GROUND WATER QUALITY BULLETIN FOR PRE-MONSOON 2024-25 FOR THE STATE OF MP

Periodic Assessment of Ground Water Quality Trends: Contamination-Wise Summary and District-Wise Quality Changes in Madhya Pradesh from 2020 to 2024

Central Ground Water Board

North Central Region, Bhopal

Ground Water Quality Bulletin for Pre-Monsoon 2024-25 for the State of MP

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Ground Water Quality Scenario of MP During Pre-Monsoon 2024-25

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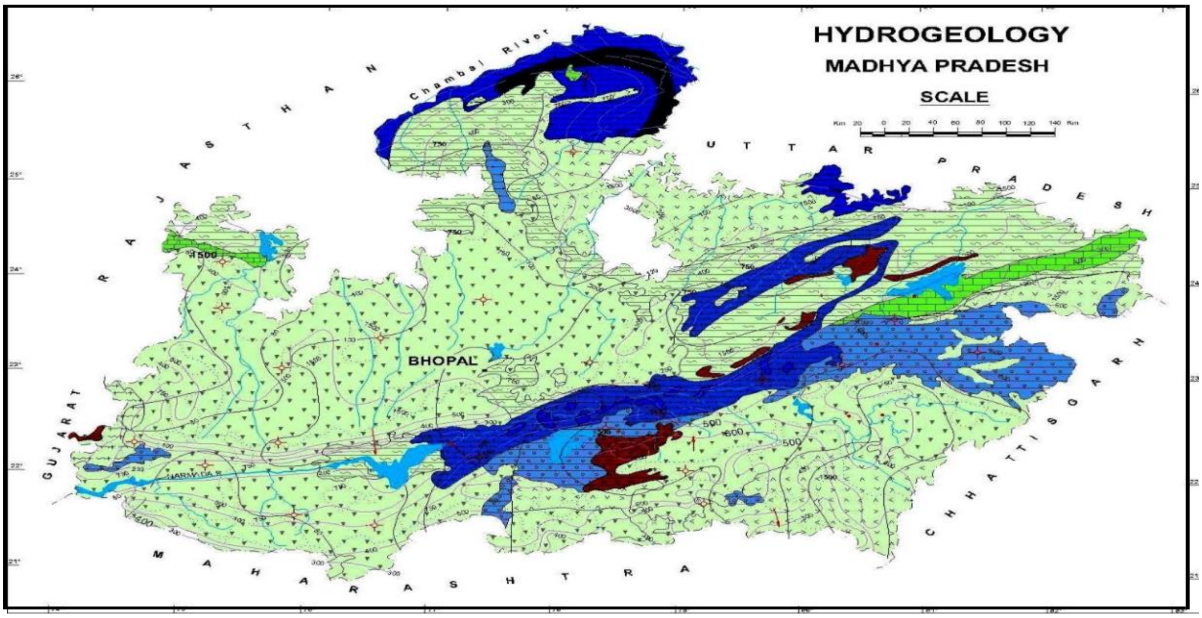
1. Introduction

The quality of groundwater is a highly sensitive issue. Besides natural changes, human activities such as sewage disposal, agricultural practices, and industrial pollution significantly impact groundwater quality. The rapid growth of population, urbanization, industrialization, and agricultural activities has put groundwater resources under stress. There is increasing concern about the deterioration of groundwater quality due to both geogenic and anthropogenic activities. Standards for groundwater quality were established in 1983 and have been revised and updated over time. In Madhya Pradesh, major contaminants include nitrate, fluoride, total hardness, iron, and manganese.

Periodic groundwater quality assessments are crucial to alert those who use it for domestic and irrigation purposes. According to standards prescribed by the Bureau of Indian Standards (BIS), groundwater has been evaluated for drinking and agricultural purposes in this report.

2. Study Area

The State of Madhya Pradesh has varied hydrogeological characteristics due to which ground water potential differs from place to place. Hard rock areas cover more than 80% of total land area of the State. These hard-rock areas show wide variations and complexities in nature and composition of rocks, geological structures, geomorphological set up and hydro meteorological conditions. Quartzite and granitites occupy about 14.7% of geographical area of the State. The basaltic rocks of Deccan lava flows are the predominant formations and occupy nearly 44.5% of total geographical area. The consolidated sedimentary rocks of Vindhyan Super Group and Mahakoshal (Cuddapah) Super Group of Proterozoic age occupy about 19.1% of total geographical area and the semi consolidated (Gondwana Formation) occupies about 6.7%. Recent unconsolidated alluvial sediments occupy about 14.4% of total geographical area. Hydrogeological map of Madhya Pradesh State has been given in the following **Fig. A**



