

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

Annual Ground Water Quality Report

2025



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सी आर पाटील
C R Paatil



जल शक्ति मंत्री
भारत सरकार
Minister of Jal Shakti
Government of India

MESSAGE

It gives me great pleasure to present the **Annual National Ground Water Quality Report – 2025**, prepared by the Central Ground Water Board (CGWB) under the Ministry of Jal Shakti. Groundwater is the silent strength of our nation, supporting agriculture, industry and the drinking water needs of millions. Protecting its quality is not only a challenge, but also an opportunity to drive innovation, resilience and inclusive growth on our path towards a water-secure and *Viksit* Bharat.

This year's report reflects a stronger, more modern scientific framework for groundwater quality monitoring. It brings together standardized protocols, digital data systems and advanced analysis to provide clearer insights into spatial and temporal trends, emerging hotspots and encouraging improvements resulting from recharge, source protection and better demand management.

The findings point to the significant progress already made and the vast potential ahead. They call for integrated, technology-enabled action—bringing together Central and State agencies, local bodies, researchers, start-ups and communities. From smart monitoring and data-driven planning to nature-based solutions and citizen-led "Jan Bhagidari", our collective efforts can transform groundwater management into a driver of health, productivity and climate resilience.

I commend the Central Ground Water Board for its scientific rigor, use of innovative tools and collaborative approach in bringing out this publication. I am confident that the **Annual National Ground Water Quality Report – 2025** will serve as a forward-looking reference for policymakers, planners and researchers, and will inspire new initiatives for the sustainable and innovative use of our precious groundwater resources.

C R PAATIL



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वी. सोमण्णा
V. Somanna



रेल एवं जल शक्ति राज्य मंत्री
भारत सरकार
Minister of State of
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Government of India

MESSAGE

It gives me great satisfaction to note that the Central Ground Water Board (CGWB), under the Ministry of Jal Shakti, has brought out the **Annual Ground Water Quality Report – 2025**. Ground water forms the backbone of our nation's socio-economic growth, fulfilling the needs of agriculture, industry, and households alike. Over the years, the focus has progressively shifted from merely enhancing ground water availability to ensuring its purity, safety, and sustainable use.

The report presents an insightful overview of the present condition of ground water quality across the country, with particular emphasis on key geogenic contaminants such as arsenic, fluoride, salinity, iron, and uranium. It also highlights notable initiatives, innovative techniques, and remedial measures being adopted to mitigate contamination and protect this vital resource.

I appreciate the dedicated and tireless efforts of the officers and scientists of the Central Ground Water Board for compiling extensive data and preparing this comprehensive document. I am confident that this report will serve as an important reference for policymakers, planners, researchers, and practitioners working towards the goal of sustainable and clean ground water management in India.

It is hoped that this report will enhance the national knowledge base on ground water quality and serve as a useful resource for policymakers, researchers, and implementing agencies engaged in the sustainable management of ground water resources.


(V. Somanna)

डॉ. राज भूषण चौधरी
Dr. Raj Bhushan Choudhary



जल शक्ति राज्य मंत्री
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MESSAGE

It is with great satisfaction that I present the **Annual Ground Water Quality Report – 2025**, prepared by the Central Ground Water Board (CGWB) under the Ministry of Jal Shakti. This report is an important contribution towards strengthening the understanding, monitoring, and management of India's groundwater quality. It reflects the Government's sustained commitment to ensuring the long-term sustainability and safety of this vital resource.

The report provides an in-depth analysis of groundwater quality trends, identifying key areas of concern such as contamination from fluoride, nitrate, arsenic, salinity and evaluates water suitability for various uses. The insights derived from this report will assist policymakers and field practitioners in formulating targeted interventions for pollution mitigation, recharge enhancement, and sustainable extraction management.

I commend the Central Ground Water Board for their scientific excellence and dedicated work in bringing out this comprehensive report. I am confident that it will serve as a valuable reference for informed decision-making and strategic planning, helping guide our collective endeavour towards sustainable groundwater management and water security for the nation.

(Raj Bhushan Choudhary)

व्ही. एल. कान्ता राव, भा.प्र.से.
सचिव
V. L. KANTHA RAO, IAS
Secretary



भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास
और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION



MESSAGE

Groundwater is a vital component of the nation's water resources and underpins domestic, agricultural and industrial water security. However, unregulated and excessive extraction has led to declining water levels, drying wells and deterioration in quality, with direct implications for drinking, irrigation and other critical uses.

Groundwater chemistry is governed by rock-water interactions and modified by human activities. Given India's diverse geological and climatic settings, aquifer systems exhibit significant variation in chemical composition. In several parts of the country, contamination by naturally occurring constituents and pollutants from industrial effluents, domestic sewage, waste disposal and mining has rendered groundwater locally unfit for use as per BIS specifications.

The report reflects the Ministry's commitment to scientific monitoring and evidence-based management of groundwater quality. I am confident it will serve as a valuable resource for administrators, planners, researchers and other stakeholders in framing policies and strategies for sustainable development and protection of this critical resource.

12 November, 2025
New Delhi

(V. L. Kantha Rao)



सुबोध यादव
अपर सचिव, एवं
अध्यक्ष, सी. जी. डब्ल्यू. बी.
Subodh Yadav
Additional Secretary, &
Chairman, C.G.W.B.

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास
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GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION



MESSAGE

Groundwater is a strategic national resource that underpins India's drinking water security, irrigation, livelihoods and ecosystem health. Once considered inherently safe and reliably available, it is now under growing pressure from intensive abstraction, changing land use, urban expansion and industrialisation. In several areas, naturally occurring contaminants such as arsenic, fluoride and uranium, together with pollution from agriculture, waste disposal and urban and industrial effluents, pose significant risks to human health and the long-term sustainability of our freshwater systems.

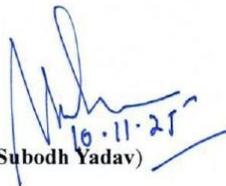
The **Annual National Ground Water Quality Report – 2025**, provides a scientifically robust assessment of groundwater quality across diverse aquifer systems in the country. Drawing on CGWB's Standard Operating Procedure for groundwater quality assessment, the report offers an evidence base for planners, policymakers, regulators, researchers and service providers to identify hotspots, design mitigation measures and integrate groundwater quality into sectoral programmes, including drinking water supply, irrigation, urban development and public health.

At the national scale, groundwater remains largely suitable for irrigation and domestic use. However, the report clearly delineates regions with localised quality concerns, where source protection, treatment solutions, safe alternative supplies and demand-side management must be prioritised. Seasonal variations in parameters such as Electrical Conductivity and fluoride underline the influence of recharge processes and the need for aquifer-level, climate-sensitive management.

The Report reflects the scientific rigor and institutional commitment of the Central Ground Water Board. I extend my sincere appreciation to all officers and scientists involved in this comprehensive assessment. I am confident that this report will serve as a key reference for policymakers, researchers, and stakeholders, supporting informed decision-making for the protection and sustainable use of groundwater resources across the nation.

November, 2025

New Delhi


10.11.25
(Subodh Yadav)



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पी.के.त्रिपाठी
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भारत सरकार
जल शक्ति मंत्रालय
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केंद्रीय भू-जल बोर्ड

Government of India
Ministry of Jal Shakti
Department of Water Resources, River
Development and Ganga Rejuvenation
Central Ground Water Board

प्रस्तावना

भूजल एक आवश्यक संसाधन है जो पेयजल आपूर्ति, कृषि, उद्योग तथा पारिस्थितिक तंत्रों को बनाए रखने में महत्वपूर्ण भूमिका निभाता है। किंतु इसकी गुणवत्ता विभिन्न भू-जनित (geogenic) तथा मानव-जनित (anthropogenic) कारकों के कारण लगातार जोखिम में है। दैनिक जीवन, कृषि तथा उद्योग में रसायनों के बढ़ते उपयोग के साथ भूजल गुणवत्ता की निगरानी और भी जटिल एवं महत्वपूर्ण हो गई है। इस प्रयास में अधिक एकरूपता और वैज्ञानिक दृढ़ता सुनिश्चित करने हेतु केंद्रीय भूजल बोर्ड ने वर्ष 2024 में पूरे देश में एकसमान सैंपलिंग, विश्लेषण और रिपोर्टिंग के लिए मानक संचालन प्रक्रिया (SOP) लागू की।

“भारत के अल्पगर्भीय जलभृतों में भूजल गुणवत्ता, 2024” पर आधारित यह रिपोर्ट विभिन्न क्षेत्रों में भूजल गुणवत्ता की स्थिति का व्यापक आकलन प्रस्तुत करती है। इस रिपोर्ट के निष्कर्ष वैज्ञानिकों, योजनाकारों, कार्यान्वयन एजेंसियों तथा अन्य हितधारकों के लिए इस मूल्यवान संसाधन के सतत प्रबंधन हेतु रणनीतियाँ विकसित करने में अत्यंत सहायक सिद्ध होंगे।

मैं इस महत्वपूर्ण प्रकाशन को तैयार करने में आँकड़ों के संकलन एवं विश्लेषण हेतु केंद्रीय भूमि जल बोर्ड के अधिकारियों और कर्मचारियों के प्रयासों की सराहना करता हूँ।


(पी. के. त्रिपाठी)
सदस्य (नीति एवं समन्वय)

फरीदाबाद
नवंबर, 2025

कार्यकारी सारांश

यह रिपोर्ट, भारत में 2023 में केंद्रीय भूमि जल बोर्ड (CGWB) द्वारा लागू की गई मानक संचालन प्रक्रिया (SOP) के तहत विकसित एक मानकीकृत कार्यप्रणाली पर आधारित राष्ट्रव्यापी भूजल गुणवत्ता निगरानी अभ्यास के निष्कर्ष प्रस्तुत करती है। इस एकरूप दृष्टिकोण का उद्देश्य भूजल गुणवत्ता के लिए एक व्यापक आधाररेखा स्थापित करना है। आधाररेखा एवं प्रवृत्ति मूल्यांकन के अतिरिक्त, CGWB राज्यों एवं संबंधित एजेंसियों को **पाक्षिक आधार पर जल गुणवत्ता अलर्ट** जारी करता है। ये अलर्ट, BIS (IS 10500:2012) सीमा से अधिक पाए गए मानकों पर समय रहते सूचना प्रदान करते हैं, जिससे त्वरित कार्रवाई, जनस्वास्थ्य संरक्षण तथा उभरते प्रदूषण हॉटस्पॉट्स के प्रबंधन में सहायता मिलती है।

❖ आधाररेखा एवं प्रवृत्ति निगरानी

वर्ष 2023 में कुल **15,259 भूजल नमूने** एकत्र किए गए, जिन्हें SOP दिशानिर्देशों के अनुसार आधाररेखा आँकड़ा स्थापित करने हेतु आधार वर्ष के रूप में लिया गया। ये 15,259 स्थान " पृष्ठभूमि जल-गुणवत्ता केंद्र " हैं, जो भविष्य के मूल्यांकनों का आधार प्रदान करते हैं। भूजल गुणवत्ता के रुझानों का अध्ययन करने के लिए, इन केंद्र के 25% हिस्से को, जो BIS 10500 मानकों के आधार पर संदूषण के प्रति संवेदनशील पाए गए, प्रवृत्ति निगरानी केंद्र के रूप में चयनित किया गया। वर्ष 2024 में, इन 5,368 ट्रेड स्टेशनों से प्री पूर्व-मानसून व पश्च-मानसून दोनों ऋतुओं में नमूने एकत्र किए गए, ताकि मौसमी पुनर्भरण के प्रभावों का आकलन किया जा सके। नमूना संग्रहण और विश्लेषण APHA (2012) मानक विधियों के अनुसार किया गया।

❖ प्रमुख निष्कर्ष एवं जल गुणवत्ता मानक:

इस रिपोर्ट का उद्देश्य पेय-उपयोग जल एवं कृषि उद्देश्यों हेतु उपयोग किए जाने वाले भूजल में अकार्बनिक जल-गुणवत्ता मापदंडों का व्यापक विश्लेषण प्रस्तुत करना है। इन मापदंडों में भौतिक-रासायनिक मानक (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , TH, CO_3^{2-} , HCO_3^- , Cl^- , SO_4^{2-} , F^- , PO_4^{3-} , NO_3^-) तथा सूक्ष्म तत्त्व (As, Fe, Mn, Zn, Cu, Pb एवं U) सम्मिलित हैं। स्थानिक संगति सुनिश्चित करने हेतु, 2023 और 2024 के बीच समान केंद्र की पहचान कर उन्हें प्रतिस्थापित किया गया। इस प्रक्रिया से वर्ष 2024 हेतु **14,978 आधाररेखा केंद्र** प्राप्त हुए, जो राष्ट्रीय स्तर पर भूजल गुणवत्ता का प्रतिनिधि परिदृश्य प्रस्तुत करते हैं।

❖ क्षेत्रीय भिन्नताएँ एवं ऋतुजन्य रुझान

भारत में भूजल गुणवत्ता में अत्यधिक क्षेत्रीय विविधता पाई जाती है। अरुणाचल प्रदेश, मिजोरम, मेघालय और जम्मू-कश्मीर में 100% नमूने BIS मानकों के अनुरूप पाए गए। इसके विपरीत, राजस्थान, हरियाणा और आंध्र प्रदेश के चयनित क्षेत्रों में अपेक्षाकृत उच्च संदूषण स्तरों का संकेत मिला

मानसून के बाद EC और फ्लोराइड मानों में हल्की कमी दर्ज की गई, जो संकेत करती है कि मानसूनी पुनर्भरण लवणों के पतलापन का कारण बनता है।

❖ जल-रासायनिक रूप-प्रकार (Hydrochemical Facies) एवं लवणीकरण:

राष्ट्रीय स्तर पर भूजल का जल-रासायनिक विश्लेषण दर्शाता है कि कैल्शियम-बाइकार्बोनेट (Ca-HCO₃) जल-प्रकार देश में सर्वाधिक प्रबल है। राजस्थान और गुजरात में प्राकृतिक प्रक्रियाओं के कारण Na-Cl प्रकार तथा उच्च क्लोराइड सांद्रता देखी जाती है। समय के साथ aquifers में गीलापन एवं सूखे के चक्रों से जल-घुलनशील लवणों का संचयन हुआ है, जो पुनर्भरण के दौरान पुनः घुलकर जल में लवणीयता बढ़ाते हैं।

❖ प्रमुख प्रदूषक

- **नाइट्रेट:** 20.7% नमूनों में BIS सीमा (>45 mg/L) से अधिक; प्रमुख कारण—कृषि उर्वरक एवं अपशिष्ट प्रबंधन की कमी।
- **फ्लोराइड:** 8.05% नमूनों में 1.5 mg/L से अधिक; मुख्यतः जियोनिक (भू-जनित) स्रोतों से।
- **EC:** 7.23% नमूनों में BIS सीमा से अधिक; विशेष रूप से शुष्क क्षेत्रों—राजस्थान, दिल्ली, हरियाणा, गुजरात में।
- **आर्सेनिक:** गंगा-ब्रह्मपुत्र बेसिन में केंद्रित भू-जनित समस्या।
- **यूरेनियम:** राजस्थान, पंजाब, हरियाणा, आंध्र प्रदेश और तेलंगाना के कुछ क्षेत्रों में अपेक्षाकृत उच्च स्तर परिलक्षित हुए।
- **मैंगनीज एवं आयरन:** कई राज्यों में इन मानकों की सांद्रता कुछ स्थानों पर अपेक्षाकृत अधिक देखी गई।

❖ मानसून पुनर्भरण का प्रभाव:

मानसून पुनर्भरण के प्रभाव विविध प्रकार के रहे। अनेक स्थलों पर जल गुणवत्ता मानकों में उल्लेखनीय सुधार (जैसे EC एवं फ्लोराइड का विलयन) देखा गया, जबकि अन्य स्थलों पर मानकों में गिरावट (सांद्रता में वृद्धि) परिलक्षित हुई। यह दर्शाता है कि भू-जल रसायन पर स्थल-विशिष्ट कारकों—जैसे जलभृत प्रकार और स्थानीय संदूषण भार—का अत्यधिक प्रभाव होता है।

❖ सिंचाई उपयुक्तता विश्लेषण:

SAR और RSC के विश्लेषण से पता चलता है कि अधिकांश भूजल सिंचाई हेतु उपयुक्त है। 94.30% नमूने SAR < 10 की श्रेणी में पाए गए, जो "उत्कृष्ट श्रेणी" को दर्शाता है तथा मृदा या फसल पर क्षारीयता के प्रभाव की संभावना न्यूनतम है।

❖ केंद्र बिंदु स्थल (Hot Spot stations) मॉनिटरिंग एवं संदूषण प्रसार विश्लेषण:

- CGWB ने बेसलाइन मॉनिटरिंग में BIS सीमा से अधिक पाए गए स्थानों के आसपास विस्तृत हॉटस्पॉट मॉनिटरिंग की।
- कुल 340 हॉटस्पॉट पहचाने गए तथा 1,540 नमूने इनके आसपास एकत्र किए गए।
- प्रत्येक हॉटस्पॉट के चारों ओर 2 km × 2 km ग्रिड पर नमूना संग्रह किया गया।
- केंद्र बिंदु HS (हॉटस्पॉट) उस स्थान का प्रतिनिधित्व करता है जहाँ प्रदूषक की सांद्रता BIS सीमा से अधिक पाई गई थी।
- इस ग्रिड से निम्न आकलन संभव हुआ:
- **स्थानीय प्रसार (Localized spread):** जहाँ प्रदूषण हॉटस्पॉट के आसपास सीमित रहता है।
- **बहुदिशीय प्रसार (Multi-directional spread):** जहाँ प्रदूषण एक या अधिक दिशाओं में फैलता है।

हॉटस्पॉट विश्लेषण आर्सेनिक, EC, फ्लोराइड, नाइट्रेट, मैंगनीज और यूरेनियम पर केंद्रित था, जिससे संदूषण के प्रसार की दिशा एवं सीमा का स्पष्ट आकलन हुआ।

❖ भूजल गुणवत्ता अलर्ट (जून 2024 – मार्च 2025):

- CGWB राज्यों एवं संबंधित एजेंसियों को पाक्षिक जल गुणवत्ता अलर्ट जारी करता है। ये अलर्ट EC, नाइट्रेट, फ्लोराइड, कुल कठोरता, क्रोमियम, मैंगनीज, आयरन, निकेल, कोबाल्ट, जिंक, आर्सेनिक, सेलेनियम, कैडमियम, लेड जैसे मानकों पर आधारित हैं।
- जून 2024 से मार्च 2025 के बीच संकलित अलर्टों में EC, नाइट्रेट, फ्लोराइड, कुल कठोरता, क्रोमियम, मैंगनीज, आयरन, निकेल, कोबाल्ट, जिंक, आर्सेनिक, सेलेनियम, कैडमियम, सीसा तथा यूरेनियम जैसे मानकों में पाए गए अतिक्रमण को इंगित किया गया है।
- इस अवधि के दौरान विभिन्न राज्यों में अतिक्रमण के मामले दर्ज किए गए, जिनमें आंध्र प्रदेश, गुजरात, मध्य प्रदेश, महाराष्ट्र, राजस्थान, पंजाब, कर्नाटक, हरियाणा तथा उत्तर प्रदेश के कुछ क्षेत्रों में लवणता, नाइट्रेट तथा भारी धातुओं से संबंधित मानकों में अपेक्षाकृत अधिक अतिक्रमण परिलक्षित हुए।
- पूर्वी एवं उत्तर-पूर्वी राज्यों में आयरन, मैंगनीज और आर्सेनिक के स्थानिक अतिक्रमण पाए गए।
- ये अलर्ट समय रहते चेतावनी प्रणाली के रूप में कार्य करते हैं और राज्यों को अनुवर्ती नमूना संग्रह, चेतावनी जारी करने एवं स्थानीय शमन उपाय लागू करने हेतु मार्गदर्शन प्रदान करते हैं।
- ये अलर्ट केंद्र सरकार के विभागों — ICAR, DDWS, CPCB, MOHUA, GSI— तथा राज्यों/केंद्रशासित प्रदेशों के संबंधित विभागों को साझा किए जाते हैं।

Executive Summary

This report presents the findings from the nationwide groundwater quality monitoring exercise based on a standardized methodology established under the Standard Operating Procedure (SOP) implemented across India in 2023 by the Central Ground Water Board (CGWB). This uniform approach aims to establish a comprehensive baseline for groundwater quality, enabling targeted interventions to address emerging concerns. In addition to baseline and trend assessments, CGWB also issues **fortnightly Water Quality Alerts** to State Governments and concerned agencies. These alerts, generated from periodic data analysis, provide early warning on parameters exceeding BIS (IS 10500:2012) limits, facilitating timely action, public health protection, and focused management of emerging contamination hotspots

❖ **Baseline and Trend Monitoring:** A total of 15,259 groundwater samples were collected during 2023 taking it as the base year to assess groundwater quality to establish the baseline data as per the SOP guidelines. These 15,259 stations are the *Background Stations* to form the foundation for future evaluations, offering a clear baseline for ongoing monitoring efforts. To examine the trends of groundwater quality, 25% of these stations, identified as *Trend Stations* which are vulnerable to contamination based on BIS 10500 standards. In 2024 groundwater quality samples were collected from the 5,368 identified trend stations during pre-monsoon and post-monsoon seasons to assess the impact of seasonal recharge on groundwater quality. Standard procedures as given in APHA, 2012 (Standard Methods for the Examination of Water & Waste Water American Public Health Association) were used for the sample collection and analysis of water sample.

❖ **Key Findings and Water Quality Parameters:** Objective of this report is to look into wide spectrum of inorganic water quality parameters in groundwater used for drinking and agriculture purpose. These parameters consist of physico-chemical parameters (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , TH, CO_3^{2-} , HCO^- , Cl^- , SO_4^{2-} , F^- , PO_4^{3-} and NO_3^-) and trace elements (As, Fe, Mn, Zn, Cu and Pb).

To ensure spatial consistency, common stations between 2023 and 2024 were identified and replaced for depicting the national quality scenario. This process resulted in 14,978 baseline stations for 2024, providing a comprehensive and representative coverage of groundwater quality across India.

Significant concerns have emerged from the analysis, particularly the high concentrations of nitrate, fluoride, and EC in groundwater. Almost 20.7% of the samples exceeded the permissible limit for nitrate, while 8.05% of samples had fluoride levels above the limit. EC contamination was found in 7.23 % of samples.

❖ **Regional Variability and Seasonal Trends:** Groundwater quality varies considerably across India. In certain states such as Arunachal Pradesh, Mizoram, Meghalaya and Jammu and Kashmir, 100% of the water samples met the BIS standards.

In contrast, states like Rajasthan, Haryana, and Andhra Pradesh faced widespread contamination. Interestingly, the monsoon season showed some improvement in water quality, particularly in areas affected by high electrical conductivity (EC) and Fluoride. Post-monsoon, a modest reduction in EC levels and Fluoride was observed in some regions, indicating that monsoon recharge can temporarily improve water quality by diluting salts.

❖ **Hydrochemical Facies and Salinization:** At the national scale, the hydro chemical characterization of groundwater in India reveals a distinct dominance of the Calcium–Bicarbonate (Ca-HCO_3) facies, which constitutes the primary water type across large parts of the country. States like Rajasthan and Gujarat face high chloride concentrations due to the natural hydrochemical processes at play and Na-Cl type formations are prevalent. Over long periods, the aquifers have undergone repeated cycles of wetting and drying. During these cycles, highly soluble Na- Cl salts become concentrated in the aquifers. When groundwater levels drop, these salts become encrusted in the alluvium bed. Upon precipitation or recharge during the monsoon, these encrusted salts re-dissolve into the groundwater, enriching the chloride concentration and contributing to the increasing salinity levels.

❖ **Major Contaminant Exceedances:**

- **Nitrate:** This contaminant demonstrated the highest frequency of exceedance, with concentrations surpassing the permissible limit (45 mg/L) in approximately **20.7 %** of the total samples. This is primarily attributed to anthropogenic sources, notably agricultural practices and improper waste disposal.
- **Fluoride:** Elevated fluoride concentrations (exceeding 1.5 mg/L) were observed in about **8.05 %** of samples. This contamination is predominantly geogenic (naturally occurring), associated with water-rock interaction in crystalline and hard rock aquifers, such as granite and gneissic formations.
- **Electrical Conductivity (EC):** EC, an indicator of total dissolved solids/salinity, exceeded permissible limits (e.g., 3000 $\mu\text{S/cm}$) in **7.23 %** of samples. Salinity concerns are particularly acute in arid and semi-arid regions of North-West India, with states like Rajasthan, Delhi, Haryana, and Gujarat showing a higher proportion of non-compliant samples.

❖ **Trace Metal and Geogenic Contaminations:**

- **Arsenic (As):** Contamination remains a major geogenic concern, specifically concentrated within the Ganga and Brahmaputra River basin.
- **Uranium (U):** Elevated uranium concentrations (exceeding 30 ppb) were detected sporadically in states including Rajasthan, Punjab, Haryana, Andhra Pradesh, and Telangana.

- **Manganese (Mn):** Persistent exceedance of Manganese was reported across multiple states (e.g., Assam, Karnataka, Odisha, Uttar Pradesh, and West Bengal).
- **Copper (Cu):** Copper levels were consistently found to be within the permissible limit (1.5 mg/L) nationwide.
- ❖ **Seasonal and Irrigation Suitability Trends:** This report presents a comprehensive assessment of groundwater quality in India, the seasonal variability and for Irrigation suitability. This report evaluates Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) values, which are key indicators of water suitability for irrigation.
- **Monsoon Recharge Impact:** The effects of monsoon recharge were heterogeneous. While many locations showed significant improvement in water quality parameters (e.g., dilution of EC and Fluoride), a comparable number of locations exhibited deterioration (increase in concentration), emphasizing that site-specific factors like aquifer type and local contamination load strongly govern groundwater chemistry.
- **Irrigation Suitability:** The groundwater quality is largely suitable for irrigation purposes. The majority of samples, 94.30%, fall into the "excellent category" based on the Sodium Adsorption Ratio (SAR < 10), indicating a low alkali hazard for soil and crop health.

According to SAR classification, Nationally, 98.9% of the samples recorded SAR \leq 26, indicating that most groundwater sources are safe for irrigation use. Only 1.11% of the samples exceeded the permissible limit (SAR > 26), suggesting limited risk of sodicity hazards at the national scale. The highest SAR values were observed in Bihar (up to 505), Delhi (up to 179.8), and Rajasthan (up to 72.6), indicating localized areas with potentially high sodium hazard. Delhi (34.8%) and Rajasthan (12%) showed the maximum proportion of samples exceeding the limit, followed by Bihar (1.4%).

Nationwide, 11.27% samples exceeded the permissible limit of RSC i.e. 2.5 meq/L, indicating potential sodicity hazards in some regions. High incidences of RSC beyond permissible limits were recorded in Delhi (51.11%), Uttarakhand (41.94%), Andhra Pradesh (26.87%), Punjab (24.60%), and Rajasthan (24.42%), signifying concern in these states. Moderate exceedances were observed in Haryana (15.54%), Karnataka (13.32%), Uttar Pradesh (13.65%), and Telangana (11.76%). In the remaining states RSC values greater than 2.5, making them unsuitable for irrigation due to the risk of sodicity and soil degradation.

❖ **Recommended Mitigation Measures:**

To ensure safe drinking water and mitigate groundwater contamination by various pollutants, a combination of preventive, treatment, and management strategies is essential.

- In **fluoride-affected regions**, water quality can be safeguarded through proper **source selection, blending of high- and low-fluoride waters**, installation of **community-based treatment plants** and **public awareness** initiatives.
- For **nitrate** contamination, emphasis is placed on efficient fertilizer management, including regular soil testing, appropriate timing of fertilizer application and use of organic fertilizers. Additional measures include maintenance of septic systems and proper management of animal wastes to prevent nitrogen leaching into groundwater.
- **Arsenic** mitigation involves both short- and long-term measures. Short-term strategies include the installation of household and community treatment units, prohibition of contaminated wells, and conjunctive use of surface and groundwater. Long-term actions focus on developing alternate safe aquifers, rainwater harvesting and deepwell construction using sealing techniques.
- In the case of **uranium** contamination, multiple treatment technologies are available, including adsorption, coagulation, extraction, reverse osmosis and evaporation. Selection of the appropriate method depends on cost, efficiency and local conditions, with combined or need-based approaches recommended for best results.
- For **iron and manganese**, remedial options include aeration, filtration, use of iron or manganese removal plants and chemical oxidation. Reverse osmosis and specialized media filters are suitable for smaller-scale or household applications.
- To address **lead** contamination, the key measures include installation of filtration systems (activated carbon, RO, or ion exchange), strict regulation of industrial effluents, lead testing in public buildings, hydrogeochemical mapping and public advisories on safe water use practices.

Overall, the integrated implementation of **source protection, treatment technologies, regulatory enforcement, and community participation** is crucial to ensuring safe and sustainable groundwater quality across affected regions.

❖ Hotspot Monitoring and Contaminant Spread Analysis

- To strengthen national surveillance of groundwater contamination, CGWB undertook detailed hotspot monitoring around locations that exceeded BIS limits during baseline monitoring. A total of 340 hotspot locations were identified, and 1,540 groundwater samples were collected around these sites.
- A 2 km × 2 km grid-based sampling design was adopted around each hotspot. The central point marked as HS (Hotspot) represented the exceedance location, with surrounding samples collected at grid nodes to evaluate:
 - Localized spread: where contamination is confined near the hotspot
 - Multi-directional spread: where contaminants migrate outward along one or more directions
- The hotspot assessment covered Arsenic, EC, Fluoride, Nitrate, Manganese, and Uranium. Results show clear spatial variability in the extent of contaminant movement. The hotspot classification (e.g., localized vs. multidirectional spread)

provides actionable insights for targeted remediation, localized source protection, and aquifer-specific management strategies.

❖ Groundwater Quality Alerts (June 2024 – March 2025)

- CGWB issues fortnightly Groundwater Quality Alerts to States and concerned agencies to facilitate early action, public health protection, and rapid response to contamination events. Alerts are generated when key water quality parameters exceed BIS limits.
- The alerts compiled during June 2024–March 2025 highlight exceedances for parameters such as EC, Nitrate, Fluoride, Total Hardness, Chromium, Manganese, Iron, Nickel, Cobalt, Zinc, Arsenic, Selenium, Cadmium, Lead, and Uranium across multiple states.
- Exceedances were recorded during this period, with notable concerns in:

Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Punjab, Karnataka, Haryana, and Uttar Pradesh, showing high occurrences of salinity, nitrate, and heavy metal exceedances.

- Eastern and north-eastern states showing isolated but occurrences of iron, manganese, and arsenic
- These alerts serve as a real-time early warning mechanism, guiding states to undertake follow-up sampling, issue advisories, and implement localized mitigation measures.
- Groundwater quality alerts are shared fortnightly with central govt. departments e.g. ICAR, DDWS, CPCB, MOHUA, GSI along with concerned departments of state/UTs.

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<https://cgwb.gov.in/cgwbpm/public/uploads/documents/176302296020936587file.pdf>

1.0 Introduction

Groundwater is a vital natural resource that supports a wide range of needs, including drinking water supply, irrigation, and industrial activities. In India, it plays an especially critical role in sustaining rural and semi-urban populations, where dependence on this invisible resource is substantial and often singular.

The quality of groundwater is influenced by several interrelated factors, including the composition of the water that infiltrates the subsurface, its interaction with geological formations, and the impact of human activities both at the surface and below ground. Consequently, the key factors that govern groundwater contamination include the natural characteristics and chemical reactivity of subsurface strata (geogenic sources) as well as pollutants originating from land use practices and anthropogenic activities. As a result, similar to surface water, groundwater quality at any given location may be affected by a combination of multiple contamination sources and challenges (Figure 1).

According to multiple global assessments, including the UNESCO World Water Development Report (2021), the World Bank's "Invisible Water Crisis" (2019), and FAO's AQUASTAT data (2021), the global pressure on groundwater resources is intensifying due to increasing consumption, pollution, and climate variability. In India, national-level analyses such as the NITI Aayog's Composite Water Management Index and reports from CPCB and CGWB have highlighted persistent challenges in maintaining groundwater quality, particularly in shallow aquifers susceptible to anthropogenic contamination.



Figure 1 : Groundwater pollution threats (Villholth et al., 2011).

In the Indian context, groundwater remains a cornerstone of water security. An estimated 87% of the groundwater extracted in the country is used for agricultural purposes, with around 11% consumed for domestic needs. Shallow aquifers are more readily accessible, form the primary source of water in most regions. Consequently, the quality of groundwater in these aquifers has a direct impact on public health, food security, and ecological balance. However, the quality of groundwater in India, particularly in shallow aquifers, is under increasing threat from both natural processes and human-induced activities. The challenge of maintaining and improving groundwater quality has grown more complex due to rising population pressures, expanding industrial zones, and unsustainable agricultural practices. The vulnerability of shallow aquifers is heightened due to their close interaction with surface-level contamination sources.

Key factors contributing to this decline in groundwater quality include:

- **Industrialization:** Rapid industrial growth, especially in urban areas, has led to the contamination of groundwater through the discharge of untreated industrial waste, including heavy metals, chemicals, and solvents.
- **Agricultural Practices:** Excessive use of fertilizers and pesticides in farming has resulted in the infiltration of harmful chemicals into groundwater, leading to nitrate contamination. Additionally, over-extraction of groundwater for irrigation is depleting aquifers and causing issues like salinization.
- **Urbanization:** As urban areas expand, improper waste disposal, sewage leakage, and landfill contamination contribute to the pollution of shallow aquifers. Industrial effluents and household waste also pose risks to groundwater quality.
- **Climate Change:** Changes in precipitation patterns and the over-extraction of groundwater can affect the natural replenishment of aquifers, leading to deteriorating water quality.

This report provides an overview of the chemical quality of groundwater in India, based on the analysis and interpretation of water samples collected from the hydrograph network stations maintained by the Central Ground Water Board, with a focus on shallow aquifers across the country.

2.0 Ground Water Quality Monitoring

This is the second consecutive year that the groundwater quality assessment has been carried out in accordance with the Standard Operating Procedure (SOP) introduced by the Central Ground Water Board (CGWB) in 2023. The implementation of this uniform SOP across all regions of India represents a landmark advancement in the standardization of groundwater quality monitoring. It has brought consistency and scientific rigor to the processes of sampling, laboratory analysis, and data reporting. The adoption of the SOP has ensured the following key improvements:

- ❖ **Uniform Methodology:** A standardized approach to sampling, testing, and data analysis across all monitoring stations enables consistent and comparable results nationwide.
- ❖ **Enhanced Data Reliability:** By adhering to scientifically validated procedures, the SOP ensures high-quality, credible data. This enhances the accuracy and dependability of findings, supporting evidence-based policy and decision-making.
- ❖ **Standardized Reporting Framework:** The SOP mandates a uniform format for data documentation and reporting. It also supports seamless data integration for national-level assessments.

The continued use of the CGWB's SOP strengthens the overall integrity of groundwater quality monitoring in India and provides a robust foundation for long-term environmental and resource planning.

To understand the seasonal and long-term variability in groundwater quality, the study adopts a structured monitoring framework guided by the Standard Operating Procedure (SOP). This approach enables the assessment of both **seasonal changes** (pre- and post-monsoon) and **year-on-year trends**, providing insights into how contamination levels evolve across different regions and over time.

2.1 Framework for Development of Composite Water Quality Database (2024)

In 2023, the Central Ground Water Board (CGWB) has 15,259 baseline monitoring stations across the country. In 2024, a total of 5,368 stations were selected for trend line monitoring stations as per SOP. To ensure spatial consistency, common stations between 2023

and 2024 were identified and replaced. This process resulted in 14,978 baseline stations for 2024, providing a comprehensive and representative coverage of groundwater quality across India.

Through this approach, a harmonized and representative dataset was developed, ensuring spatial continuity and temporal consistency across the monitoring network. The database thus prepared formed the basis for interpretation and preparation of this Year **Annual Ground Water Quality Report**.

2.2 National Water Quality Overview

Groundwater samples were analyzed for a comprehensive set of physico-chemical parameters, including major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+), anions (F^- , CO_3^{2-} , HCO_3^- , SO_4^{2-} , Cl^- , NO_3^- , PO_4^{3-}), silica (SiO_2), general indicators (pH, Electrical Conductivity, Total Hardness), and trace metals such as arsenic (As), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and lead (Pb). Because of their potential health risks, regulatory importance and role as indicators of broader water quality issues these parameters have been discussed in the report.

In general, groundwater quality across most parts of India is considered **good to excellent**. However, certain regions face **localized contamination challenges**:

- **Arsenic** contamination is a major concern in the **Ganga and Brahmaputra River basins**.
- **Fluoride** and **nitrate** levels are found to be **moderately elevated** in several regions.
- **Uranium** contamination, although less widespread, has been **sporadically detected** in parts of **Rajasthan, Punjab, Haryana, Andhra Pradesh, and Telangana**.
- Elevated manganese levels have been reported in some locations in states, including **Assam, Karnataka, Odisha, Tamil Nadu, Uttar Pradesh, and West Bengal**.
- Lead Contamination was **localized and limited**, with a **small number of samples from Assam, Karnataka, Madhya Pradesh, Uttar Pradesh, Punjab, and Rajasthan** showing lead levels above the standard.

These findings highlight the need for **region-specific interventions** and **continued monitoring**, particularly in vulnerable aquifers and high-risk zones.

2.3 Groundwater Quality Data Validation

Ensuring the accuracy, reliability, and consistency of groundwater quality data is essential for making sound scientific assessments and policy decisions. The following key validation procedures have been adopted to uphold data integrity:

❖ **Checking of Data Consistency:** Checking of the data for consistency by comparing the measurements of a particular parameter over time. This will help identify any changes in the groundwater quality due to measurement methodology or equipment.

