17	4	0.17	BDL	0.451	0
92	Mumbai Sub-urban	Vakola	19.08056	72.8586	DW	7.32	455	291.1	165	42.08	14.58	21.07	6.81	0	207.5	31.91	10	11	0.24	BDL	0.713	0.1
93	Mumbai Sub-urban	Ranicha Bagh	18.97917	72.8347	DW	7.65	890	569.3	240	40.08	34.02	83.32	3.98	0	427.1	56.72	20	8	0.6	0.816	2.338	2.2
94	Mumbai Sub-urban	Gorai Beach	19.24278	72.7853	DW	7.34	323	206.5	115	24.05	13.37	15.98	5.08	0	152.6	21.27	12	3	0.38	BDL	0.648	0.2
95	Mumbai Sub-urban	Manori	19.21417	72.785	DW	7.18	493	315.8	160	38.08	15.8	26.84	6.82	0	183.1	39	38	5	0.47	0.748	0.923	-0.2

Annexure V

DYNAMIC GROUND WTARER RESOURCES ASSESSMENT OF MUMBAI CITY AND MUMBAI SUBURBAN DISTRICT, 2025

GROUND WATER RECHARGE

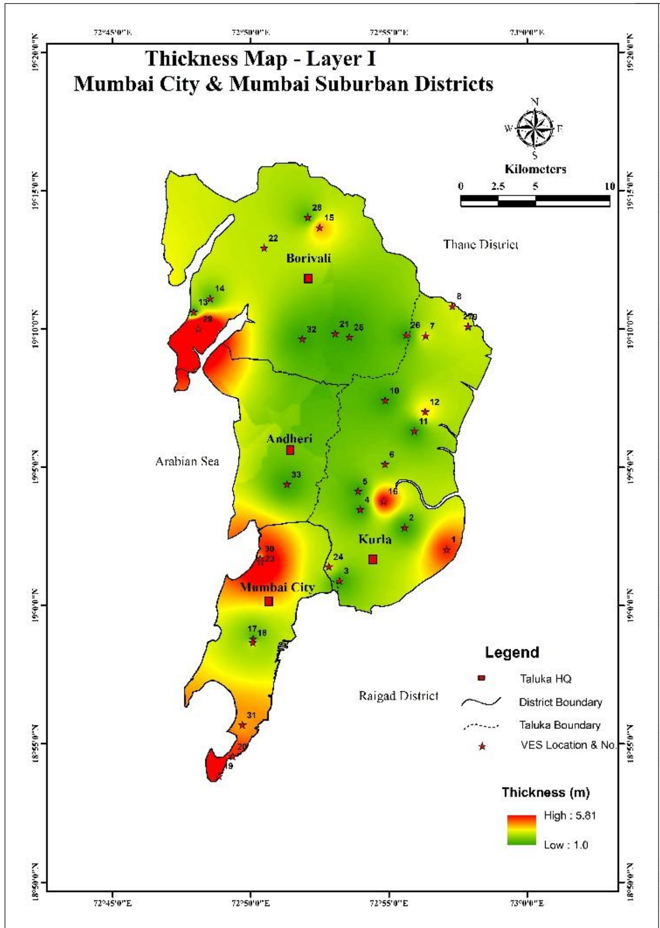
S.No.	District	Taluk	Total Geographical Area	Recharge Worthy Area	Recharge from Rainfall-MON	Recharge from Other Sources-MON	Recharge from Rainfall-NM	Recharge from Other Sources-NM	Total Annual Ground Water (Ham) Recharge	Total Natural Discharges (Ham)	Annual Extractable Ground Water Resource (Ham)
1	Mumbai Sub	Kurla	15165	15165	3413.98	110.88	0	90.72	3615.58	361.56	3254.02
2	Mumbai Sub	Borivali	14413	14413	2679.8	21.38	0	17.5	2718.68	135.94	2582.74
3	Mumbai Sub	Andheri	6916	6916	1501.9	0	0	0	1501.9	75.1	1426.8
	Mumbai Sub	**TOTAL**	**36494**	**36494**	**7595.68**	**132.26**	**0**	**108.22**	**7836.16**	**572.6**	**7263.56**
4	Mumbai	Mumbai	7004	7004	1365.05	104.7	0	85.67	1555.42	77.77	1477.65
	Mumbai	**TOTAL**	**7004**	**7004**	**1365.05**	**104.7**	**0**	**85.67**	**1555.42**	**77.77**	**1477.65**