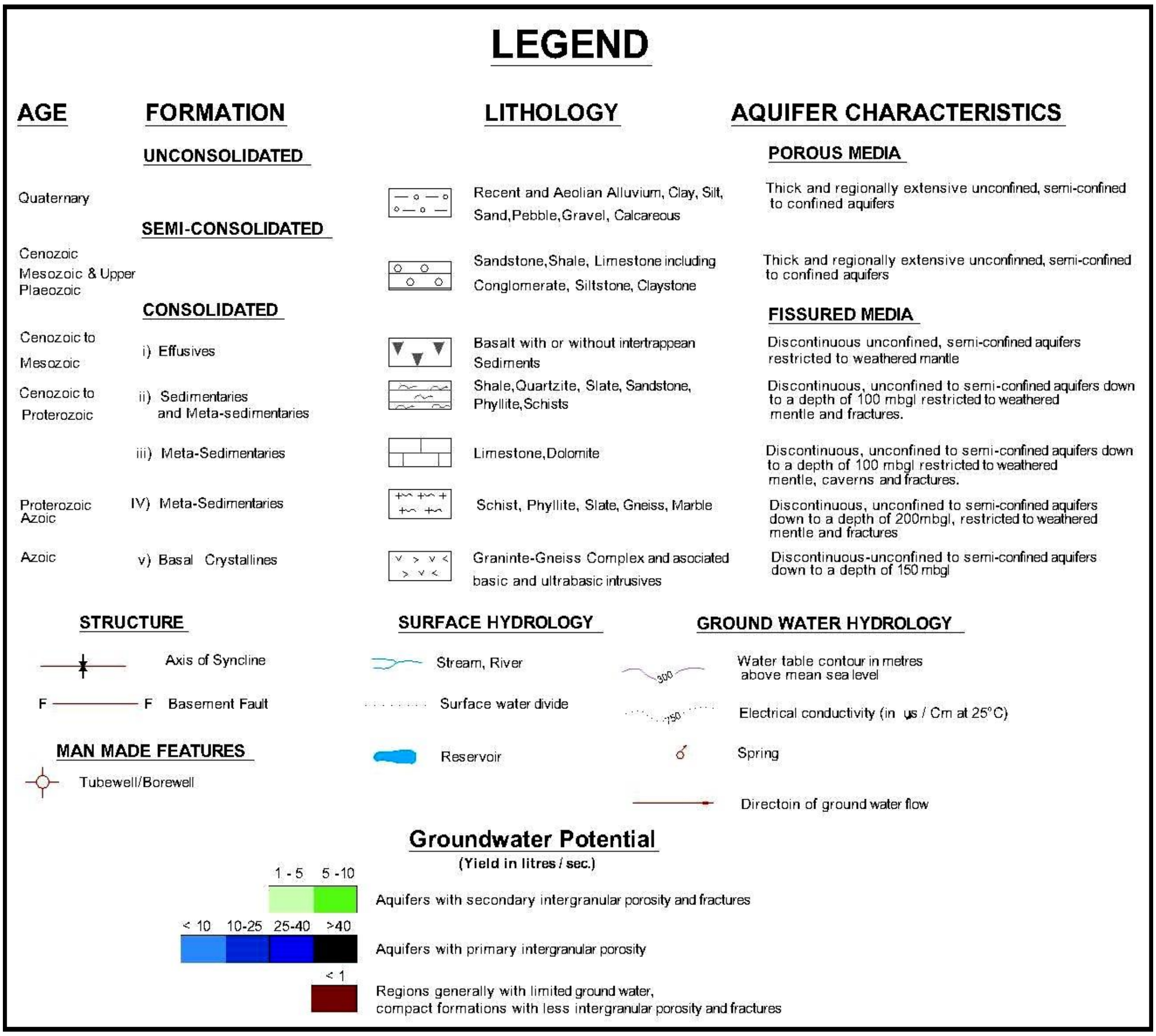


Fig A: Hydrogeology Map of MP.

3. Ground Water Quality Monitoring

The Central Ground Water Board has been conducting chemical quality monitoring of shallow groundwater twice annually—during the pre-monsoon (PRM) and post-monsoon (POM) periods—since 2023. In the PRM phase of 2024-25, following directives from CHQ, water quality samples were collected from 614 locations under the National Hydrograph Stations (NHS) program, categorized as trend analysis samples. Additionally, as part of Special Purpose Monitoring, samples were collected from identified hotspot locations where concentrations of Arsenic, Lead, Iron, Manganese, Uranium, and Fluoride exceeded BIS standards. Furthermore, samples were also collected from industrial areas, including the Ujjain (Nagda) and Dewas industrial clusters, bringing the total hotspot samples to 544.

Basic parameter analysis was performed at the Regional Chemical Laboratory, NCR, Bhopal, adhering to standard operating procedures. Additionally, trace metal analysis was conducted on a total of 1,158 samples, comprising 614 trend samples and 544 hotspot samples. These analyses were carried out at CGWB, NER, Guwahati, using ICP-MS technology. This bulletin highlights the evolving water quality trends observed in CGWB's network wells between 2020 and 2024.