❖ Correlation between Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

A widely accepted quality check is the correlation between EC and TDS values, as these parameters are typically related by a constant factor:

$$\text{TDS} = \text{EC (mS/cm)} \times \text{K}$$

The constant **K** varies with the **chemical composition** of water.

Higher K values are observed in chloride-dominated waters, while **lower K values** are seen in sulphate-rich waters.

This relationship helps in detecting discrepancies or errors in reported TDS or EC values.

Acceptable Range: $0.55 \times \text{EC (mS/cm)} < \text{TDS (mg/L)} < 0.75 \times \text{EC (mS/cm)}$

❖ Cation–Anion Balance (Charge Balance Error Check)

One of the most important validation tools in hydrochemistry is the **cation–anion balance**, which ensures that the measured concentrations of major ions are chemically plausible.

The sum of cation equivalents (meq/L) should be approximately equal to the sum of anion equivalents (meq/L):

$$\sum \text{Cations} \approx \sum \text{Anions}$$

To quantify the balance, the **Electronic Charge Balance (ECB)** is calculated as:

$$\text{ECB (\%)} = \frac{|\sum \text{Cations} - \sum \text{Anions}|}{\sum \text{Cations} + \sum \text{Anions}} \times 100$$

All concentrations must be converted to milliequivalents per litre (meq/L).

Acceptability Criterion:

An ECB greater than $\pm 10\%$ indicates potential analytical errors in at least one major cation or anion measurement.

For the 2024 groundwater dataset, samples with an ECB exceeding 10% have been excluded from the final analysis to maintain data accuracy.

These validation procedures—data consistency checks, EC-TDS correlation analysis, and cation-anion balance assessment—are critical for ensuring high-quality, scientifically sound groundwater quality data. They provide confidence in the dataset and strengthen the foundation for regional and national-scale water resource planning.

2.4 Comparison with BIS Drinking Water Standard

A key objective of this study is to evaluate whether groundwater from shallow aquifers complies with the **Bureau of Indian Standards (BIS) specifications for drinking water quality (IS 10500)**.

By comparing the measured concentrations of various water quality parameters with the permissible limits prescribed in **BIS:10500**, the study assesses the suitability of groundwater for drinking and other domestic uses. This comparison serves as a benchmark to determine the extent and nature of contamination, identify non-compliant regions, and support evidence-based water resource management.

The table-1 summarizes the **Indian Bureau of Standards (BIS:10500)** guidelines for drinking water quality, providing both the acceptable limits and the permissible limits in the absence of an alternative source for key water quality parameters. For basic parameters such as electrical conductivity (EC), chloride, fluoride, and nitrate, exceedances are associated with health concerns ranging from cardiovascular complications and gastrointestinal discomfort to dental and skeletal fluorosis and methemoglobinemia (blue baby syndrome) in infants. For trace metals, the guidelines are more stringent because of their toxicological significance even at low concentrations.

Elevated levels of iron and manganese can cause aesthetic and biological issues in water supply systems, while copper in excess may damage the liver. Lead, arsenic, and uranium are of particular concern due to their neurological effects, carcinogenic potential, and kidney toxicity, with no relaxation in permissible limits provided for these contaminants. These standards serve as a benchmark for assessing groundwater quality across India and highlight the health risks associated with exceedance of different parameters.

Table 1: The Indian Bureau of Standards guidelines for contaminants levels in drinking water

Indian Bureau of Standards Guidelines			
Analyte	Acceptable Limit	Permissible Limit in Absence of Alternative Source	Health effects
EC (µs/cm at 25°C)	750	3000	Anaesthetic effect, may lead to Cardiovascular complications
Cl (mg/L)	250	1000	Eye/nose irritation; stomach discomfort
F (mg/L)	1	1.5	Bone disease (pain and tenderness of the bones); children may get mottled teeth
Nitrate (mg/L)	45	No relaxation	High nitrate levels in drinking water can cause blue baby syndrome
Zn (mg/L)	5	15	Gastrointestinal issues.
Fe (mg/L)	1	No relaxation	Anaesthetic effect, promotes iron bacteria
Mn (mg/L)	0.1	0.3	Neurological issues in infants and children
Cu (mg/L)	0.5	1.5	Excess can cause liver damage
Pb (mg/L)	10	No relaxation	Neurological issues
As (µg/L)	10	No relaxation	Skin damage, increased risk of cancer
U(µg/L)	30	No relaxation	Increased risk of cancer, kidney toxicity

2.5 Water Quality Criteria for Irrigation Purpose

Groundwater is a critical resource for irrigation in India, particularly in regions with insufficient surface water. The quality of groundwater used for irrigation directly affects soil health and crop productivity. Many problems originate due to inefficient management of water for agriculture use, especially when it carries high salt loads.

Table 2 : Safe Limits for electrical conductivity for irrigation water (IS:11624-1986)

<i>Nature of soil</i>	Crop Growth	Upper permissible safelimit of Electrical Conductivity in water µs/cm at 25°C
<i>Deep black soil and alluvial soilshaving clay content more than 30%; soils that are fairly to moderately well Drained</i>	Semi- tolerant	1500
	Tolerant	2000
<i>Textured soils having clay contents of 20-30%; soils that are well drained internally and have good surface drainage system</i>	Semi- tolerant	2000
	Tolerant	4000
<i>Medium textured soils having clay 10-20%; internally very well drained and having good surface drainage system</i>	Semi- tolerant	4000
	Tolerant	6000

Areas that rely heavily on irrigation face significant salinity issues. When water is extracted from groundwater for irrigation purposes, salts that were once contained in the groundwater can accumulate on the soil’s surface, leading to **soil salinization**. This, in turn, reduces crop yields and degrades soil health, further exacerbating the water quality crisis in these regions.

These effects are visible in plants by their stunted growth, low yield, discoloration and even leaf burns at margin or top. The safe limits of electrical conductivity for crops of different

degrees of salt tolerances under varying soil textures and drainage conditions are presented in **Table - 2**.

2.5.1 Sodium Adsorption Ratio (SAR) & Residual Sodium Carbonate (RSC)

SAR is an important parameter used to assess the suitability of groundwater for irrigation in terms of **sodium content**. It is the ratio of the concentration of sodium (Na⁺) to the concentrations of calcium (Ca²⁺) and magnesium (Mg²⁺) in water.

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

High levels of sodium in water can lead to the dispersion of soil particles, resulting in **soil structure degradation** and reduced **water infiltration**. This condition is known as **alkali soil** or **sodium toxicity**, which can severely reduce crop growth. A SAR value of less than 10 is considered **suitable** for most soils (Table 3).

Residual Sodium Carbonate (RSC) is an important index that helps assess the potential for water to cause alkalinity in the soil. Alkaline water can adversely affect soil structure, crop yield, and overall land productivity. RSC is a measure of the excess amount of carbonate ions in water, which can combine with calcium and magnesium in the soil, leading to soil sodicity (high levels of sodium).

The formula to calculate RSC is as follows:

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

Sodium Percentage (Na%) refers to the proportion of **sodium ions (Na⁺)** relative to the total cation concentration (which includes sodium, calcium, and magnesium ions) in the water. It is an important indicator for assessing the **sodicity** potential of irrigation water, as high sodium concentrations can lead to **soil dispersion** and reduce soil permeability, which makes it harder for water and air to reach plant roots. The formula to calculate the **Sodium Percentage (Na%)** is:

$$\%Na = \frac{(Na + K)}{(Ca + Mg + Na + K)} * 100$$

Table 3: Guidelines for evaluation of quality of irrigation water

<i>Water Class</i>	<i>SAR</i>	<i>RSC</i>	<i>%Na</i>
Low	< 10	< 1.25	< 20
Medium	>10 – 18	1.25 – 2.5	20 - 60
High	>18 – 26	>2.5	> 60
Very High	> 26		

3.0 Principal Aquifers of India

The **Principal Aquifer Map of India** provides an overview of the major hydrogeological formations that constitute the country's groundwater reservoirs. The map delineates the spatial distribution of key aquifer types such as **alluvium, basalt (Deccan Traps), granite, gneiss, sandstone, limestone, schist, and shale**, along with complex formations like **basement gneissic complexes and charnockites**.

The geological framework of an area significantly impacts the quality of groundwater, especially in terms of the presence and concentration of certain contaminants like **fluoride, uranium, iron** and **arsenic**. The specific rock types, along with their weathering characteristics, mineral composition, and hydrological properties, influence how these elements are mobilized or dissolved into groundwater under favorable conditions.

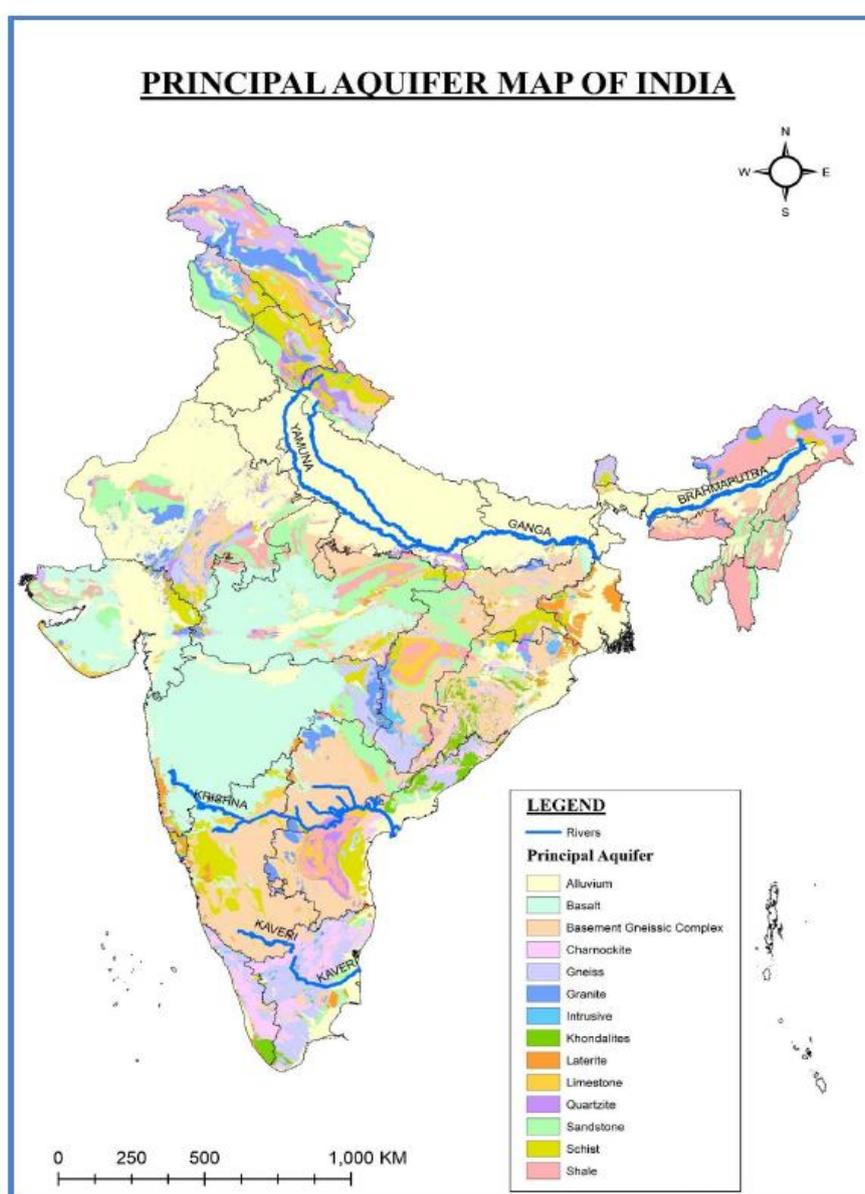


Figure 2: Principal Aquifers in India.

4.0 Ground Water Quality Scenario In India

4.1 Groundwater Quality – Basic Parameters

The pie chart (Fig-3) presents the compliance status of groundwater samples with respect to BIS:10500 (Drinking Water Standards), total no. of ground water samples 14,978. The groundwater quality assessment (n = 14,978) shows that about 71.7% of samples comply with BIS (IS 10500) permissible limits for drinking water. Around 28.3% of samples exceed the permissible limit for one or more parameters, indicating localized quality concerns. Overall, most samples meet the prescribed standards, though some areas reflect the need for focused monitoring and quality improvement measures.

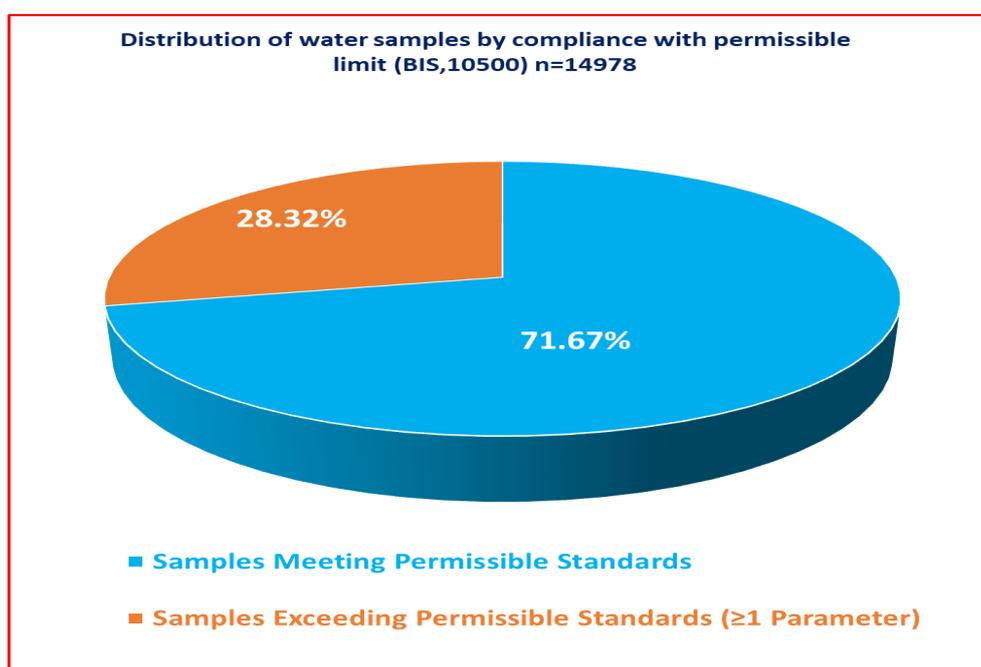


Figure 3: Distribution of water samples in compliance with permissible limit (BIS, 10500).

The figure - 4 illustrates the parameter-wise distribution of groundwater samples that exceeded permissible limits (BIS:10500) during the pre-monsoon, 2024. The groundwater quality assessment (n = 14,978) indicates that **nitrate** exceeds the permissible limit in about **20.7%** of samples, showing its relatively wider presence in some areas. **Fluoride (8.05%)** and **EC (7.23%)** also exceed permissible limits at a few locations, reflecting local variations in groundwater quality. Overall, the results suggest that while nitrate exceedance is more common, fluoride and EC issues are observed in certain regions.

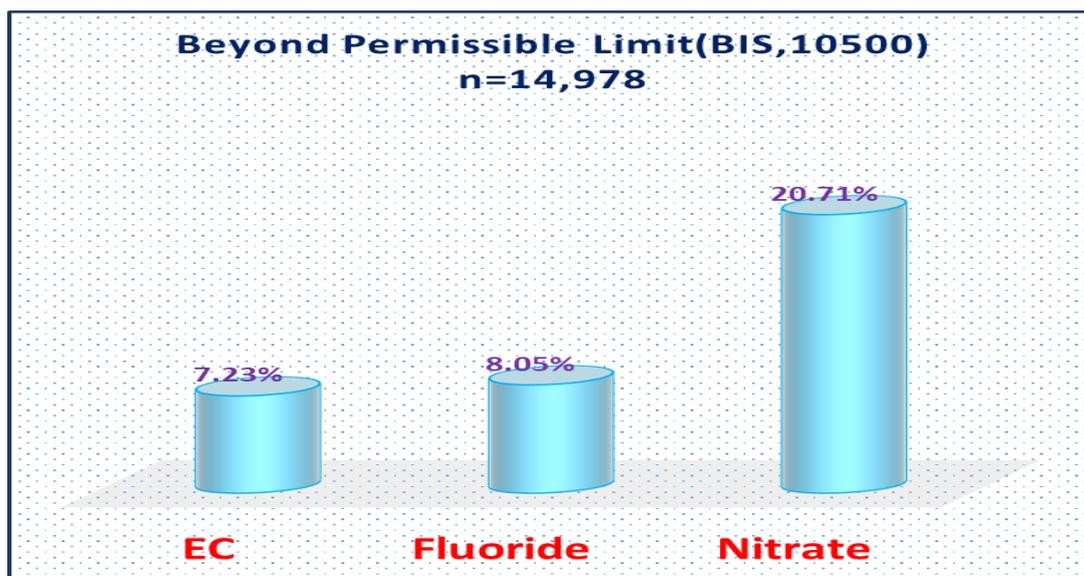


Figure 4: Groundwater Samples Beyond Permissible Limits and their Parameter-wise Distribution (Pre-monsoon, 2024).

4.2 Groundwater Quality – Trace Metals

Exceeding trace metal concentrations in groundwater is of critical concern as it directly affects both human health and environmental safety. Toxic metals such as arsenic, lead, and uranium can cause severe neurological, skeletal, kidney, and cancer-related problems, while elevated iron and manganese levels pose risks, especially to infants and children. Such exceedance compromises the potability of groundwater, reducing its suitability for drinking and domestic use, and can also lead to the accumulation of metals in soils and crops, thereby impacting agriculture and food security. Moreover, elevated trace metal levels serve as indicators of geogenic release from aquifer systems or contamination from anthropogenic sources such as industrial effluents, mining, and fertilizers. Thus, their presence beyond permissible limits underscores the urgent need for systematic monitoring, preventive measures, and sustainable groundwater management.

The overall proportion of non-compliant samples is lower compared to basic parameters such as nitrate, fluoride, and salinity. Exceedances are largely attributed to geogenic factors such as aquifer lithology and mineral dissolution, along with localized anthropogenic inputs including industrial effluents and improper waste disposal.



Figure 5: Distribution of water samples for Trace Metals in compliance with permissible limit (BIS, 10500).

The figure-5 presents the parameter-wise distribution of groundwater samples exceeding permissible limits for trace metals (BIS:10500) during pre-monsoon 2024.

The groundwater quality analysis for pre-monsoon 2024 shows that iron (11.71%) and manganese (10.94%) are the most common parameters exceeding the BIS (IS 10500) permissible limits. Uranium (5.34%) and arsenic (3.45%) show moderate exceedances, while lead (0.93%) and zinc (0.16%) remain within permissible limits at most locations. **Copper** is within permissible limits in all samples. Although iron exceedance is relatively frequent, it is primarily of aesthetic concern (causing taste, staining, or turbidity issues) and does not pose major health risks. Overall, the findings indicate localized groundwater quality concerns rather than widespread contamination.

4.3 Electrical Conductivity

Electrical Conductivity (EC) is one of the most widely used parameters for assessing groundwater quality, as it provides an indirect measure of the total dissolved solids (TDS) present in water. It reflects the ability of water to conduct an electric current, which is directly proportional to the concentration of dissolved ions such as **calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate**. Higher EC values generally indicate elevated salinity levels, which may be attributed to natural processes such as **mineral dissolution, rock-water interaction, and seawater ingress**, or to anthropogenic influences including **irrigation return flows, industrial effluents, and improper waste disposal**.

Electrical conductance is directly related to the abundance of charged ionic compounds (Hem 1985). Salinity always exists in ground water but in variable amounts. It is mostly influenced by aquifer material, solubility of minerals, duration of contact and factors such as the permeability of soil, drainage facilities, and quantity of rainfall and above all, the climate of the area. The salinity of groundwater in coastal areas in addition to the above may be due to air borne salts originating from air water interface over the sea and due to over pumping of fresh water which overlays saline water in coastal aquifer systems.

Monitoring EC is important because it influences the **suitability of groundwater for drinking, irrigation, and industrial use**. While water with low EC may be unsuitable due to corrosiveness and lack of essential minerals, excessively high EC imparts undesirable taste, reduces crop productivity through soil salinization, and may lead to long-term health concerns. As per **BIS:10500 guidelines**, the acceptable limit for EC is **750 $\mu\text{S}/\text{cm}$ at 25°C** , with a permissible limit of **3000 $\mu\text{S}/\text{cm}$** in the absence of an alternative source. Given its significance as a rapid indicator of groundwater quality, EC serves as a baseline parameter in water quality assessments, providing insights into the **extent of salinity, hydrogeochemical processes, and anthropogenic stress on aquifers**.

In the pre-monsoon EC is ranging from 14 to 32970 $\mu\text{S}/\text{cm}$ with a mean value of 1305.7 $\mu\text{S}/\text{cm}$. In **Fig. 7**, the EC values (in $\mu\text{S}/\text{cm}$ at 25°C) of ground water from observation/monitoring wells have been used to show distribution patterns of electrical conductivity in different ranges of suitability for drinking purposes. It is apparent from the map that majority of the waters having EC values less than $750\mu\text{S}/\text{cm}$ at 25°C occur mostly in the states of J & K, Himachal Pradesh, Uttarakhand, N-Uttar Pradesh, Kerala, Sikkim, Chhattisgarh, Orissa, Western Ghats of Maharashtra & Karnataka and North- Eastern states such as Asam, Meghalaya, Arunachal Pradesh, Tripura etc., of the country. Groundwater with EC ranging between 750 and $3000\mu\text{S}/\text{cm}$ at 25°C falling under ‘permissible’ range are confined mainly to parts of Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Jharkhand and Punjab.

However, in some cases, relatively high values of EC in excess of $3000 \mu\text{S}/\text{cm}$ are observed in many parts of the country. Especially in Rajasthan, Gujarat, Haryana, Andhra Pradesh, Maharashtra, Tamil Nadu, Karnataka etc. Coastal states like Tamil Nadu, Andhra Pradesh, Gujarat and Maharashtra face **seawater intrusion** in coastal aquifers. As freshwater levels deplete, saltwater from the sea moves inland, raising EC levels. This is especially true in areas where groundwater extraction rates are higher than recharge rates. In arid and semi-arid regions

such as **Rajasthan, Punjab, and Haryana**, high evaporation rates lead to **concentration of salts** in groundwater. When water evaporates, salts in the soil or groundwater become more concentrated, contributing to higher EC.

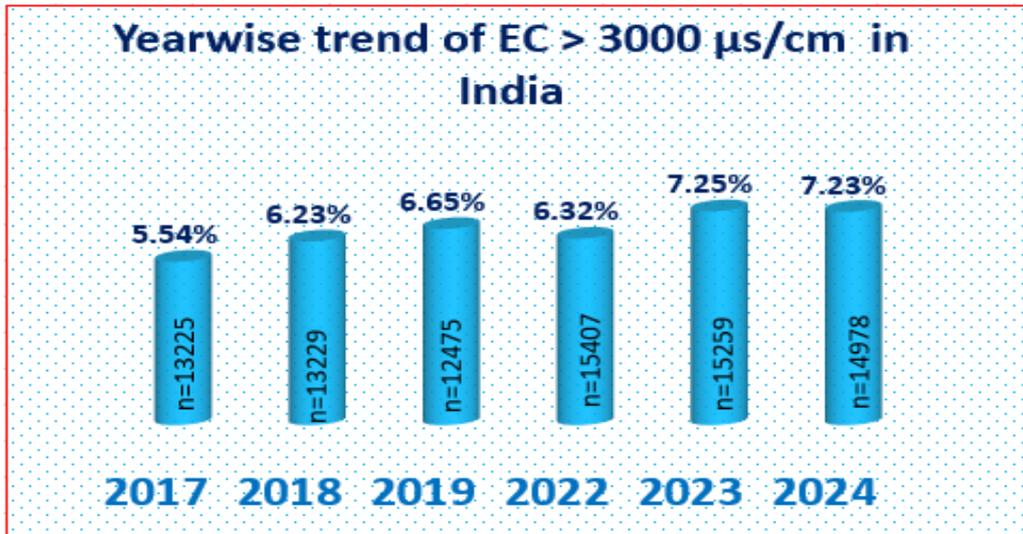


Figure 6: Year wise trend in Electrical Conductivity in Pre-Monsoon Samples During 2017-2024.

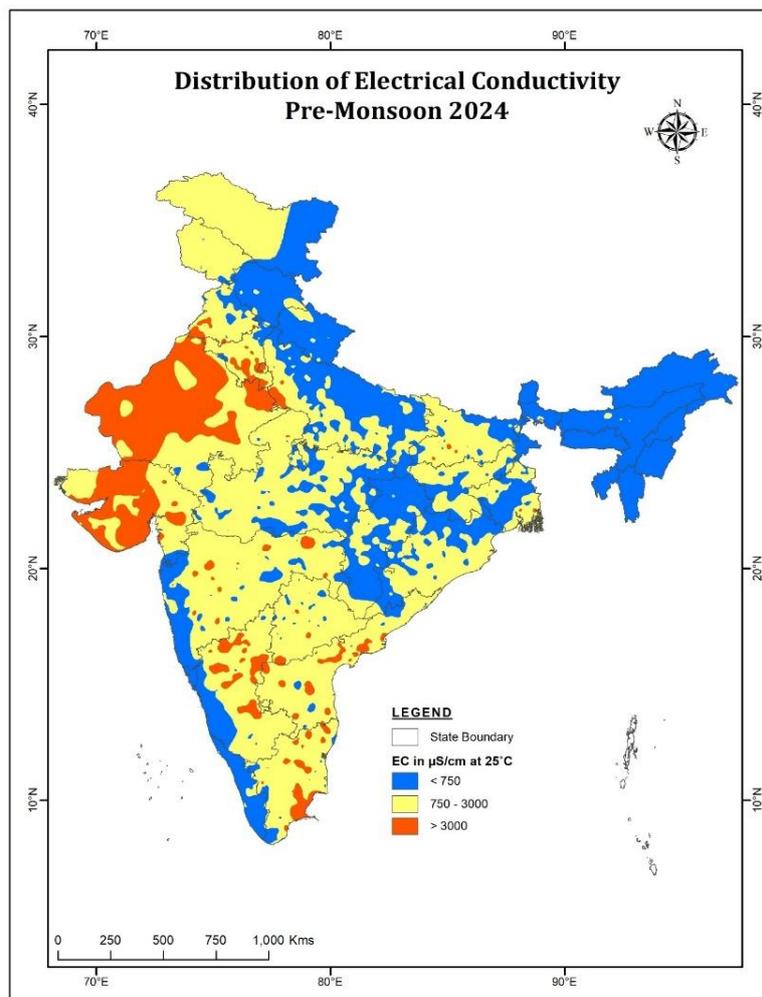


Figure 7: Distribution of Electrical Conductivity in India during Pre-monsoon

The year-wise data (Figure-6) show a slight increase in the proportion of groundwater samples with EC > 3000 $\mu\text{S}/\text{cm}$, from 5.54% in 2017 to 7.23% in 2024. The values have remained almost stable during 2023 and 2024, indicating that overall salinity levels have not changed significantly in recent years. The results suggest that salinity is present in some areas, but it is not widespread at the national level. Overall, the data reflect a mild upward trend in salinity, possibly influenced by factors such as evaporation, mineral dissolution, or saline ingress in certain regions, though the extent remains moderate at the national scale.

The state-wise distribution of groundwater samples exceeding the permissible limit of Electrical Conductivity (EC > 3000 $\mu\text{S}/\text{cm}$), Table-4 highlights significant regional disparities in groundwater salinity across India.

Table 4: State-wise Groundwater Samples Exceeding BIS (IS 10500:2012) Permissible Limit.

Sl. No.	State / UT	Samples Analyzed	Samples > Permissible Limit	% Above Limit
1	Rajasthan	643	303	47.12
2	NCT of Delhi	135	45	33.33
3	Haryana	811	167	20.59
4	Gujarat	618	113	18.28
5	Karnataka	398	60	15.08
6	Tamil Nadu	929	98	10.55
7	Andhra Pradesh	1135	111	9.78
8	Punjab	756	53	7.01
9	Telangana	1114	30	2.69
10	Maharashtra	1565	40	2.56
11	Uttar Pradesh	1333	31	2.33
12	West Bengal	875	13	1.49
13	Odisha	654	7	1.07
14	Bihar	584	5	0.86
15	Madhya Pradesh	726	6	0.83
16	Chhattisgarh	830	1	0.12
17	Andaman & Nicobar Islands	115	0	0.00
18	Arunachal Pradesh	15	0	0.00
19	Assam	145	0	0.00
20	Chandigarh (UT)	9	0	0.00
21	Dadra & Nagar Haveli and Daman & Diu	16	0	0.00
22	Goa	7	0	0.00
23	Himachal Pradesh	161	0	0.00
24	Jammu & Kashmir	247	0	0.00
25	Jharkhand	381	0	0.00
26	Kerala	361	0	0.00
27	Manipur	3	0	0.00
28	Meghalaya	39	0	0.00
29	Nagaland	67	0	0.00
30	Tripura	49	0	0.00
31	Puducherry (UT)	9	0	0.00
32	Uttarakhand	248	0	0.00
Total	India	14,978	1,083	7.23

Nationally, 7.23% of groundwater samples exceeded BIS (IS 10500:2012) limits for EC. Rajasthan, Delhi, Haryana, and Gujarat show higher proportions of non-compliant samples. Kerala, Himachal Pradesh, Assam, and Northeastern States recorded 0% exceedance, indicating generally good groundwater quality in respect of EC. Overall, the data suggests that groundwater salinity is most acute in arid and semi-arid regions, particularly in north-west India, while eastern and central states show comparatively minimal impact.

4.3.1: Understanding the Impact of Seasonal Variation of Groundwater Electrical Conductivity (Pre- and Post-Monsoon 2024)

The maps (Fig. 8) present the spatial distribution of Electrical Conductivity (EC) in groundwater across India during pre- and post-monsoon, 2024. The categorization is based on BIS guidelines: <math><750 \mu\text{S/cm}</math> (desirable), $750\text{--}3000 \mu\text{S/cm}$ (within permissible range), and $>3000 \mu\text{S/cm}$ (beyond permissible limit).

During the pre-monsoon, large areas of Rajasthan, Gujarat, Haryana, and parts of Tamil Nadu and Karnataka exhibit EC values above $3000 \mu\text{S/cm}$, indicating severe salinity problems. Post-monsoon, there is a slight reduction in high EC zones, particularly in central and southern India, reflecting the dilution effect of rainfall recharge. However, Rajasthan, parts of Gujarat, and coastal belts continue to remain critical hotspots of groundwater salinity even after the monsoon.

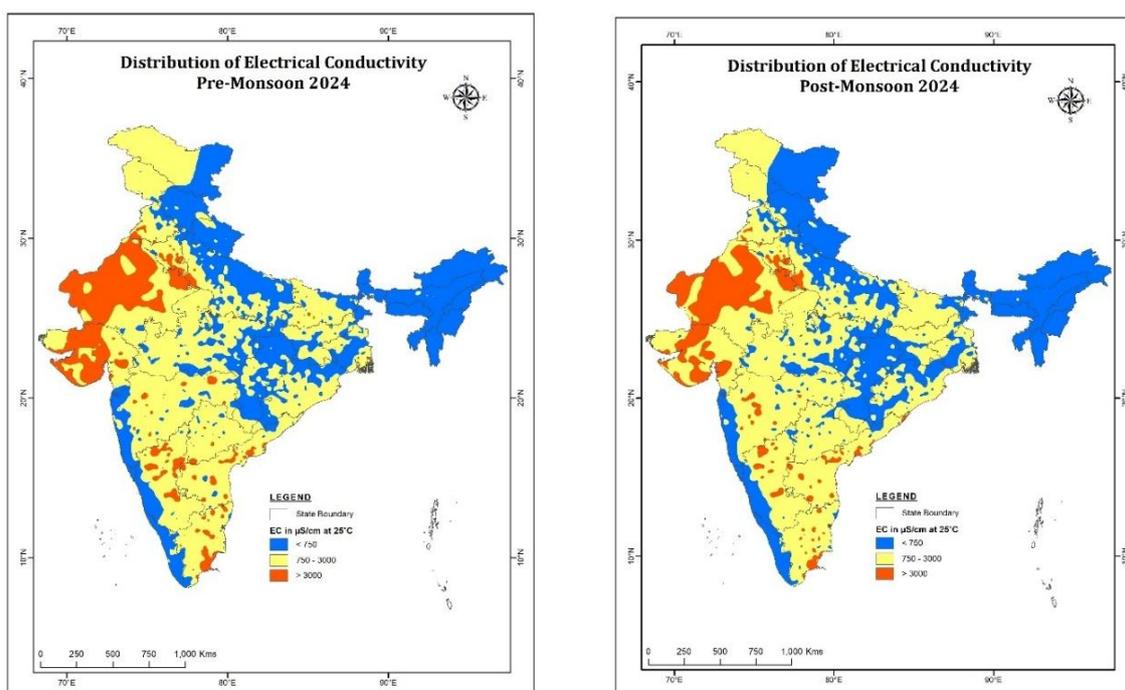


Figure 8: Distribution of Groundwater Electrical Conductivity in India (Pre- and Post-Monsoon 2024).

Overall, the comparison highlights that while monsoon recharge helps improve water quality in some regions, salinity remains a persistent issue in arid and semi-arid zones, requiring continuous monitoring and management interventions.

One interesting aspect of water quality is how it changes with seasons particularly before and after monsoon. In the **pre-monsoon** period, **7.17%** of the samples had **EC values greater than 3000 $\mu\text{S}/\text{cm}$** , after the **monsoon recharge**, this percentage decreased to **6.38%**, showing a **slight improvement** in groundwater quality in post-monsoon, likely due to the **recharge effect** of rainfall, which dilutes the salts in the aquifers (Fig. 9).

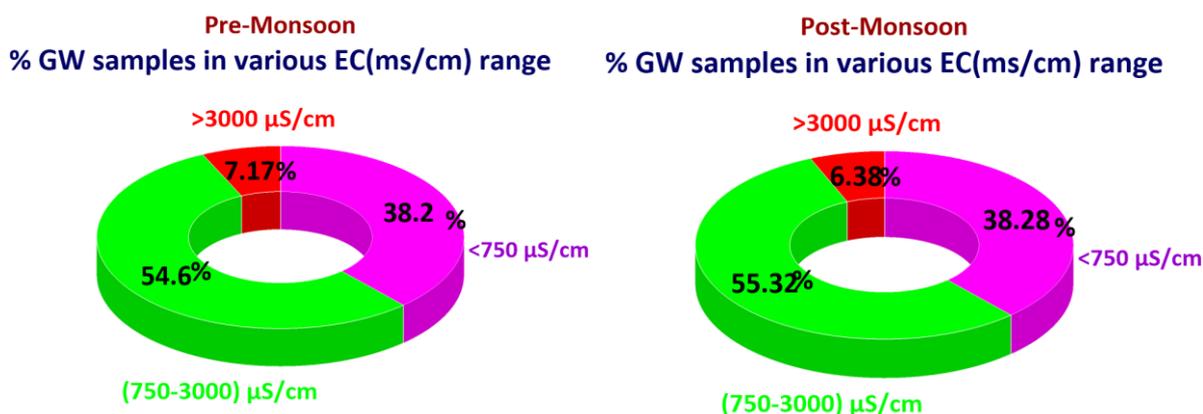


Figure 9: Percentage groundwater samples in various EC range, 2024 (Pre & Post).

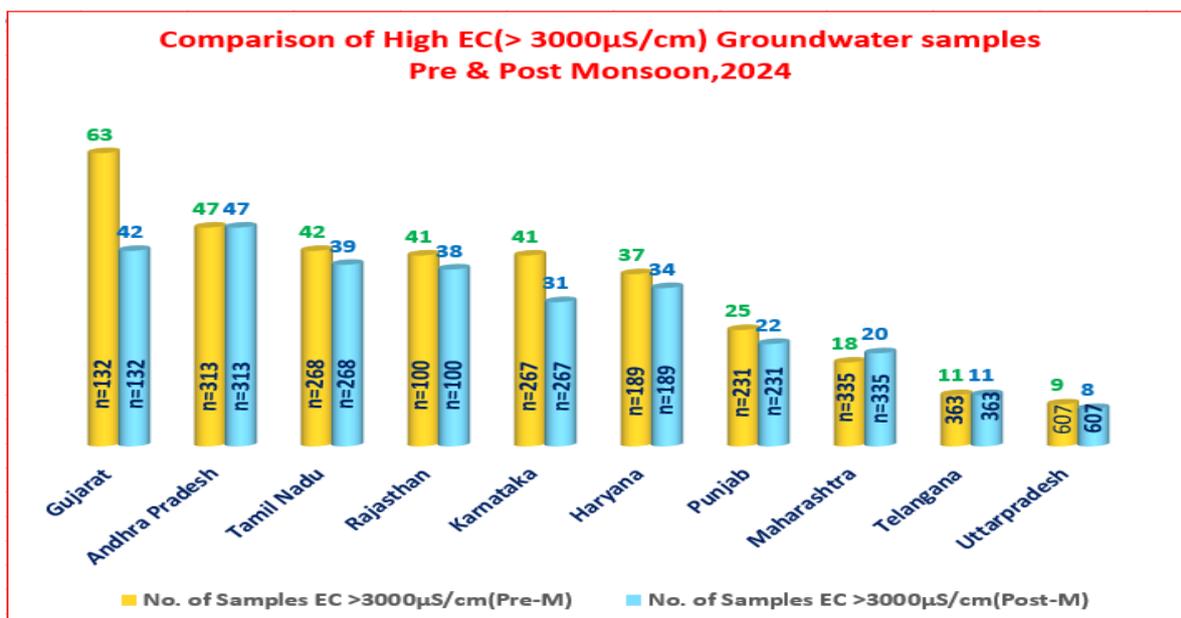


Figure 10: Comparison of High EC Groundwater samples during pre & post-monsoon, 2024.