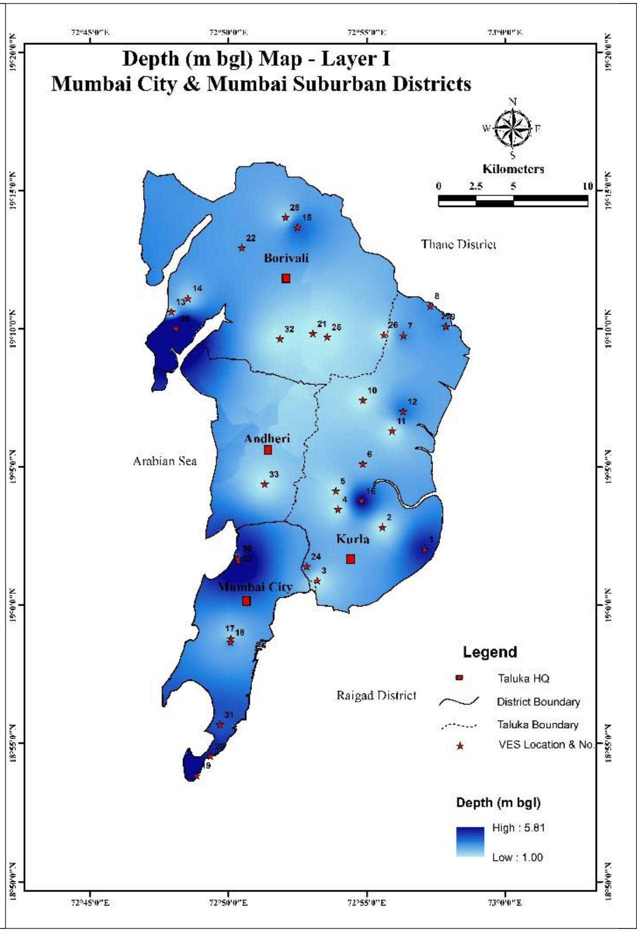
GROUND WATER EXTRACTION

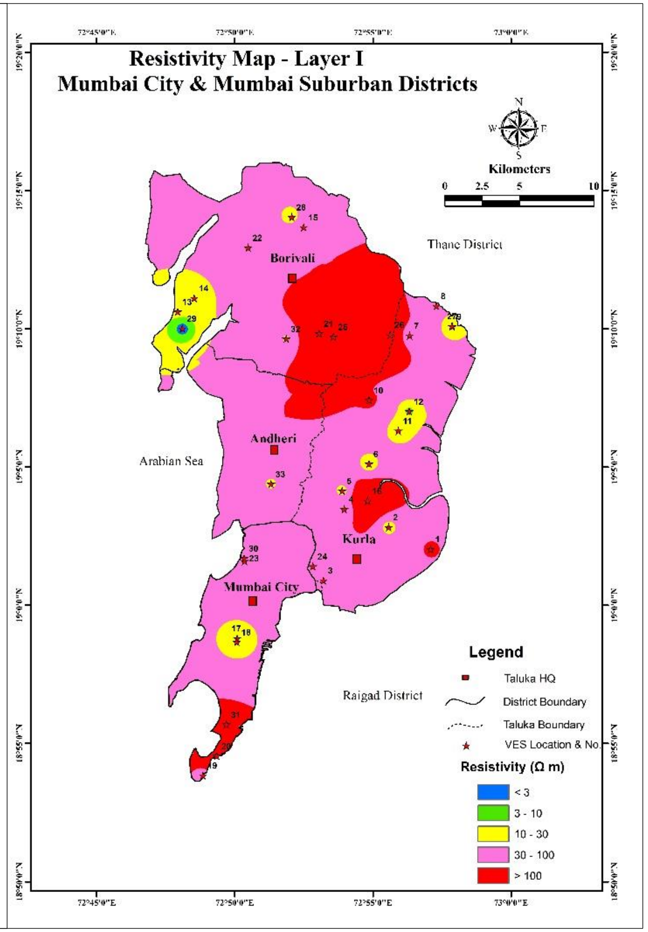
S.No.	District	Taluk	Annual Extractable Ground Water Resource (Ham)	Irrigation Use (Ham)	Industrial Use (Ham)	Domestic Use (Ham)	Total Extraction (Ham)	Annual GW Allocation for Domestic Use as on 2025 (Ham)	Net Ground Water Availability for future use (Ham)	Stage of Ground Water Extraction (%)	Categorization (OE/ Critical/ Semi-critical/ Safe)
1	Mumbai Sub	Kurla	3254.02	0	29.82	595.89	625.7	595.89	2628.32	19.23	safe