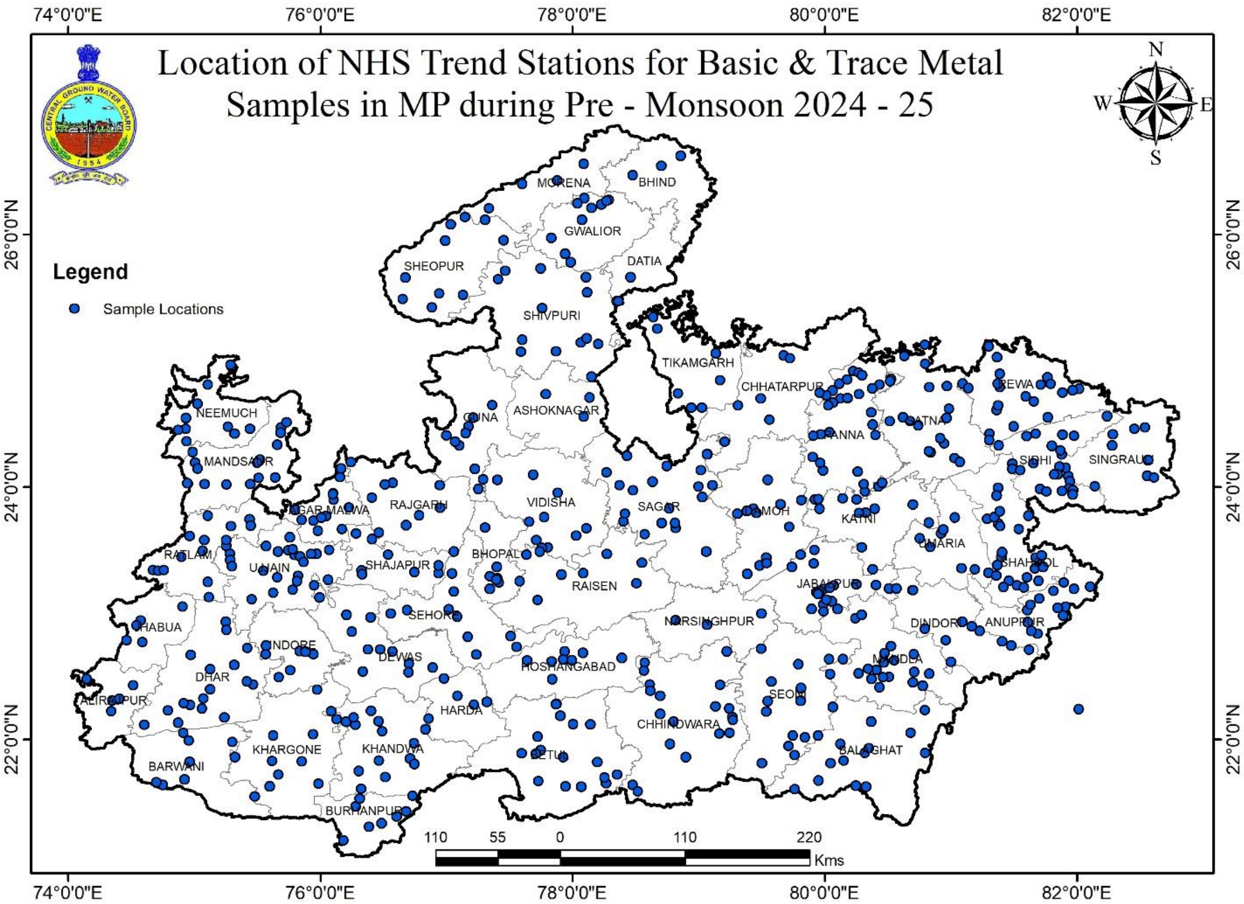


Fig B: Location Map of Sampling Points of NHS Trend Stations (614) for Basic and Trace Parameters in MP during Pre-monsoon 2024-25

Table 1: District-Wise Distribution of Water Quality Monitoring Stations							
Sl.No.	***District***	***Nos. of Quality Monitoring Stations***					
		2020	**2021**	**2022**	**2023 (Basic)**	**2023 (Trace)**	**2024 (Basic & Trace)**
1	AGAR MALWA	12	13	12	8	11	13
2	ALIRAJPUR	10	12	13	4	4	5
3	ANUPPUR	17	20	20	16	17	14
4	ASHOK NAGAR	14	17	18	4	18	3
5	BALAGHAT	38	37	39	20	40	13
6	BARWANI	9	8	20	5	9	7
7	BETUL	26	27	28	12	30	17
8	BHIND	19	19	18	7	16	3
9	BHOPAL	26	23	26	5	24	9
10	BURHANPUR	10	17	17	8	11	8
11	CHHATARPUR	23	32	29	15	27	8
12	CHHINDWARA	28	32	38	21	36	19
13	DAMOH	18	20	16	15	18	12
14	DATIA	12	12	8	3	9	1
15	DEWAS	18	18	24	8	19	11
16	DHAR	25	26	25	13	27	17
17	DINDORI	12	14	14	12	13	13
18	GUNA	19	21	21	7	20	9
19	GWALIOR	18	18	25	20	24	10
20	HARDA	12	12	12	5	12	5
21	HOSHANGABAD	19	19	19	9	19	9
22	INDORE	5	22	22	8	22	8

23	JABALPUR	12	31	34	9	19	18
24	JHABUA	9	10	11	4	8	5
25	KATNI	14	16	16	9	9	9
26	KHANDWA	26	28	30	19	30	17
27	KHARGONE	20	22	20	11	21	10
28	MANDLA	27	29	29	21	26	20
29	MANDSAUR	24	24	14	18	22	15
30	MORENA	14	14	13	8	11	4
31	NARSINGPUR	17	19	17	9	14	3
32	NEEMUCH	22	23	13	12	20	10
33	PANNA	24	25	21	15	25	30
34	RAISEN	26	24	28	2	21	9
35	RAJGARH	18	20	20	5	14	10
36	RATLAM	28	28	24	14	23	15
37	REWA	25	25	22	17	26	21
38	SAGAR	31	41	33	24	35	21
39	SATNA	40	43	41	9	48	19
40	SEHORE	19	18	19	9	21	10
41	SEONI	39	43	44	24	39	16
42	SHAHDOL	27	26	28	23	25	24
43	SHAJAPUR	18	19	14	7	13	8
44	SHEOPUR	20	21	21	14	18	10
45	SHIVPURI	31	32	30	9	28	15
46	SIDHI	22	25	26	18	24	23
47	SINGRAULI	19	14	26	11	18	10
48	TIKAMGARH	14	20	17	11	19	7
49	UJJAIN	19	28	20	15	24	23
50	UMARIA	15	15	15	10	11	8
51	VIDISHA	27	27	29	7	26	10
Total		**1037**	**1149**	**1139**	**589**	**1064**	**614**

Under the Special Purpose Monitoring initiative, a total of 544 samples were collected from areas where contamination of Iron, Manganese, Uranium, Arsenic, Lead, and Fluoride had been identified in previous studies conducted by CGWB. Additionally, two prominent industrial clusters—Nagda Industrial Area in Ujjain district and Dewas Industrial Area—were included for hotspot sample collection due to their potential impact on groundwater quality.

To ensure comprehensive analysis, locations with significantly high contamination levels of Uranium, Fluoride, Arsenic, and Lead identified in earlier studies were subjected to detailed investigation. This involved collecting additional samples within a 2x2 grid pattern around these critical areas. For other locations with a potential risk of contamination, as indicated by previous studies, a single sample was collected to assess groundwater quality.

The distribution of sampling points for hotspot sample collection, covering both basic parameters and trace metals, during the Pre-Monsoon 2024-25 period in Madhya Pradesh is illustrated in Fig C.