The comparison of groundwater samples with EC > 3000 $\mu\text{S}/\text{cm}$ (Fig.10) during pre- and post-monsoon 2024 indicates that high salinity levels are more prevalent before the monsoon. The proportion of such samples decreased slightly in the post-monsoon period, suggesting dilution effects due to rainfall recharge.

Table 5: State/UT-wise Electrical Conductivity (EC) values during Pre- and Post-Monsoon 2024 at common locations.

Sl. No.	District	No. of Samples Analysed (Common Locations-2024)	Electrical Conductivity <750 $\mu\text{S}/\text{cm}$ at 25 °C		Electrical Conductivity 750-3000 $\mu\text{S}/\text{cm}$ at 25 °C		Electrical Conductivity >3000 $\mu\text{S}/\text{cm}$ at 25 °C	
			Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	19	22	9	6	0	0
2	Andhra Pradesh	313	26	25	240	241	47	47
3	Arunachal Pradesh	15	15	15	0	0	0	0
4	Assam	127	119	118	8	9	0	0
5	Bihar	115	31	22	81	91	3	2
6	Chandigarh	8	7	7	1	1	0	0
7	Chhattisgarh	249	165	197	83	52	1	0
8	Delhi	86	8	4	41	44	37	38
9	Goa	2	2	2	0	0	0	0
10	Gujarat	132	1	3	68	87	63	42
11	Haryana	189	51	59	101	96	37	34
12	Himachal Pradesh	43	31	13	12	30	0	0
13	Jammu & Kashmir	61	17	13	44	48	0	0
14	Jharkhand	138	50	46	88	90	0	2
15	Karnataka	267	32	39	194	197	41	31
16	Kerala	185	159	170	26	15	0	0
17	Madhya Pradesh	577	206	208	367	369	4	0
18	Maharashtra	335	81	87	236	228	18	20
19	Meghalaya	38	38	38	0	0	0	0
20	Nagaland	67	63	65	4	2	0	0
21	Odisha	413	165	154	243	256	5	3
22	Punjab	231	66	75	140	134	25	22
23	Rajasthan	100	9	8	50	54	41	38
24	Tamil Nadu	286	38	42	207	205	41	39
25	Telangana	363	58	70	294	282	11	11
26	Uttar Pradesh	607	353	306	249	293	5	8
27	Uttarakhand	103	95	95	8	8	0	0
28	West Bengal	236	99	105	131	126	6	5
	Total	5368	2051	2055	2932	2970	385	343

The post-monsoon period showed a modest improvement in groundwater quality, as indicated by the slight reduction in high EC values. Pre-Post changes in EC in Ground Water in states have been presented in Table 5.

Table 6: Effect of monsoon recharge on salinity at common locations during pre and post monsoon.

Sl. No.	District	No. of Samples Analysed (Common Locations for Pre- and Post-M)	No. of Locations (Where Improvement is within 20% w.r.t Pre-M Value)	No. of Locations (Where Improvement is beyond 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is within 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is beyond 20% w.r.t Pre-M Value)
			<i>No Significant improvement</i>	<i>Significant Improvement</i>	<i>No Significant Deterioration</i>	<i>Significant Deterioration</i>
1	A&N Islands	28	8	11	7	2
2	Andhra Pradesh	313	96	60	81	74
3	Arunachal Pradesh	15	4	5	1	5
4	Assam	127	24	37	22	44
5	Bihar	115	23	26	26	40
6	Chandigarh	8	7	1	0	0
7	Chhattisgarh	249	57	95	47	50
8	Delhi	86	19	17	21	28
9	Goa	2	2	0	0	0
10	Gujarat	132	33	47	29	23
11	Haryana	189	68	31	56	31
12	Himachal Pradesh	43	5	1	6	31
13	Jammu & Kashmir	61	11	6	24	19
14	Jharkhand	138	15	19	40	64
15	Karnataka	267	78	75	53	61
16	Kerala	185	40	85	32	27
17	Madhya Pradesh	577	262	90	120	103
18	Maharashtra	335	83	84	82	86
19	Manipur	3	0	0	1	2
20	Meghalaya	38	9	6	6	17
21	Nagaland	67	22	13	15	16
22	Odisha	413	80	116	72	144
23	Punjab	231	89	58	48	36
24	Rajasthan	100	34	12	43	11
25	Tamil Nadu	286	63	108	42	70
26	Telangana	363	90	101	99	71
27	Tripura	44	13	7	8	16
28	UT of Puducherry	7	1	0	3	3
29	Uttar Pradesh	607	184	50	215	152
30	Uttarakhand	103	37	29	23	14
31	West Bengal	236	63	41	78	53
	Total	5368	1520	1231	1300	1293

The table-6 presents a state-wise comparison of groundwater quality trends between pre- and post-monsoon 2024 at common monitoring locations. Overall, 1,520 locations showed no significant improvement and 1,231 locations exhibited significant improvement in water quality with respect to pre-monsoon values. On the other hand, deterioration was observed in 1300 locations within 20% variation and in 1,293 locations beyond 20% variation. These results indicate that while post-monsoon recharge processes led to improvement in many areas, there

are still several districts where groundwater quality worsened significantly, requiring focused attention for mitigation measures.

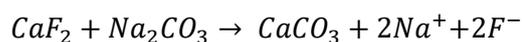
4.4 Fluoride

Excessive fluoride in groundwater used for drinking poses a significant health concern, as prolonged consumption can lead to waterborne fluorosis, manifesting in dental and skeletal disorders. The presence of fluoride in groundwater is influenced by both geological conditions and anthropogenic activities. Geogenic contributions primarily arise from the dissolution of fluoride-bearing minerals such as biotite, muscovite, fluorite, hornblende, mica, fluorapatite, and tourmaline, which occur across sedimentary, metamorphic, and igneous formations.

The average fluoride concentration in the continental crust is about 611 mg/kg, though its distribution varies with rock type: basalt (360 µg/g), granite (810 µg/g), limestone (220 µg/g), sandstone (180 µg/g), shale (800 µg/g), oceanic sediments (730 µg/g), and soils (285 µg/g). While fluoride is generally sparingly soluble, its mobility and presence in natural waters are governed by its high electronegativity and its tendency to occur exclusively in the fluoride ion state. In acidic waters, the dominant species is HF. Fluoride forms strong complexes with metals such as aluminum, beryllium, and iron (III), particularly under sub-neutral pH conditions. Furthermore, due to its similar ionic radius and charge to hydroxyl (OH⁻), fluoride readily substitutes in hydroxyl-bearing mineral structures, leading to the formation of F-OH complexes. Under strongly acidic conditions, it may also associate with silica in rare six-coordinated complexes.

In the hard rock areas, in some water samples fluoride concentration has been found more than permissible limit. In the fluoride affected area, decreasing Ca concentrations have been found under alkaline conditions with a corresponding rise in Na.

Earlier also so many researchers have opined that, Na-HCO₃ type water provides favourable condition for dissolution of fluoride.



pH value of aquifer solution between 5-6.5 leads to adsorption of F⁻ on clay minerals. The reverse is the situation in alkaline conditions having pH value more than 7. In these circumstances, OH⁻ group replaces the exchangeable F⁻ of clay minerals (biotite, muscovite, apatite, hornblende, and amphiboles), as both of these contain almost identical ionic radius (0.136 nm), consequently resulting in enhanced F⁻ concentration in aquifer. Besides these minerals, the anthropogenic activities include agriculture and industry may also contribute a

certain amount of fluoride to groundwater. Unlike the rather slow natural process of fluoride mobilization through rock-water interaction, its mobilization increases manifold during phosphate fertilizer production due to the strongly acidic reaction conditions encountered. Single superphosphate (SSP) is a popular phosphate fertilizer.

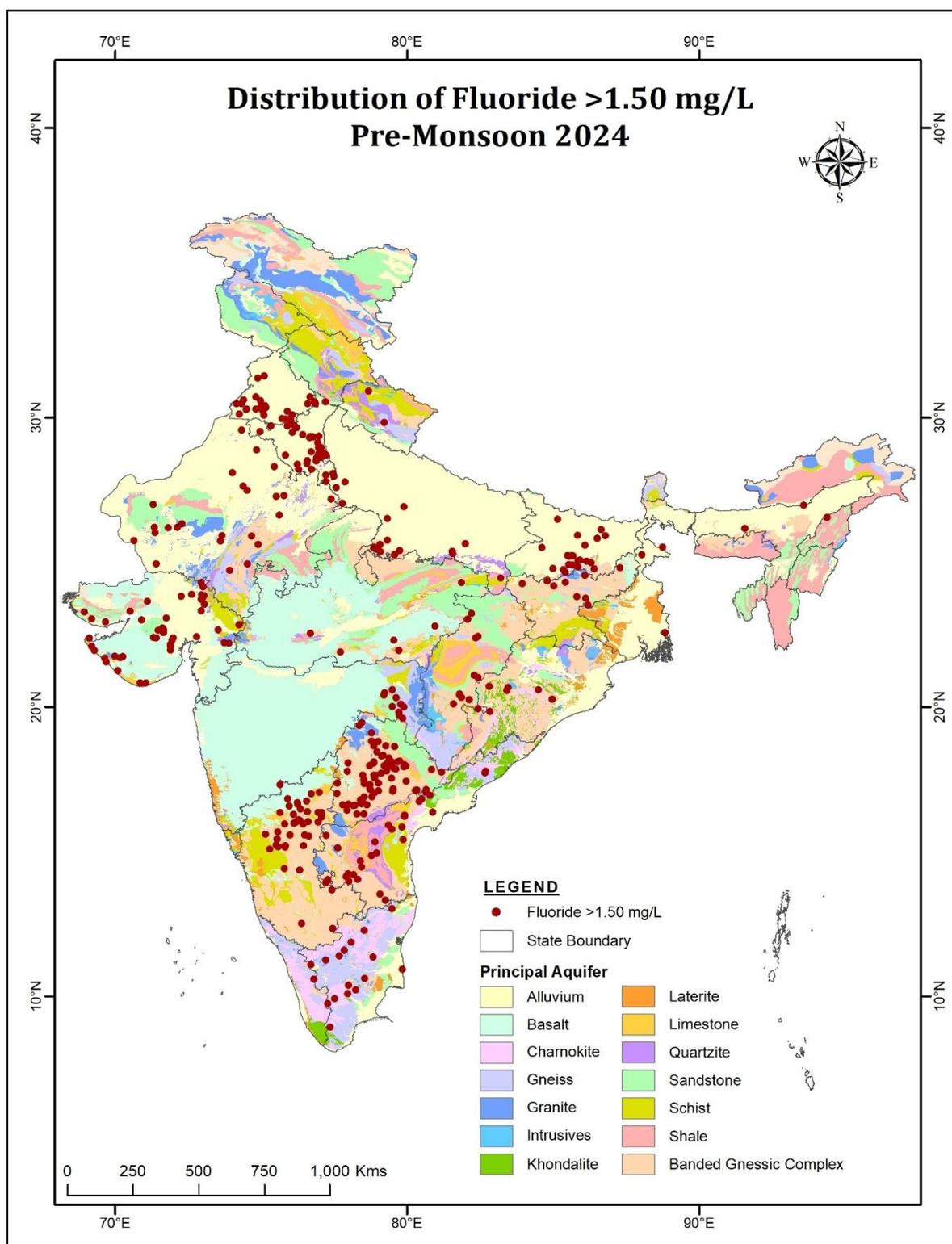


Figure 11: Distribution of Fluoride concentration in India during Pre-monsoon (May, 2024).

The occurrence of fluoride in natural water is affected by the type of rocks, climatic conditions, nature of hydrogeological strata and time of contact between rock and the circulating ground water. Presence of other ions, particularly bicarbonate and calcium ions also affect the concentration of fluoride in ground water. It is well known that small amounts of fluoride (less than 1.0 mg/L) have proven to be beneficial in reducing tooth decay. However, high concentrations such as 1.5 mg/L of F and above have resulted in staining of tooth enamel while at still higher levels of fluoride ranging between 5.0 and 10 mg/L, further pathological changes such as stiffness of the back and difficulty in performing natural movements may take place. BIS has recommended an upper desirable limit of 1.0 mg/L of F⁻ as desirable concentration of fluoride in drinking water, which can be extended to 1.5 mg/L of F in case no alternative source of water is available. In the pre-monsoon Fluoride is ranging from BDL to 22 mg/L with a mean value of 0.71 mg/L. The distribution of ground water samples with fluoride concentration more than 1.5 mg/L in pre and post monsoon, 2024 have been depicted on the map as **Fig. 11**. Elevated fluoride levels are observed mainly in parts of Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu, and Madhya Pradesh, indicating that fluoride enrichment is largely confined to specific regions.

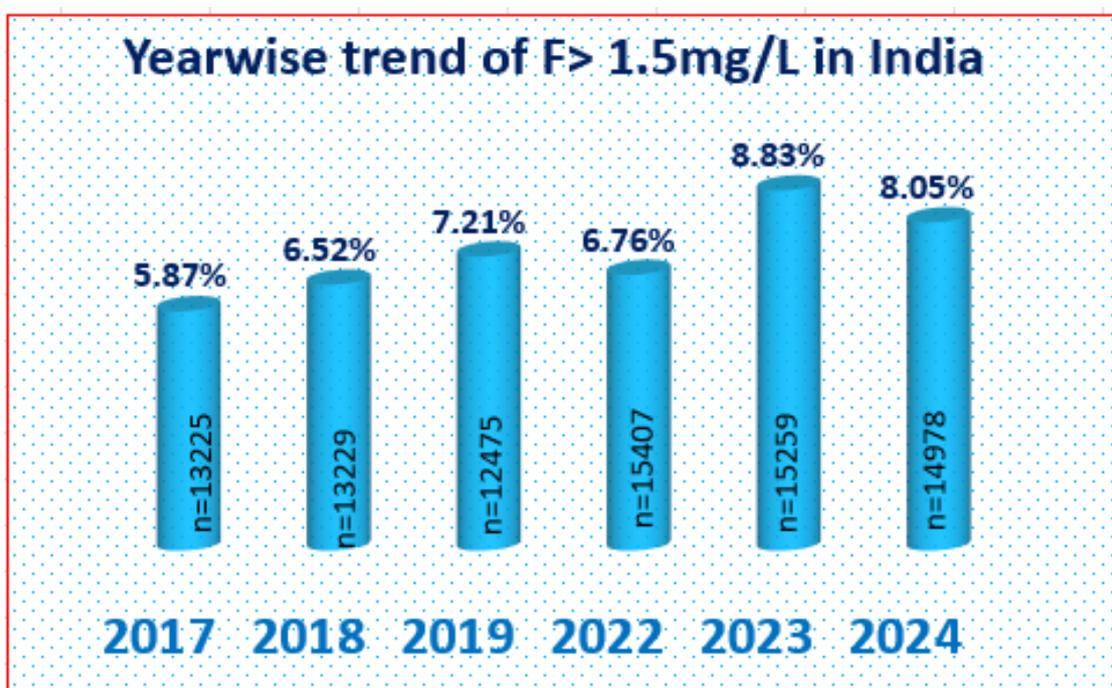


Figure 12: Year wise trend in Fluoride in Pre-Monsoon Samples During 2017-2024.

The year-wise trend of groundwater samples with fluoride concentration exceeding 1.5 mg/L (Fig.12) shows minor fluctuations between 2017 and 2024. The proportion of such samples increased gradually from 5.87% in 2017 to 8.83% in 2023, followed by a slight decline

to 8.05% in 2024. This indicates that fluoride occurrence remains relatively stable at the national level, with localized variations likely influenced by hydrogeological and climatic conditions.

Table 7: State-wise Groundwater Samples Exceeding BIS (IS 10500:2012) Permissible Limit.

Sl. No.	State/UT	No. of Samples	No. of Samples above Permissible Limit (Fluoride >1.5 mg/L)	Percentage of samples above Permissible Limit (Fluoride >1.5 mg/L)
1	Rajasthan	643	264	41.06
2	Haryana	811	177	21.82
3	NCT of Delhi	135	24	17.78
4	Karnataka	398	67	16.83
5	Telangana	1114	167	14.99
6	Punjab	756	85	11.24
7	UT of Puducherry	9	1	11.11
8	Gujarat	618	56	9.06
9	Andhra Pradesh	1135	102	8.99
10	Tamil Nadu	929	72	7.75
11	Bihar	584	39	6.68
12	Arunachal Pradesh	15	1	6.67
13	Uttar Pradesh	1333	54	4.05
14	Jharkhand	381	15	3.94
15	Chhattisgarh	830	22	2.65
16	Maharashtra	1565	28	1.79
17	Nagaland	67	1	1.49
18	Himachal Pradesh	161	2	1.24
19	Uttarakhand	248	3	1.21
20	Odisha	654	7	1.07
21	Madhya Pradesh	726	7	0.96
22	West Bengal	875	8	0.91
23	Assam	145	1	0.69
24	Kerala	361	2	0.55
25	Andaman & Nicobar Islands	115	0	0.00
26	Chandigarh UT	9	0	0.00
27	Dadra Nagar Haveli & Daman - Diu	16	0	0.00
28	Goa	7	0	0.00
29	Jammu & Kashmir	247	0	0.00
30	Manipur	3	0	0.00
31	Meghalaya	39	0	0.00
32	Tripura	49	0	0.00
	Total	14978	1205	8.05

The occurrence of high fluoride is commonly associated with crystalline and hard rock aquifers, such as granite and gneissic formations, where prolonged water–rock interaction leads to the dissolution of fluoride-bearing minerals. Table-7 highlights significant regional disparities in groundwater fluoride concentration across India. Several States and Union Territories — Andaman & Nicobar Islands, Chandigarh, Dadra & Nagar Haveli & Daman & Diu, Goa, Jammu & Kashmir, Manipur, Meghalaya, and Tripura — recorded 0% exceedance, reflecting generally good groundwater quality with respect to fluoride. Overall, the data indicate

that fluoride occurrence is region-specific, mainly affecting hard rock areas in arid and semi-arid zones, while most other regions remain within safe limits

4.4.1: Understanding the Impact of Seasonal Variation of Groundwater Fluoride concentration (Pre- and Post-Monsoon 2024).

The maps (Fig. 13) present the spatial distribution of Fluoride in groundwater across India during pre- and post-monsoon, 2024. The categorization is based on BIS guidelines, 10500. High fluoride occurrences are prominently observed in the arid and semi-arid regions of Rajasthan, Gujarat, Madhya Pradesh, Telangana, Andhra Pradesh, Karnataka, and parts of Odisha.

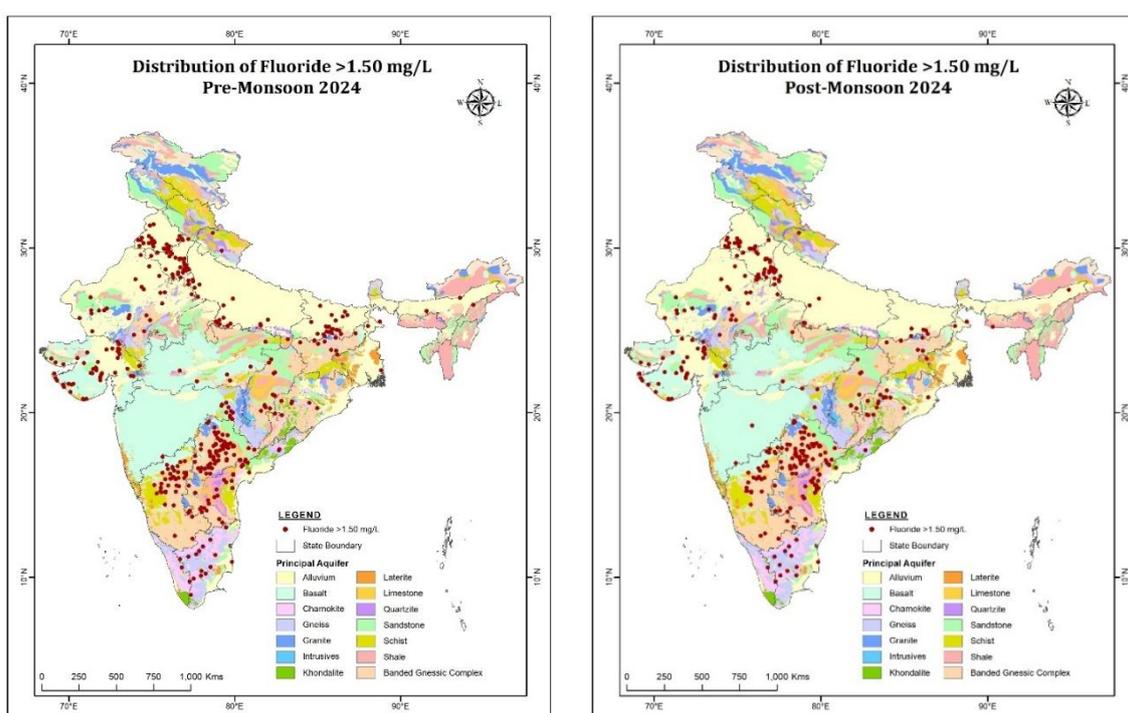


Figure 13: Distribution of Groundwater Fluoride (>1.5 mg/L) in India (Pre- and Post-Monsoon 2024).

The post-monsoon distribution shows a slight reduction in the density of high-fluoride locations in certain areas such as southern Rajasthan, Gujarat, and northern Karnataka, possibly due to dilution from rainfall recharge.

However, persistent hotspots remain in central and southern India, indicating limited flushing and strong geogenic control on fluoride occurrence.

Overall, the comparison highlights that while monsoon recharge helps improve water quality in some regions, salinity remains a persistent issue in arid and semi-arid zones, requiring continuous monitoring and management interventions.

One interesting aspect of water quality is how it changes with seasons particularly before and after monsoon. The analysis of groundwater samples during 2024 reveals distinct seasonal variations in fluoride concentration across India. During the pre-monsoon, about 82.56% of samples recorded fluoride concentrations below 1.0 mg/L, indicating that the majority of groundwater sources fall within the desirable limit prescribed by BIS (IS 10500:2012). Approximately 10.1% of the samples showed fluoride levels between 1.0 and 1.5 mg/L, representing marginally high concentrations. Around 7.34% of samples exceeded the permissible limit of 1.5 mg/L, reflecting areas of concern where long-term exposure could pose health risks such as dental or skeletal fluorosis.

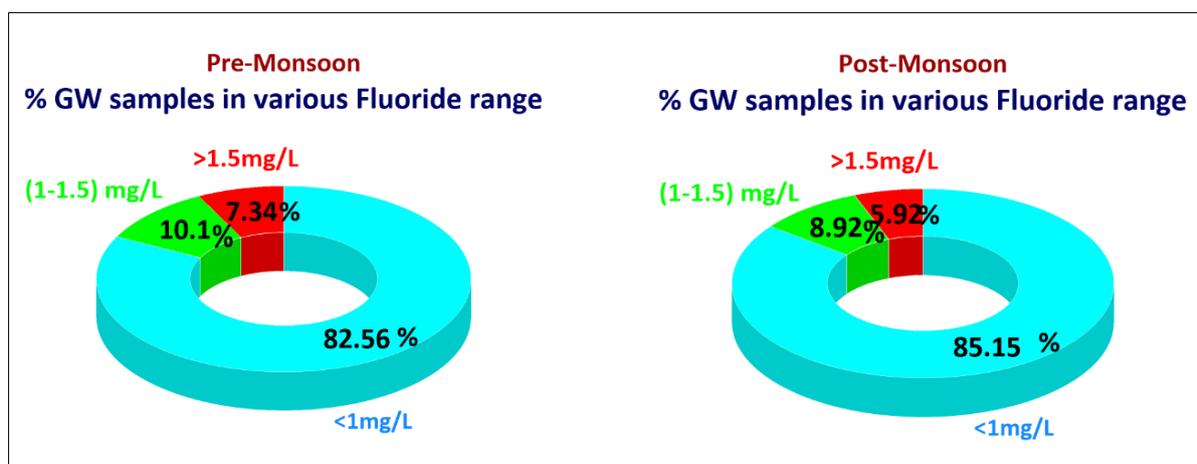


Figure 14: Percentage groundwater samples in various EC range, 2024 (Pre & Post)

In the **post-monsoon** period, a marginal improvement in groundwater quality was observed. The proportion of samples with fluoride below 1.0 mg/L increased to **85.15%**, while the percentage of samples exceeding 1.5 mg/L decreased slightly to **5.92%**. This reduction suggests a **dilution effect due to monsoon recharge**, which temporarily lowers fluoride concentrations in the aquifer system.

The proportion of samples exceeding **1.5 mg/L** declined from **7.34% in pre-monsoon to 5.92%**. Concurrently, the share of samples with fluoride below **1.0 mg/L** increased to **85.15%**, further supporting the dilution.

Overall, the comparison (Fig.14) indicates a general decline in the number of samples exceeding 1.5 mg/L fluoride concentration during the post-monsoon, attributed mainly to dilution from monsoon recharge. However, the persistence of high fluoride levels in Telangana, Gujarat, and Karnataka highlights areas where fluoride contamination is dominantly geogenic and less influenced by seasonal recharge processes. Pre-Post changes in Fluoride concentration in Ground Water in states have been presented in Table 8. Figure - 15 compares the number of

groundwater sampling locations with fluoride concentrations above the permissible limit (1.5 mg/L) during pre-monsoon and post-monsoon 2024 across major states.

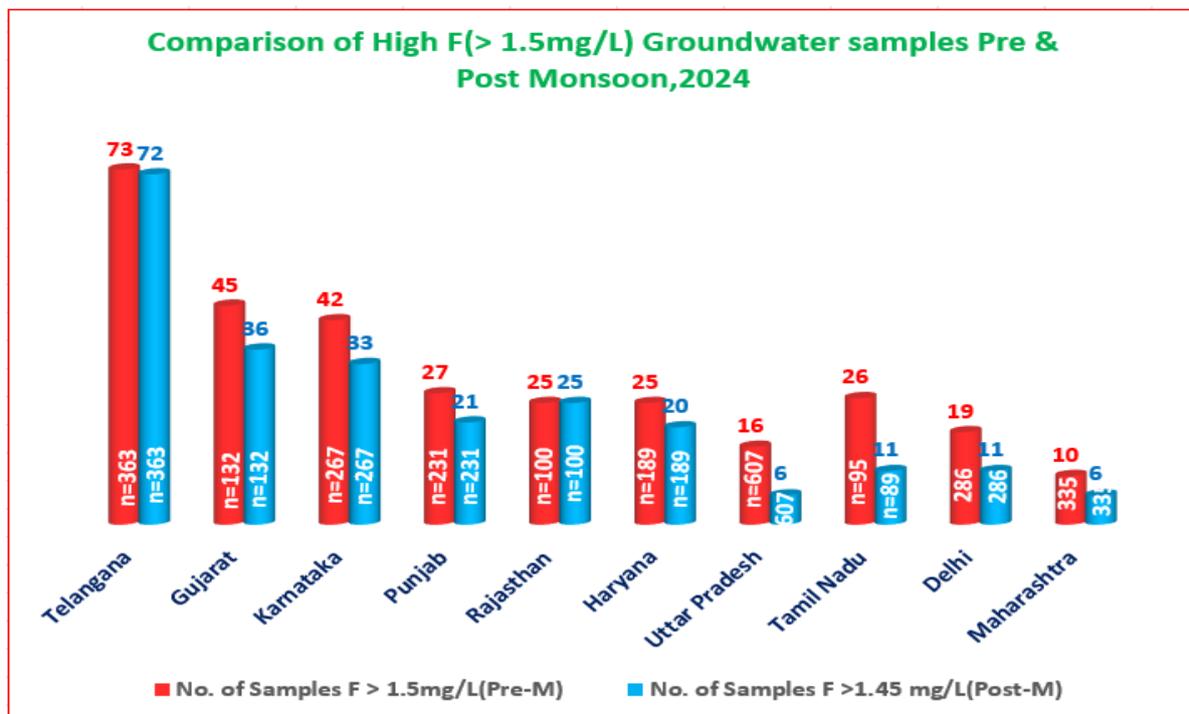


Figure 15 :Comparison of High Fluoride Groundwater samples during pre & post-monsoon,2024.

In most states, the number of high-fluoride sites remains broadly similar before and after the monsoon, with slight reductions seen in Gujarat, Delhi and Uttar Pradesh.

Table 8: State/UT-wise Fluoride values during Pre- and Post-Monsoon 2024 at common location.

Sl. No.	District	No. of Samples Analysed (Common Locations-2024)	No. of Samples					
			Fluoride <1.0 mg/L		Fluoride 1-1.5 mg/L		Fluoride > 1.5 mg/L	
			Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	27	28	1	0	0	0
2	Andhra Pradesh	313	228	246	54	40	31	27
3	Arunachal Pradesh	15	13	15	1	0	1	0
4	Assam	127	117	126	9	0	1	1
5	Bihar	115	70	86	23	24	22	5
6	Chandigarh	8	7	8	1	0	0	0
7	Chhattisgarh	249	209	234	28	8	12	7
8	Delhi	86	57	54	10	11	19	21
9	Goa	2	2	2	0	0	0	0
10	Gujarat	132	63	65	24	31	45	36
11	Haryana	189	137	133	27	36	25	20

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Sl. No.	District	No. of Samples Analysed (Common Locations-2024)	No. of Samples					
			Fluoride <1.0 mg/L		Fluoride 1-1.5 mg/L		Fluoride > 1.5 mg/L	
			Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
12	Himachal Pradesh	43	41	42	1	1	1	0
13	Jammu & Kashmir	61	60	60	1	1	0	0
14	Jharkhand	138	103	117	26	16	9	5
15	Karnataka	267	175	186	50	48	42	33
16	Kerala	185	178	181	5	3	2	1
17	Madhya Pradesh	577	532	552	39	24	6	1
18	Maharashtra	335	313	313	12	17	10	5
19	Manipur	3	3	3	0	0	0	0
20	Meghalaya	38	38	37	0	0	0	1
21	Nagaland	67	63	67	3	0	1	0
22	Odisha	413	381	366	26	32	6	15
23	Punjab	231	179	181	25	29	27	21
24	Rajasthan	100	54	58	21	17	25	25
25	Tamil Nadu	286	244	245	28	30	14	11
26	Telangana	363	225	244	65	47	73	72
27	Tripura	44	43	44	1	0	0	0
28	UT of Puducherry	7	6	6	0	0	1	1
29	Uttar Pradesh	607	531	545	60	56	16	6
30	Uttarakhand	103	101	96	0	6	2	1
31	West Bengal	236	232	231	1	2	3	3
	Total	5368	4432	4571	542	479	394	318

Table 9: Status of Improvement and Deterioration in Groundwater Quality (Pre- vs. Post-Monsoon 2024).

Sl. No.	District	No. of Samples Analysed (Common Locations for Pre- and Post-M)	No. of Improved Locations	No. of Deteriorated Locations	No. of Locations (Where Improvement is within 20% w.r.t Pre-M Value)	No. of Locations (Where Improvement is beyond 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is within 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is beyond 20% w.r.t Pre-M Value)
					No Significant improvement	Significant Improvement	No Significant Deterioration	Significant Deterioration
1	A&N Islands	28	14	13	2	12	7	6
2	Andhra Pradesh	313	180	130	53	127	28	102
3	Arunachal Pradesh	15	13	2	0	13	0	2
4	Assam	127	77	47	2	75	3	44
5	Bihar	115	87	27	11	76	5	22
6	Chandigarh	8	4	3	4	0	1	2

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Sl. No.	District	No. of Samples Analysed (Common Locations for Pre- and Post-M)	No. of Improved Locations	No. of Deteriorated Locations	No. of Locations (Where Improvement is within 20% w.r.t Pre-M Value)	No. of Locations (Where Improvement is beyond 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is within 20% w.r.t Pre-M Value)	No. of Locations (Where Deterioration is beyond 20% w.r.t Pre-M Value)
					No Significant improvement	Significant Improvement	No Significant Deterioration	Significant Deterioration
7	Chhattisgarh	249	191	53	18	173	8	45
8	Delhi	86	34	47	10	24	9	38
9	Goa	2	2	0	0	2	0	0
10	Gujarat	132	68	64	21	47	22	42
11	Haryana	189	72	114	32	40	32	82
12	Himachal Pradesh	43	21	20	1	20	1	19
13	Jammu & Kashmir	61	38	23	14	24	5	18
14	Jharkhand	138	70	66	16	54	14	52
15	Karnataka	267	130	136	33	97	31	105
16	Kerala	185	91	67	13	78	6	61
17	Madhya Pradesh	577	288	270	82	206	51	219
18	Maharashtra	335	130	194	32	98	37	157
19	Manipur	3	1	2	0	1	0	2
20	Meghalaya	38	13	24	0	13	0	24
21	Nagaland	67	31	35	2	29	0	35
22	Odisha	413	197	200	38	159	35	165
23	Punjab	231	87	138	42	45	35	103
24	Rajasthan	100	59	36	24	35	16	20
25	Tamil Nadu	286	151	120	47	104	31	89
26	Telangana	363	212	147	64	148	45	102
27	Tripura	44	31	13	0	31	0	13
28	UT of Puducherry	7	2	2	1	1	1	1
29	Uttar Pradesh	607	355	224	117	238	107	117
30	Uttarakhand	103	27	75	4	23	3	72
31	West Bengal	236	92	132	49	43	33	99
	Total	5368	2768	2424	732	2036	566	1858

The table-9 presents a comparative assessment of groundwater quality variations between pre- and post-monsoon 2024, based on common monitoring locations across India.

A closer analysis shows that 20% or greater improvement (significant improvement) was observed at 2,036 locations, whereas significant deterioration (>20% increase in concentration) occurred at 1858 locations, reflecting localized recharge and contamination dynamics. States such as Odisha, Uttar Pradesh, Chhattisgarh, and Telangana recorded a higher

number of improved sites, suggesting positive monsoonal recharge effects and dilution of Fluoride.

Overall, the analysis highlights that nearly half of the monitored locations showed quality improvement post-monsoon, emphasizing the beneficial dilution effect of rainfall recharge, while the persistence of deterioration at comparable proportions indicates site-specific factors such as aquifer type, land use, and contamination load governing groundwater chemistry.

4.4.2 Remedial Measures for Fluoride

The fluoride remedial measures broadly adopted are ex-situ techniques. They can be classified into three major categories (Fig.16).

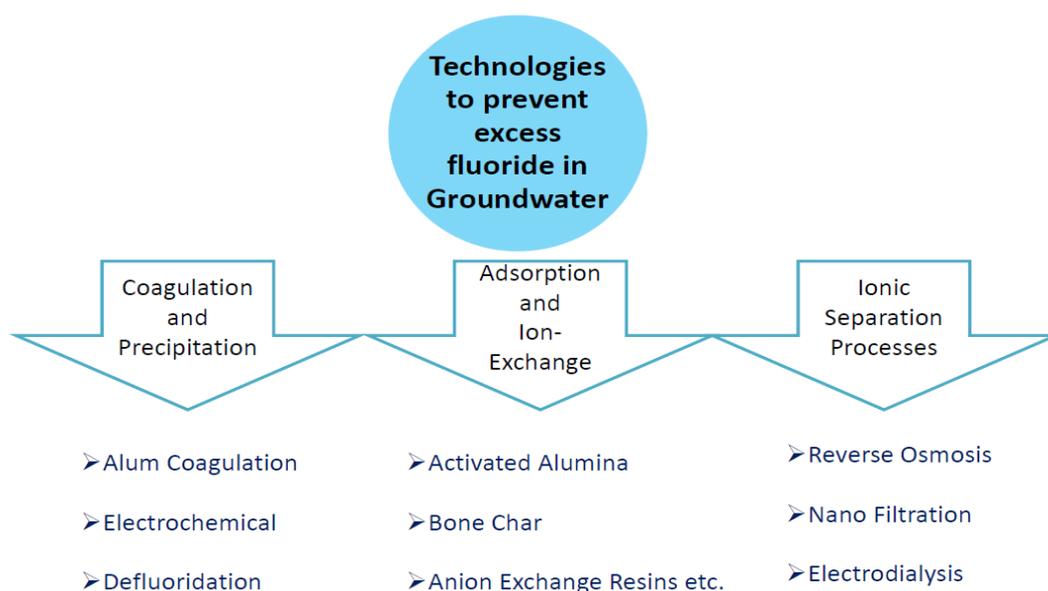


Figure 16: Process-Based Classification of Fluoride Mitigation Methods.

(a) Adsorption and ion exchange

This technique functions on the adsorption of fluoride ions onto the surface of an active agent such as activated alumina, red mud, bone char, brick pieces column, mud pot and natural adsorbents where fluoride is removed by ion exchange or surface chemical reaction with the solid bed matrix. Amidst the commonly employed methods for fluoride removal, the adsorption approach provides a outstandingly effective and economical procedure for reducing fluoride levels from water within the permissible level of 1.5 mg/L. In adsorption process fluoride enriched water is passed through a contact bed of adsorbent used, the Fluoride gets adsorbed on adsorbent surface and easily gets removed by ion exchange or surface chemical reaction. After

a period of operation, saturated adsorbents must be refilled or regenerated. Various adsorbents used for fluoride removal include Activated Alumina (AA), Bone char, Bauxite, Hematite, Magnesia, various rare earth materials, fly ash, limestone and clay, polymeric resins, granular ceramics.

(b) Coagulation-precipitation

Precipitation methods are based on the addition of chemicals (coagulants and coagulant aids) and the subsequent precipitation of a sparingly soluble fluoride salt as insoluble. Fluoride removal is accomplished with separation of solids from liquid. Aluminium salts (eg. Alum), lime, Poly Aluminium Chloride, Poly Aluminium Hydroxy sulphate and Brushite are some of the frequently used materials in defluoridation by precipitation technique. The best example for this technique is the famous Nalgonda technique.

Nalgonda Technique

Nalgonda technique involves addition of Aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. It is opined that this technique is preferable at all levels because of the low price and ease of handling, is highly versatile and can be used in various scales from household level to community scale water supply.