2	Mumbai Sub	Borivali	2582.74	0	29.16	595.89	625.05	595.89	1957.69	24.20	safe
3	Mumbai Sub	Andheri	1426.8	0	23.29	595.89	619.16	595.89	807.64	43.40	safe
	Mumbai Sub	**TOTAL**	**7263.56**	**0**	**82.27**	**1787.66**	**1869.91**	**1787.67**	**5393.65**	**25.74**	
4	Mumbai	Mumbai	1477.65	0	60.77	619.37	680.14	619.37	797.51	46.03	safe
	Mumbai	**TOTAL**	**1477.65**	**0**	**60.77**	**619.37**	**680.14**	**619.37**	**797.51**	**46.03**	

PLATES

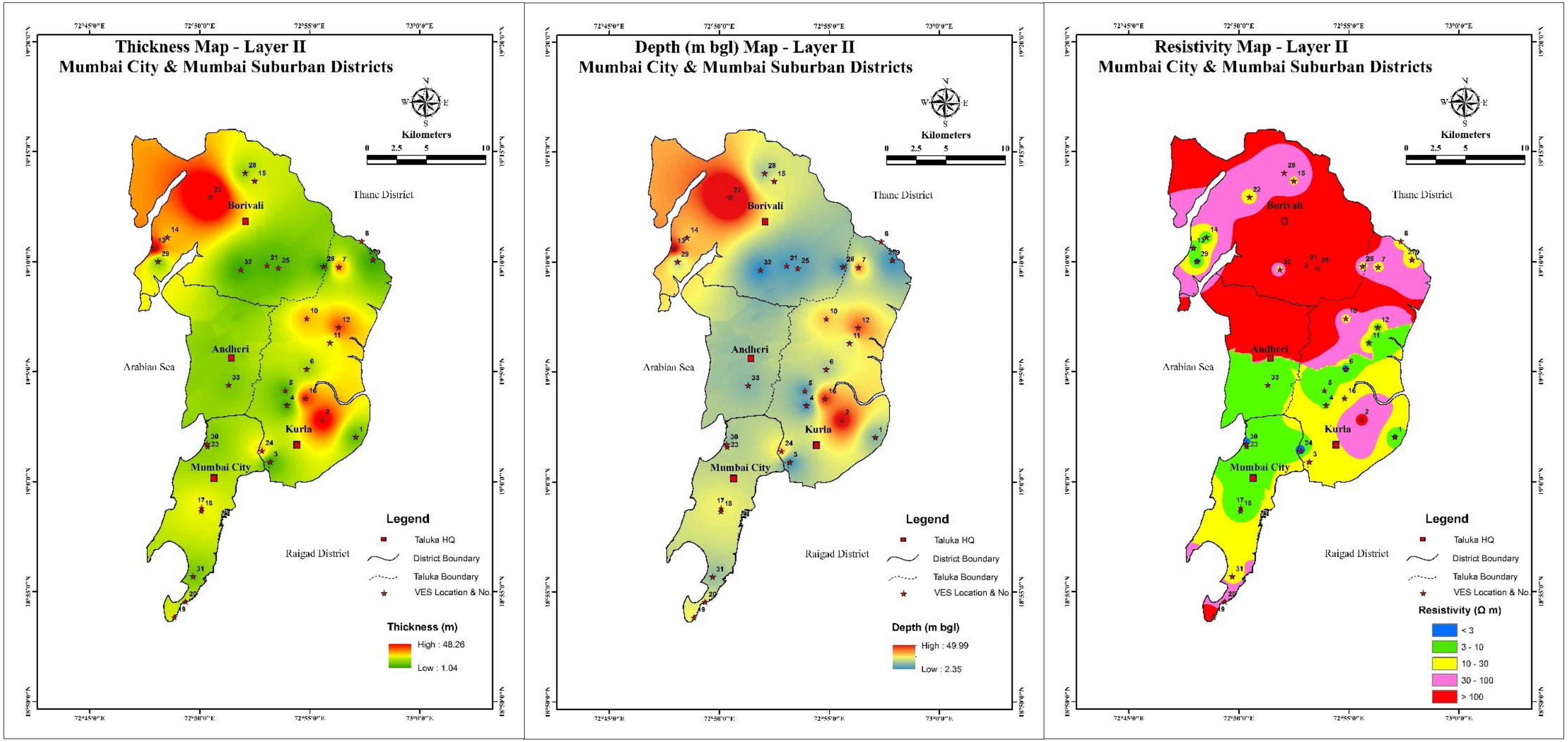
PLATES 1: MAPS SHOWING GEOELECTRICAL LAYERS GENERATED AFTER GEOPHYSICAL INVESTIGATION