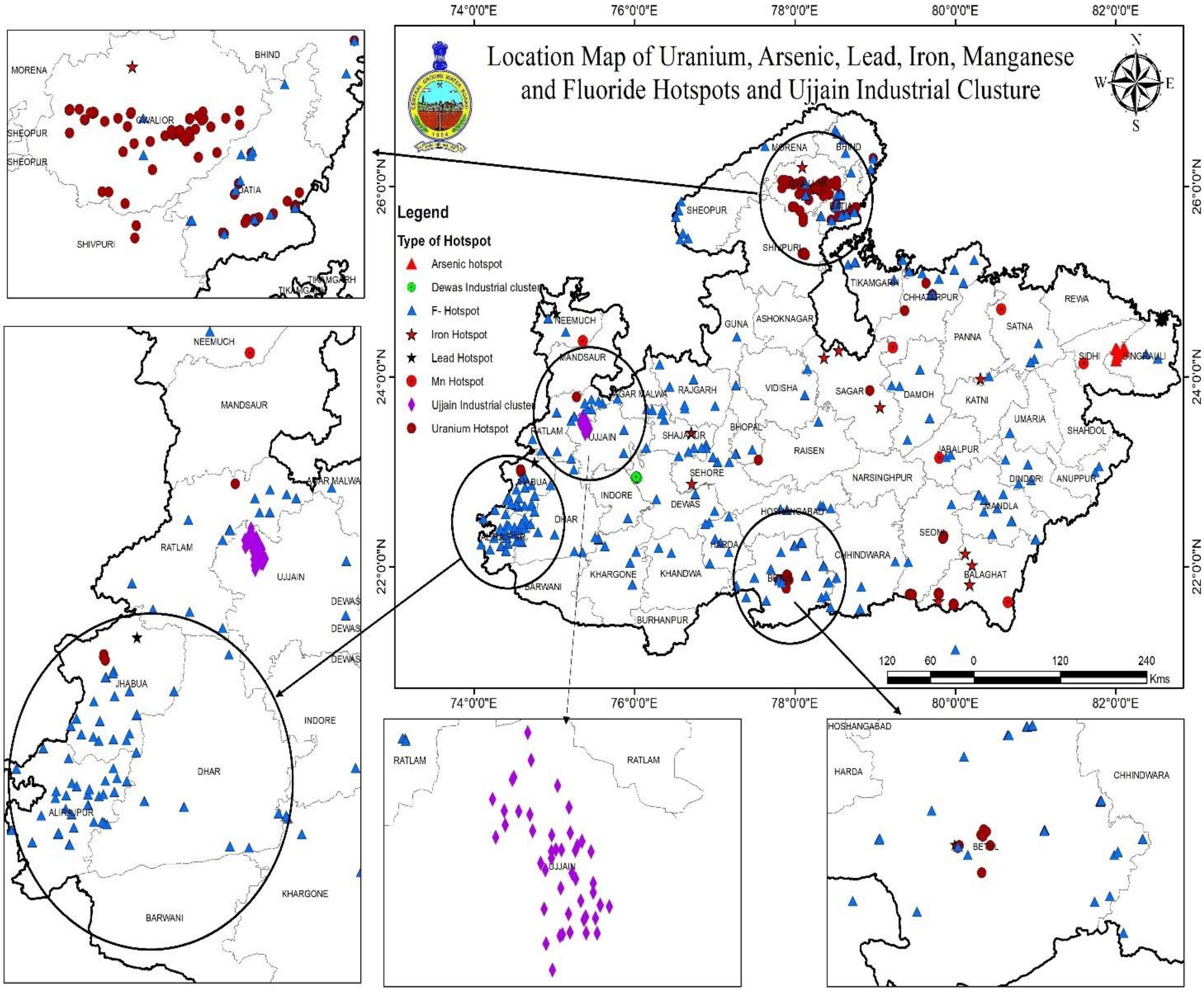


Fig C: Location Map of Sampling Points of Special purpose Monitoring Stations i.e. Hotspot samples (544) for Basic and Trace Parameters in MP during Pre-monsoon 2024-25

4. Ground Water Quality Scenario in NHS Trend Stations

The primary objectives of groundwater quality monitoring are to assess its suitability for drinking purposes, as the quality of drinking water significantly impacts community health. The Bureau of Indian Standards (BIS), in its document IS: 10500:2012, Edition 3.2 (2012-15), has recommended quality standards for drinking water. Groundwater samples collected from phreatic aquifers are analysed for major inorganic parameters. The results indicate that groundwater in Madhya Pradesh is predominantly of the calcium bicarbonate (Ca-HCO_3) type when total salinity is below 500 mg/L (corresponding to an electrical conductance of 750 µS/cm at 25°C). It is of mixed cation and mixed anion types when the electrical conductance is between 750 and 3000 µS/cm, and of the sodium chloride (Na-Cl) type when the electrical conductance exceeds 3000 µS/cm. Other types of water are also found, which may be due to local variations in hydro-chemical environments caused by anthropogenic activities. Additionally, high concentrations of certain water quality parameters, such as salinity (EC), Fluoride, Nitrate, Iron, and Uranium, and changes in water quality based on these parameters have been observed in various parts of Madhya Pradesh.