The Nalgonda technique can be used for raw water having fluoride concentration between 1.5 and 20 mg/L and the total dissolved solids should be <1500 mg/L, and total hardness < 600 mg/L. The alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to it and to retain a minimum residual alkalinity of 1 - 2 meq/L in the treated water to achieve a pH of 6.5 - 8.5 in treated water. Several researchers have attempted to improve the technique by increasing the removal efficiency of fluoride using Poly Aluminium Chloride (PAC) and Poly Aluminium Hydroxy Sulphate (PAHS).

(c) Ionic Separation Processes

Reverse osmosis, nanofiltration, dialysis and electro dialysis are physical methods that have been tested for defluoridation of water. Though they are effective in removing fluoride salts from water, however, there are certain procedural disadvantages that limit their usage on a large scale.

4.4.3 Recommended Interventions for Fluoride-affected Regions

To safeguard drinking water quality in fluoride-affected regions, a combination of source selection, blending, treatment, and community awareness measures is recommended. High-yielding wells with naturally low fluoride concentrations should be identified and prioritized for supplying drinking water to populations dependent on fluoride-enriched wells. Where feasible, blending of water from high-fluoride wells with that from low-fluoride sources may be adopted to achieve concentrations within the permissible limit.

Further, multi-village piped water supply schemes utilizing surface water with conventional treatment should be developed, particularly in areas where groundwater consistently exhibits excess fluoride. The design and implementation of such schemes should be guided by the hydrogeological setting and local economic conditions, ensuring both sustainability and affordability.

In regions where no alternate source is available, water treatment plants (WTPs) provide a viable option for ensuring safe drinking water. For example, the Public Health Engineering Department, Government of Bihar has already implemented WTPs to supply potable water to fluoride-affected rural households.

In addition to technological interventions, public awareness campaigns are crucial. Communities residing in high-fluoride areas must be sensitized to the adverse health impacts of dental and skeletal fluorosis and encouraged to adopt safe water practices. Reducing both the concentration of fluoride in drinking water and the duration of continuous exposure remains essential to mitigate long-term health risks.

4.5 Nitrate

Nitrate in drinking water is a serious health concern. It mainly comes from excessive use of fertilizers, animal waste, and sewage seeping into groundwater. In India, nearly **20.71% of groundwater samples** have been reported to exceed the permissible limit of **45 mg/L**, as prescribed by the **World Health Organization (WHO)** and the **Bureau of Indian Standards (IS 10500)** for drinking water quality. Elevated nitrate concentrations pose serious health risks, most notably **methemoglobinemia (blue baby syndrome)** in infants, while prolonged exposure may also affect adults, although they can tolerate slightly higher levels. Importantly, the prescribed limits must not be exceeded in public water supply systems, as any exceedance renders the water **unfit for human consumption**. The aqueous geochemical behavior of nitrogen is strongly influenced by its essential role in plant and animal nutrition. Among the

various nitrogen species, **nitrate (NO_3^-)** is the most common contaminant detected in groundwater systems. Since the natural nitrogen content of soils is generally low, farmers frequently rely on external inputs such as **ammonium nitrate, calcium nitrate, urea, and diammonium hydrogen phosphate** to meet crop nutrient requirements.

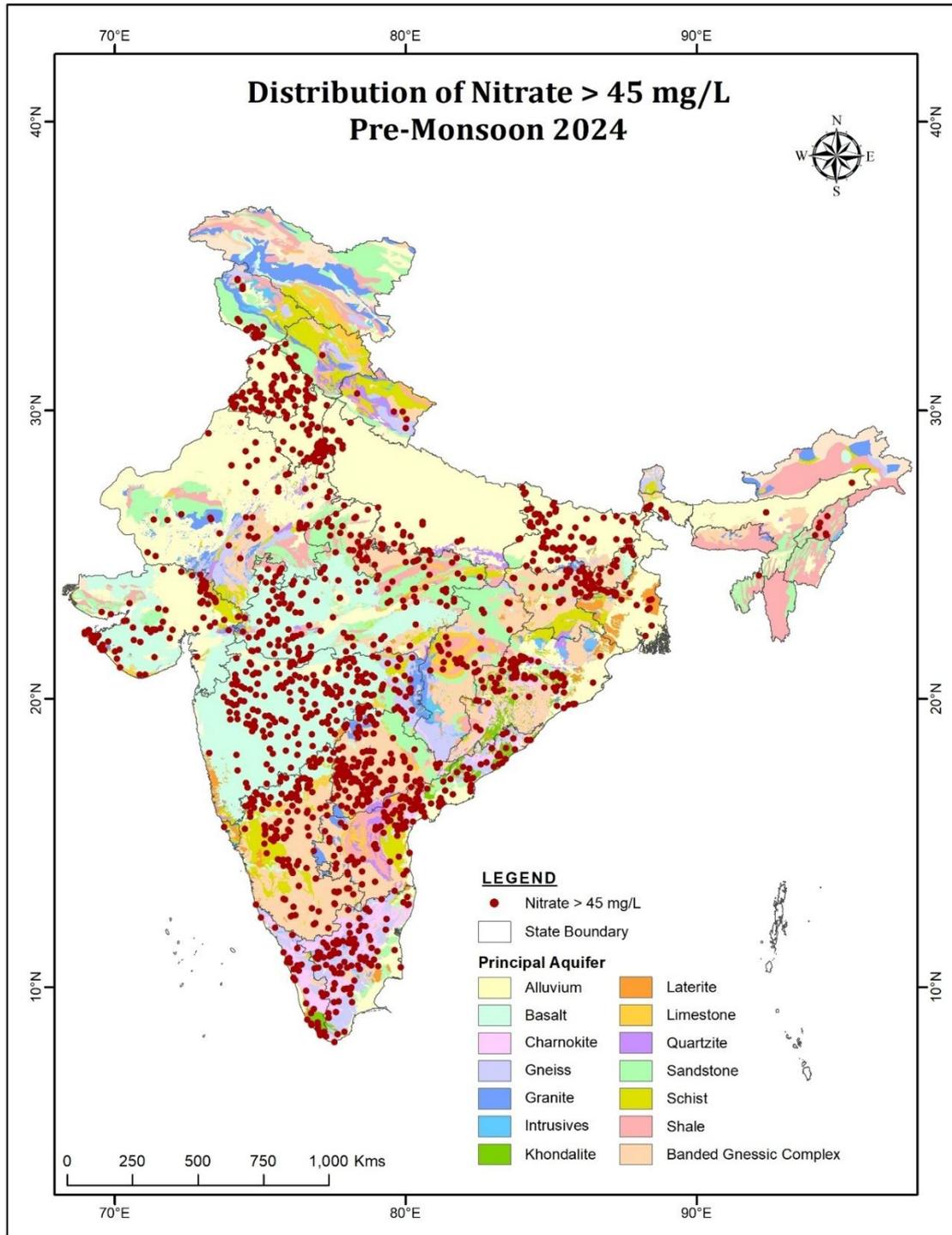


Figure 17: Distribution of Nitrate concentration in India during Pre-monsoon (May, 2024)

Although nitrate is the predominant form of nitrogen in groundwater, other dissolved species may also be present, including **ammonium (NH₄⁺)**, **ammonia (NH₃)**, **nitrite (NO₂⁻)**, **molecular nitrogen (N₂)**, **nitrous oxide (N₂O)**, and **organically bound nitrogen**. The occurrence of nitrate in groundwater typically originates from nitrogen sources at or near the land surface, particularly within the soil zone or shallow subsoil layers where nitrogen-rich wastes are deposited. In many cases, elevated nitrate concentrations result from the leaching of **fertilizers, animal wastes, or other nitrogenous residues** applied to agricultural fields, which subsequently percolate into the aquifer system.

The occurrences of Nitrate in ground water beyond permissible limit (45 mg /L) have been shown on the map as a point source in **Fig 17**. In the pre-monsoon Nitrate is ranging from BDL to 2070 mg/L with a mean value of 32 mg/L. High nitrate concentrations are prominently observed in northwestern and central India, particularly in the states of Rajasthan, Haryana, Punjab, Gujarat, Madhya Pradesh, and Maharashtra, extending further into parts of Telangana, Andhra Pradesh, Karnataka, and Tamil Nadu. These areas correspond largely to alluvial and hard-rock aquifers, where intensive agricultural practices, excessive fertilizer application, and improper disposal of domestic and animal wastes contribute to nitrate enrichment. Elevated nitrate levels in the Indo-Gangetic plains (Uttar Pradesh, Bihar, and West Bengal) indicate impacts of shallow groundwater vulnerability due to unlined sanitation systems and leaching from agricultural fields.

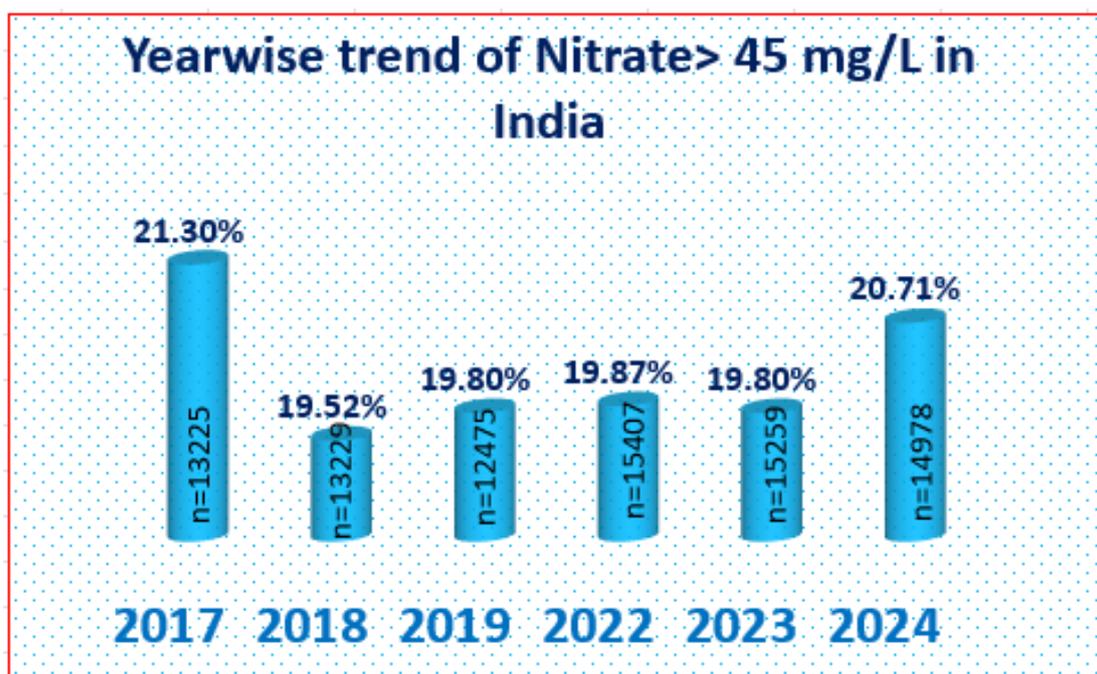


Figure 18:Year wise trend in Nitrate in Pre-Monsoon Samples During 2017-2024.

The yearwise trend of groundwater samples exceeding 45 mg/L nitrate concentration (Fig.18) indicates that the extent of nitrate contamination in India has remained largely consistent over the years, with minor annual fluctuations. The proportion of samples exceeding the permissible limit ranged between 19.5% and 21.3% during 2017–2024.

Table 10: State-wise Groundwater Samples Exceeding BIS (IS 10500:2012) Permissible Limit.

Sl. No.	State/UT	No. of Samples	No. of Samples above Permissible Limit (Nitrate >45 mg/L)
1	Rajasthan	643	325
2	Karnataka	398	181
3	Tamil Nadu	929	337
4	Maharashtra	1565	531
5	Telangana	1114	290
6	NCT of Delhi	135	33
7	Andhra Pradesh	1135	275
8	Madhya Pradesh	726	160
9	Gujarat	618	117
10	Jharkhand	381	66
11	Punjab	756	111
12	Goa	7	1
13	Haryana	811	115
14	Bihar	584	78
15	Uttarakhand	248	33
16	Odisha	654	84
17	Himachal Pradesh	161	19
18	UT of Puducherry	9	1
19	Kerala	361	39
20	Chhattisgarh	830	88
21	Nagaland	67	7
22	Jammu & Kashmir	247	23
23	West Bengal	875	78
24	Uttar Pradesh	1333	107
25	Tripura	49	1
26	Assam	145	2
27	Andaman & Nicobar Islands	115	0
28	Arunachal Pradesh	15	0
29	Chandigarh UT	9	0
30	Dadra and Nagar Haveli and Daman and Diu	16	0
31	Manipur	3	0
	Total	14978	3102

State-wise no. of water samples analysed and no. of locations having Nitrate > 45 mg/L during pre-monsoon is presented in **Table 10**.

4.5.1: Understanding the Impact of Seasonal Variation of Groundwater Nitrate concentration (Pre- and Post-Monsoon 2024).

The maps (Fig. 19) present the spatial distribution of Nitrate in groundwater across India during pre- and post-monsoon, 2024. The spatial distribution of groundwater samples with

nitrate concentration exceeding 45 mg/L (BIS permissible limit) during pre- and post-monsoon 2024 reveals that nitrate contamination is widespread across the country, with minor seasonal variation between the two periods.

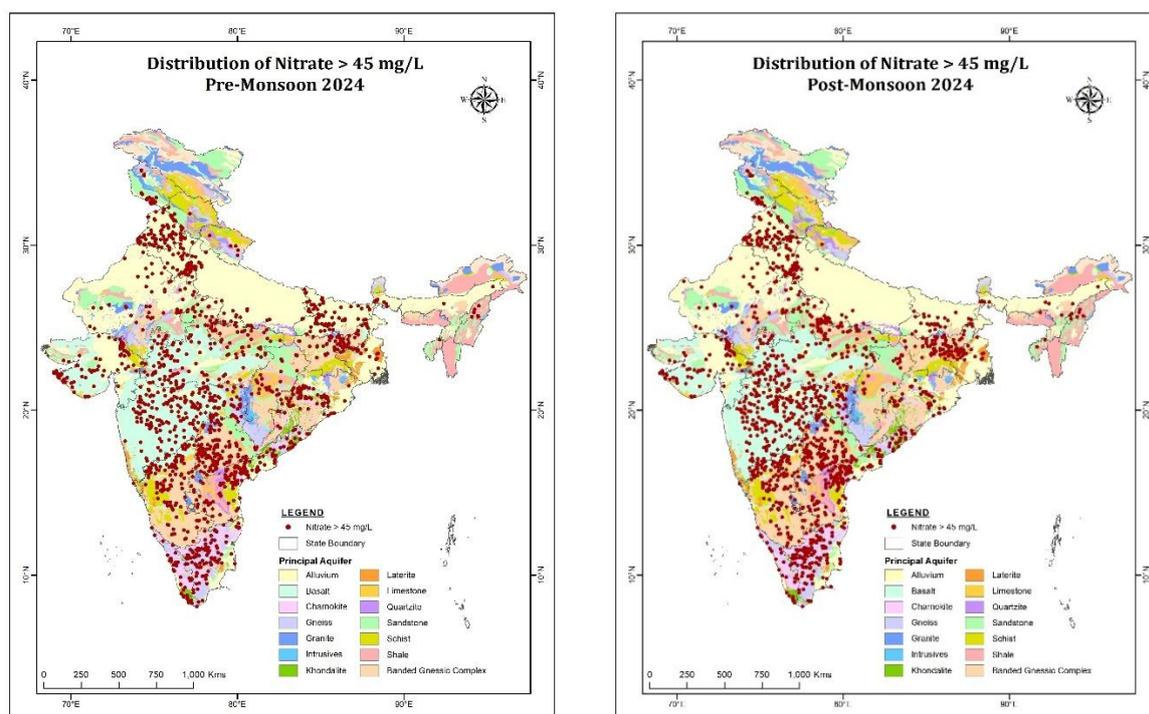


Figure 19: Distribution of Groundwater Nitrate (>45 mg/L) in India (Pre- and Post-Monsoon 2024).

One interesting aspect of water quality is how it changes with seasons particularly before and after monsoon.

During the pre-monsoon period, about 73.53% of samples were within the permissible limit, while 26.47% exceeded it (Fig.20). In the post-monsoon period, compliance remained nearly similar, with 72.95% of samples meeting the standard and 27.05% exceeding it. This indicates that nitrate contamination persists with only marginal seasonal variation, suggesting that rainfall recharge has limited dilution effect on nitrate concentrations in groundwater.

The consistent exceedance of nitrate levels in approximately one-fourth of the monitored samples highlights the continued influence of anthropogenic sources such as fertilizer leaching, domestic wastewater infiltration, and unlined sanitation systems, especially in shallow aquifers. The findings emphasize the need for sustainable nutrient management and improved waste disposal practices to control nitrate loading in groundwater.

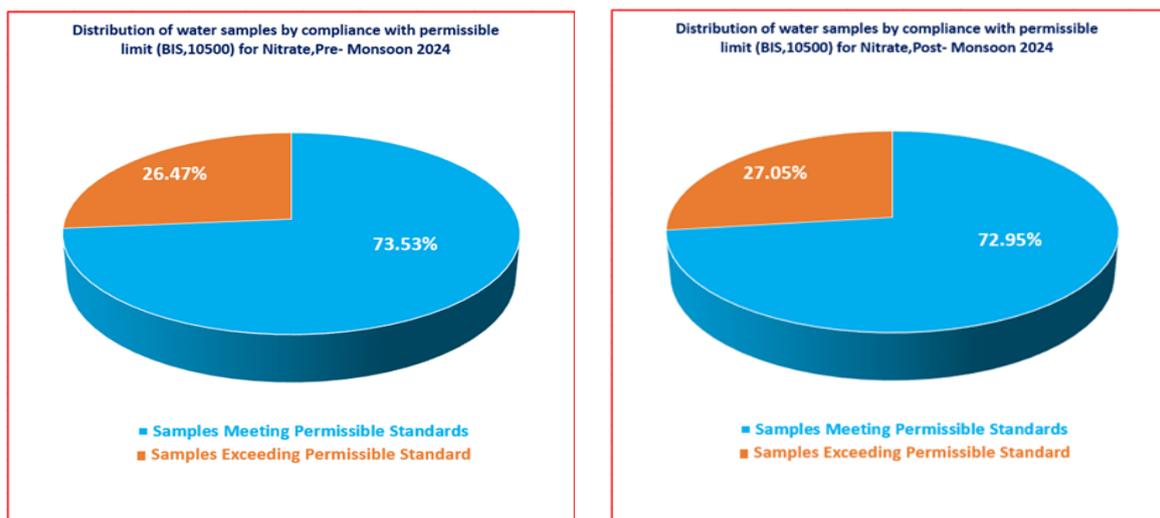


Figure 20: Status of Nitrate Contamination in Groundwater: Pre- and Post-Monsoon Comparison (2024)

The comparison of groundwater samples exceeding 45 mg/L nitrate concentration shows that nitrate occurrence is widespread across several states, with only minor seasonal variation between pre- and post-monsoon 2024. Higher numbers of affected samples are observed in Maharashtra, Madhya Pradesh, Andhra Pradesh, Telangana, and Karnataka, indicating continued influence of agricultural and domestic sources.

In a few states such as Punjab, Uttar Pradesh, and Gujarat, a slight reduction in high-nitrate samples after the monsoon suggests some dilution effect from rainfall recharge.

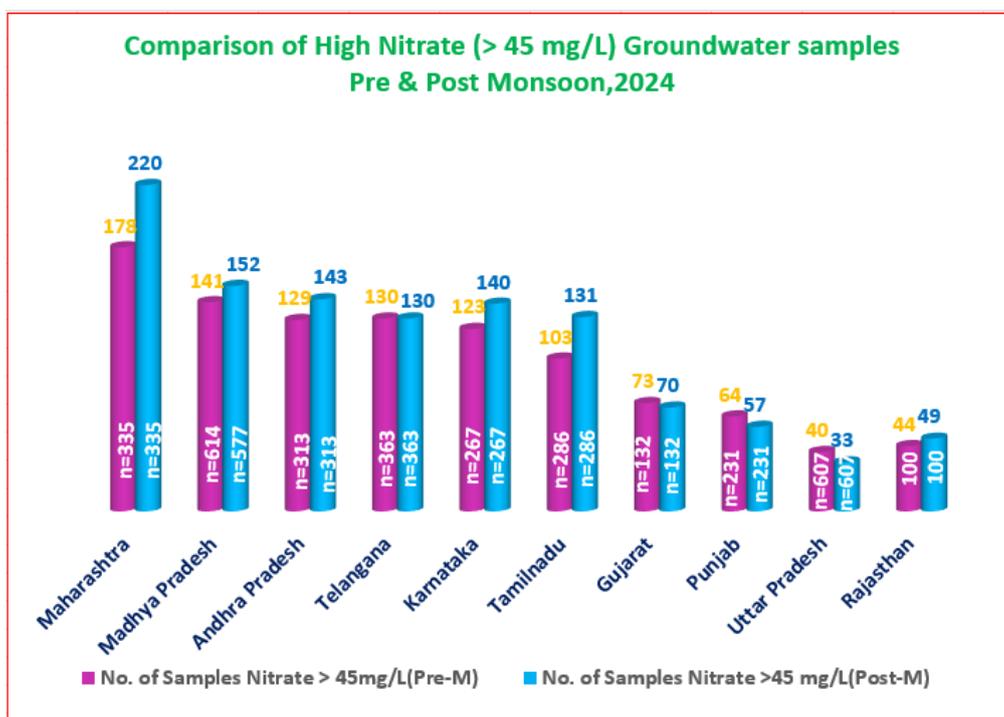


Figure 21: Comparison of High Fluoride Groundwater samples during pre & post-monsoon, 2024

Table 11: State/UT-wise Nitrate values during Pre- and Post-Monsoon 2024 at common location.

Sl. No.	District	No. of Samples Analysed (Common Locations-2024)	No. of Samples			
			Nitrate <45 mg/L		Nitrate > 45 mg/L	
			Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	28	28	0	0
2	Andhra Pradesh	313	184	170	129	143
3	Arunachal Pradesh	15	15	15	0	0
4	Assam	127	125	122	2	5
5	Bihar	115	44	89	71	26
6	Chandigarh	8	8	8	0	0
7	Chhattisgarh	249	223	230	26	19
8	Delhi	86	61	63	25	23
9	Goa	2	1	1	1	1
10	Gujarat	132	59	62	73	70
11	Haryana	189	154	143	35	46
12	Himachal Pradesh	43	28	35	15	8
13	Jammu & Kashmir	61	40	39	21	22
14	Jharkhand	138	84	78	54	60
15	Karnataka	267	144	127	123	140
16	Kerala	185	153	160	32	25
17	Madhya Pradesh	577	436	425	141	152
18	Maharashtra	335	157	115	178	220
19	Manipur	3	3	3	0	0
20	Meghalaya	38	38	37	0	1
21	Nagaland	67	60	60	7	7
22	Odisha	413	341	375	72	38
23	Punjab	231	167	174	64	57
24	Rajasthan	100	56	51	44	49
25	Tamil Nadu	286	183	155	103	131
26	Telangana	363	233	233	130	130
27	Tripura	44	43	42	1	2
28	UT of Puducherry	7	7	5	0	2
29	Uttar Pradesh	607	567	574	40	33
30	Uttarakhand	103	98	102	5	1
31	West Bengal	236	207	195	29	41
	Total	5368	3947	3916	1421	1452

Table 12: Comparative Status of Nitrate Improvement and Deterioration in Groundwater, 2024

Sl. No.	District	No. of Samples Analysed (Common Locations for Pre- and Post-M)	No. of Improved Locations	No. of Deteriorated Locations	No. of Locations (Where Improvement is within 20% w.r.t Pre-M Value)		No. of Locations (Where Deterioration is beyond 20% w.r.t Pre-M Value)	
					No Significant Improvement	Significant Improvement	No Significant Deterioration	Significant Deterioration
1	A&N Islands	28	15	11	0	15	1	10
2	Andhra Pradesh	313	150	158	31	119	25	133
3	Arunachal Pradesh	15	7	6	1	6	0	6
4	Assam	127	54	61	6	48	4	57
5	Bihar	115	94	20	6	88	3	17
6	Chandigarh	8	2	3	0	2	0	3
7	Chhattisgarh	249	144	80	44	100	12	68
8	Delhi	86	45	34	11	34	6	28
9	Goa	2	2	0	0	2	0	0
10	Gujarat	132	62	64	14	48	14	50
11	Haryana	189	63	97	25	38	20	77
12	Himachal Pradesh	43	29	12	9	20	0	12
13	Jammu & Kashmir	61	36	24	6	30	3	21
14	Jharkhand	138	62	75	16	46	16	59
15	Karnataka	267	115	147	25	90	15	132
16	Kerala	185	97	70	13	84	11	59
17	Madhya Pradesh	577	211	359	65	146	48	311
18	Maharashtra	335	91	239	27	64	51	188
19	Manipur	3	0	2	0	0	0	2
20	Meghalaya	38	22	11	4	18	1	10
21	Nagaland	67	24	34	3	21	2	32
22	Odisha	413	230	165	41	189	15	150
23	Punjab	231	111	84	28	83	15	69
24	Rajasthan	100	52	41	19	33	9	32
25	Tamil Nadu	286	111	169	23	88	17	152
26	Telangana	363	187	166	27	160	20	146
27	Tripura	44	21	18	5	16	1	17
28	UT of Puducherry	7	1	6	1	0	0	6
29	Uttar Pradesh	607	273	217	83	190	39	178
30	Uttarakhand	103	60	13	6	54	1	12
31	West Bengal	236	79	122	18	61	13	109
	Total	5368	2450	2508	557	1893	362	2146

The comparative assessment of nitrate concentration between pre- and post-monsoon 2024, based on 5368 common monitoring locations across the country, shows a mixed pattern of improvement and deterioration in groundwater quality. Out of the total locations, 2450 sites exhibited improvement, while 2508 sites showed deterioration, indicating an almost balanced overall trend with minor seasonal variability.

A detailed examination reveals that 1893 locations showed significant improvement (beyond 20% reduction in nitrate concentration), whereas 2146 locations experienced significant deterioration (beyond 20% increase).

4.5.2 Nitrate Removal Options in Groundwater

The removal of nitrate from groundwater can be achieved through both non-treatment approaches and treatment-based technologies, though it is important to note that no single method is capable of eliminating all nitrogen species completely.

a) Methods involving no treatment: In order to use any of these options the nitrate problem must be local-scale. Common methods are –

- Raw water source substitution
- Blending with low nitrate waters

This greatly reduces expenses and helps to provide safer drinking water to larger numbers of people.

b) Methods involving Treatment:

They are as follows

- Adsorption/Ion Exchange
- Reverse Osmosis
- Electrodialysis
- Bio-chemical Denitrification (By using denitrifying bacteria and microbes)
- Catalytic Reduction/Denitrification (using hydrogen gas)

The **mechanism of nitrate persistence in groundwater** is influenced by **complex biogeochemical processes**, including recharge conditions and water–rock interactions. Unlike other contaminants such as fluoride, arsenic, or heavy metals, nitrate is highly soluble with limited potential for co-precipitation or adsorption, making traditional treatment methods such as coagulation, lime softening, or filtration largely ineffective.

According to King et al. (2012), nitrate treatment technologies can be broadly categorized into:

- **Nitrate removal technologies** – physical processes (e.g., RO, ion exchange, electrodialysis) that extract nitrate without altering its chemical state.

- **Nitrate reduction technologies** – biochemical or catalytic processes that transform nitrate ions into other nitrogen species, such as **ammonia** or harmless **nitrogen gas**.

Bioremediation has emerged as a promising and sustainable technique for the mitigation of nitrate contamination in groundwater. This method relies on the activity of **denitrifying bacteria and microorganisms**, which reduce nitrate ions (NO_3^-) into gaseous forms of nitrogen (N_2 or N_2O) under anaerobic conditions, thereby permanently removing nitrate from the water system. The efficiency of this process depends on factors such as the availability of organic carbon, redox potential, aquifer geochemistry, and groundwater flow conditions.

In-situ bioremediation involves enhancing the natural microbial activity within the aquifer by injecting suitable electron donors (e.g., acetate, ethanol, or molasses), which stimulate denitrification at the contamination site. **Ex-situ bioremediation**, on the other hand, treats pumped groundwater through bioreactors or constructed wetlands before re-injecting or supplying it for use.

Compared to physicochemical processes like reverse osmosis or ion exchange, bioremediation offers the advantages of **lower operational costs, minimal secondary waste generation, and long-term sustainability**. However, its application requires careful monitoring to avoid the production of undesirable by-products (such as nitrite or ammonium) and to ensure stable microbial activity. Recent studies also highlight the potential of **engineered bio-barriers and permeable reactive zones**, which use organic substrates to promote denitrification as groundwater flows through them.

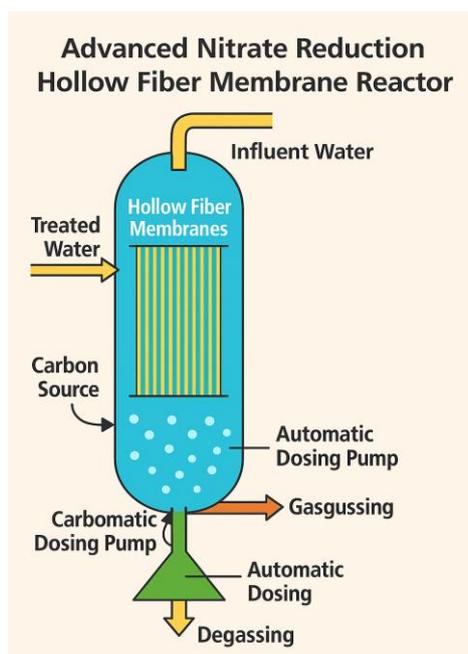


Figure 22: Advanced Nitrate Reduction Hollow Fiber Membrane Reactor (Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India)

Below are the strategies and practices to prevent and mitigate high nitrate contamination in groundwater:

4.5.3 Management Interventions to Control Nitrate Contamination

Efficient Fertilizer Management

- ❖ **Soil Testing:** Conduct regular soil tests to assess nutrient levels and determine precise fertilizer requirements. This ensures that fertilizers are applied in the correct amounts, reducing wastage.
- ❖ **Fertilizer Timing:** Apply fertilizers during periods when crops are most likely to absorb nutrients, minimizing the potential for nitrate runoff or leaching.
- ❖ **Use of Organic Fertilizers:** Encourage the use of organic fertilizers, which release nutrients more slowly and can help improve soil structure and water retention.

Septic System Maintenance

- ❖ **Regular Inspection and Maintenance:** Ensure that septic systems are inspected and pumped regularly to avoid leaks and overflow, which can contribute to nitrate contamination.
- ❖ **Proper Location:** Install septic systems at appropriate distances from wells and water sources to prevent contamination.

Proper Management of Animal Wastes

- ❖ **Manure Storage:** Properly store animal waste in sealed and impermeable structures to prevent nitrogen from leaching into the soil and groundwater.
- ❖ **Integrated Nutrient Management:** Incorporate animal waste into nutrient management systems to balance the application of organic and synthetic fertilizers, preventing excess nitrogen from entering the soil.

4.6 Arsenic

Excessive and prolonged consumption of inorganic arsenic through drinking water is a major health concern, leading to a condition known as arsenicosis. This progressive and debilitating disease is marked by skin lesions, abnormal pigmentation, and the development of patches on the palms and soles. Chronic arsenic exposure can ultimately result in serious health outcomes, including skin and internal cancers. In addition to its carcinogenic effects, long-term

exposure to arsenic has also been linked to cardiovascular complications and an increased risk of diabetes. These health impacts underscore the critical need for monitoring and controlling arsenic levels in drinking water sources.

Arsenic contamination in groundwater has been reported in several Indian states, including Assam, Bihar, Chhattisgarh, Jharkhand, Punjab, and Uttar Pradesh (Fig. 23). In states such as Bihar, West Bengal, Assam and Uttar Pradesh, the presence of arsenic is primarily associated with alluvial formations found in the Ganga and Brahmaputra River basins. These sedimentary deposits are particularly susceptible to arsenic mobilization under certain geochemical conditions.

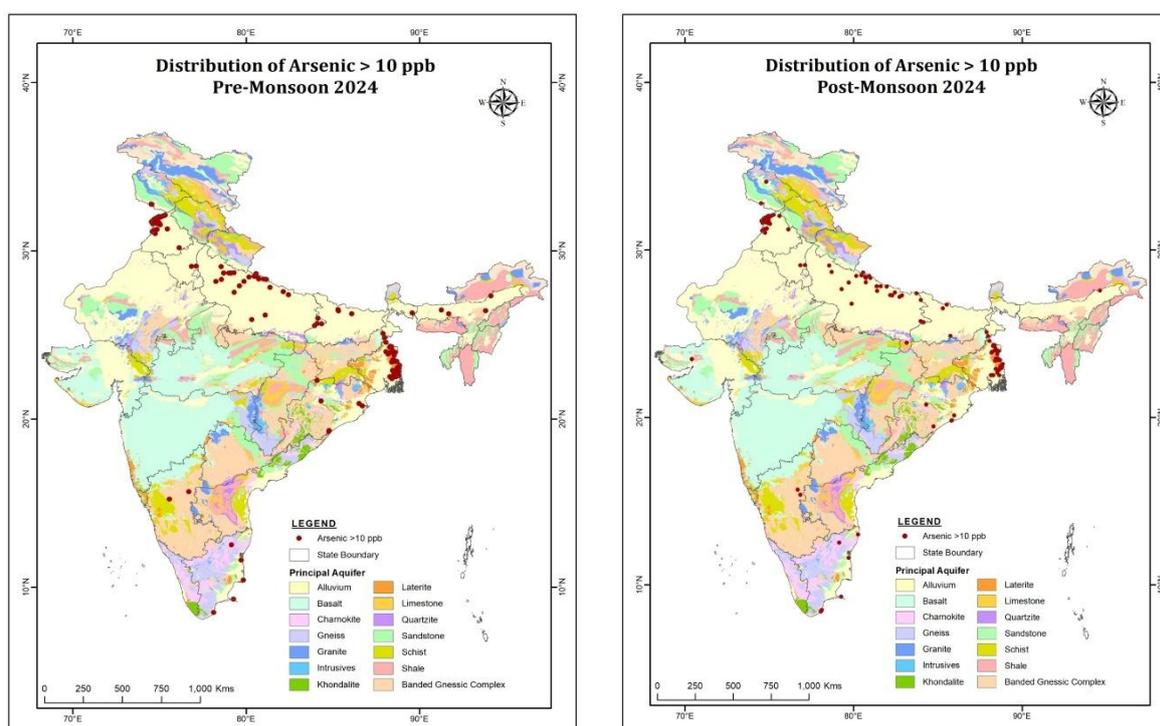


Figure 23: Distribution of Arsenic concentration in India (Pre- and Post-Monsoon 2024).

In contrast, the occurrence of arsenic in Chhattisgarh is geologically distinct, as it is confined to volcanic rock formations within the north-south trending Dongargarh-Kotri ancient rift zone. This highlights the varying geological settings responsible for arsenic contamination across different regions. Understanding these regional and geological variations is essential for developing targeted mitigation strategies and managing the risks associated with arsenic in drinking water sources.

In arsenic-prone regions, especially in alluvial plains (e.g., Ganga-Brahmaputra basins), post-monsoon reducing conditions can cause desorption of arsenic from iron oxides, increasing its mobility in groundwater.

Overall, the results highlight that arsenic contamination in groundwater is **spatially concentrated**, with **eastern and northern states** (West Bengal, Bihar, Punjab, J&K, and parts of Uttar Pradesh and Assam) contributing the majority of arsenic-affected samples. In contrast, central and southern states show minimal exceedance. This indicates the need for **region-specific monitoring and mitigation strategies**, particularly in high-risk states such as West Bengal and Bihar, where arsenic exposure poses a significant risk to public health.

4.6.1: Understanding the Impact of Seasonal Variation of Groundwater Arsenic concentration (Pre- and Post-Monsoon 2024).

The distribution of groundwater samples with respect to arsenic concentration (permissible limit: 0.01 mg/L as per BIS 10500:2012) indicates that the majority of samples comply with the standard during both pre- and post-monsoon 2024.

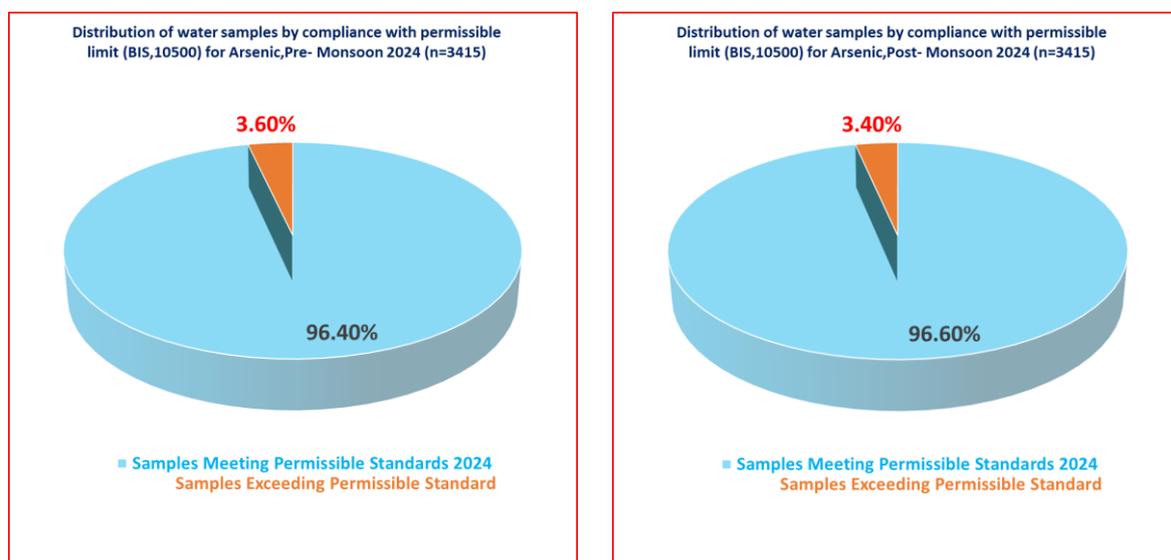


Figure 24: % Arsenic Samples exceeding permissible limits in Pre and Post monsoon.