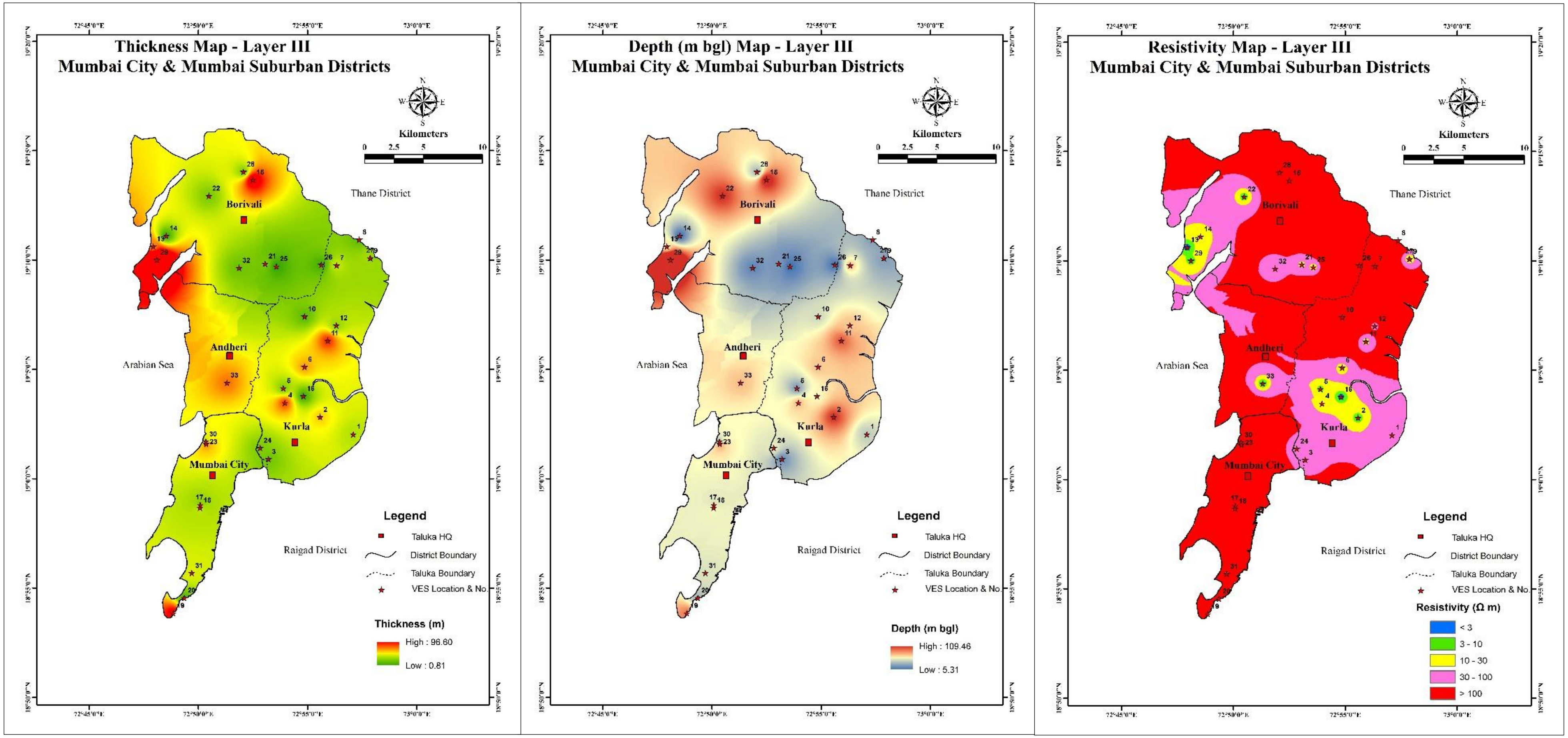




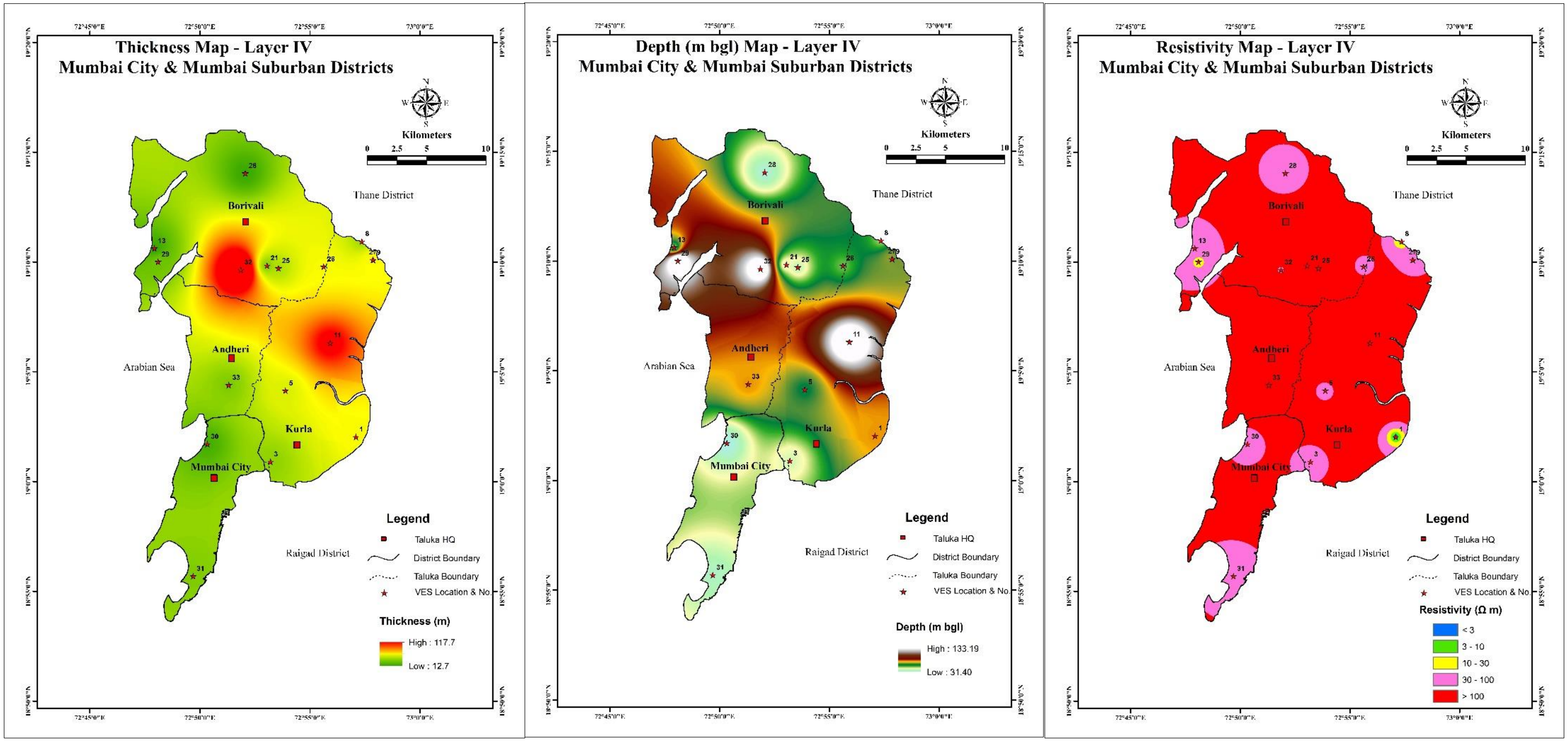
P-I: Geophysical Investigations –Geo-electrical Layer I: Top soil