Quality Assessment of Groundwater in Unconfined Aquifers

Unconfined aquifers are extensively used for water supply and irrigation throughout the state, making their quality critically important. Key chemical parameters such as EC(Electrical Conductivity), Fluoride, Nitrate, Iron, Arsenic, and Uranium are the primary constituents that define the quality of groundwater in these aquifers. Therefore, the presence of these parameters and the changes in chemical quality with respect to these elements in groundwater samples collected during NHS monitoring in 2024 are discussed below:

1. Electrical Conductivity (> 3000 µS/cm)
2 Fluoride (>1.5 mg/litre)
3. Nitrate (>45 mg/litre)
4. Iron (>1.0 mg/litre)
5. Arsenic (>0.01 mg/litre)
6. Uranium (>30 ppb)

4.1 Electrical Conductivity (EC)

In general, water with an electrical conductivity (EC) of less than 1500 µS/cm is considered fresh water, while EC between 1500 and 15000 µS/cm is considered brackish water, and EC greater than 15000 µS/cm is considered saline water. Salinity is always present in groundwater, but in varying amounts. It is primarily influenced by factors such as the aquifer material, the solubility of minerals, the duration of contact, soil permeability, drainage facilities, rainfall quantity, and the area's climate. The Bureau of Indian Standards (BIS) has recommended a drinking water standard for total dissolved solids (TDS), with a limit of 500 mg/L (corresponding to an EC of about 750 µS/cm at 25°C), which can be extended to a TDS of 2000 mg/L (corresponding to an EC of about 3000 µS/cm at 25°C) if no alternative source is available. Water with TDS above 2000 mg/L is not suitable for drinking purposes.

Current Year Scenario in MP Regarding Electrical Conductivity (EC)

The electrical conductivity (EC) of groundwater samples collected during the pre-monsoon period of 2024 ranged from 160 to 3,700 µS/cm. The distribution of EC values across Madhya Pradesh is presented in the chart below. A significant proportion of the samples fell within the EC range of 751–2,250 µS/cm, representing the typical groundwater quality in the region.

However, EC levels exceeding 3,000 µS/cm were recorded at four specific locations in the Gwalior, Indore, Narmadapuram, and Shivpuri districts, out of the 614 samples analyzed. These elevated EC levels indicate the presence of saline water in these areas, which may be attributed to localized geological or anthropogenic factors.

The highest EC value of 3,700 µS/cm was observed at Methwada in Indore district, highlighting the need for targeted monitoring and potential mitigation measures in this region.

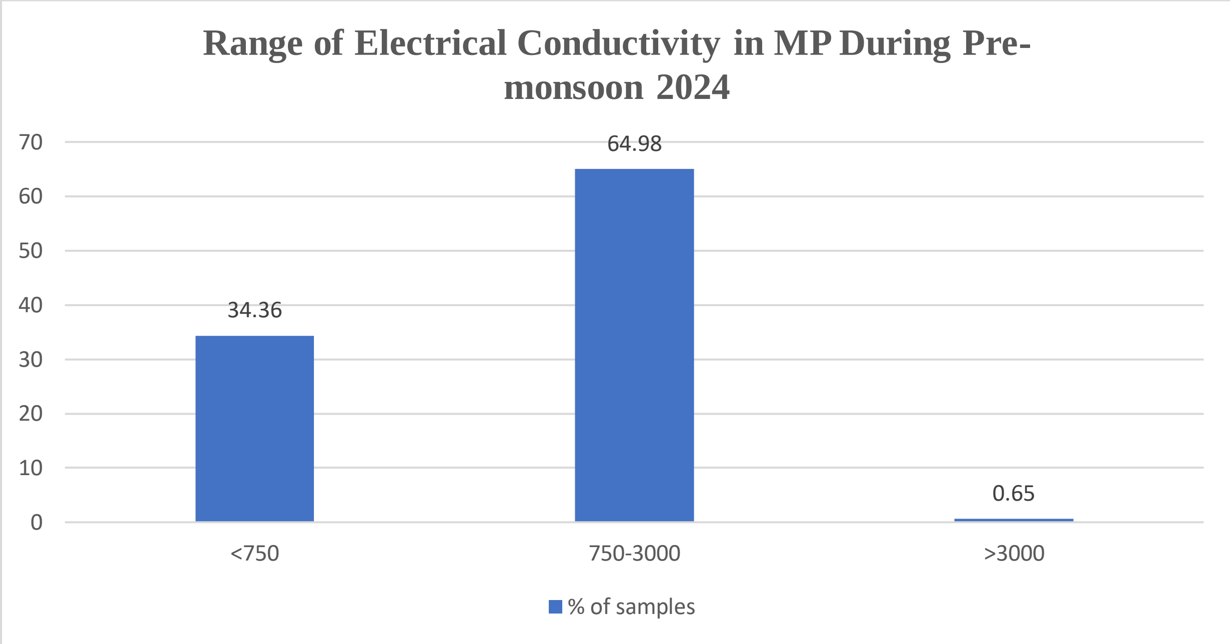


Chart A: Range of EC in MP during Pre-monsoon 2024.