In the pre-monsoon period, 96.40% of the samples were within the permissible limit, while only 3.60% exceeded it. During the post-monsoon, compliance improved marginally to 96.60%, with 3.40% of samples showing arsenic concentration above the standard. This slight reduction in non-compliant samples after the monsoon suggests a minor dilution effect due to recharge, though the overall change remains limited.

The consistently low proportion of arsenic exceedances indicates that arsenic contamination in groundwater is localized rather than widespread.

Table 13: Comparative Overview of Arsenic exceedance (no. of Samples) – Pre- and Post-Monsoon 2024.

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples Arsenic >10 ppb	
			Pre-M	Post-M
1	A&N Islands	28	0	0
2	Andhra Pradesh	0	0	0
3	Arunachal Pradesh	15	0	0
4	Assam	154	4	1
5	Bihar	13	6	5
6	Chandigarh	8	0	0
7	Chhattisgarh	257	0	0
8	Delhi	86	0	0
9	Goa	6	0	0
10	Gujarat	114	0	1
11	Haryana	160	2	2
12	Himachal Pradesh	0	0	0
13	Jammu & Kashmir	17	2	2
14	Jharkhand	0	0	0
15	Karnataka	118	2	2
16	Kerala	185	0	0
17	Madhya Pradesh	49	0	0
18	Maharashtra	0	0	0
19	Manipur	3	0	0
20	Meghalaya	38	0	0
21	Mizoram	0	0	0
22	Nagaland	66	0	0
23	Odisha	413	6	5
24	Punjab	296	27	28
25	Rajasthan	100	0	0
26	Tamil Nadu	286	5	7
27	Telangana	0	0	0
28	Tripura	44	0	0
29	UT of Puducherry	7	0	0
30	Uttar Pradesh	612	23	26
31	Uttarakhand	104	0	0
32	West Bengal	236	46	37
		3415	123	116

A total of 3,415 groundwater samples were analyzed across 32 States/UTs during both pre-monsoon and post-monsoon seasons to assess the occurrence of arsenic contamination (>10 ppb).

- During the pre-monsoon season, 123 samples (3.6%) exceeded the permissible limit of 10 ppb for arsenic.
- In the post-monsoon season, 116 samples (3.4%) exceeded this limit, indicating a marginal decline in arsenic occurrence after the monsoon.

High arsenic concentrations were predominantly observed in the Indo-Gangetic alluvial plains, particularly in West Bengal (19.5% pre-monsoon; 15.7% post-monsoon), Uttar Pradesh (3.8% pre-monsoon; 4.2% post-monsoon), and Punjab (9.1% pre-monsoon; 9.5% post-monsoon). Minor occurrences were also reported from Assam, Odisha, Jammu & Kashmir, Haryana, Karnataka, and Tamil Nadu. States such as A&N Islands, Goa, Kerala, Madhya Pradesh, Rajasthan, and others showed no detectable arsenic contamination in any of the analyzed samples.

Overall, the data suggest that arsenic contamination remains localized but persistent in parts of eastern and northwestern India, emphasizing the need for continued monitoring and mitigation efforts in the affected regions.

4.6.2 Remedial Measures and Recommendations (Arsenic):

Short-Term Mitigation

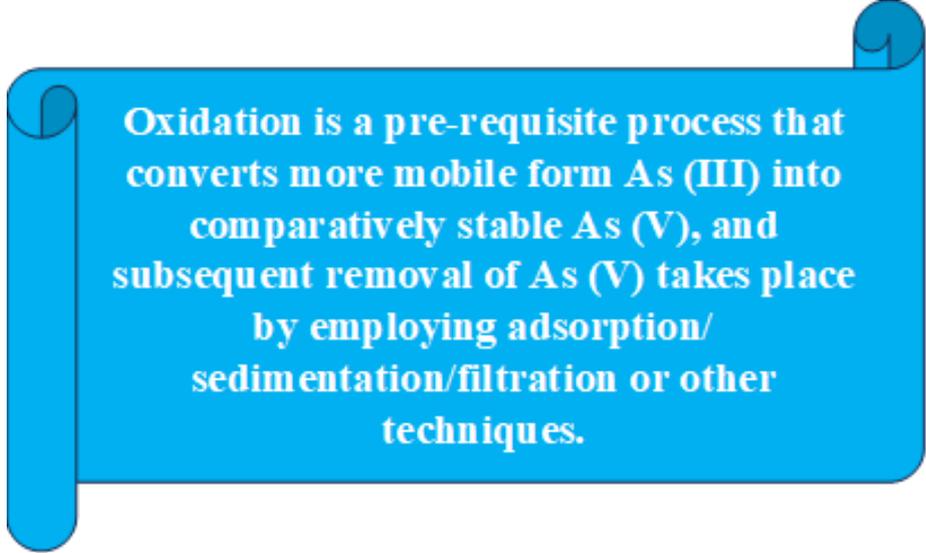
- ❖ Adoption of household treatment plants which are effective, efficient and low cost
- ❖ Conjunctive use of piped surface and GW
- ❖ Construction of hand pumps with removal plants
- ❖ Installing community water supply systems
- ❖ Replacement of affected wells with tube wells of As free aquifer.

Long-Term Mitigation

- ❖ Tapping alternate safe aquifer for drinking purposes
- ❖ Adoption of Mini water supply scheme attached with treatment plants
- ❖ Construction of deeper wells with cement sealing technique method of CGWB
- ❖ Adoption of rain water harvesting
- ❖ Public awareness and education
- ❖ Research and Development: To explore new and more efficient treatment technologies and strategies

Arsenic Remediation Mechanism

- ❖ Oxidation
- ❖ Precipitation
- ❖ Membrane Techniques
- ❖ Bioremediation



Oxidation is a pre-requisite process that converts more mobile form As (III) into comparatively stable As (V), and subsequent removal of As (V) takes place by employing adsorption/ sedimentation/filtration or other techniques.

4.6.3 Work Done by CGWB towards Mitigation of Arsenic Contamination

Based on the findings of the studies and experience of ground water exploration, CGWB has developed certain methods for constructing arsenic free wells by employing suitable designing of wells and cement sealing techniques. Such techniques of construction of contaminant free bore wells/ tube wells are shared with the state ground water departments to use them in similar terrains.

In the multi-aquifer system, the cement sealing technique was adopted to prevent the mixing of arsenic contaminated water with arsenic free ground water. So far, 522 exploratory wells tapping arsenic safe aquifers have been constructed under NAQUIM programme including 40 in Bihar, 188 in West Bengal and 294 in Uttar Pradesh with this technique. The innovative cement sealing technique of CGWB has been shared with the state agencies to utilize to construct arsenic free wells.

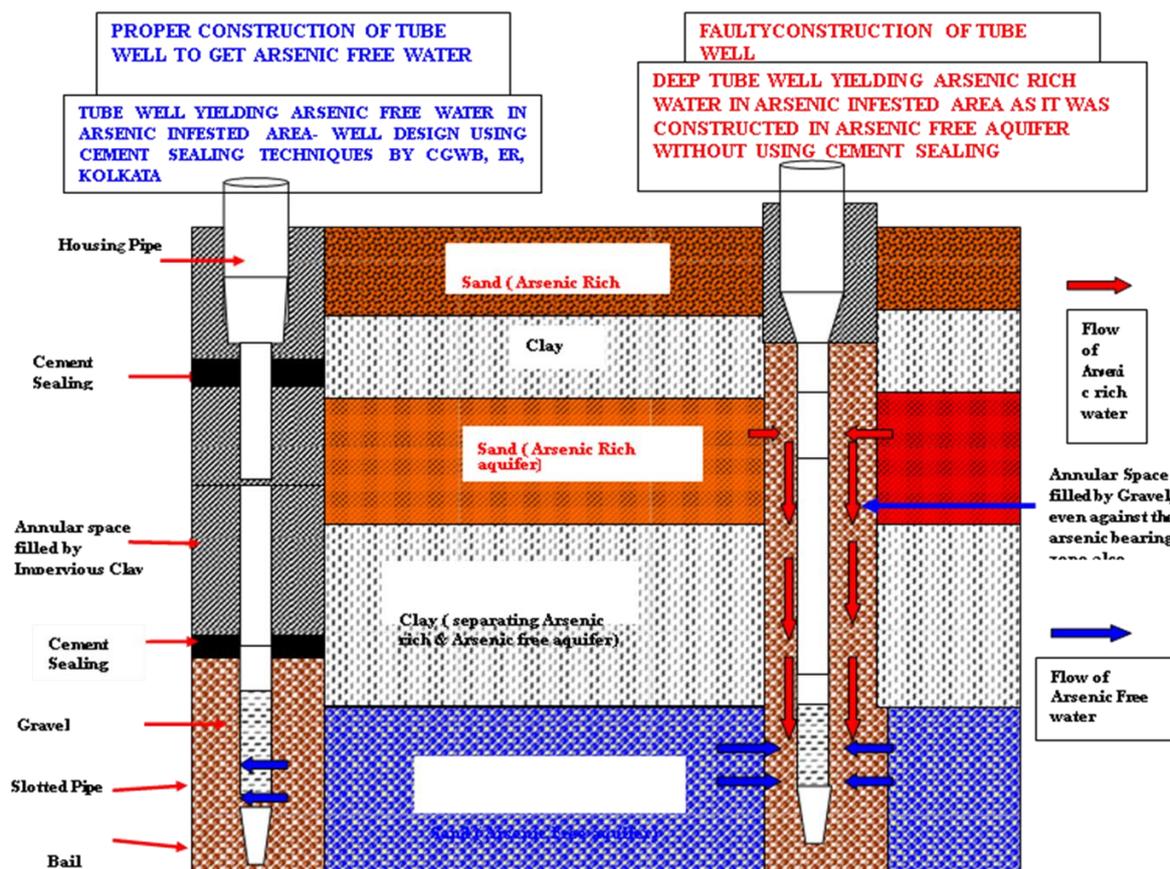


Figure 25: Cement sealing technique to prevent the mixing of arsenic contaminated water with arsenic free ground water.

4.7 Uranium

Uranium occurs naturally in groundwater and surface water. Being a radioactive mineral, high uranium concentration can cause impact on water, soil and health. Uranium has both natural and anthropogenic source that could lead to the aquifer. These sources include leaching from natural deposits, release in mill tailings, and emissions from the nuclear industry, combustion of coal and other fuels and the use of phosphate fertilizers that contains uranium and contribute to ground water pollution. Uranium enters in human tissues mainly through drinking water, food, air and other occupational and accidental exposures. Intake of uranium through air and water is normally low, but in circumstances in which uranium is present in a drinking water source, the majority of intake can be through drinking water. Permissible uranium concentration limits in drinking water across different countries is given in **Table 17**.

Water with uranium concentration above the recommended maximum permissible concentration of 30 ppb (BIS,10500:2012) is not safe for drinking purposes as it can cause damage to internal organs, on continuous intake. Elevated uranium concentrations in drinking

water have been associated with many epidemiological studies such as urinary track cancer as well as kidney toxicity. A recent study, found a strong correlation between uranium concentration in drinking water and uranium in bone, suggesting that bones are good indicators of uranium exposed via ingestion of drinking water. Therefore, such studies trigger further assessment of uranium’s adverse health effects on humans and/or the environment for countries where elevated uranium concentration in drinking water has been observed. Hence, it becomes important to study the level of uranium in drinking water for health risk assessment.

Uranium concentration in the shallow ground water varies primarily due to recharge and discharge, which would have dissolved or leached the uranium from the weathered soil to groundwater zone. High uranium concentrations observed in groundwater may be due to local geology, anthropogenic activities, urbanization and use of phosphate fertilizers in huge quantity for agriculture purpose.

Studies have shown that phosphate fertilizer possess uranium concentration ranging from 1 mg/kg to 68.5 mg/kg (Brindha K et al., 2011). Hence, the phosphate fertilizers manufactured from phosphate rocks may also contribute uranium to ground water in agriculture region. In ores, uranium is found as uranite (UO_2^{2+}) and pitchblende ($U_3O_8^{2+}$) or in the form of secondary minerals (complex oxides, silicates, phosphates, vanadates).

Table 14: Summary of uranium concentrations in different types of rocks.

Rocks	Range(mg/kg)
Granite	3.4
Limestone/dolomite	2.2
Argillaceous shale	3.7
Sediments	1.4-53
Phosphates	30-100

Table 15: Standards and guidelines for uranium in drinking water in various countries.

Sl. No	Country	Guideline value (µg/L)	Reference
1	Australia	GV 17	NHMRC, Australia (2011)
2	Bulgaria	ML 60	European Food Safety Authority (2009)
3	Canada	MAC 20	Health Canada (2019)
4	Finland	RV 100	European Food Safety Authority (2009)
5	India	RBL 60	AERB, India (2004)
6	India	PL 30	BIS,2012
7	Malaysia	MAV 2	Ministry of Health Malaysia (2004)
8	USA	MCL 30	USEPA (2011)
9	WHO	PGV 30	WHO 2011

GV, Guideline value; ML, Maximum limit; MAC, Most acceptable concentration; RV, Recommended value; RBL, Radiological based limit; PL, Permissible Limit; MAV, Maximum acceptable value; MCL, Maximum contaminant level; PGV, Provisional guideline value

To assess the Uranium concentration and distribution in the ground water, Central Ground Water Board (CGWB) carried out Uranium sampling of its National Hydrograph Network Stations (NHNS) during pre& post monsoon monitoring (2024). The sample collection and storage were done according to the standard protocols prescribed by APHA (2017). The groundwater samples were collected in HDPE bottles. Uranium (U) was detected using Inductively Coupled Plasma Mass-spectrometry and LED Fluorimeter Uranium analyser. To ensure quality control, duplicate and standard checks were performed on every ten samples. In addition, a trace element standard reference material was examined.

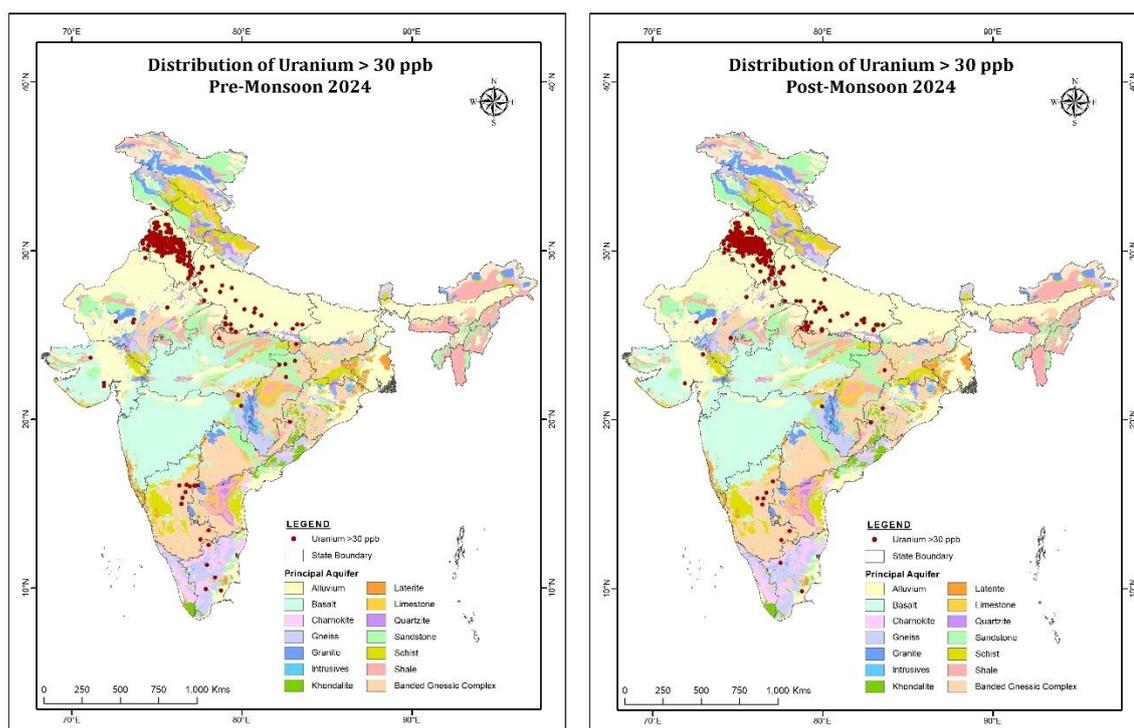


Figure 26: Spatial Distribution of Uranium in Groundwater – Pre & Post Monsoon, 2024.

High uranium concentrations are mainly observed in northwestern and central India, particularly across Punjab, Haryana, Rajasthan, and parts of Gujarat and Madhya Pradesh (Fig.26). Localized occurrences are also noted in parts of Telangana, Karnataka, and Jharkhand.

4.7.1 : Understanding the Impact of Seasonal Variation of Groundwater Uranium concentration (Pre- and Post-Monsoon 2024).

During the pre-monsoon, about 93.29% of samples were within the permissible limit, while 6.71% exceeded it. In the post-monsoon period, compliance slightly declined to 92.09%, with 7.91% of samples showing concentrations above the standard.

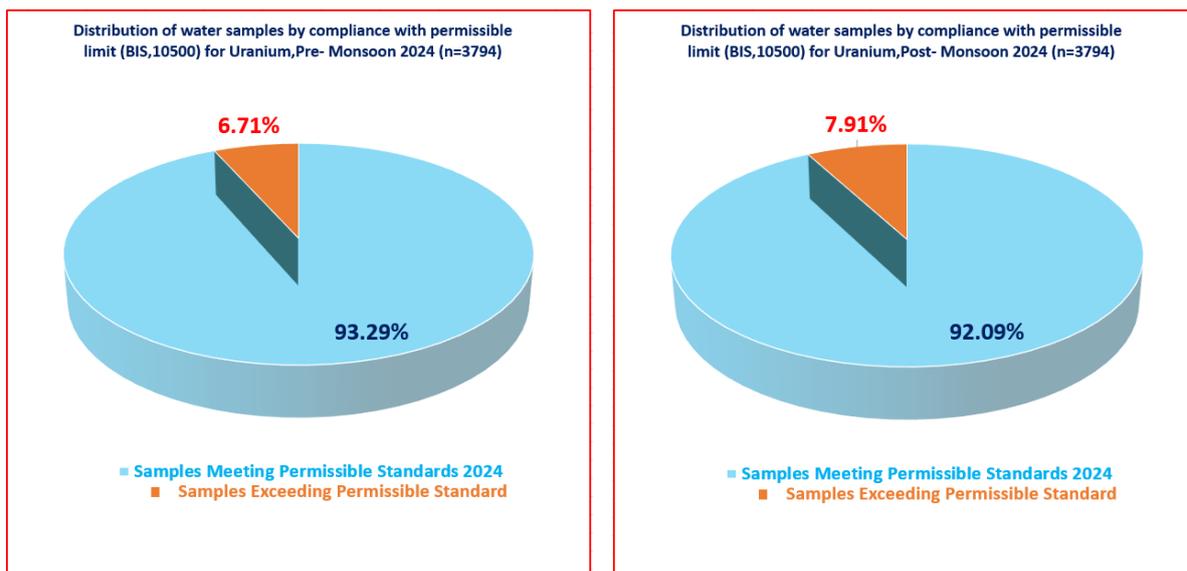


Figure 27:: % Uranium Samples exceeding permissible limits in Pre and Post monsoon

A total of 3,754 groundwater samples were tested across India during Pre- and Post-Monsoon 2024 to check uranium concentration. Samples with uranium levels above the safe limit of 30 ppb were found in 6.71% during the Pre-Monsoon and 7.91% during the post-monsoon, showing a slight increase after rainfall.

The highest uranium contamination was observed in Punjab, where over half of the samples (53.04% pre-monsoon and 62.50% post-monsoon) exceeded the limit. High levels were also found in Haryana (15–23.75%), Delhi (13–15.66%), Karnataka (6–8%), and Uttar Pradesh (5–6%). Moderate contamination occurred in Rajasthan and Chhattisgarh, while most other states showed uranium levels within safe limits.

Spatially, northwestern India (Punjab, Haryana, Delhi, parts of Rajasthan and Uttar Pradesh) emerged as the main hotspot of uranium contamination, likely due to geogenic factors, groundwater depletion, and aquifer characteristics. In contrast, eastern and southern India recorded minimal contamination.

Overall, the study shows that while most groundwater in India is safe, certain regions face rising uranium levels, emphasizing the need for regular monitoring and local mitigation measures to protect drinking water quality and health.

Table 16: Comparative Overview of Uranium exceedance (% of Samples) – Pre- and Post-Monsoon 2024.

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples having Uranium >30 ppb		Percentage of Samples having Uranium >30 ppb	
			Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	27	0	0	0.00	0.00
2	Andhra Pradesh	0	0	0	0	0
3	Arunachal Pradesh	15	0	0	0.00	0.00
4	Assam	154	0	0	0.00	0.00
5	Bihar	13	0	0	0.00	0.00
6	Chandigarh	8	0	0	0.00	0.00
7	Chhattisgarh	257	4	1	1.56	0.39
8	Delhi	83	11	13	13.25	15.66
9	Goa	6	0	0	0.00	0.00
10	Gujarat	126	3	2	2.38	1.59
11	Haryana	160	24	38	15.00	23.75
12	Himachal Pradesh	0	0	0	0	0
13	Jammu & Kashmir	17	1	0	5.88	0.00
14	Jharkhand	0	0	0	0	0
15	Karnataka	118	10	7	8.47	5.93
16	Kerala	185	0	0	0.00	0.00
17	Madhya Pradesh	51	0	0	0.00	0.00
18	Maharashtra	331	2	1	0.60	0.30
19	Manipur	3	0	0	0.00	0.00
20	Meghalaya	38	0	0	0.00	0.00
21	Mizoram	0	0	0	0	0
22	Nagaland	66	0	0	0.00	0.00
23	Odisha	413	1	2	0.24	0.48
24	Punjab	296	157	185	53.04	62.50
25	Rajasthan	100	5	7	5.00	7.00
26	Tamil Nadu	286	5	2	1.75	0.70
27	Telangana	0	0	0	0	0
28	Tripura	44	0	0	0.00	0.00
29	UT of Puducherry	7	0	0	0.00	0.00
30	Uttar Pradesh	612	29	39	4.74	6.37
31	Uttarakhand	103	0	0	0.00	0.00
32	West Bengal	235	0	0	0.00	0.00
		3754	252	297	6.71	7.91

4.7.2. Remedial Measures

Finding a remedy for the uranium contaminated groundwater effectively and thoroughly, has become need of day. Remediation technologies can be classified into physical, chemical and biological methods. Bioremediation is divided into plant and microorganism methods. Each method consists of both advantages and disadvantages and the appropriate mitigation techniques should be need based.

Adsorption has a high removal efficiency, but costs are also higher. The coagulation process is simple and comparatively economical, but the standard effluent concentration is hard

to reach, so there is a need for follow-up treatment. Combined with adsorption, coagulation can remove 99% of U. The extraction process can remove effluent U concentrations of less than 0.05mg / L, but it will produce a lot of sludge. Reverse osmosis is referred as a best technology, but due to its high cost it can not be used on community scale. The evaporation method is simple and effective, the removal rate is high, but there are high costs and sludge needs that must be dealt with. A review of various treatment technologies for Uranium removal from water and their technical achievability as reported by various researchers are given below in **Table 25**.

Table 17: Comparison of treatment methods for removal of Uranium.

Treatment Method	Technical Achievability (%)
Coagulation/filtration at high pH (10+)	> 95
Lime softening	85-99
Anion exchange	99
Reverse osmosis	>95
Activated alumina	90
Coagulation/filtration	80-89

(Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India).

4.8 Iron

Iron is a naturally occurring element commonly found in groundwater, especially in areas with iron-rich soils and rocks. It typically enters groundwater through the dissolution of iron-bearing minerals. The most common forms of iron in groundwater are ferrous (Fe^{2+}), which is soluble and clear, and ferric (Fe^{3+}), which forms reddish-brown precipitates.

While not harmful to health at low levels, high concentrations of iron can cause aesthetic and operational issues, such as metallic taste, staining of laundry and plumbing fixtures, and clogging of pipes and water systems. Iron levels above 1 mg/L are generally considered undesirable by drinking water standards.

The distribution of groundwater samples exceeding 1 mg/L iron concentration (the BIS permissible limit), Fig. 28 indicates that iron contamination is widespread and predominantly geogenic in nature.

High iron concentrations are notably observed across the eastern and northeastern states, including Assam, West Bengal, Bihar, Odisha, Jharkhand, and Chhattisgarh, extending into parts of Uttar Pradesh and Tripura. These regions are characterized by alluvial and lateritic

aquifers, where low-oxygen and acidic environments facilitate the release of soluble ferrous iron into groundwater.

Scattered occurrences are also seen in parts of Kerala, Maharashtra, and Madhya Pradesh, indicating localized geochemical influence. The pattern suggests that iron enrichment in groundwater is primarily natural, resulting from rock–water interaction and reductive dissolution processes, rather than from anthropogenic activities.

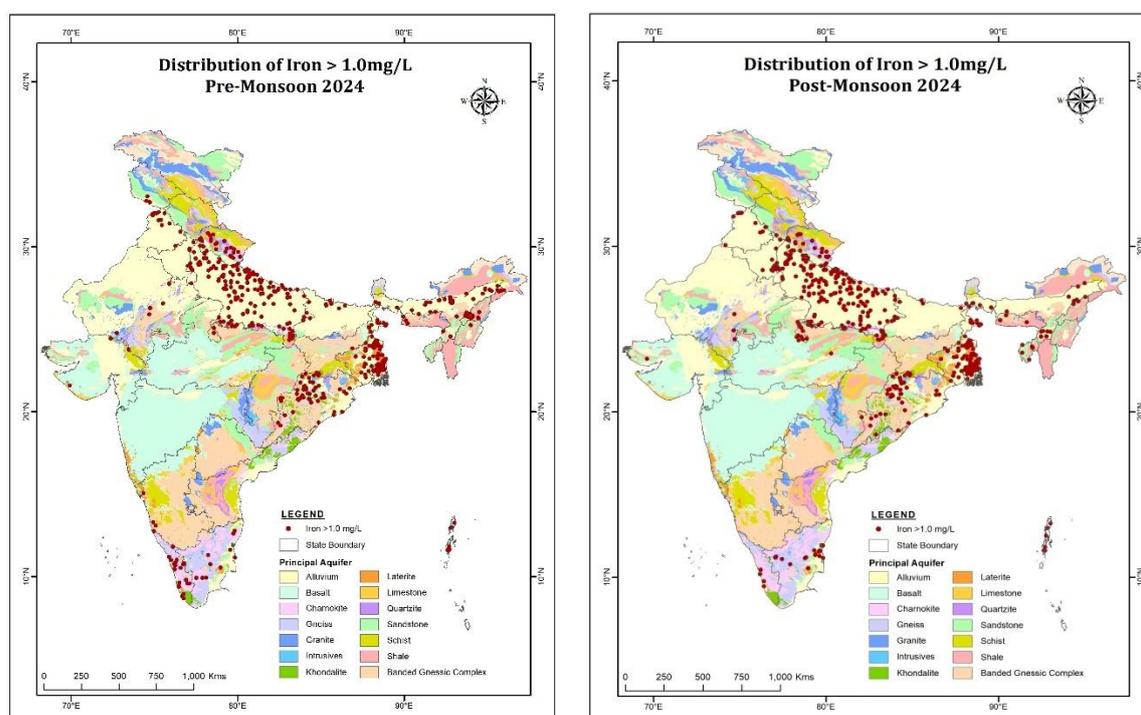


Figure 28: Distribution of Iron concentration in India (Pre- and Post-Monsoon 2024)

4.8.1: Understanding the Impact of Seasonal Variation of Groundwater Iron concentration (Pre- and Post-Monsoon 2024).

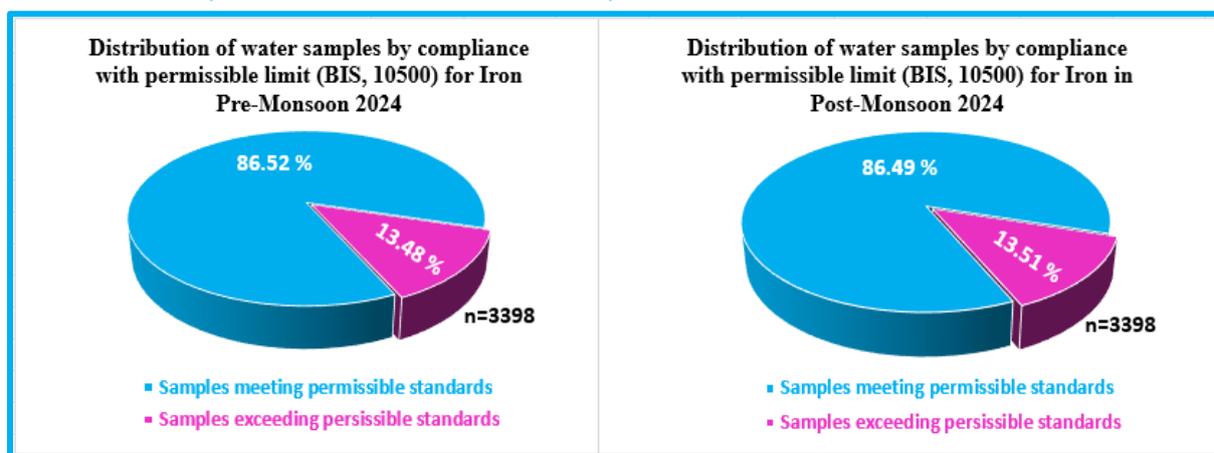


Figure 29: % Iron Samples exceeding permissible limits in Pre and Post monsoon.

During the pre-monsoon, about 86.52% of samples were within the permissible limit, while 13.48% exceeded it. In the post-monsoon period, compliance remained almost

unchanged, with 86.49% of samples meeting the standard and 13.51% exceeding it. This indicates that seasonal variation in iron concentration is negligible, and monsoon recharge has little influence on iron mobilization in groundwater.

Table 18: Comparative Overview of Iron exceedance (% of Samples) – Pre- and Post-Monsoon 2024.

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples having Iron >1.0 mg/L		Percentage of Samples having Iron >1.0 mg/L	
			Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	8	6	28.57	21.43
2	Andhra Pradesh	0	0	0	0	0
3	Arunachal Pradesh	15	2	0	13.33	0.00
4	Assam	154	28	12	18.18	7.79
5	Bihar	13	8	6	61.54	46.15
6	Chandigarh	8	0	0	0.00	0.00
7	Chhattisgarh	257	0	0	0.00	0.00
8	Delhi	86	7	13	8.14	15.12
9	Goa	6	0	0	0.00	0.00
10	Gujarat	132	2	1	1.52	0.76
11	Haryana	160	5	9	3.13	5.63
12	Himachal Pradesh	0	0	0	0	0
13	Jammu & Kashmir	12	3	0	25.00	0.00
14	Jharkhand	0	0	0	0	0
15	Karnataka	118	3	0	2.54	0.00
16	Kerala	181	21	4	11.60	2.21
17	Madhya Pradesh	34	0	1	0.00	2.94
18	Maharashtra	0	0	0	0	0
19	Manipur	3	1	0	33.33	0.00
20	Meghalaya	38	5	3	13.16	7.89
21	Mizoram	0	0	0	0	0
22	Nagaland	66	12	3	18.18	4.55
23	Odisha	413	58	47	14.04	11.38
24	Punjab	296	11	12	3.72	4.05
25	Rajasthan	100	7	3	7.00	3.00
26	Tamil Nadu	286	10	15	3.50	5.24
27	Telangana	0	0	0	0	0
28	Tripura	44	0	5	0.00	11.36
29	UT of Puducherry	7	0	4	0.00	57.14
30	Uttar Pradesh	601	144	173	23.96	28.79
31	Uttarakhand	104	31	28	29.81	26.92
32	West Bengal	236	92	114	38.98	48.31
		3398	458	459	13.48	13.51

A total of 3,398 groundwater samples from 32 States/UTs were analyzed for iron concentration during pre- and post-monsoon seasons.

458 samples (13.48%) in the pre-monsoon and 459 samples (13.51%) in the post-monsoon exceeded the permissible limit of 1.0 mg/L for iron, indicating no significant overall seasonal variation at the national level.

Elevated iron concentrations were primarily observed in West Bengal (39–48%), Uttar Pradesh (24–29%), Bihar (46–62%), and A&N Islands (21–29%), reflecting regional persistence of iron enrichment.

Moderate occurrences were noted in Assam, Odisha, Uttarakhand, and Kerala, while most other states, including Gujarat, Haryana, Rajasthan, Tamil Nadu, and Delhi, showed isolated or minor occurrences.

A slight increase in post-monsoon iron concentration was observed in Uttar Pradesh, West Bengal, and Delhi, possibly due to mobilization of iron from aquifer sediments under reducing post-recharge conditions.

Conversely, reduction in iron concentration was noted in Assam, Bihar, Kerala, and Nagaland, suggesting dilution effects following monsoonal recharge.

Overall, the data indicate that iron contamination in groundwater is widespread but spatially variable, with no major seasonal improvement or deterioration at the national scale. However, localized fluctuations reflect site-specific hydrogeochemical and redox processes influenced by monsoon recharge.

4.8.2 Remedial Measures and Recommendations (Iron):

- ❖ **Aeration and Filtration:** Oxidizing ferrous iron to ferric form followed by filtration.
- ❖ **Use of Iron Removal Plants (IRPs):** Especially in rural or community water supply schemes.
- ❖ **Activated Media Filters:** Such as manganese greensand or catalytic carbon for small-scale use.
- ❖ **Chemical Oxidation:** Using chlorine, ozone, or potassium permanganate in severe cases.

4.9 Manganese

Manganese is a naturally occurring element commonly found in groundwater, especially in areas with manganese-rich soils and rocks. It exists mainly in dissolved form (Mn^{2+}) under low-oxygen (reducing) conditions. While essential in small amounts, excessive manganese in drinking water can pose health risks. As per BIS standards, the acceptable limit is **0.1 mg/L**, with a permissible limit of **0.3 mg/L** in the absence of an alternative source.

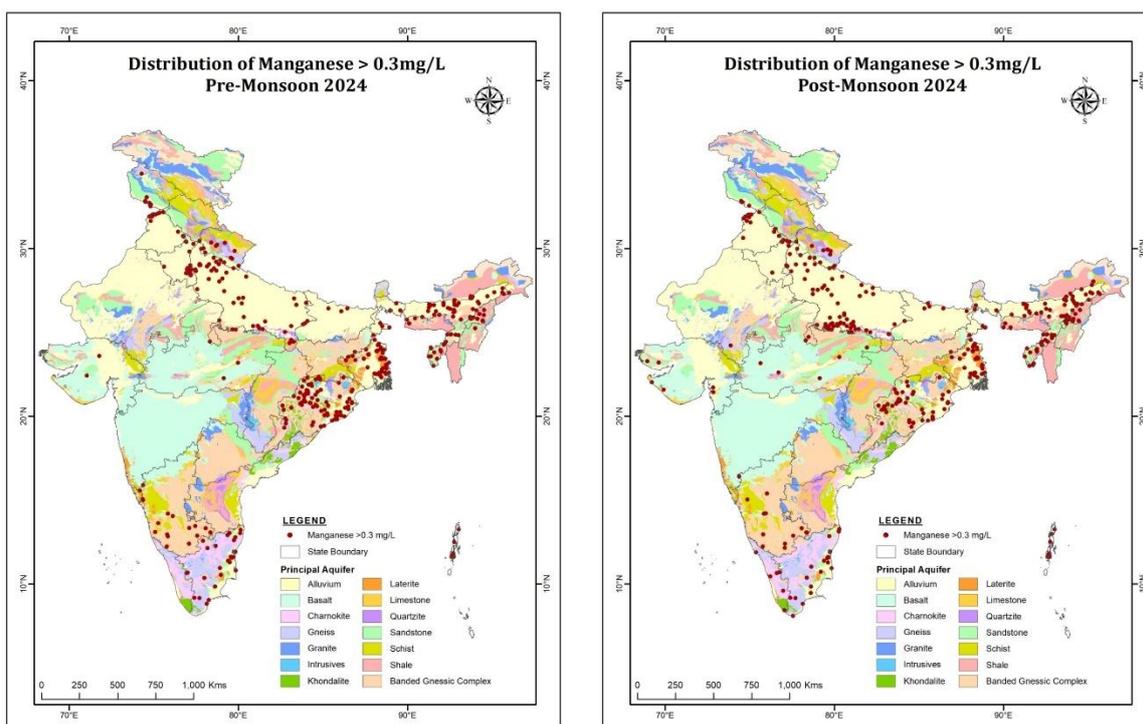


Figure 30: Spatial Distribution of Manganese in Groundwater – Pre & Post Monsoon, 2024.

Elevated manganese levels have been reported in several states, including Assam, Karnataka, Odisha, Tamil Nadu, Uttar Pradesh, and West Bengal, with contamination observed during both pre-monsoon and post-monsoon seasons, indicating persistent groundwater quality concerns in these regions.

4.9.1: Understanding the Impact of Seasonal Variation of Groundwater Manganese concentration (Pre- and Post-Monsoon 2024).

A total of 3,170 groundwater samples were analyzed across India to assess manganese (Mn) concentration exceeding the permissible limit of 0.3 mg/L.