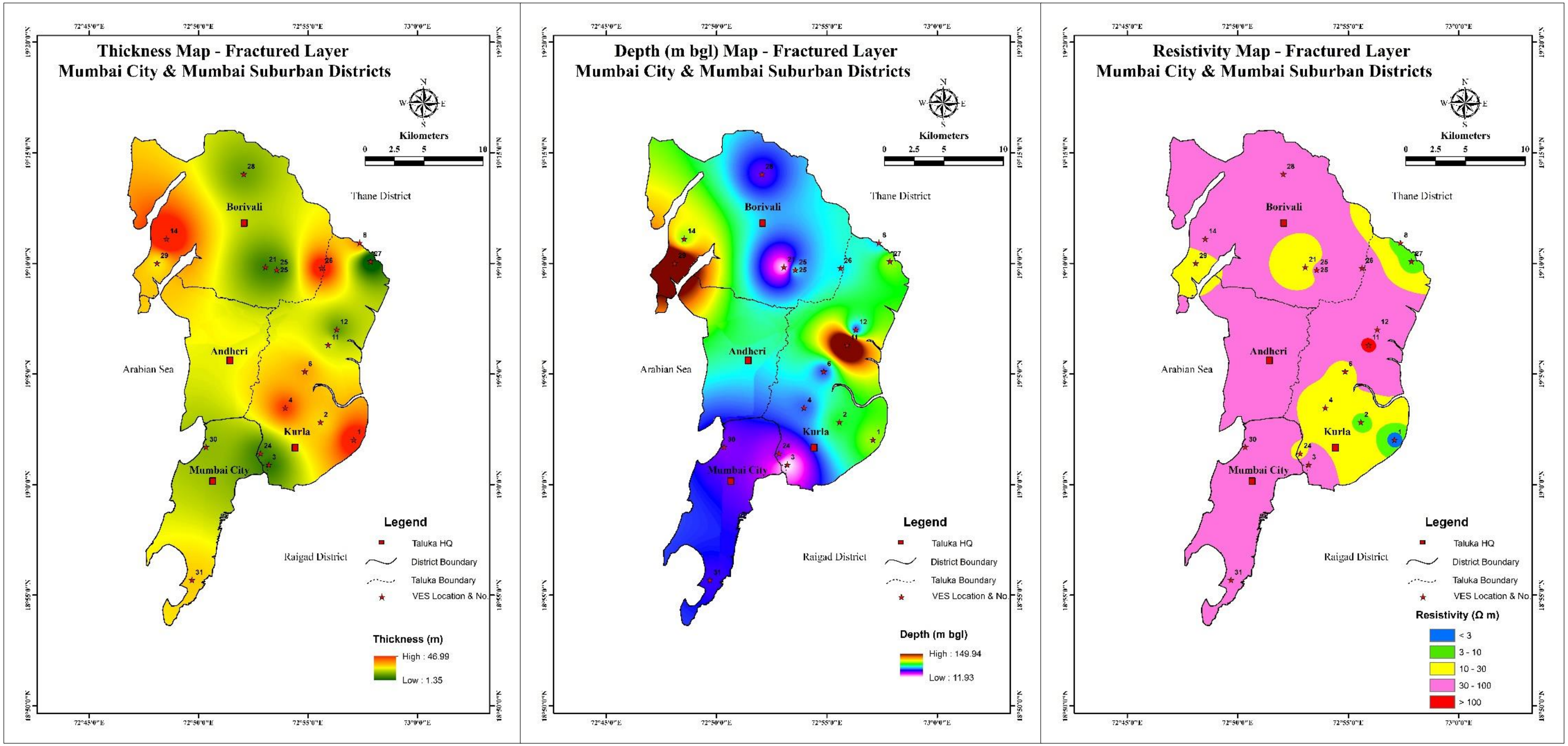
P-II: Geophysical Investigations –Geo-electrical Layer II: Weathered Formation