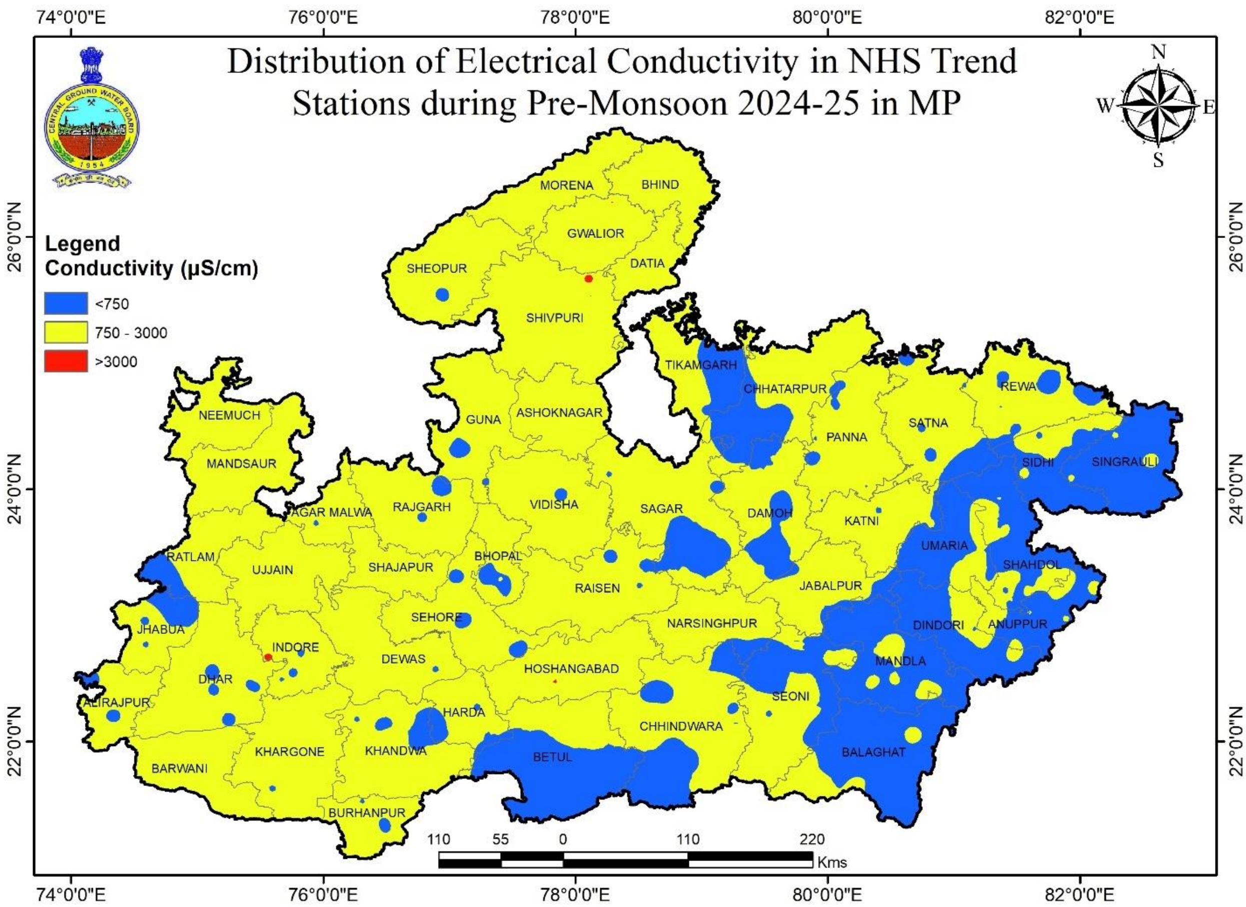


Fig D: Map Showing Distribution of EC in MP during Pre-Monsoon 2024

Table 2 below presents the number of samples analysed per district, along with their minimum, maximum, and mean EC values, based on Pre-monsoon NHS 2024 Trend stations data.

	Table 2: District Wise Range and Distribution of EC in Shallow GW of MP During Pre-Monsoon 2024.									
	Electrical Conductivity (Pre-Monsoon 2024)									
SL. No	***District***	***Nos. of Samples (Basic)***	***Permissible limit***	***Basic Statistics***				***No of samples (%)***		
			µS/cm at 25°C	***Min.***	***Max.***	***Mean***	***S.D.***	***<750***	***750-3000***	***> 3000***
1	AGAR MALWA	13	3000	585	1712	1025	263	1	12	0
2	ALIRAJPUR	5	3000	612	1156	843	228	3	2	0
3	ANUPPUR	14	3000	177	1042	635	267	8	6	0
4	ASHOKNAGAR	3	3000	812	1410	1026	272	0	3	0
5	BALAGHAT	13	3000	160	1042	613	309	8	5	0
6	BARWANI	7	3000	742	1456	1086	211	1	6	0
7	BETUL	17	3000	280	1660	771	364	10	7	0
8	BHIND	3	3000	1185	1875	1449	304	0	3	0
9	BHOPAL	9	3000	412	1082	775	215	3	6	0
10	BURHANPUR	8	3000	504	1500	962	297	2	6	0
11	CHHATARPUR	8	3000	312	2045	1003	557	2	6	0
12	CHHINDWARA	19	3000	265	2240	821	423	10	9	0
13	DAMOH	12	3000	312	1187	791	266	4	8	0
14	DATIA	1	3000	2785	2785	2785	0	0	1	0
15	DEWAS	11	3000	703	2456	1186	491	1	10	0
16	DHAR	17	3000	555	1898	1066	431	6	11	0
17	DINDORI	13	3000	478	912	685	145	9	4	0
18	GUNA	9	3000	512	1456	934	286	2	7	0
19	GWALIOR	10	3000	790	3256	1695	661	0	9	1
20	HARDA	5	3000	505	1320	924	292	2	3	0
21	HOSHANGABAD	9	3000	546	3145	1188	747	2	6	1
22	INDORE	8	3000	452	3700	1317	968	3	4	1
23	JABALPUR	18	3000	505	1502	859	236	7	11	0
24	JHABUA	5	3000	445	1289	854	336	3	2	0
25	KATNI	9	3000	577	1823	1239	404	1	8	0
26	KHANDWA	17	3000	512	1656	957	308	4	13	0
27	KHARGONE	10	3000	712	1326	1103	205	1	9	0
28	MANDLA	20	3000	302	1345	649	289	14	6	0
29	MANDSAUR	15	3000	810	2750	1439	528	0	15	0
30	MORENA	4	3000	989	1989	1630	385	0	4	0
31	NARSINGHPUR	3	3000	1152	1342	1239	78	0	3	0
32	NEEMUCH	10	3000	945	2953	1709	656	0	10	0
33	PANNA	30	3000	312	2265	979	414	9	21	0
34	RAISEN	9	3000	641	1612	1095	388	4	5	0
35	RAJGARH	10	3000	623	1565	958	286	2	8	0
36	RATLAM	15	3000	462	2435	1064	463	3	12	0
37	REWA	21	3000	317	2387	908	501	10	11	0
38	SAGAR	21	3000	412	1789	908	345	6	15	0
39	SATNA	19	3000	393	2133	1026	466	4	15	0
40	SEHORE	10	3000	412	1653	820	323	3	7	0
41	SEONI	16	3000	265	2812	883	547	8	8	0
42	SHAHDOL	24	3000	200	1540	704	329	16	8	0
43	SHAJAPUR	8	3000	789	1326	1050	188	0	8	0
44	SHEOPUR	10	3000	542	1785	1158	335	1	9	0
45	SHIVPURI	15	3000	715	3365	1271	741	1	13	1
46	SIDHI	23	3000	245	1298	649	272	18	5	0
47	SINGRAULI	10	3000	420	898	633	174	7	3	0
48	TIKAMGARH	7	3000	446	1483	915	343	3	4	0
49	UJJAIN	23	3000	898	2256	1438	368	0	23	0
50	UMARIA	8	3000	265	952	628	196	6	2	0
51	VIDISHA	10	3000	589	1689	1105	382	3	7	0
	TOTAL	614						211	399	4