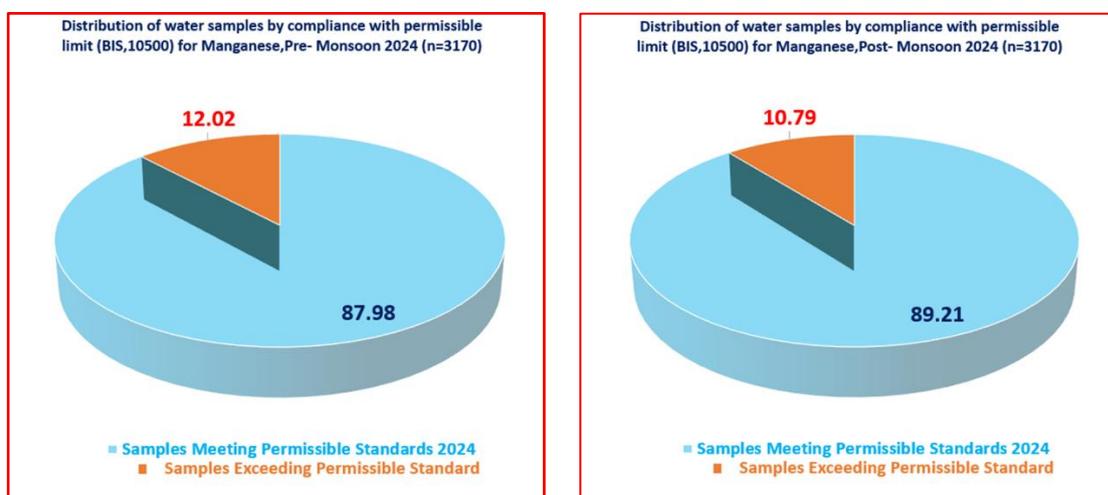


Figure 31: % Manganese Samples exceeding permissible limits in Pre and Post monsoon.

Nationally, 12.02% of samples during the Pre-Monsoon and 10.79% during the post-monsoon period exceeded the limit, indicating a slight improvement in water quality after the monsoon.

Overall, while manganese contamination decreased slightly post-monsoon, several regions continue to show high Mn levels, likely due to natural geogenic sources, reducing aquifer conditions, and limited groundwater circulation. Continuous monitoring and treatment are essential to ensure safe drinking water in these affected zones.

During the pre-monsoon, about 87.98% of samples complied with the permissible limit, while 12.02% exceeded it. In the post-monsoon period, the compliance improved slightly to 89.21%, with the proportion of samples exceeding the limit reducing to 10.79%. This minor improvement after monsoon suggests a dilution effect due to recharge and enhanced oxygenation in some aquifers.

The occurrence of high manganese concentrations is mainly attributed to geogenic factors, particularly reducing aquifer conditions, which promote the release of manganese from manganese-bearing minerals and iron–manganese oxides. Such conditions are more common in alluvial and lateritic aquifers of eastern and northeastern India.

Table 19: Comparative Overview of Manganese exceedance (% of Samples) – Pre- and Post-Monsoon 2024.

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples having Manganese >0.3 mg/L		Percentage of Samples having Manganese >0.3 mg/L	
			Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	14	12	50.00	42.86
2	Andhra Pradesh	0	0	0	0	0
3	Arunachal Pradesh	15	3	4	20.00	26.67
4	Assam	155	41	44	26.45	28.39
5	Bihar	13	5	6	38.46	46.15
6	Chandigarh	8	2	1	25.00	12.50
7	Chhattisgarh	0	0	0	0	0
8	Delhi	86	16	0	18.60	0.00
9	Goa	6	1	0	16.67	0.00
10	Gujarat	132	2	6	1.52	4.55
11	Haryana	159	5	6	3.14	3.77
12	Himachal Pradesh	0	0	0	0	0
13	Jammu & Kashmir	17	7	4	41.18	23.53
14	Jharkhand	0	0	0	0	0
15	Karnataka	118	16	13	13.56	11.02
16	Kerala	185	0	6	0.00	3.24
17	Madhya Pradesh	46	2	5	4.35	10.87
18	Maharashtra	0	0	0	0	0
19	Manipur	3	1	0	33.33	0.00
20	Meghalaya	38	5	3	13.16	7.89
21	Mizoram	0	0	0	0	0
22	Nagaland	67	12	21	17.91	31.34
23	Odisha	413	82	47	19.85	11.38

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples having Manganese >0.3 mg/L		Percentage of Samples having Manganese >0.3 mg/L	
			Pre-M	Post-M	Pre-M	Post-M
24	Punjab	296	12	17	4.05	5.74
25	Rajasthan	98	0	1	0.00	1.02
26	Tamil Nadu	286	26	17	9.09	5.94
27	Telangana	0	0	0	0	0
28	Tripura	44	11	11	25.00	25.00
29	UT of Puducherry	7	2	2	28.57	28.57
30	Uttar Pradesh	610	49	64	8.03	10.49
31	Uttarakhand	104	14	11	13.46	10.58
32	West Bengal	236	53	41	22.46	17.37
	Total	3170	381	342	12.02	10.79

4.9.1 Remedial Measures and Recommendations (Manganese):

- ❖ Using aeration or chemical oxidants followed by sand or media filtration.
- ❖ RO: Effective but more suitable for household or industrial applications
- ❖ Manganese-Specific Media Filters: Such as greensand or filters.

5.0 Lead

Lead is a toxic heavy metal that is not typically found in natural groundwater in significant concentrations but can enter through corroded plumbing, industrial pollution, or leaching from lead-bearing rocks and soils. Even low-level exposure can cause serious health effects, particularly in children, including neurological damage, developmental delays, and kidney issues.

As per the Bureau of Indian Standards (BIS), the permissible limit for lead in drinking water is 10 ppb (0.01 mg/L).

5.1 Sources of Lead in Groundwater

Geogenic Sources:

- Weathering of **lead-bearing minerals** such as galena (PbS).
- Presence of lead in **igneous or sedimentary rocks**.

Anthropogenic Sources:

- Corrosion of plumbing materials (pipes, joints, fittings) containing lead.
- Battery manufacturing and recycling industries.
- Improper disposal of electronic waste (e-waste).
- Agricultural runoff (use of pesticides historically containing lead arsenate).
- Atmospheric deposition from combustion of leaded fuels (though now largely phased out globally).

It is apparent from table 20, a total of 2,537 groundwater samples were analyzed across India during Pre- and Post-Monsoon 2024 to assess lead (Pb) contamination. The findings indicate that lead concentrations exceeding the permissible limit of 0.01 mg/L were detected in 0.95% of samples during the Pre-Monsoon and 0.79% during the post-monsoon period, showing a slight improvement after rainfall.

Higher incidences of lead contamination were observed in Delhi (9.30%), Assam (3.23%), and Rajasthan (2.04%) during the Pre-Monsoon season, and in Odisha (2.91%) and Uttarakhand (0.96%) during post-monsoon. Most other states recorded either no contamination or negligible levels.

Overall, while lead contamination in groundwater remains low nationally, localized hotspots require targeted monitoring and remedial action to prevent health risks associated with heavy metal exposure.

Table 20: Comparative Overview of Lead exceedance (% of Samples) – Pre- and Post-Monsoon 2024

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon		No. of Samples Lead >0.01 mg/L		Percentage of Samples having Lead >0.01 mg/L	
		Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	0	0	0	0	0.00	0.00
2	Andhra Pradesh	0	0	0	0	0.00	0.00
3	Arunachal Pradesh	15	0	0	0	0.00	0.00
4	Assam	155	5	1	3.23	0.65	
5	Bihar	12	0	0	0.00	0.00	
6	Chandigarh	8	0	0	0.00	0.00	
7	Chhattisgarh	0	0	0	0.00	0.00	
8	Delhi	86	8	0	9.30	0.00	
9	Goa	6	0	0	0.00	0.00	
10	Gujarat	0	0	0	0.00	0.00	
11	Haryana	160	0	0	0.00	0.00	
12	Himachal Pradesh	0	0	0	0.00	0.00	
13	Jammu & Kashmir	12	0	0	0.00	0.00	
14	Jharkhand	0	0	0	0.00	0.00	
15	Karnataka	118	1	1	0.85	0.85	
16	Kerala	0	0	0	0.00	0.00	
17	Madhya Pradesh	28	0	0	0.00	0.00	
18	Maharashtra	0	0	0	0.00	0.00	
19	Manipur	3	0	0	0.00	0.00	
20	Meghalaya	38	0	0	0.00	0.00	
21	Mizoram	0	0	0	0.00	0.00	
22	Nagaland	67	0	0	0.00	0.00	
23	Odisha	413	3	12	0.73	2.91	
24	Punjab	296	1	2	0.34	0.68	

25	Rajasthan	98	2	2	2.04	2.04
26	Tamil Nadu	286	2	1	0.70	0.35
27	Telangana	0	0	0	0.00	0.00
28	Tripura	44	0	0	0.00	0.00
29	UT of Puducherry	7	0	0	0.00	0.00
30	Uttar Pradesh	581	2	0	0.34	0.00
31	Uttarakhand	104	0	1	0.00	0.96
32	West Bengal	0	0	0	0.00	0.00
	Total	2537	24	20	0.95	0.79

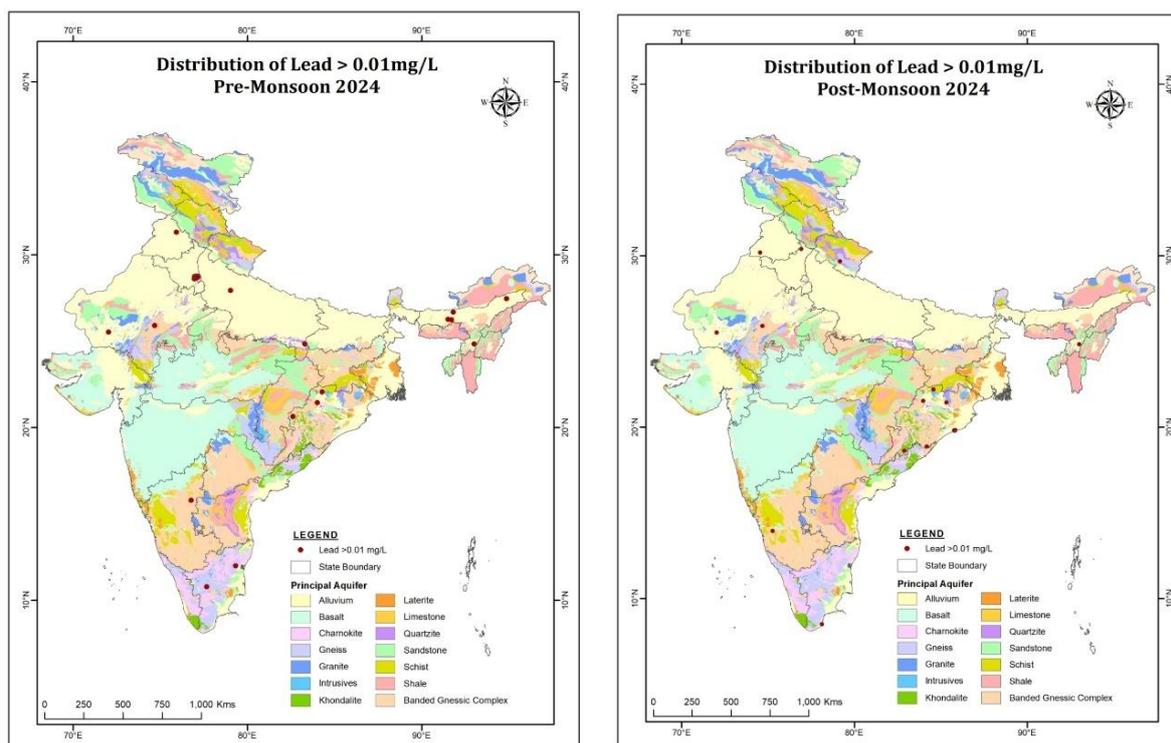


Figure 32: Spatial Distribution of Lead in Groundwater – Pre & Post Monsoon, 2024.

5.2 Remedial Measures for Lead Contamination

- ❖ **Filtration Systems:** Install activated carbon filters, reverse osmosis systems, or ion exchange filters at household and community levels. These systems can effectively remove lead from drinking water.
- ❖ **Strict Regulations on Industrial Effluents:** Enforce stronger regulations on industries and encourage them to treat and properly dispose of lead-containing waste.
- ❖ **Require lead testing in schools, health centres, and public buildings,** particularly those with older plumbing systems.
- ❖ Encourage hydrogeochemical mapping to identify natural geogenic lead sources and assess long-term risk.

- ❖ Encourage households to run taps for a short time before use if plumbing systems are suspected to contain lead.

6.0 Zinc

Zinc is an essential trace element for human health and is commonly found in natural water sources. In groundwater, zinc typically originates from the weathering of zinc-bearing minerals, and in some cases, from industrial discharges, galvanization processes, and the use of zinc-containing fertilizers and pesticides.

While zinc is not considered highly toxic, elevated concentrations can affect water quality by imparting an unpleasant taste and causing issues like corrosion of pipes or staining. Excessive intake over time may also pose health concerns, particularly in sensitive populations.

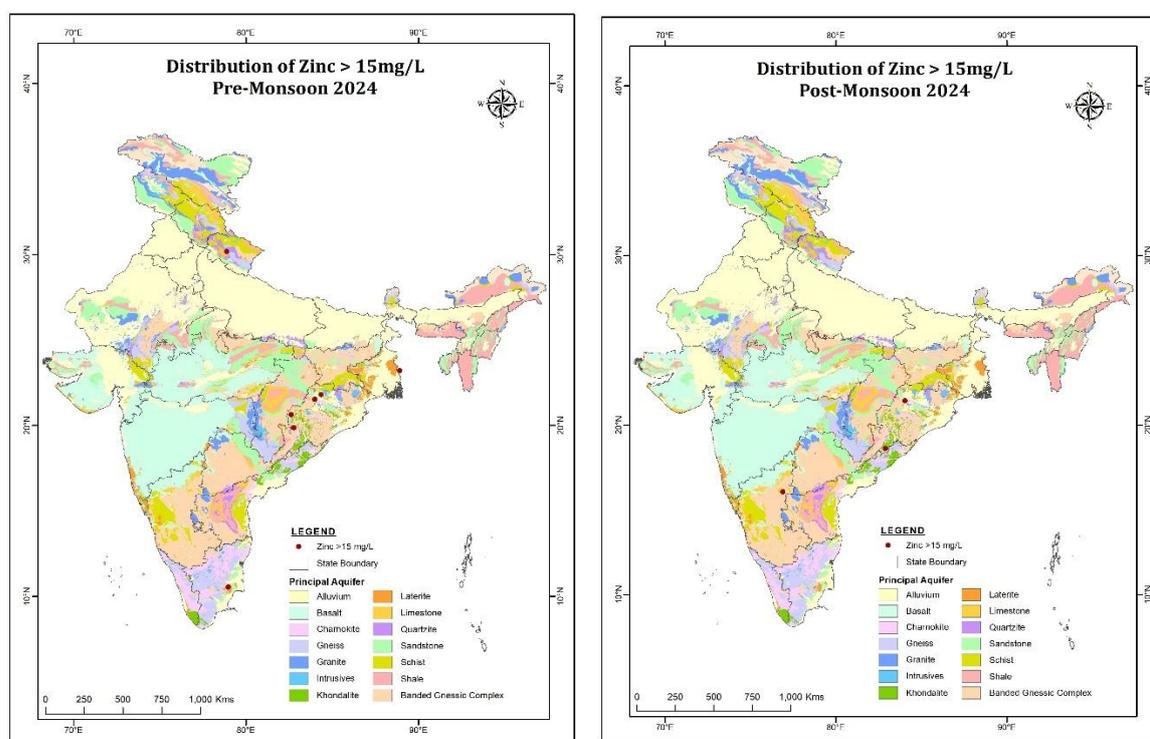


Figure 33: Spatial Distribution of Zinc in Groundwater – Pre & Post Monsoon, 2024.

As per the Bureau of Indian Standards (BIS), the acceptable limit for zinc in drinking water is 5 mg/L, with a permissible limit of 15 mg/L in the absence of an alternative source. A total of 2,988 groundwater samples were analyzed across India during Pre- and Post-Monsoon 2024 to assess zinc (Zn) concentration in groundwater. The results indicate that zinc levels exceeding the permissible limit of 15 mg/L were found in only 0.23% of samples during the Pre-Monsoon and 0.10% during the post-monsoon, showing an overall improvement after rainfall.

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Exceedances were observed in Odisha (0.97%), Uttarakhand (0.96%), Tamil Nadu (0.35%), West Bengal (0.42%), and Karnataka (0.85%), while all other states recorded zinc levels within safe limits.

Overall, the findings suggest that zinc contamination in groundwater is minimal and within safe limits nationally, though localized exceedances call for periodic monitoring to ensure continued groundwater safety and prevent potential impacts on drinking water quality.

Table 21: Comparative Overview of Lead exceedance (% of Samples) – Pre- and Post-Monsoon 2024

Sl. No.	District	No. of Samples Analysed in both seasons i.e. pre-Monsoon and Post-Monsoon	No. of Samples having Zinc >15 mg/L		Percentage of Samples having Zinc >15 mg/L	
			Pre-M	Post-M	Pre-M	Post-M
1	A&N Islands	28	0	0	0.00	0.00
2	Andhra Pradesh	0	0	0	0	0
3	Arunachal Pradesh	15	0	0	0.00	0.00
4	Assam	154	0	0	0.00	0.00
5	Bihar	10	0	0	0.00	0.00
6	Chandigarh	8	0	0	0.00	0.00
7	Chhattisgarh	0	0	0	0	0
8	Delhi	86	0	0	0.00	0.00
9	Goa	6	0	0	0.00	0.00
10	Gujarat	132	0	0	0.00	0.00
11	Haryana	160	0	0	0.00	0.00
12	Himachal Pradesh	0	0	0	0	0
13	Jammu & Kashmir	16	0	0	0.00	0.00
14	Jharkhand	0	0	0	0	0
15	Karnataka	118	0	1	0.00	0.85
16	Kerala	0	0	0	0	0
17	Madhya Pradesh	54	0	0	0.00	0.00
18	Maharashtra	0	0	0	0	0
19	Manipur	3	0	0	0.00	0.00
20	Meghalaya	38	0	0	0.00	0.00
21	Mizoram	0	0	0	0	0
22	Nagaland	66	0	0	0.00	0.00
23	Odisha	413	4	2	0.97	0.48
24	Punjab	296	0	0	0.00	0.00
25	Rajasthan	98	0	0	0.00	0.00
26	Tamil Nadu	286	1	0	0.35	0.00
27	Telangana	0	0	0	0	0
28	Tripura	44	0	0	0.00	0.00
29	UT of Puducherry	7	0	0	0.00	0.00
30	Uttar Pradesh	610	0	0	0.00	0.00
31	Uttarakhand	104	1	0	0.96	0.00
32	West Bengal	236	1	0	0.42	0.00
	Total	2988	7	3	0.23	0.10

6.1 Remedial Measures for Zinc Contamination

- ❖ Regulate industrial discharges and agricultural runoff that may contribute to elevated zinc levels. Stricter monitoring and enforcement of **zinc-based fertilizer** usage can also help reduce contamination.
- ❖ **Reverse Osmosis (RO)** and **Ion Exchange** methods can be used at the household or community level to effectively reduce zinc concentrations in drinking water.
- ❖ **Coagulation and filtration** processes can be adopted for larger-scale water treatment systems.
- ❖ Seasonal monitoring can be incorporated to track variations and ensure that concentrations remain within acceptable limits throughout the year.

7.0 Copper

Copper is an essential trace element for human health, playing a key role in the formation of red blood cells and the functioning of the immune system. In natural settings, copper occurs in groundwater primarily as copper ions (Cu^{2+}), typically originating from the weathering of copper-bearing minerals or natural deposits. It can also be introduced into water from anthropogenic sources, such as industrial effluents, corrosion of copper pipes, and agricultural runoff containing copper-based pesticides or fungicides.

While copper is necessary in small quantities, excessive concentrations in drinking water can lead to health concerns, especially when levels exceed the permissible limits. The Bureau of Indian Standards (BIS) sets the permissible limit for copper in drinking water at 1.5 mg/L, in line with guidelines from the World Health Organization (WHO).

In both **pre-monsoon** and **post-monsoon** periods, copper concentrations in groundwater across India were found to be **well within the permissible limit** of 1.5 mg/L as set by the **Bureau of Indian Standards (BIS)**. No instances of copper contamination exceeding the acceptable threshold were reported across the country, indicating that copper levels in groundwater are generally **safe** and **pose minimal health risk**.

8.0 Suitability of Groundwater for Irrigation Purpose

The **quality of groundwater** is critically important for determining its **suitability for irrigation** because it directly influences both the **health of the soil** and the **growth of crops**. Poor quality groundwater can result in long-term damage to soil structure, plant health, and overall agricultural productivity. Poor water quality (e.g., high concentrations of sodium,

chloride, or bicarbonates) can interfere with a plant's ability to absorb essential nutrients, resulting in **nutrient deficiencies**. High **sodium (Na)** can be toxic to plants, affecting their **photosynthesis**, growth, and root development.

In areas where natural drainage is inadequate, the irrigation water infiltrating the root zone will cause water table to rise excessively. In addition to problems caused by excessive concentration of dissolved solids, certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations. Irrigation indices viz. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) have been evaluated to assess the suitability of ground water for irrigation purposes.

8.1 Alkali Hazard Assessment and Its Impact on Irrigation Suitability

In the irrigation water, it is characterized by absolute and relative concentrations of cations. If the sodium concentrations are high, the alkali hazard is high and if the calcium & magnesium levels are high, this hazard is low. The alkali soils are formed by the accumulation of exchangeable sodium and are characterized by poor tilt and low permeability. The U.S. Salinity laboratory has recommended the use of sodium adsorption ratio (SAR) as it is closely related to adsorption of sodium by the soil.

SAR is derived by the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

The water with regard to SAR is classified into four categories

- **S₁ – Low Sodium Water** (SAR <10)
- Such waters can be used on practically all kinds of soils without any risk or increase in exchangeable sodium.
- **S₂ – Medium Sodium Water** (SAR 10-18)
- Such waters may produce an appreciable sodium hazard in fine textured soil having high cation exchange capacity under low leaching.
- **S₃ – High Sodium Water** (SAR >18-26)
- Such waters indicate harmful concentrations of exchangeable sodium in most of the soil and would require special management, good drainage, high leaching and addition of

organic matter to the soil. If such waters are used on gypsiferous soils the exchangeable sodium could not produce harmful effects.

- **S₄ – Very High Sodium Waters (SAR >26)**
- Generally, such waters are unsatisfactory for irrigation purposes except at low or perhaps at medium salinity where the solution of calcium from the soil or addition of gypsum or other amendments makes the use of such waters feasible.

It is apparent from **Fig. 34** that 94.16 % samples belong to excellent category (S₁) and only 1.11 % water samples are associated with very high sodium category (S₄) and is unsuitable for irrigation.

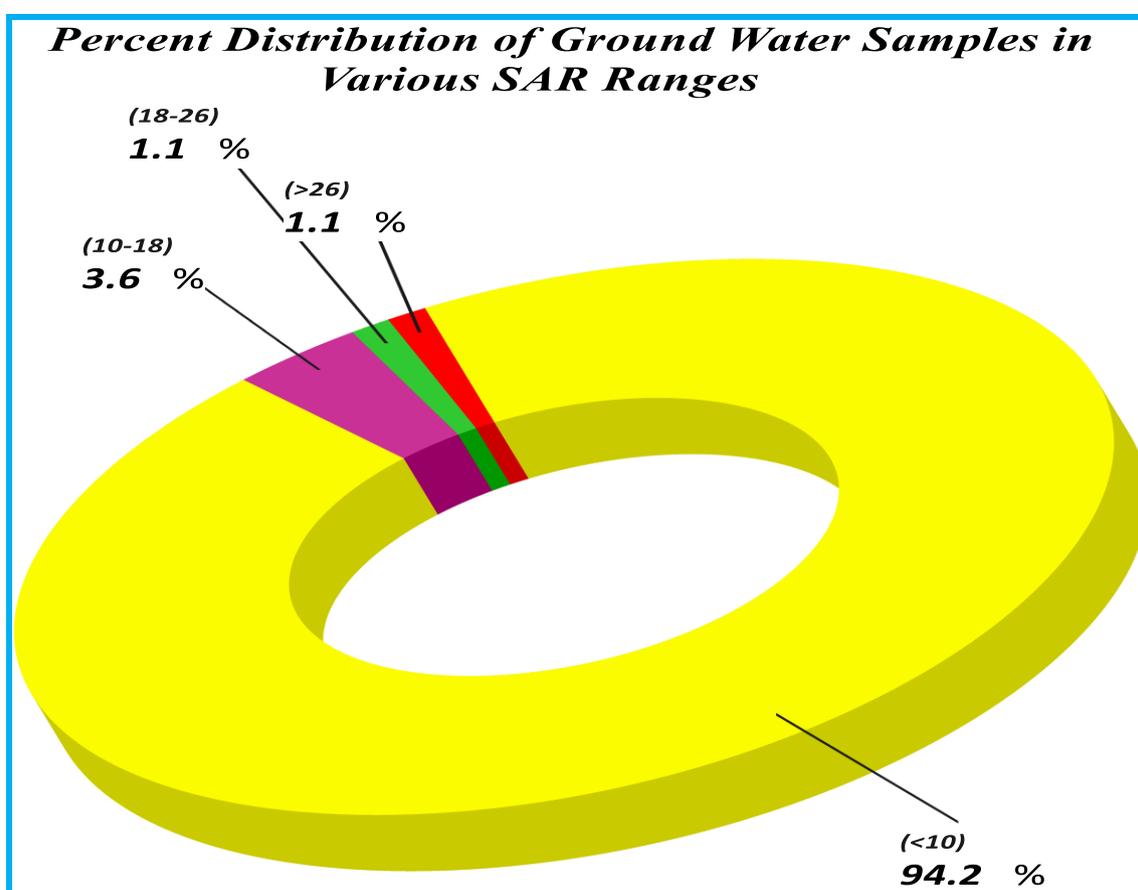


Figure 34: Percent Distribution of Ground Water Samples in SAR Ranges

Nationally, 98.9% of the samples recorded SAR ≤ 26, indicating that most groundwater sources are safe for irrigation use. Only 1.11% (166 samples) exceeded the permissible limit (SAR > 26), suggesting limited risk of sodicity hazards at the national scale. The highest SAR values were observed in Bihar (up to 505), Delhi (up to 179.8), and Rajasthan (up to 72.6), indicating localized areas with potentially high sodium hazard. Delhi (34.8%) and

Rajasthan (12%) showed the maximum proportion of samples exceeding the limit, followed by Bihar (1.4%).

Overall, elevated SAR values are primarily confined to arid and semi-arid regions, especially in northwestern India, where intensive groundwater use and evaporation may contribute to sodium accumulation. Continuous monitoring and adoption of sustainable irrigation and soil management practices are recommended to mitigate potential long-term impacts on soil productivity.

Table 22 : Percent Distribution of SAR Values in Different States/UTs

S. No.	State/UT	No. of Samples	min.	max.	No. of Samples (SAR > 26)	% of Samples (SAR > 26)
1	Andaman & Nicobar Islands	115	0.2	9.2	0	0.00
2	Andhra Pradesh	1135	0.0	116.2	10	0.88
3	Arunachal Pradesh	15	0.2	0.8	0	0.00
4	Assam	145	0.0	16.7	0	0.00
5	Bihar	584	0.0	505.0	8	1.37
6	Chandigarh UT	9	0.2	4.8	0	0.00
7	Chhattisgarh	830	0.0	23.9	0	0.00
8	Dadra And Nagar Haveli and Daman and Diu	16	0.5	10.8	0	0.00
9	Delhi	135	0.2	179.8	47	34.81
10	Goa	7	0.3	1.5	0	0.00
11	Gujarat	618	0.3	37.8	6	0.97
12	Haryana	811	0.0	43.0	4	0.49
13	Himachal Pradesh	161	0.0	29.4	1	0.62
14	Jammu & Kashmir	247	0.1	5.4	0	0.00
15	Jharkhand	381	0.1	15.5	0	0.00
16	Karnataka	398	0.2	22.0	0	0.00
17	Kerala	361	0.2	4.8	0	0.00
18	Madhya Pradesh	726	0.1	11.5	0	0.00
19	Maharashtra	1565	0.1	20.0	0	0.00
20	Manipur	3	0.4	0.7	0	0.00
21	Meghalaya	39	0.1	1.8	0	0.00
22	Nagaland	67	0.1	1.7	0	0.00
23	Odisha	654	0.1	19.7	0	0.00
24	Punjab	756	0.1	38.2	5	0.66
25	Rajasthan	643	0.1	72.6	77	11.98
26	Tamil Nadu	929	0.1	34.7	2	0.22
27	Telangana	1114	0.1	25.3	0	0.00
28	Tripura	49	0.4	3.9	0	0.00
29	UT of Puducherry	9	0.7	6.5	0	0.00
30	Uttar Pradesh	1333	0.1	36.4	3	0.23
31	Uttarakhand	248	0.0	30.6	1	0.40
32	West Bengal	875	0.0	28.2	2	0.23
	Total	14978	0.0	505.0	166	1.11

Overall, elevated SAR values are primarily confined to arid and semi-arid regions, especially in northwestern India, where intensive groundwater use and evaporation may contribute to sodium accumulation. Continuous monitoring and adoption of sustainable irrigation and soil management practices are recommended to mitigate potential long-term impacts on soil productivity.

8.2 Residual Sodium Carbonate (RSC) and its impact on Irrigation Suitability

If the enriched carbonate (residual) concentration becomes relatively high, carbonates get together with calcium and magnesium to form precipitates. The relative abundance of sodium in comparison to alkaline earths and the quantity of bicarbonate and carbonate in excess of alkaline earths also influences the suitability of water for irrigation. This excess is represented in terms of “Residual Sodium Carbonate” (RSC).

The highly soluble sodium carbonate known as residual sodium carbonate (RSC) is defined as;

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

Waters with high RSC produces harmful effects on plant development and is not suitable for irrigation. Waters associated with $RSC < 1.25$ are of excellent irrigation quality and can be safely applied for irrigation for almost all crops without the risks associated with residual sodium carbonate (Wilcox et al.,1954). If the RSC values lie between 1.25 and 2.5, the water is of an acceptable quality for irrigation. Waters associated with RSC values higher than 2.5 are not acceptable for irrigation.

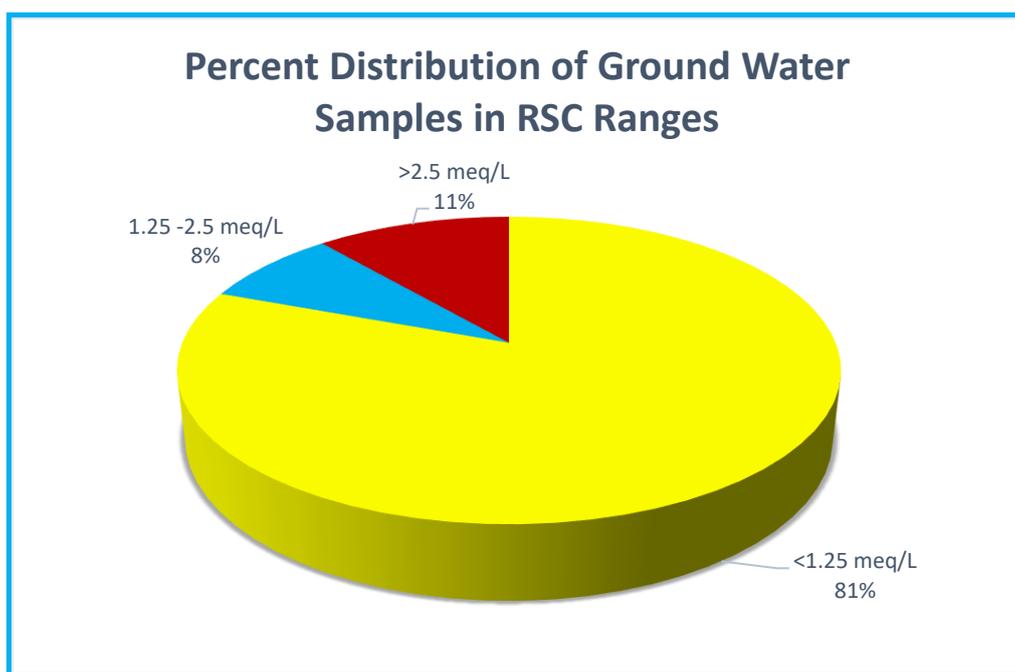


Figure 35: Percent Distribution of Ground Water Samples in RSC Ranges

11.27% exceeded the permissible limit of 2.5 meq/L, indicating potential sodicity hazards in some regions. High incidences of RSC beyond permissible limits were recorded in Delhi (51.11%), Uttarakhand (41.94%), Andhra Pradesh (26.87%), Punjab (24.60%), and Rajasthan (24.42%), signifying concern in these states. Moderate exceedances were observed in Haryana (15.54%), Karnataka (13.32%), Uttar Pradesh (13.65%), and Telangana (11.76%). Most other States/UTs showed RSC values within safe limits, reflecting overall satisfactory groundwater quality in terms of alkalinity hazard, except for localized high-RSC zones requiring monitoring and management for irrigation use.

Table 23: Percent Distribution of RSC Values in Different States/UTs

S. No.	State/UT	No. of Samples	min.	max.	No. of Samples (RSC > 2.5 meq/L)	% of Samples (RSC > 2.5 meq/L)
1	Andaman & Nicobar Islands	115	-5.4	4.1	1	0.87
2	Andhra Pradesh	1135	-133.0	79.1	305	26.87
3	Arunachal Pradesh	15	-0.9	0.4	0	0.00
4	Assam	145	-6.4	8.0	11	7.59
5	Bihar	584	-11.7	14.1	36	6.16
6	Chandigarh UT	9	-1.0	4.2	1	11.11
7	Chhattisgarh	830	-14.4	7.0	14	1.69
8	Dadra And Nagar Haveli and Daman and Diu	16	-10.4	6.0	1	6.25
9	Delhi	135	-1484.8	796.3	69	51.11
10	Goa	7	-2.3	0.1	0	0.00
11	Gujarat	618	-161.8	21.0	66	10.68
12	Haryana	811	-87.3	16.6	126	15.54
13	Himachal Pradesh	161	-5.4	3.8	2	1.24
14	Jammu & Kashmir	247	-7.5	5.2	10	4.05
15	Jharkhand	381	-10.4	6.6	6	1.57
16	Karnataka	398	-38.9	16.1	53	13.32
17	Kerala	361	-15.9	1.9	0	0.00
18	Madhya Pradesh	726	-17.8	9.6	24	3.31
19	Maharashtra	1565	-58.6	12.2	82	5.24
20	Manipur	3	-1.4	-0.1	0	0.00
21	Meghalaya	39	-2.3	1.5	0	0.00
22	Nagaland	67	-6.5	2.0	0	0.00
23	Odisha	654	-25.1	9.8	15	2.29
24	Punjab	756	-29.0	17.0	186	24.60
25	Rajasthan	643	-124.8	23.6	157	24.42
26	Tamil Nadu	929	-40.9	11.4	22	2.37
27	Telangana	1114	-57.1	13.7	131	11.76
28	Tripura	49	-1.6	1.2	0	0.00
29	UT of Puducherry	9	-14.0	1.8	0	0.00
30	Uttar Pradesh	1333	-47.4	23.8	182	13.65
31	Uttarakhand	248	-4.1	1030.4	104	41.94
32	West Bengal	875	-46.2	10.9	84	9.60
	Total	14978	-1484.8	1030.4	1688	11.27

8.3 Wilcox Diagram

EC and sodium concentration are very important in classifying irrigation water. The Wilcox diagram (Wilcox 1948) relating EC and % Na shows (Fig. 36) that all the samples are plotted in excellent to good and good to permissible categories in most of the water samples indicating their suitability for irrigation. Most of the samples associated with doubtful to unsuitable zone for irrigation belong to Kerala, Madhya Pradesh, Bihar and Telangana. Wilcox diagram of some of the States of India is presented as Fig. 37.