P-III: Geophysical Investigations –Geo-electrical Layer III: Fractured formation



P-IV: Geophysical Investigations –Geo-electrical Layer IV: Massive Formation



P-V: Geophysical Investigations Map: Fractured Layer

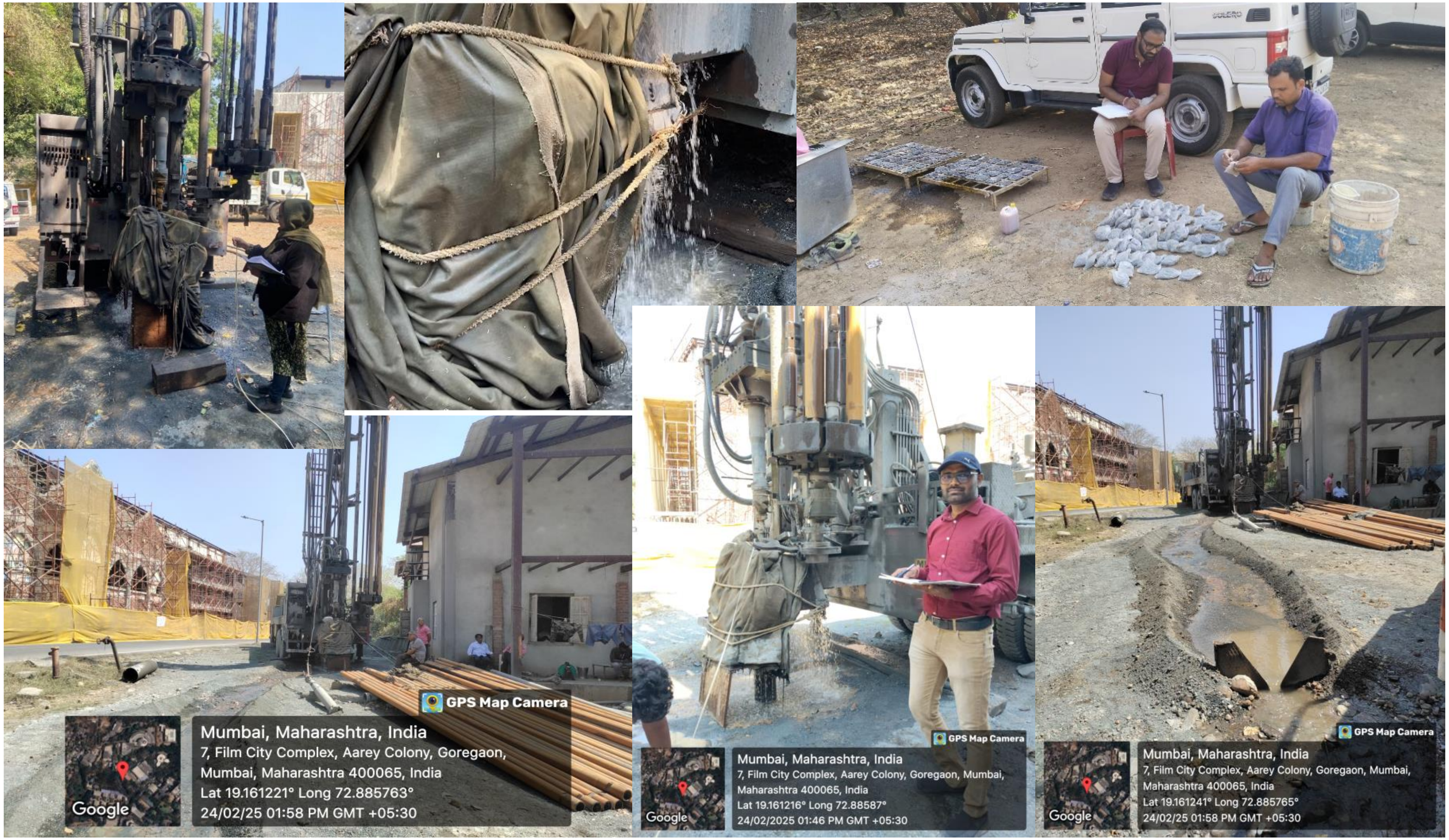


PLATE 2: PHOTOGRAPHS FROM FIELD:
GROUND WATER EXPLORATION

PLATE 3: PHOTOGRAPHS FROM FIELD:
SOIL INFILTRATION STUDIES

PLATE 4: MEETINGS WITH ADDITIONAL MUNICIPAL COMMISSIONER, BMC, MUMBAI

REFERENCES

1. Systematic Hydrogeological Survey for Greater Mumbai, Central Ground Water Board (CR,) Nagpur, 1989-90

2. Groundwater potential of greater Bombay Area, Central Ground Water Board, (CR,) Nagpur 1993

3. Reappraisal Hydrogeological Studies in Mumbai suburban area, Central Ground Water Board, (CR,) Nagpur, 1999-2000

4. District Groundwater Information Brochure, Mumbai district, Central Ground Water Board, (CR,) Nagpur 2013

5. Environment status Report, BMC, Mumbai (Brihanmumbai Municipal Corporation), 2020-21, 2023-2024

6. Drinking water specification (Second Revision) IS 10500:2012, Publication Unit, BIS, New Delhi, India (2015)

7. City Profile of Greater Mumbai, DRMMP, BMC, Mumbai (Brihanmumbai Municipal Corporation), 2011, G Arvind, P Ashok Kumar, S Girish Karthi and C R Suribabu