From the data presented in the above table, it is evident that the majority of sampling locations reported Electrical Conductivity (EC) values within the range of 750–3,000 µS/cm. This range encompasses typical groundwater quality across most regions of Madhya Pradesh. However, only four specific locations recorded EC values exceeding 3,000 µS/cm, indicating significantly higher salinity levels in these areas **(See Table 2, Fig D & Chart A).**

Temporal Variation of EC in Ground Water during the Period from 2020 to 2023 .

Table 3: Comparative change in number of locations having EC > 3000 µS/cm in various Districts from 2020 to 2023.

S.No	District	2020	2021	2022	2023	2024
1	AGAR MALWA	1	1			
2	ALIRAJPUR	1				
3	ANUPPUR					
4	ASHOK NAGAR					
5	BALAGHAT					
6	BARWANI					
7	BETUL					
8	BHIND	2	1	4	1	
9	BHOPAL					
10	BURHANPUR					
11	CHHATARPUR					
12	CHHINDWARA					
13	DAMOH					
14	DATIA				1	
15	DEWAS					
16	DHAR			1		
17	DINDORI					
18	GUNA					
19	GWALIOR			3	3	1
20	HARDA					
21	HOSHANGABAD					1
22	INDORE		1	1		1
23	JABALPUR					
24	JHABUA					
25	KATNI					
26	KHANDWA					
27	KHARGONE					
28	MANDLA					
29	MANDSAUR					
30	MORENA					
31	NARSINGHPUR					
32	NEEMUCH	1	1	1	1	
33	PANNA					
34	RAISEN					
35	RAJGARH					
36	RATLAM					
37	REWA					
38	SAGAR					
39	SATNA					
40	SEHORE					
41	SEONI		1			
42	SHAHDOL					
43	SHAJAPUR					
44	SHEOPUR					
45	SHIVPURI	1	1	1	1	1
46	SIDHI					
47	SINGRAULI					
48	TIKAMGARH					
49	UJJAIN	2	2	1		
50	UMARIA					
51	VIDISHA					
	Total	8	8	12	7	4

In comparison to the period from 2020 to 2023, a noticeable reduction in the number of districts reporting Electrical Conductivity (EC) values exceeding 3,000 µS/cm was observed in 2024. This decline suggests an improvement in groundwater quality in terms of salinity levels across certain areas of Madhya Pradesh. The decrease may be attributed to natural recharge processes, effective water resource management, or reduced anthropogenic impacts during this period. Further analysis is required to confirm the contributing factors and sustain these positive trends in groundwater quality (*See* **Table 3,4 & Chart B**).

Table 4: Periodic Variation in Suitability Class of Groundwater for EC of MP.

Parameter	Class	Percentage of Samples					Periodic Variation (2020 to 2024)
		2020 (n=1037)	2021 (n=1149)	2022 (n=1139)	2023 (n=589)	2024 (n=614)	
Salinity as EC	**< 750**	36.07	38.56	34.33	35.27	34.4	**-0.55**
	750 - 3000	63.16	60.75	64.62	63.12	65.0	**0.54**
	> 3000	0.77	0.70	1.05	1.61	0.7	**1.28**