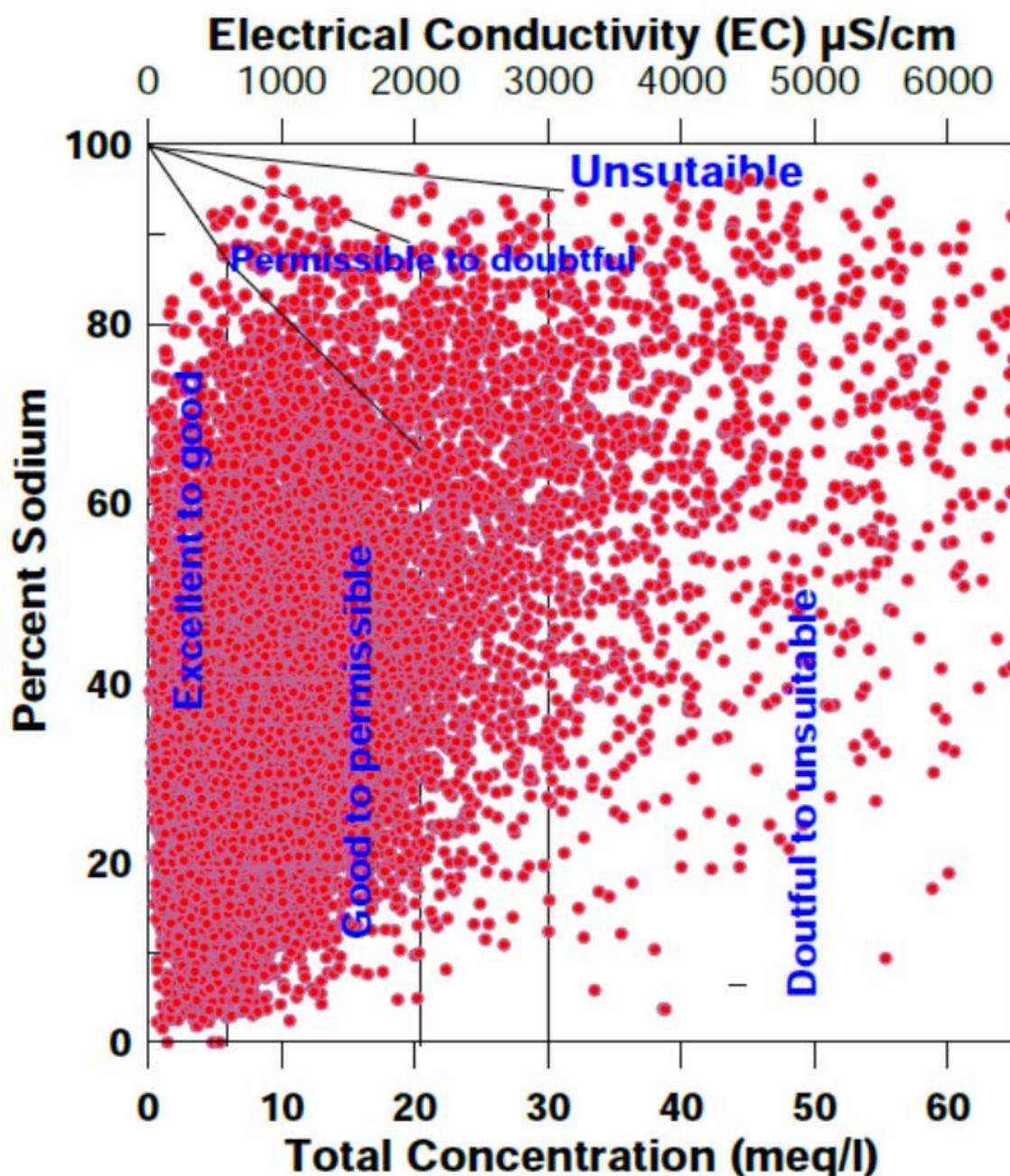


Figure 36: Plots of sodium percent versus electrical conductivity (after Wilcox 1955) in groundwater samples of India.

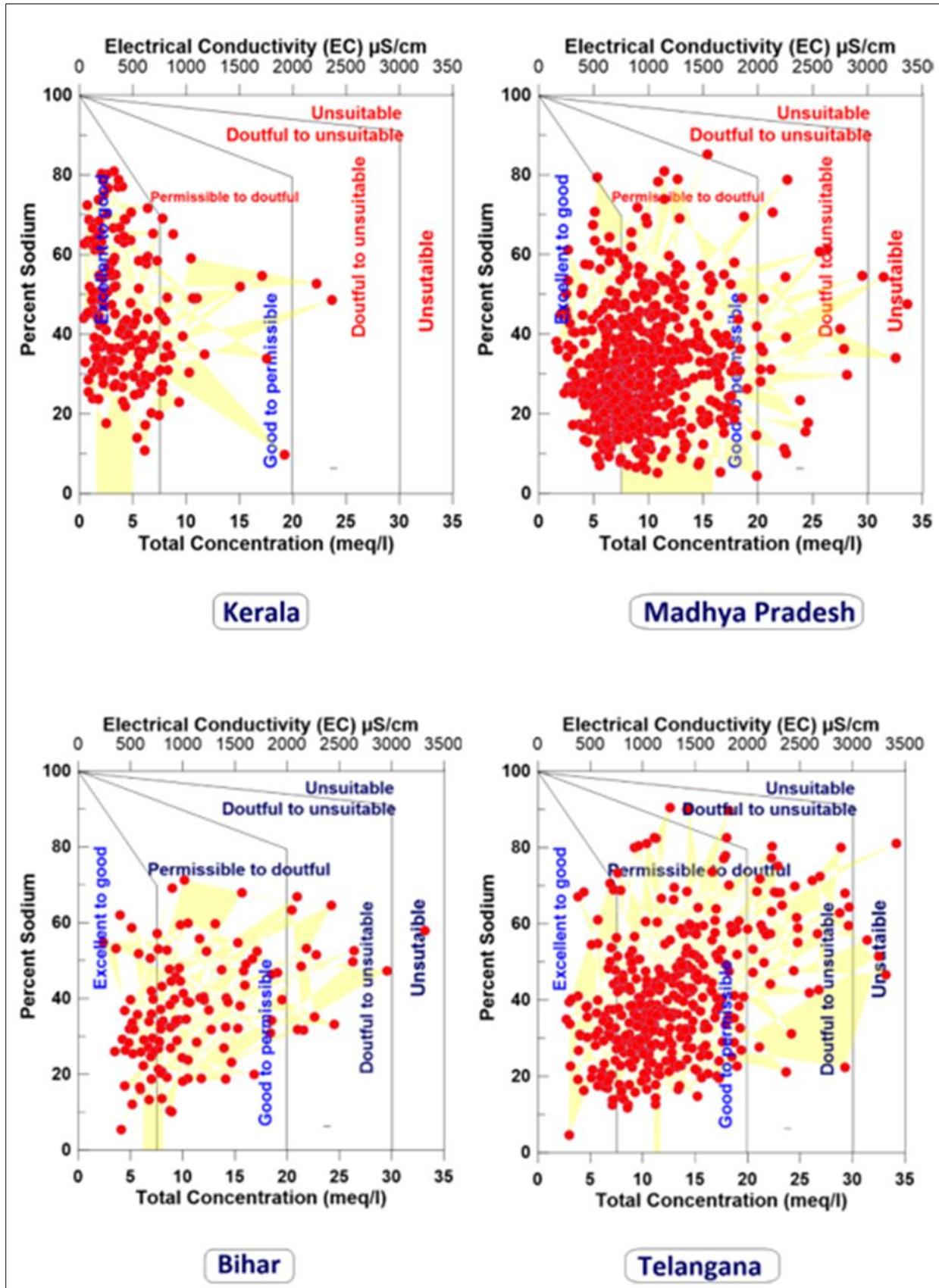


Figure 37: Plots of sodium percent versus electrical conductivity (after Wilcox 1955) in groundwater samples Kerala, Madhya Pradesh, Bihar and Telangana.

Although the majority of groundwater is still suitable for irrigation, the gradual deterioration in quality is evident. If this trend continues unchecked, it may accelerate soil sodicity problems and compromise agricultural sustainability. To mitigate risks, continuous monitoring, gypsum application.

9.0 Hydrogeochemical Plots

Hydrogeochemistry plots are valuable tools for assessing groundwater quality data. These plots help visualize the chemical composition of groundwater and reveal important trends, relationships, and potential issues related to the water quality.

Piper plot (Piper 1944) is a crucial tool in a water quality report, especially for groundwater studies, as it provides a clear visual representation of the chemical composition of groundwater quality data. It helps **interpret complex ionic data** and enables the comparison of water samples based on their dominant ion composition. Water quality reports often contain complex and voluminous data, including numerous ionic concentrations.

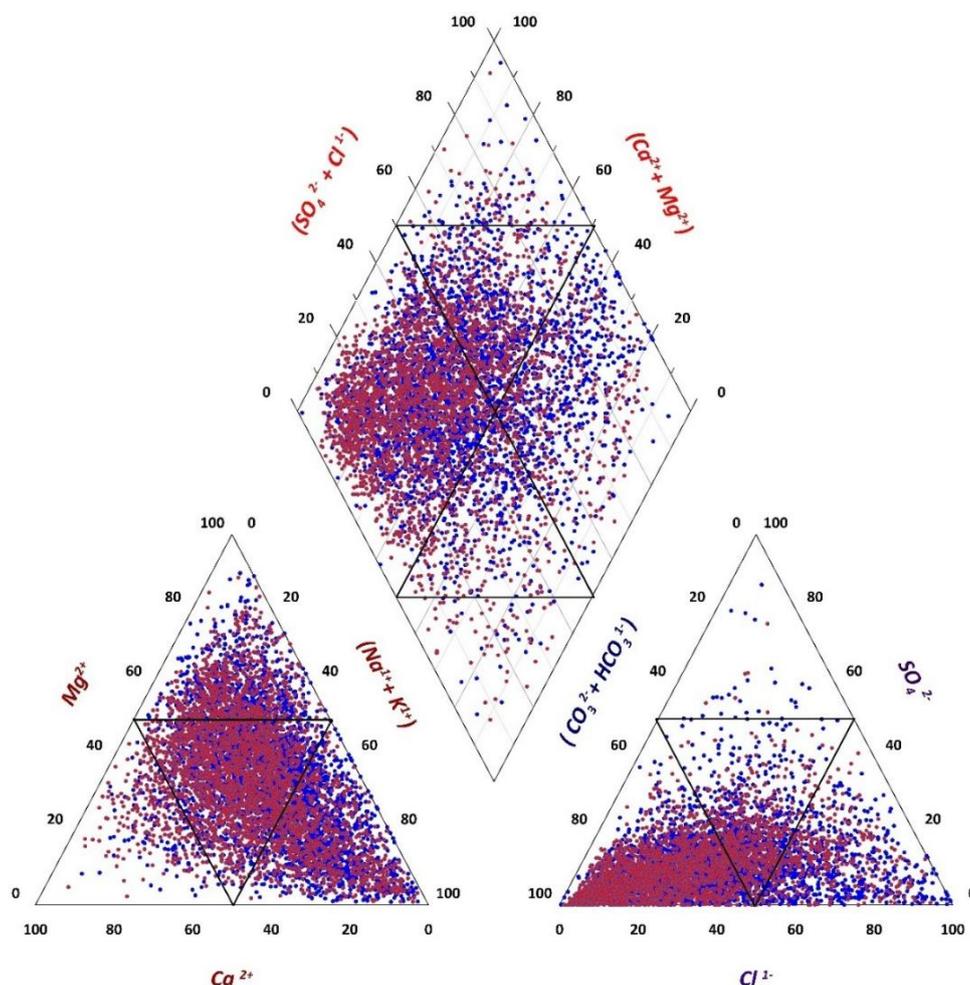


Figure 38: Piper diagram of groundwater of India.

The Piper plot simplifies this complexity by condensing the data into a **single visual representation**, making it easier for stakeholders to understand the water quality status and its implications. Based on the major cation and major anion content in the water samples and plotting them in the trilinear diagram, hydrochemical facies could be identified.

In India, cation chemistry is dominated by calcium is followed by Calcium, Sodium and Potassium. In anion side bicarbonate is dominating anion followed by chloride and sulphate.

Facies-Wise Summary of National Groundwater Chemistry

1. Na-HCO₃ Type (Alkali Bicarbonate Water)

Na-HCO₃ facies is moderately represented across India, with significant dominance in Punjab (39.6%), Haryana (28.1%), and Andhra Pradesh (26.7%). States such as Jharkhand, Kerala, Chhattisgarh, Jammu & Kashmir, and Tripura report negligible or no presence. Overall, Na-HCO₃ occurs mostly in alluvial plains (Punjab, Haryana, UP) and hard rock terrains (Andhra, Karnataka), indicating cation exchange and alkali enrichment in groundwater.

2. Ca-HCO₃ Type (Temporary Hardness, Freshwater Signature)

Ca-HCO₃ is the most widespread facies, dominating in many states. High proportions are seen in Jammu & Kashmir (95.9%), Uttarakhand (90.4%), Uttar Pradesh (82.8%), Chhattisgarh (77.8%), and Madhya Pradesh (70.8%). This facies reflects carbonate weathering and recharge from fresh rainfall, and it marks the primary hydro chemical signature in Himalayan foothills, central India, and Indo-Gangetic plains.

3. CaCl₂ Type (Permanent Hardness Water)

CaCl₂ facies is generally minor but notable in some regions. The highest values occur in Haryana (9.2%), Delhi (6.3%), and Himachal Pradesh (6.7%). Most other states report less than 3%. Its occurrence is linked to saline intrusion, industrial effluents, and evaporite dissolution, often concentrated in urban/semi-arid regions.

4. Mixed Type (Ca–Mg–Cl–SO₄ and Variable Combinations)

Mixed facies are widespread and significant, with particularly high proportions in Jharkhand (89.1%), Kerala (81%), Meghalaya (73.7%), Tamil Nadu (56.9%), and West Bengal (54.3%). This indicates areas where multiple hydro chemical processes interact, often influenced by complex lithology, anthropogenic inputs, and hydrogeological mixing. Southern and northeastern states show clear dominance of mixed water types.

5. NaCl Type (Saline Water)

NaCl (saline facies) is strongly dominant in coastal and arid regions, especially Gujarat (53.7%), Rajasthan (55%), and Delhi (47.4%). Other significant shares appear in Nagaland (24.2%) and Tripura (23.3%). This facies is strongly associated with marine influence

(coastal areas), salinity ingress in aquifers, and anthropogenic contamination. Its dominance in western India (Rajasthan, Gujarat) reflects arid climate and evaporation-driven salinization.

At the national scale, the hydro chemical characterization of groundwater in India reveals a distinct **dominance of the Calcium–Bicarbonate (Ca-HCO₃) facies**, which constitutes the primary water type across large parts of the country. These facies, indicative of carbonate weathering and recharge through recent precipitation, is particularly prominent in the Himalayan foothill states, the Indo-Gangetic alluvial plains, and central India, signifying the prevalence of fresh recharge conditions and relatively unaltered geochemical environments. The Mixed facies emerge as the second most significant category, with high representation in the southern peninsular states and the northeastern region, reflecting the influence of complex lithological settings, anthropogenic activities, and multi-ion interactions that lead to mixed hydrochemical signatures. The sodium–chloride (NaCl) facies, strongly developed in arid and semi-arid zones of western India (Rajasthan and Gujarat) and in metropolitan Delhi, highlights the processes of salinity ingress, evaporative concentration, and possible anthropogenic contamination.

The hydrochemical facies analysis of groundwater in India during Pre-Monsoon 2024 reveals that Ca-HCO₃ type water dominates, accounting for 44.25% of samples, indicating that carbonate weathering and temporary hardness define the baseline groundwater chemistry across much of the country. The Mixed type facies is the second most common, constituting 37.55%, reflecting transitional hydrochemical conditions influenced by both carbonate and non-carbonate sources.

In contrast, NaCl type waters represent 9.21%, highlighting localized zones of salinity and evaporite dissolution, often observed in arid to semi-arid regions. The Na-HCO₃ facies accounts for 7.39%, which is typically associated with cation exchange processes and alkali enrichment in certain aquifers. The least represented is CaCl₂ facies (1.60%), indicating localized permanent hardness and possible salinity intrusion, often in urban or stressed aquifer zones.

Overall, the dominance of Ca-HCO₃ and Mixed type facies reflects the natural buffering capacity of aquifers, but the presence of saline and alkali-rich waters (NaCl and Na-HCO₃) in nearly 17% of samples points to increasing water quality stress in specific hydrogeological settings.

Percent Distribution of Hydrochemical Facies in Groundwater of India (Pre-Monsoon 2024)

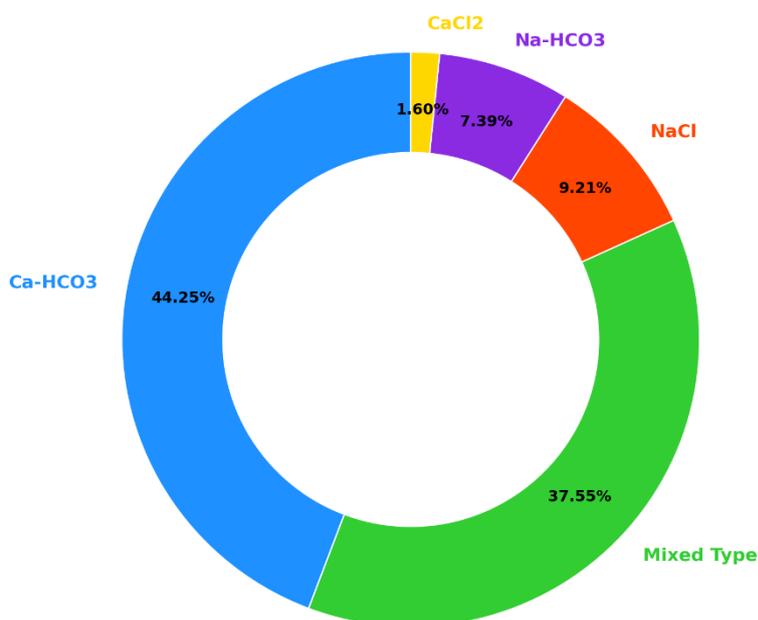


Figure 39: Percent Distribution of Percent Distribution of hydro chemical facies in Ground Water of INDIA (Pre-M :2024)

The alkali–bicarbonate (Na-HCO₃) facies, though less dominant nationally, shows considerable development in Punjab, Haryana, and Andhra Pradesh, likely due to cation exchange processes and alkali enrichment within aquifer matrices. The calcium–chloride (CaCl₂) facies, though relatively minor, is prominent in urbanized and semi-arid regions, reflecting localized salinity intrusion and evaporite dissolution. Overall, while Ca-HCO₃ waters define the baseline hydrochemical character of Indian groundwater systems, significant regional heterogeneity persists—shaped by climatic regimes, geological controls, and human interventions.

10.0 Hotspot Monitoring of Ground Water Quality

Groundwater quality hotspot monitoring was undertaken by the Central Ground Water Board (CGWB) to assess contaminant distribution and spatial spread in areas where concentrations of key water quality parameters exceeded the permissible limits prescribed by the Bureau of Indian Standards (BIS: 10500:2012). The objective of this exercise was to delineate localized contamination zones and understand the extent of contaminant migration within the surrounding areas.

The hotspot monitoring focused on parameters of major concern at the national level—Arsenic, Electrical Conductivity (EC), Fluoride, Nitrate, and Uranium. Sampling was carried out around

the locations identified as exceeding permissible limits in the baseline monitoring network.

The Figure 39 illustrates the sampling grid layout adopted around each identified groundwater quality hotspot during detailed hotspot monitoring. The central point marked as HS (Hotspot) represents the location where a contaminant concentration exceeded the permissible limit during baseline monitoring.

Around each hotspot, groundwater samples were collected in a 2 km × 2 km grid pattern, This systematic grid-based approach ensures uniform spatial coverage and helps delineate the extent and direction of contaminant spread from the hotspot.

Each grid node (indicated by stars) represents a sampling location where groundwater was analyzed for key parameters — Arsenic, EC, Manganese, Fluoride, Nitrate, and Uranium. The resulting data enable assessment of:

- Whether contamination is localized (confined near the hotspot), or
- Spread in one or multiple directions, indicating possible contaminant migration pathways.

This grid-based design provides a scientifically robust framework to characterize contamination zones, understand hydrogeochemical processes, and support targeted mitigation planning.

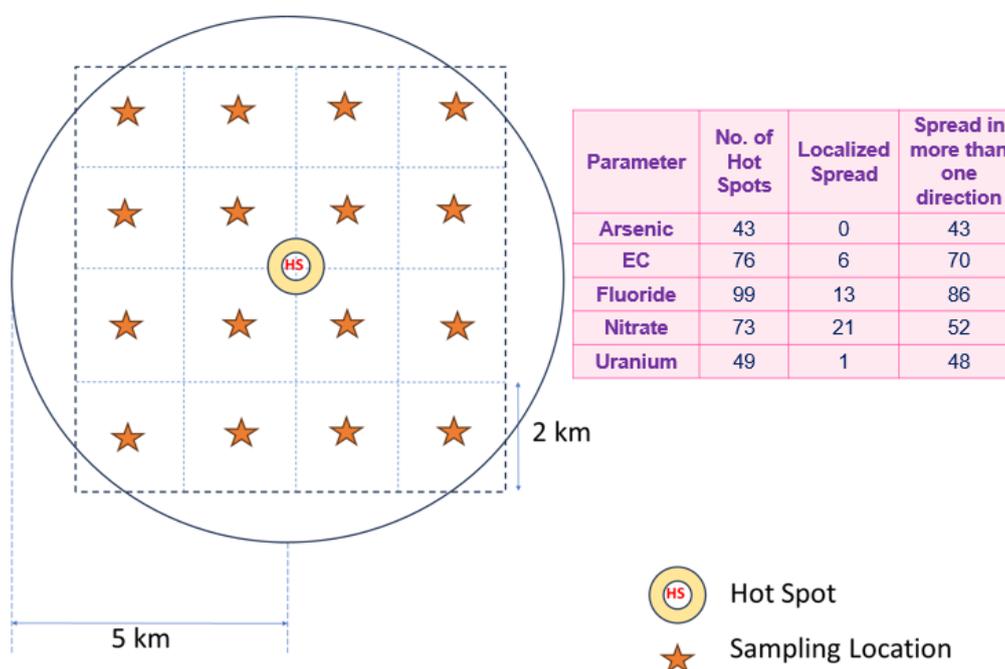


Figure 40: Grid-wise Sampling Design around Identified Groundwater Quality Hotspot (2 km × 2 km Pattern)

The analytical results were compiled, validated, and mapped at the national scale for each parameter separately. In these maps, hotspot locations have been prominently highlighted within state boundaries to depict the concentration zones and surrounding contamination

gradients. To complement the spatial representation, detailed analytical results of samples around each hotspot have been tabulated and appended as Annexures for reference and data transparency.

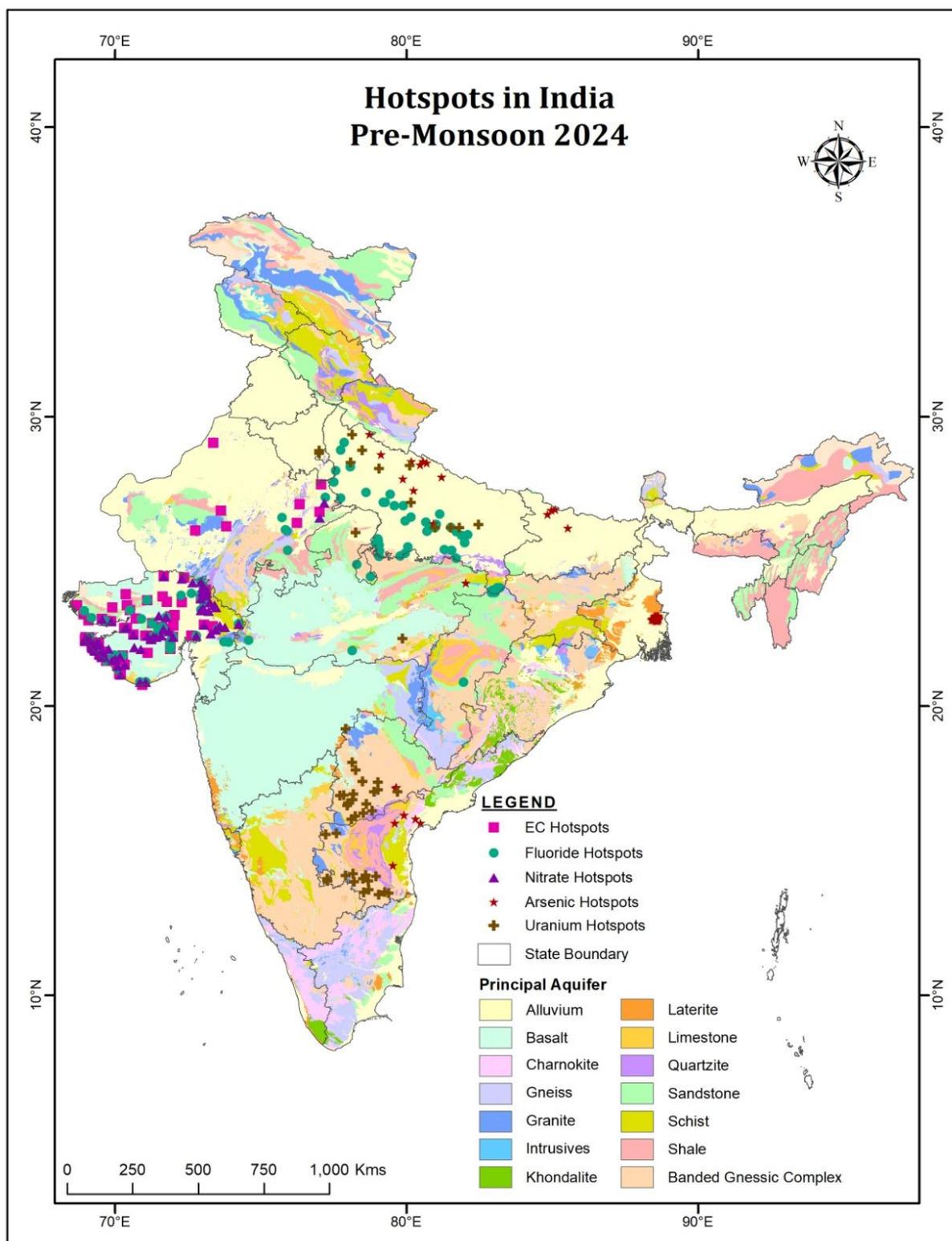


Figure 41: Location of hot spot location identified in 10 states (Pre-Monsoon 2024)

The results generated through this exercise serve as a crucial input for understanding

contaminant behavior, supporting remedial planning, and prioritizing areas for detailed hydrochemical and source investigations.

Hot spot sampling was undertaken in the states of Andhra Pradesh, Bihar, Madhya Pradesh, Telangana, Uttar Pradesh, West Bengal, Chhattisgarh, Gujarat, Rajasthan, and Delhi. Sampling sites were identified based on groundwater quality monitoring data indicating parameter concentrations exceeding the permissible limits. Locations (Table 24 to 28 & Annexure-X to XIV) were selected for detailed hot spot investigations to assess the extent and pattern of contamination. The identified hot spots primarily correspond to exceedances of Arsenic (As), Electrical Conductivity (EC), Fluoride (F⁻), Nitrate (NO₃⁻), and Uranium (U), which constitute the major groundwater quality concerns across the studied regions. Observations indicate that the spread of contamination around most hot spots is more than one direction.

Table 24: Groundwater Nitrate Hotspot Locations Exceeding BIS Limit (45 mg/L).

Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	Nitrate (mg/L)
1	Rajasthan	Karauli	Karauli	Karauli	77.01720	26.50140	Dug Well	226
2	Rajasthan	Bharatpur	Weir	Weir	77.16730	27.02000	Dug Well	140
3	Gujarat	Anand	Petlad	Dharmaj	72.78741	22.42074	Dug Well	214
4	Gujarat	Kheda	Mahudha	Alina	73.04766	22.80567	Dug Well	295
5	Gujarat	Vadodara	Savli	Juna samalya	73.27419	22.50406	Dug Well	138
6	Gujarat	Jamnagar	Jodiya	Bedanpur	70.31252	22.68747	Dug Well	960
7	Gujarat	Jamnagar	Jodiya	Kesiya	70.39706	22.69661	Dug Well	210
8	Gujarat	Devbhumi Dwarka	Bhanvad	Nawagam	69.76564	21.97634	Dug Well	116
9	Gujarat	Porbandar	Porbandar	Kolikhada	69.63681	21.68157	Dug Well	207
10	Gujarat	Porbandar	Porbandar	Mojiwana	69.57426	21.85995	Dug Well	496
11	Gujarat	Devbhumi Dwarka	Khambhalia	Hanzdapur	69.43681	22.18885	Dug Well	252
12	Gujarat	Devbhumi Dwarka	Kalyanpur	Juvanpur	69.36493	22.16769	Dug Well	253
13	Gujarat	Porbandar	Porbandar	Kuchhadi	69.54887	21.68100	Dug Well	366
14	Gujarat	Porbandar	Porbandar	Palkhada	69.48491	21.76032	Dug Well	223
15	Gujarat	Porbandar	Porbandar	Visavada	69.45381	21.77523	Dug Well	396
16	Gujarat	Devbhumi Dwarka	Kalyanpur	Lambha	69.30844	21.91130	Dug Well	382
17	Gujarat	Devbhumi Dwarka	Kalyanpur	Bhogat	69.24428	21.99049	Dug Well	212
18	Gujarat	Devbhumi Dwarka	Kalyanpur	Khakharda	69.37210	22.10477	Dug Well	420
19	Gujarat	Devbhumi Dwarka	Kalyanpur	Kalyanpur	69.05421	22.30758	Dug Well	70
20	Gujarat	Devbhumi Dwarka	Kalyanpur	Navadra	69.28649	21.93994	Dug Well	56
21	Gujarat	Devbhumi Dwarka	Kalyanpur	Gojines	69.20424	22.02455	Dug Well	420
22	Gujarat	Devbhumi Dwarka	Kalyanpur	Vamansa	69.18870	22.08400	Dug Well	210
23	Gujarat	Devbhumi Dwarka	Kalyanpur	Gurgadh	69.19093	22.19470	Dug Well	406
24	Gujarat	Devbhumi Dwarka	Okhamandal	Varwada	68.96145	22.29772	Dug Well	420
25	Gujarat	Devbhumi Dwarka	Okhamandal	Mojap	68.97956	22.36145	Dug Well	165
26	Gujarat	Devbhumi Dwarka	Okhamandal	Dwarka	68.96044	22.24068	Dug Well	220
27	Gujarat	Devbhumi Dwarka	Okhamandal	Samrasar	69.10628	22.36993	Dug Well	376
28	Gujarat	Porbandar	Kutiyana	Kutiyana	70.01126	21.62841	Dug Well	496
29	Gujarat	Porbandar	Ranavav	Bhoddar	69.89493	21.57514	Dug Well	306
30	Gujarat	Junagadh	Mangrol	Osa	70.06416	21.37289	Dug Well	437
31	Gujarat	Junagadh	Mangrol	Arena	70.17712	21.08075	Dug Well	332
32	Gujarat	Junagadh	Vanthali	Khokharda	70.31756	21.42010	Dug Well	218
33	Gujarat	Banaskantha	Tharad	Dudhba NHS DW	71.66902	24.47940	Dug Well	112
34	Gujarat	Banaskantha	Danta	Ganapipli NHS DW	72.94666	24.29364	Dug Well	71

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	Nitrate (mg/L)
35	Gujarat	Banaskantha	Amirgadh	Virmpur NHS DW	72.65233	24.26640	Dug Well	48
36	Gujarat	Banaskantha	Deesa	Meda NHS DW	72.28531	24.39793	Dug Well	88
37	Gujarat	Kachchh	Mundra	Nani Tumbdi	69.54897	22.99628	Dug Well	274
38	Gujarat	Kachchh	Mundra	Vadala	69.85378	22.91676	Dug Well	210
39	Gujarat	Ahmedabad	Dhandhuka	Dhandhuka1 NHS DW	71.98774	22.37606	Dug Well	506
40	Gujarat	Gir Somnath	Kodinar	Dolasa	70.84720	20.81937	Dug Well	100
41	Gujarat	Gir Somnath	Una	Una2	71.04157	20.82239	Dug Well	150
42	Gujarat	Rajkot	Gondal	Gogavadar	70.88018	21.96486	Dug Well	153
43	Gujarat	Rajkot	Gondal	Kolithad1	70.65164	22.01909	Dug Well	99
44	Gujarat	Rajkot	Paddhari	Movaiya	70.62754	22.45793	Dug Well	309
45	Gujarat	Rajkot	Upleta	Ganod	70.16931	21.68879	Dug Well	769
46	Gujarat	Surendranagar	Chotila	Moti Moladi	71.10400	22.41789	Dug Well	459
47	Gujarat	Surendranagar	Dasada	Malvan	71.75028	23.06139	Dug Well	450
48	Gujarat	Surendranagar	Dhrangadhra	Kukavati (Jesda)	71.48887	23.11516	Dug Well	255
49	Gujarat	Surendranagar	Limdi	Choraniya	71.85087	22.57200	Dug Well	991
50	Gujarat	Surendranagar	Sayla	Dhajala	71.39799	22.38069	Dug Well	48
51	Gujarat	Surendranagar	Sayla	Nagadka	71.57913	22.42688	Dug Well	150
52	Gujarat	Surendranagar	Sayla	Piprali	71.31166	22.39531	Dug Well	220
53	Gujarat	Surendranagar	Wadhwan	Vaghela	71.65718	22.65774	Dug Well	926
54	Gujarat	Surendranagar	Chotila	Sanosara	71.23044	22.29886	Dug Well	654
55	Gujarat	Sabarkantha	Talod	Umedpura	72.96444	23.30361	Dug Well	47
56	Gujarat	Sabarkantha	Talod	Harsoli	73.01667	23.37778	Dug Well	55
57	Gujarat	Sabarkantha	Talod	Kesarpura(Mayal)	72.94889	23.32222	Dug Well	69
58	Gujarat	Sabarkantha	Himatnagar	Gadhal	72.94167	23.70833	Dug Well	334
59	Gujarat	Sabarkantha	Idar	Revas	73.11667	23.82083	Dug Well	60
60	Gujarat	Sabarkantha	Vadali	Choriwad	73.11944	23.90000	Dug Well	86
61	Gujarat	Sabarkantha	Vadali	Kesharpura	73.14528	23.91528	Dug Well	82
62	Gujarat	Sabarkantha	Vadali	Wadali	73.03333	23.93333	Dug Well	58
63	Gujarat	Sabarkantha	Vadali	Hatharva	72.99349	23.94541	Dug Well	126
64	Gujarat	Sabarkantha	Khedbrahma	Silwad	73.11667	24.00833	Dug Well	221
65	Gujarat	Sabarkantha	Khedbrahma	Matoda	73.00833	24.11111	Dug Well	168
66	Gujarat	Dahod	Dahod	Dahod2	74.23333	22.82500	Dug Well	100
67	Gujarat	Arvalli	Modasa	Gadada	73.25306	23.57528	Dug Well	150
68	Gujarat	Arvalli	Modasa	Seenawad	73.39861	23.48639	Dug Well	62
69	Gujarat	Arvalli	Malpur	Hamirpur	73.45833	23.40833	Dug Well	59
70	Gujarat	Arvalli	Bayad	Alwa Kampa	73.20833	23.27472	Dug Well	53
71	Gujarat	Panchmahal	Kalol	Kalol UR 2	73.44787	22.63207	Dug Well	110
72	Gujarat	Panchmahal	Ghoghamba	Ranipura	73.75833	22.72500	Dug Well	120
73	Gujarat	Panchmahal	Godhra	Godhra UR 2	73.59111	22.76917	Dug Well	126

Table 25: Groundwater Arsenic Hotspot Locations Exceeding BIS Limit (10 ppb).

Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	As (ppb)
1	Bihar	East Champaran	Turkauliya	Bairiya Bazaar	84.84336	26.60995	H.P.	85.6
2	Bihar	East Champaran	Motihari	Lakhwara	84.97741	26.75819	H.P.	16.9
3	Bihar	East Champaran	Ghorasahan	Bhelwa	85.10897	26.78612	H.P.	36.8
4	Bihar	Muzaffarpur	Bochaha	Chak Nuran	85.54685	26.13468	H.P.	15.8
5	Madhya Pradesh	Singrauli	Deosar	Karda	82.03920	24.24200	DW	42.9
6	West Bengal	Nadia	Chakdah	Ghugia Sasitola	88.52560	23.09290	Hand Pump	46.9
7	West Bengal	Nadia	Chakdah	Dhanicha	88.55990	23.08848	Hand Pump	19.2
8	West Bengal	Nadia	Chakdah	Khamarpara	88.61310	23.10930	Hand Pump	54.3
9	West Bengal	Nadia	Chakdah	Bahir Silinda	88.65060	23.09500	Hand Pump	37.4
10	West Bengal	Nadia	Chakdah	Khamarpota	88.53300	23.05230	Hand Pump	33.3
11	West Bengal	Nadia	Chakdah	Rukminidanga	88.57680	23.05900	Hand Pump	30.9
12	West Bengal	Nadia	Chakdah	Tengra	88.62850	23.05190	Hand Pump	163.3
13	West Bengal	Nadia	Chakdah	Ballavpur	88.65520	23.04690	Hand Pump	19.2
14	West Bengal	Nadia	Chakdah	Charborpara	88.43390	23.00490	Hand Pump	62.3

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	As (ppb)
15	West Bengal	Nadia	Chakdah	Napatipara	88.51980	23.02510	Hand Pump	24.2
16	West Bengal	Nadia	Harringhata	Darapur	88.56368	22.99178	Deep HP	61.9
17	West Bengal	Nadia	Harringhata	Mitrapur	88.61286	23.00443	Hand Pump	16.5
18	West Bengal	Nadia	Chakdah	Sarrapur East	88.65990	23.01700	Hand Pump	46.5
19	West Bengal	Nadia	Chakdah	Sahidpally	88.41690	22.95870	Hand Pump	141.7
20	West Bengal	Nadia	Chakdah	Jaydebbati	88.48340	22.98270	Hand Pump	18.5
21	West Bengal	Nadia	Harringhata	Harringhata Bdo Office	88.57295	22.95507	Hand Pump	12.7
22	West Bengal	Nadia	Harringhata	Nimtala Bazar	88.66083	22.98056	Hand Pump	12.6
23	West Bengal	Nadia	Chakdah	Gayeshpur	88.49610	22.94850	Hand Pump	26.5
24	West Bengal	Nadia	Harringhata	Dakshin Brahmapur	88.56096	22.92498	Hand Pump	11.3
25	West Bengal	Nadia	Harringhata	Haripukuria	88.61568	22.93531	Hand Pump	12.7
26	West Bengal	Nadia	Harringhata	Hapania	88.64257	22.92902	Hand Pump	10.9
27	Andhra Pradesh	Bapatla	Bapatla	Mulapalem	80.47600	15.93870	DW	14.9
28	Andhra Pradesh	Guntur	Pedanandipadu	Varagami	80.30833	16.07639	DW	12.4
29	Andhra Pradesh	Nellore	Atmakur	Kartamoadu	79.53852	14.46795	DW	39.1
30	Andhra Pradesh	Palnadu	Rompicherla2	Rompicherla	79.91330	16.21000	DW	10.1
31	Andhra Pradesh	Prakasam	Kurichedu	Vengaihpalem	79.59390	15.93190	DW	12.4
32	Telangana	Suryapet	Suryapet	Suryapet-Pz	79.63073	17.13283	BW	17.5
33	Telangana	Suryapet	Suryapet	Kudakuda	79.64444	17.18167	DW	22.9
34	Uttar Pradesh	Rampur	Milak	Brijpur	79.12907	28.67988	Handpump	15.3
35	Uttar Pradesh	Bijnor	Afzalgarh	Afzalgarh Block	78.73179	29.37940	Handpump	28.0
36	Uttar Pradesh	Raebareli	Kheron	Block Hq	80.92767	26.29174	HP India Mark	71.9
37	Uttar Pradesh	Hardoi	Tadiyawan	Block Hq	80.24056	27.43792	India Mark II HP	19.5
38	Uttar Pradesh	Lakhimpur Kheri	Ishanagasr	Block Hq	81.20733	27.90759	India Mark II HP	27.2
39	Uttar Pradesh	Lakhimpur Kheri	Palia	Bhagawant Nagar	80.69248	28.38561	India Mark II HP	86.8
40	Uttar Pradesh	Lakhimpur Kheri	Palia Kalan	Palia	80.57762	28.43734	India Mark II HP	51.9
41	Uttar Pradesh	Lakhimpur Kheri	Bankeyganj	Bhira	80.47131	28.32348	India Mark II HP	11.7
42	Uttar Pradesh	Shahjahanpur	Dadraul	Block Hq	79.87013	27.83672	India Mark II HP	13.1
43	Uttar Pradesh	Pilibhit	Puranpur	Sabalpur Khas	80.16879	28.43746	India Mark II HP	35.9

Table 26: Groundwater Fluoride Hotspot Locations Exceeding BIS Limit (1.5 mg/L)

Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	F (mg/L)
1	Chhattisgarh	Gariyaband	Chhura	Pond	81.95103	20.81598	HP	1.95
2	Madhya Pradesh	Betul	Amla	Ramli-1	78.13700	21.91100	HP	4.50
3	Madhya Pradesh	Alirajpur	Alirajpur	Fatta	74.58310	22.26600	DW	5.20
4	Rajasthan	Jaipur	Phagi	Didwata	75.72934	26.49840	TW	4.56
5	Rajasthan	Tonk	Tonk	Ghans	75.88950	26.04389	HP	6.22
6	Rajasthan	Bundi	Keshorai Patan	Maija	75.91890	25.37740	TW	1.65
7	Rajasthan	Bharatpur	Nadbai	Nadbai	77.21300	27.20800	TW	1.60
8	Rajasthan	Tonk	Tonk	Rustamganj	75.83680	26.08800	TW	3.90
9	Uttar Pradesh	Agra	Achhnera	Block Office	77.74618	27.17744	HP IM-II	1.72
10	Uttar Pradesh	Bulandshahr	Shikarpur	Nawada	78.06319	28.25947	HP IM-II	1.80
11	Uttar Pradesh	Farrukhabad	Mohammadabad	Block Office	79.43679	27.30800	HP IM-II	1.78
12	Uttar Pradesh	Fatehpur	Malwan	Malwan	80.70700	26.03640	Hand Pump (IM-II)	1.95
13	Uttar Pradesh	Firozabad	Eka	Block Office	78.60743	27.37907	HP IM-II	1.61
14	Uttar Pradesh	Gautam Buddha Nagar	Jewar	Block H.Q	77.56720	28.12500	HP IM-II	1.70
15	Uttar Pradesh	Jhansi	Bamaur	Samserpura	79.03611	25.68806	HP	1.92

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	F (mg/L)
16	Uttar Pradesh	Jhansi	Bangra	Banda	79.05583	25.15972	HP	1.52
17	Uttar Pradesh	Jhansi	Chirgaon	Kalyanpura	78.94111	25.60639	HP	2.09
18	Uttar Pradesh	Jhansi	Gursarai	Ghuraiya	79.05972	25.54639	HP	1.65
19	Uttar Pradesh	Jhansi	Mauranipur	Sinora	79.07583	25.36000	HP	2.00
20	Uttar Pradesh	Jhansi	Moth	Panarri	79.02333	25.76889	HP	1.68
21	Uttar Pradesh	Kannauj	Haseran	Haseran Block Office	79.58062	26.91851	Indian Mk.II HP	2.20
22	Uttar Pradesh	Kannauj	Umarda	Thathiya	79.89128	26.91626	Indian Mk.II HP	6.60
23	Uttar Pradesh	Kanpur Dehat	Akberpur	Akberpur Block Office	79.95612	26.38233	Indian Mk. II HP	6.00
24	Uttar Pradesh	Kanpur Dehat	Maitha	Matikapur	80.15629	26.51586	Indian Mk. II HP	4.50
25	Uttar Pradesh	Kaushambi	Newada	Bohagara Sarai	81.54417	25.37806	HP-II	3.00
26	Uttar Pradesh	Kaushambi	Sarsawan	Chanderi	81.30000	25.39444	HP-II	1.68
27	Uttar Pradesh	Lalitpur	Jakhora	Baroda Swami	78.29611	24.87861	HP	2.05
28	Uttar Pradesh	Lalitpur	Mahroni	Gadoli	78.77222	24.45639	HP	1.53
29	Uttar Pradesh	Lucknow	Mohanlalganj	Nagram	81.13333	26.61972	IM HP-II	1.64
30	Uttar Pradesh	Mahoba	Kabrai	Barbai	80.04352	25.48447	Hand Pump (IM -II)	1.54
31	Uttar Pradesh	Mahoba	Kabrai	Ghutbai	79.95504	25.27283	Hand Pump (IM -II)	1.50
32	Uttar Pradesh	Mahoba	Kabrai	Srinagar	79.77889	25.17372	Hand Pump (IM -II)	1.69
33	Uttar Pradesh	Mainpuri	Kishni	Block Office	79.26555	27.03160	HP IM-II	1.81
34	Uttar Pradesh	Mainpuri	Kishni	Near Katra Saman Chauraha, Shiv Temple	79.19820	27.03046	HP IM-II	1.65
35	Uttar Pradesh	Mathura	Chhata	Block Hq	77.50080	27.72620	HP IM-II	3.50
36	Uttar Pradesh	Meerut	Kharkhoda	In Block Office	77.74662	28.83104	IM-II	1.60
37	Uttar Pradesh	Pratapgarh	Baba Belkhar Nath	Inside Block Office	82.09990	25.90720	HP-II	2.40
38	Uttar Pradesh	Pratapgarh	Gaura	Block Office	77.85528	29.09583	HP-II	1.60
39	Uttar Pradesh	Pratapgarh	Sadar	Tonipur	81.89250	25.88917	HP-II	5.00
40	Uttar Pradesh	Pratapgarh	Sangipur	Bashuapur	81.71083	26.01583	HP-II	1.68
41	Uttar Pradesh	Prayagraj	Baharia	Dunnaiya	82.00167	25.63778	HP-II	2.04
42	Uttar Pradesh	Prayagraj	Shankargarh	Gadaya Lonipara	81.70306	25.09750	HP-II	1.56
43	Uttar Pradesh	Prayagraj	Baharia	Dunnaiya	82.00167	25.63778	HP-II	2.04
44	Uttar Pradesh	Raebareli	Chhatoh	Block Hq	81.52105	26.15987	HP India Mark	2.21
45	Uttar Pradesh	Raebareli	Lalgaanj	Block Hq	80.97926	26.16814	HP India Mark	1.51
46	Uttar Pradesh	Raebareli	Sareni	Block Hq	80.82752	26.15500	HP India Mark	2.04
47	Uttar Pradesh	Raebareli	Satawan	Sekhapur, Guru Buxaganj	81.02583	26.27207	HP	1.99
48	Uttar Pradesh	Sonbhadra	Babhani	Adhoura	83.03480	23.91110	H.P	1.95
49	Uttar Pradesh	Sonbhadra	Babhani	Mohua Dohar	82.91680	23.90960	H.P	1.90
50	Uttar Pradesh	Sonbhadra	Myorpur	Liladewa	82.94020	23.99280	H.P	1.55
51	Uttar Pradesh	Sonbhadra	Myorpur	Lovuhan	83.11560	24.08290	Dugwell	2.05
52	Uttar Pradesh	Sonbhadra	Myorpur	Nodiya	83.21390	24.08150	H.P	1.95
53	Uttar Pradesh	Unnao	Bighapur	Block Office	80.66526	26.35220	IM HP-II	1.53
54	Gujarat	Anand	Petlad	Dharmaj	72.78741	22.42074	Dug Well	1.58
55	Gujarat	Chhota Udaipur	Jetpur Pavi	Bhindol	73.89710	22.20107	Dug Well	2.32
56	Gujarat	Chhota Udaipur	Bodeli	Govindpura	73.73999	22.21554	Dug Well	2.60
57	Gujarat	Porbandar	Porbandar	Kolikhada	69.63681	21.68157	Dug Well	1.80
58	Gujarat	Devbhumi Dwarka	Kalyanpur	Navadra	69.28649	21.93994	Dug Well	1.77
59	Gujarat	Devbhumi Dwarka	Kalyanpur	Vamansa	69.18870	22.08400	Dug Well	1.62
60	Gujarat	Devbhumi Dwarka	Okhamandal	Samrasar	69.10628	22.36993	Dug Well	2.25
61	Gujarat	Porbandar	Kutyana	Khageshri	69.98349	21.75168	Dug Well	1.72
62	Gujarat	Porbandar	Porbandar	Oddar	69.69211	21.55290	Dug Well	1.86
63	Gujarat	Junagadh	Mangrol	Kalej	70.08500	21.24962	Dug Well	2.08
64	Gujarat	Banaskantha	Danta	Ganapipli Nhs Dw	72.94666	24.29364	DW	2.34
65	Gujarat	Mehsana	Kheralu	Kheralu-1 Nhs Dw	72.60754	23.88716	DW	1.78
66	Gujarat	Patan	Patan	Balisana	72.25416	23.81439	DW	1.53
67	Gujarat	Patan	Santalpur	Piprala 1	71.09675	23.64620	Dug Well	9.10

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	F (mg/L)
68	Gujarat	Kachchh	Abdasa	Tera	68.94026	23.28290	DW	1.58
69	Gujarat	Kachchh	Mandvi	Kotadi	69.19380	23.04167	DW	6.37
70	Gujarat	Kachchh	Mundra	Karagoga	69.66186	22.93800	DW	2.14
71	Gujarat	Kachchh	Bhachau	Samkhiari	70.50414	23.30665	DW	3.33
72	Gujarat	Ahmedabad	Dhandhuka	Dhandhuka1 Nhs Dw	71.98774	22.37606	DW	6.00
73	Gujarat	Ahmedabad	Dhandhuka	Tagadi1 Nhs Dw(Hotspot)	71.94673	22.29710	DW	3.40
74	Gujarat	Botad	Barwala	Barwala	71.89420	22.16242	DW	5.65
75	Gujarat	Bhavnagar	Vallabhipur	Ayodhyapuram	71.88446	21.95218	DW	5.74
76	Gujarat	Bhavnagar	Vallabhipur	Lundhara Nhs Dw(Hotspot)	71.89315	22.09637	DW	2.20
77	Gujarat	Gir Somnath	Kodinar	Dolasa	70.84720	20.81937	DW	2.30
78	Gujarat	Gir Somnath	Una	Una2	71.04157	20.82239	DW	2.06
79	Gujarat	Morbi	Morvi	Jetpar	70.89472	23.00278	DW	2.16
80	Gujarat	Rajkot	Upleta	Ganod	70.16931	21.68879	DW	2.67
81	Gujarat	Rajkot	Upleta	Upleta1	70.25202	21.72951	DW	3.44
82	Gujarat	Surendranagar	Dasada	Malvan	71.75028	23.06139	DW	5.42
83	Gujarat	Surendranagar	Dhrangadhra	Ratanpur	71.27473	22.85552	DW	3.28
84	Gujarat	Surendranagar	Muli	Muli	71.46444	22.63895	DW	2.90
85	Gujarat	Surendranagar	Sayla	Dhajala	71.39799	22.38069	DW	1.86
86	Gujarat	Surendranagar	Sayla	Piprali	71.31166	22.39531	DW	5.11
87	Gujarat	Surendranagar	Wadhwan	Surendranagar2	71.61667	22.71755	DW	2.45
88	Gujarat	Surendranagar	Wadhwan	Vadod	71.65222	22.55944	DW	2.15
89	Gujarat	Surendranagar	Wadhwan	Vaghela	71.65718	22.65774	DW	1.99
90	Gujarat	Sabarkantha	Talod	Kesarpura(Mayal)	72.94889	23.32222	DW	1.78
91	Gujarat	Sabarkantha	Himatnagar	Gadhal	72.94167	23.70833	DW	1.91
92	Gujarat	Sabarkantha	Himatnagar	Sakrodiya	73.04800	23.54542	DW	1.83
93	Gujarat	Sabarkantha	Idar	Bhadreshwar (Daramli)	72.97917	23.74583	DW	1.53
94	Gujarat	Sabarkantha	Idar	Idar	73.03070	23.84197	DW	5.15
95	Gujarat	Sabarkantha	Idar	Sabalwad	72.96306	23.87417	DW	4.50
96	Gujarat	Sabarkantha	Khedbrahma	Hingatiya	73.01063	24.14659	DW	1.57
97	Gujarat	Dahod	Dahod	Dahod2	74.23333	22.82500	DW	1.90
98	Gujarat	Dahod	Dahod	Dahod Urban-2	74.26666	22.84470	DW	2.95
99	Gujarat	Panchmahal	Kalol	Khadki Vadiya	73.52277	22.65877	DW	4.10

Table 27: Groundwater Electrical Conductivity Hotspot Locations Exceeding BIS Limit (3000 $\mu\text{S/cm}$)

Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	EC
1	Rajasthan	Sawai Madhopur	Bonli	Bonali	76.23680	26.32460	TW	3090
2	Rajasthan	Jodhpur	Bhopalgarh	Daarmi	73.63250	26.74450	TW	5540
3	Rajasthan	Jodhpur	Luni	Dhawa	72.74000	26.06238	DW	4140
4	Rajasthan	Bharatpur	Nagar	Gopalgarh	77.06330	27.65470	DW	8950
5	Rajasthan	Karauli	Hindaun	Islampur	77.01700	26.70000	DW	3940
6	Rajasthan	Dausa	Dausa	Jasuta	76.33300	26.96700	DW	4650
7	Rajasthan	Ganganagar	Anupgarh	Khal	73.36700	29.08300	DW	6850
8	Rajasthan	Pali	Jaitaran	Prathvipura	73.81670	26.20000	TW	5620
9	Gujarat	Anand	Khambhat	Laxmipura	72.60833	22.41667	Dug Well	4347
10	Gujarat	Kheda	Mahudha	Alina	73.04766	22.80567	Dug Well	3044
11	Gujarat	Vadodara	Desar	Veipur2	73.35385	22.74351	Dug Well	3477
12	Gujarat	Jamnagar	Jodiya	Bedanpur	70.31252	22.68747	Dug Well	9620
13	Gujarat	Jamnagar	Jodiya	Kesiya	70.39706	22.69661	Dug Well	4688
14	Gujarat	Porbandar	Porbandar	Mojiwana	69.57426	21.85995	Dug Well	9966
15	Gujarat	Devbhumi Dwarka	Khambhalia	Hanzdapur	69.43681	22.18885	Dug Well	3236

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	EC
16	Gujarat	Porbandar	Porbandar	Kuchhadi	69.54887	21.68100	Dug Well	3697
17	Gujarat	Porbandar	Porbandar	Palkhada	69.48491	21.76032	Dug Well	3085
18	Gujarat	Porbandar	Porbandar	Visavada	69.45381	21.77523	Dug Well	3684
19	Gujarat	Devbhumi Dwarka	Kalyanpur	Lambha	69.30844	21.91130	Dug Well	3159
20	Gujarat	Devbhumi Dwarka	Kalyanpur	Bhogat	69.24428	21.99049	Dug Well	3791
21	Gujarat	Devbhumi Dwarka	Kalyanpur	Khakharda	69.37210	22.10477	Dug Well	4585
22	Gujarat	Devbhumi Dwarka	Kalyanpur	Gojines	69.20424	22.02455	Dug Well	6630
23	Gujarat	Devbhumi Dwarka	Kalyanpur	Vamansa	69.18870	22.08400	Dug Well	3208
24	Gujarat	Devbhumi Dwarka	Kalyanpur	Gurgadh	69.19093	22.19470	Dug Well	4229
25	Gujarat	Devbhumi Dwarka	Okhamandal	Varwada	68.96145	22.29772	Dug Well	11650
26	Gujarat	Devbhumi Dwarka	Okhamandal	Mojap	68.97956	22.36145	Dug Well	5209
27	Gujarat	Devbhumi Dwarka	Okhamandal	Dwarka	68.96044	22.24068	Dug Well	3374
28	Gujarat	Devbhumi Dwarka	Okhamandal	Samrasar	69.10628	22.36993	Dug Well	12150
29	Gujarat	Porbandar	Kutiyana	Kutiyana	70.01126	21.62841	Dug Well	5732
30	Gujarat	Porbandar	Ranavav	Bhoddar	69.89493	21.57514	Dug Well	3951
31	Gujarat	Junagadh	Mangrol	Osa	70.06416	21.37289	Dug Well	14300
32	Gujarat	Porbandar	Porbandar	Oddar	69.69211	21.55290	Dug Well	4613
33	Gujarat	Junagadh	Mangrol	Shardagram	70.14308	21.10378	Dug Well	7594
34	Gujarat	Junagadh	Mangrol	Arena	70.17712	21.08075	Dug Well	5696
35	Gujarat	Junagadh	Mangrol	Khorada	70.18758	21.07218	Dug Well	5708
36	Gujarat	Junagadh	Vanthali	Khokharda	70.31756	21.42010	Dug Well	3175
37	Gujarat	Banaskantha	Tharad	Dudhba NHS DW	71.66902	24.47940	DW	6895
38	Gujarat	Banaskantha	Dantiwada	Gangodra NHS DW	72.36474	24.43968	DW	4004
39	Gujarat	Mehsana	Mehsana	Maguna NHS DW	72.29041	23.57722	DW	3016
40	Gujarat	Patan	Sankheshwar	Moti Chander	71.77034	23.59916	DW	32970
41	Gujarat	Patan	Sami	Gochanad	71.62457	23.77126	DW	6994
42	Gujarat	Patan	Santalpur	Piprala 1	71.09675	23.64620	Dug Well	11087
43	Gujarat	Kachchh	Bhachau	Ratanpur Khadir	70.36247	23.86222	DW	3486
44	Gujarat	Kachchh	Bhachau	Kakarwa	70.40660	23.47989	DW	7305
45	Gujarat	Kachchh	Bhuj	Lodai	69.89996	23.39712	Dug Cum Bore Well	3391
46	Gujarat	Kachchh	Lakhpat	Kharai 1	68.68365	23.47248	DW	9598
47	Gujarat	Kachchh	Abdasa	Kothara	68.90880	23.16338	DW	3387
48	Gujarat	Kachchh	Mandvi	Bambhdai	69.08171	22.94111	DW	5505
49	Gujarat	Kachchh	Mundra	Karagoga	69.66186	22.93800	DW	3652
50	Gujarat	Kachchh	Mundra	Nani Tumbdi	69.54897	22.99628	DW	3699
51	Gujarat	Kachchh	Mundra	Vadala	69.85378	22.91676	DW	3920
52	Gujarat	Kachchh	Bhachau	Samkhiari	70.50414	23.30665	DW	5190
53	Gujarat	Ahmedabad	Virangam	Virangam2 NHS well(Hotspot)	72.03836	23.13669	DW	4982
54	Gujarat	Ahmedabad	Dhandhuka	Dhandhuka1 NHS DW	71.98774	22.37606	DW	7349
55	Gujarat	Botad	Barwala	Barwala	71.89420	22.16242	DW	4125
56	Gujarat	Bhavnagar	Vallabhipur	Ayodhyapuram	71.88446	21.95218	DW	4491
57	Gujarat	Amreli	Amreli	Devaliya NHS well(Hotspot)	71.10833	21.82083	DW	6972
58	Gujarat	Diu	Diu	Zolawadi(Hotspot)	70.93060	20.72420	DW	14980
59	Gujarat	Morbi	Maliya	Sarvad	70.70714	23.00650	DW	3201
60	Gujarat	Rajkot	Padadhari	Movaiya	70.62754	22.45793	DW	7906
61	Gujarat	Rajkot	Upleta	Ganod	70.16931	21.68879	DW	5887
62	Gujarat	Rajkot	Upleta	Upleta1	70.25202	21.72951	DW	3110
63	Gujarat	Surendranagar	Chotila	Bamanbor	71.03729	22.41474	DW	17060

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Village	Longitude (DD)	Latitude (DD)	Source of Sample	EC
64	Gujarat	Surendranagar	Chotila	Moti Moladi	71.10400	22.41789	DW	8307
65	Gujarat	Surendranagar	Dasada	Moti majethi	71.88526	23.08660	DW	3351
66	Gujarat	Surendranagar	Dhrangadhra	Ratanpur	71.27473	22.85552	DW	4155
67	Gujarat	Surendranagar	Limdi	Choraniya	71.85087	22.57200	DW	6484
68	Gujarat	Surendranagar	Limdi	Ranagarh	71.98846	22.77895	DW	6527
69	Gujarat	Surendranagar	Sayla	Dhajala	71.39799	22.38069	DW	4191
70	Gujarat	Surendranagar	Sayla	Piprali	71.31166	22.39531	DW	4085
71	Gujarat	Surendranagar	Wadhwan	Surendranagar2	71.61667	22.71755	DW	3053
72	Gujarat	Surendranagar	Wadhwan	Vaghela	71.65718	22.65774	DW	7809
73	Gujarat	Surendranagar	Chotila	Sanosara	71.23044	22.29886	DW	8141
74	Gujarat	Sabarkantha	Himatnagar	Gadhali	72.94167	23.70833	DW	3570
75	Gujarat	Sabarkantha	Idar	Bhadreshwar (Daramli)	72.97917	23.74583	DW	3403
76	Gujarat	Sabarkantha	Khedbrahma	Silwad	73.11667	24.00833	DW	5043

Table 28: Groundwater Uranium Hotspot Locations Exceeding BIS Limit (10ppb)

Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Sample Location around hot Spot	Longitude (DD)	Latitude (DD)	Source of Sample	U (ppb)
1	Delhi	North	Narela	Auchandi	76.99722	28.81944	TW	42.0
2	Delhi	North West	Kanjhawala	Nizampur Ew-1	77.00853	28.73072		46.5
3	Madhya Pradesh	Gwalior	Dabra	Bharthari (Chhak)	78.25410	25.98700	BW	235.6
4	Madhya Pradesh	Seoni	Keolari	Dhangada-4-I	79.85920	22.32200	BW	553.6
5	Andhra Pradesh	Annamayya	Galiveedu	Bowreeddygaripalli	78.59031	14.14071	Pz	458.2
6	Andhra Pradesh	Annamayya	Galiveedu	Galiveedu-Alt	78.50271	14.02485	DW	80.3
7	Andhra Pradesh	Annamayya	Chinnamandyam	Chinnamandyam	78.68845	13.94948	BW	428.5
8	Andhra Pradesh	Annamayya	Madanapalle	Basani Khonda-Dw14	78.52983	13.55127	DW	158.1
9	Andhra Pradesh	Annamayya	Nimmanapalle	Chintaparti-1	78.70485	13.64421	DW	85.2
10	Andhra Pradesh	Annamayya	Veeraballe	Sanipai	78.94972	14.10753	DW	1827.4
11	Andhra Pradesh	Kurnool	Devanakonda	Karivemula	77.59670	15.59420	DW	50.7
12	Andhra Pradesh	Kurnool	Adoni	Naganathanahalli	77.22214	15.56070	DW	63.6
13	Andhra Pradesh	Sri Sathyasa Sai	Kadiri	Alampur	78.16560	14.19400	DW	696.9
14	Andhra Pradesh	Sri Sathyasa Sai	Madakasira	Madakasira1	77.27600	13.94110	DW	119.4
15	Andhra Pradesh	Sri Sathyasa Sai	Puttaparthi	Kambalparthi	77.90990	14.13770	DW	164.0
16	Andhra Pradesh	Sri Sathyasa Sai	Madakasira	Asvattarayana Roppam, Ew Of Aq-I (1st Well)	77.27370	14.02690	EW	30.8
17	Andhra Pradesh	Sri Sathyasa Sai	Tanakal	Tanakallu-Pz	78.19600	13.91710	BW	87.5
18	Andhra Pradesh	Tirupati	Pakala	Damalcheruvu	79.04815	13.47804	DW	1882.2
19	Andhra Pradesh	Tirupati	Chandragiri	Mungilipattu	79.24931	13.56087	DW	85.3
20	Andhra Pradesh	Tirupati	Kammappalli	Balijepalli	79.38072	13.52126	DW	46.3
21	Telangana	Hyderabad	Nampally	Koti-Pz	78.48464	17.38432	PZ	148.8
22	Telangana	Mahabubnagar	Balanagar	Balanagar (Hotspot)	78.17780	16.94470	PZ	36.7
23	Telangana	Mahabubnagar	Mosapet	Janampet (Hotspot)	77.98940	16.63390	PZ	37.5
24	Telangana	Mahabubnagar	Addakal	Kondur(Hotspot)	77.96000	16.55670	PZ	55.0
25	Telangana	Mahabubnagar	Jadcherla	Jadcherla (Hotspot)	78.14470	16.74750	PZ	49.6

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Hot Spot No.	State/ UT	District	Block/ Taluka	Hot Spot Location/Sample Location around hot Spot	Longitude (DD)	Latitude (DD)	Source of Sample	U (ppb)
26	Telangana	Mahabubnagar	Gandeed	Nancherla (Hotspot)	77.85050	16.90650	PZ	35.5
27	Telangana	Medak	Narsapur	Reddypalli-Pz	78.25861	17.78000	BW	44.0
28	Telangana	Medak	Papannapet	Yusufpeta-Dw13	78.13611	18.04750	BW	104.2
29	Telangana	N.Kurnool	Lingal	Lingal (Hotspot)	78.51330	16.29500	PZ	63.6
30	Telangana	N.Kurnool	Kodair	Narsaipalli (Hotspot)	78.24270	16.18130	PZ	74.3
31	Telangana	N.Kurnool	Vangoor	Vangoor (Hotspot)	78.62130	16.61320	PZ	90.4
32	Telangana	N.Kurnool	Amrabad	Amrabad (Hotspot)	78.82000	16.37470	PZ	55.0
33	Telangana	Nalgonda	Marriguda	Antampet Pz1	78.88889	17.03611	BW	65.5
34	Telangana	Narayanpet	Kosgi	Gundmal (Hotspot)	77.71040	16.89600	DW	40.2
35	Telangana	Nirmal	Kubeer	Sonari	77.91121	19.20197	Hand pump	128.0
36	Telangana	Suryapet	Penpahad	Penpahad	79.68647	17.02464	BW	34.7
37	Telangana	Suryapet	Munugode	Chikatimamidi	79.02467	17.09838	DW	34.3
38	Telangana	Wanaparathi	Chinnambavi	Velagandla (Hotspot)	78.10420	16.08440	DW	70.2
39	Telangana	Yadadri Bhuvanagiri	Valigonda	Nagaram Aq-I	79.02000	17.35694	Borewell	57.2
40	Uttar Pradesh	Amroha	Joya	Block Office	78.47319	28.83557	Handpump	63.9
41	Uttar Pradesh	Bijnor	Mohammadpur Deomal	Chakrani/ Gidarpara	78.13236	29.37647	Handpump	136.3
42	Uttar Pradesh	Raebareli	Lalganj	Block Hq	80.97926	26.16814	HP India Mark	67.8
43	Uttar Pradesh	Raebareli	Chhathoh	Block Hq	81.52105	26.15987	HP India Mark	65.6
44	Uttar Pradesh	Sultanpur	Dostpur	Block Hq	82.46609	26.27015	HP India Mark	45.2
45	Uttar Pradesh	Amethi	Amethi	Pwd Dak Bangla	81.80860	26.15618	HP India Mark	51.5
46	Uttar Pradesh	Hardoi	Mallawan	Block Hq(In Premises of Block)	80.15470	27.02580	HP India Mark	35.1
47	Uttar Pradesh	Shahjahanpur	Banda	Mouddinpur	80.10815	28.30645	HP India Mark	58.0
48	Uttar Pradesh	Budaun	Wajirganj	Block Hq(In Premises of Block Office)	79.05810	28.20450	HP India Mark	48.5
49	Uttar Pradesh	Bulandshahr	Jahangirabad	Block H.Q.	78.08850	28.41390	HP India Mark	105.8

11.0 Ground Water Quality Alert

Ground Water Quality Alerts are issued fortnightly to the State Governments and concerned departments to facilitate timely action and awareness regarding water quality issues. These alerts are generated based on periodic monitoring and analysis of key parameters that exceed the BIS (IS 10500:2012) permissible limits, indicating potential risks to groundwater suitability for drinking and other uses.

A summary of groundwater quality alerts compiled annually is presented in the accompanying table. It highlights the state-wise and parameter-wise occurrence of exceedances,

providing an overview of areas requiring attention, follow-up investigation, or remedial measures.

Table 29: State-wise distribution of samples exceeding permissible limits for analysed parameters as per fortnightly water quality alerts between June 2024 to March 2025.

S. No.	State	EC	Nitrate	Fluoride	Total Hardness	Cr	Mn	Fe	Ni	Co	Zn	As	Se	Cd	Pb	U
1	Andaman and Nicobar	22	12	14	28		61	33		21	20	8				
2	Andhra Pradesh	1196	621	616	1145											
3	Arunachal Pradesh		4		1		13	6								
4	Assam	9	14	24	84	4	219	88	9	4	3	16	3	3	12	3
5	Bihar	275	126	97	335	71	108	119		68	68	71			78	87
6	Chandigarh	1		1	2		2									
7	Chhattisgarh	240	119	282	209											89
8	Goa	49	52	42	51	2	23	10	4	5	2	7	2	2	3	2
9	Gujarat	739	389	387	708	305	160	15		149		27				65
10	Haryana	633	246	378	657	53	122	80	55	57	53	58	56	52	53	202
11	Jammu and Kashmir	8	52	13	175	6	85	68	6	6	6	23	6	6	6	8
12	Jharkhand	180	118	164	236		6	3		1	1	3				3
13	Karnataka	747	473	427	779	213	364	229	217	218	223	222	225	213	218	417
14	Kerala	82	53	38	86		12	66		1						12
15	Ladakh		1	2	9											
16	Madhya Pradesh	1585	764	458	1765	56	227	284	32	14	3	21	16	4	159	132
17	Maharashtra	1291	970	252	1604		25		1				1		12	90
18	Manipur						2	1								
19	Meghalaya	9	12	9	9	9	31	14	9	10	9	9	9	9	9	9
20	Mizoram		1													
21	Nagaland			1	2		15	4								
22	Odisha	484	188	168	502		376	199	25	6	9	11	1	15	32	61
23	Puducherry	13	3	5	12	6	6	6	6	6	6	6	6	6	6	6
24	Punjab	476	281	284	525	107	211	135	112	114	104	228	121	104	106	538
25	Rajasthan	443	283	340	413			4								18
26	Tamil Nadu	713	428	317	725	250	253	252	250	250	250	251	250	250	252	251
27	Telangana	804	548	564	802											
28	Tripura		4	4	2		38		3							
29	Uttar Pradesh	121	95	123	186	113	403	493		115	116	151			114	156
30	Uttarakhand	2	12	5	1	1	1	78	1	1	1	20	1	1	1	1
31	West Bengal	329	227	193	374	1	560	423		145	153	180			8	
	Grand Total	10451	6096	5208	11427	1197	3323	2610	730	1191	1027	1312	697	665	1069	2150

12.0 Conclusion

The Central Ground Water Board (CGWB) has undertaken an extensive assessment of groundwater quality across India during the Pre-Monsoon and Post-Monsoon periods of 2024, covering approximately 5368 monitoring wells. This dual-season monitoring marks the first time such an initiative has been implemented, offering a more holistic and timely understanding of seasonal variations in groundwater quality.

13.1 Key Objectives

- Evaluate seasonal changes in groundwater quality.
- Identify the presence and concentrations of contaminants like fluoride, nitrate, arsenic, uranium, and other trace metals.
- Highlight regional variations and the impact of monsoon-driven recharge on water quality.
- Provide actionable insights for policy makers, water managers, and public health authorities.

13.2 Major Findings

- About 71.67% of samples complied with BIS standards, while 28.32% exceeded permissible limits for one or more parameters. Nitrate contamination was the most widespread, followed by fluoride and salinity.
- Exceedances of > 45 mg/L nitrate concentration fluctuated between **19.5–21.3% (2017–2024)**. Seasonal analysis for 2024 shows only marginal increase (<0.058%) post-monsoon, indicating anthropogenic dominance over natural recharge effects.
- Fluoride contamination above 1.5 mg/L is expanding, with 8.05%. Hard rock aquifers are particularly vulnerable, especially in Rajasthan, Gujarat, Andhra Pradesh, Telangana, and Karnataka, where over-extraction enhances mobilization of fluoride-bearing minerals.
- High EC values are concentrated in northwestern states (Rajasthan, Haryana, Delhi, Gujarat, Punjab) and coastal belts. The proportion of affected locations rose from 5.54% in 2017 to 7.23% in 2024. Seasonal improvement is minor, with post-monsoon recharge providing temporary dilution.
- Arsenic: Contamination is geogenically controlled and spatially concentrated in the Indo-Gangetic and Brahmaputra alluvial plains, with the highest exceedances in West Bengal, Uttar Pradesh, Bihar and Punjab. In 2024, 3.6% of pre-monsoon and 3.4% of post-monsoon samples exceeded the 10 µg/L permissible limit as per BIS,10500.
- Uranium exceedances (>30 ppb) have been found at some locations in Punjab, Haryana, Uttarpradesh and Karnataka.
- Iron and Manganese: Exceedances of iron (>1 mg/L) were observed in 13.48% (pre-monsoon) and 13.51% (post-monsoon) samples. Notable increases post-monsoon occurred in Uttar Pradesh and West Bengal, suggesting seasonal redox-driven mobilization. Manganese exceeded permissible limits in 12.02% (pre-monsoon) and 10.79% (post-monsoon) of samples.
- Lead contamination remains localized mainly at few locations in Assam, Odisha, Rajasthan, Punjab, and Tamil Nadu. Zinc exceedances are rare (<0.2%), while copper concentrations remain well within permissible limits nationwide.
- The groundwater quality is largely suitable for irrigation purposes. The majority of samples, 94.30%, fall into the "excellent category" based on the Sodium Adsorption Ratio (SAR < 10), indicating a low alkali hazard for soil and crop health.
- Wilcox plots confirm most samples are in excellent to good categories, with localized stress in Andhra Pradesh, Gujarat, Haryana, Rajasthan, and Punjab.

- Monsoon Recharge Impact: The effects of monsoon recharge were heterogeneous. While many locations showed significant improvement in water quality parameters (e.g., dilution of EC and Fluoride), a comparable number of locations exhibited deterioration (increase in concentration), emphasizing that site-specific factors like aquifer type and local contamination load strongly govern groundwater chemistry.
- At the national scale, the hydro chemical characterization of groundwater in India reveals a distinct dominance of the Calcium–Bicarbonate (Ca-HCO₃) facies, followed by Mixed facies, NaCl and Na-HCO₃ hydrochemical facies. Waters. CaCl₂ waters are minor and locally significant in urban/semi-arid areas.
- To strengthen national surveillance of groundwater contamination, CGWB undertook detailed hotspot monitoring around locations that exceeded BIS limits during baseline monitoring. A total of 340 hotspot locations were identified, and 1,540 groundwater samples were collected around these sites.
- A 2 km × 2 km grid-based sampling design was adopted around each hotspot. The central point marked as HS (Hotspot) represented the exceedance location, with surrounding samples collected at grid nodes to evaluate:
 - The hotspot assessment covered Arsenic, EC, Fluoride, Nitrate, Manganese, and Uranium. Results show clear spatial variability in the extent of contaminant movement. The hotspot classification (e.g., localized vs. more than one direction spread) provides actionable insights for targeted remediation, localized source protection, and aquifer-specific management strategies.
 - CGWB issues fortnightly Groundwater Quality Alerts to States and concerned agencies to facilitate early action, public health protection, and rapid response to contamination events. Alerts are generated when key water quality parameters exceed BIS limits.
 - The alerts compiled during June 2024–March 2025 highlight exceedances for parameters such as EC, Nitrate, Fluoride, Total Hardness, Chromium, Manganese, Iron, Nickel, Cobalt, Zinc, Arsenic, Selenium, Cadmium, Lead, and Uranium across multiple states.
 - Exceedances were recorded during this period, with notable concerns in: Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Punjab, Karnataka, Haryana, and Uttar Pradesh, showing high occurrences of salinity, nitrate, and heavy metal exceedances.
 - Eastern and north-eastern states showing isolated but occurrences of iron, manganese, and arsenic
 - These alerts serve as a real-time early warning mechanism, guiding states to undertake follow-up sampling, issue advisories, and implement localized mitigation measures.
 - Groundwater quality alerts are shared fortnightly with central govt. departments e.g. ICAR, DDWS, CPCB, MOHUA, GSI along with concerned departments of state/UTs.

India's groundwater is generally safe, but localized contamination with nitrates, fluoride, arsenic, uranium, and manganese environmental risks. The 2024 dual-season

monitoring provides a more nuanced understanding of these threats, allowing for better-targeted mitigation strategies and policy interventions. Continued surveillance, source protection, and community awareness are critical to ensuring long-term groundwater sustainability and public health safety.

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