8. School of Civil Engineering, SASTRA University, Thanjavur – 613 401, India., IOP Conf. Series: Earth and Environmental Science 80 (2017) 012067 do i :10.1088/1755-1315/80/1/012067; Statistical Analysis of 30 Years Rainfall Data: A Case Study, (2017)

9. Indian Meteorological Department,110 years (1901-2010) Monthly Rainfall Data series for Districts, States and Met Sub-Divisions and All India, Ministry of Earth Science, Indian Meteorological Department, o/o Additional Director General of Meteorology (Research) Climate Application Group.

10. Evaluation of Vulnerability Zone of a Coastal Aquifer Through GALDIT GIS Index Techniques; Gnanachandrasamy Gopalakrishnan, Thirunavukkarasu Ramkumar, Venkatramanan Senapathi, Sivaprakasam Vasudevan; DOI:10.1016/B978-0-12-815413-7.00015-8; GIS and Geostatistical Techniques for Groundwater Science, Publisher: Elsevier

11. Sudha Rani Nalakurthi, N.V., Behera, M.R. & Bhaskaran, P.K. Land subsidence detection using sentinel-1 interferometer and its relation with environmental drivers: a case study for coastal Mumbai city. *Spat. Inf. Res.* 32, 665–681 (2024). https://doi.org/10.1007/s41324-024-00588-8

Central Ground Water Board
Bhujal Bhawan, NH-IV,
Faridabad - 121001
Website : www.cgwb.gov.in
Email : tsmpolicy-cgwb@gov.in