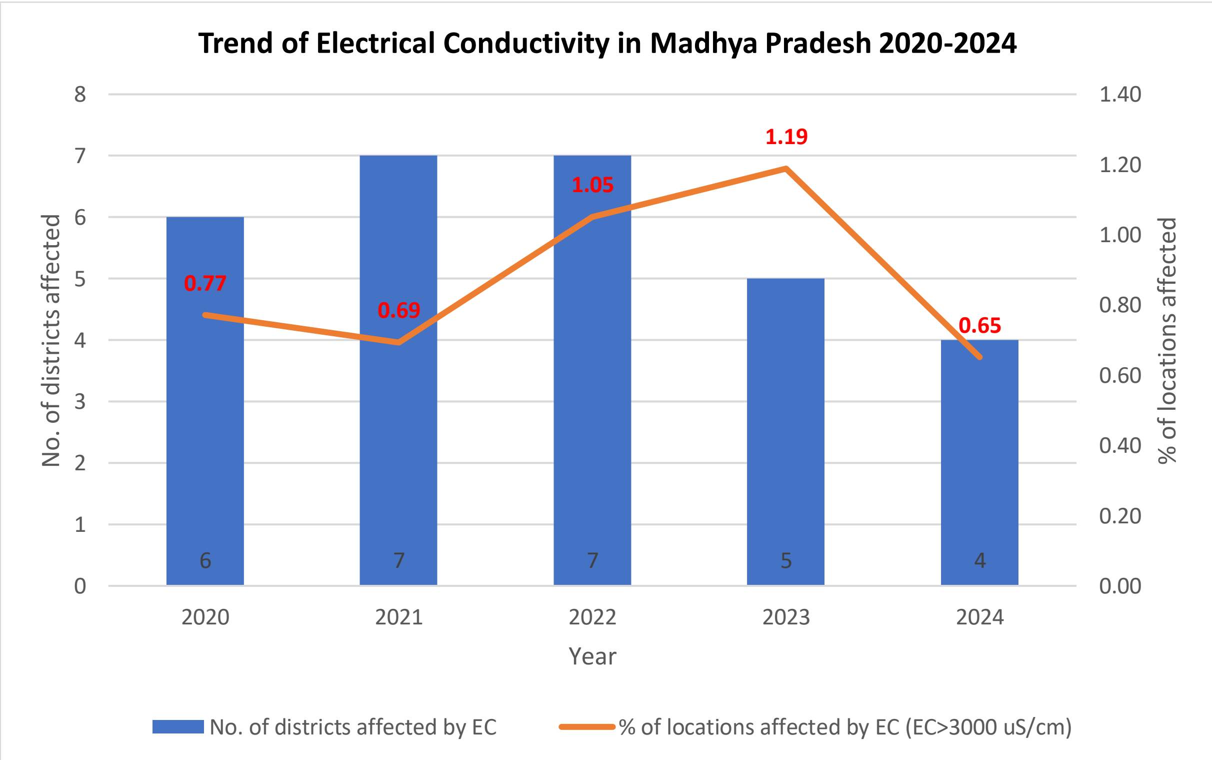


Chart B: Trend of Electrical Conductivity in Madhya Pradesh from 2020-2024.

4.2 NITRATE

Naturally occurring nitrate forms when nitrogen and oxygen combine in soil, primarily sourced from atmospheric nitrogen. Groundwater nitrate mainly originates from chemical fertilizers, animal manure leaching, and sewage discharge. Distinguishing between natural and man-made sources is challenging. Chemical and microbiological processes such as nitrification and denitrification also impact groundwater nitrate levels. According to the BIS standard for drinking water, the maximum desirable limit of nitrate concentration in groundwater is 45 mg/L. Although nitrate is considered relatively non-toxic, high concentrations in drinking water pose an environmental health concern, particularly due to the increased risk of methemoglobinemia in infants. Adults can tolerate slightly higher concentrations.

Current Year Scenario in Madhya Pradesh Regarding Nitrate

The nitrate concentrations in the samples collected during the pre-monsoon period of 2024 varied from 0 to 287 mg/l. The chart below depicts the distribution of these concentrations. Notably, 75.24% of the samples had nitrate levels below the BIS-prescribed permissible limit of 45 mg/l.

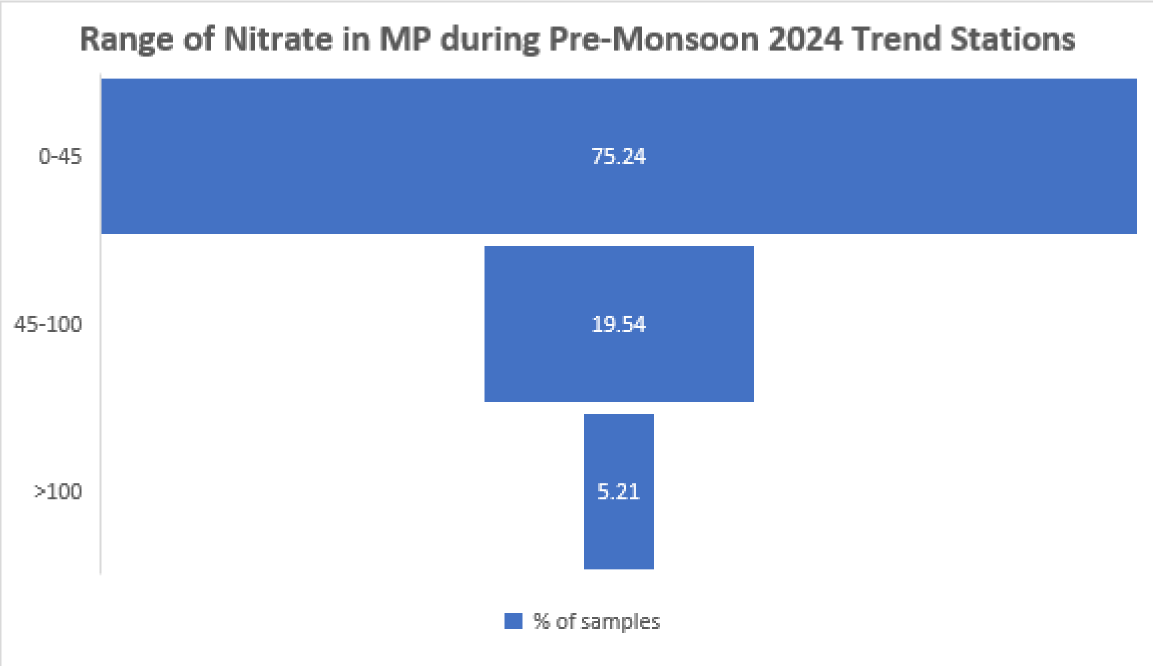


Chart C: Range of Nitrate in MP during Pre-monsoon 2024.

Nitrate levels exceeding 45 mg/l were detected at 150 locations across various districts of Madhya Pradesh, including Agar Malwa, Alirajpur, Balaghat, Barwani, Betul, Bhind, Burhanpur, Chhatarpur, Chhindwara, Damoh, Datia, Dewas, Dhar, Guna, Gwalior, Harda, Indore, Jabalpur, Jhabua, Katni, Khandwa, Khargone, Mandla, Mandsaur, Morena, Neemuch, Panna, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Shahdol, Shajapur, Sheopur, Shivpuri, Sidhi, Singrauli, Tikamgarh, Ujjain, Umaria, and Vidisha. Among the 614 samples analyzed, nitrate levels exceeding 100 mg/l were recorded at 32 locations, indicating significant contamination in these areas. The highest nitrate concentration, 287 mg/l, was observed at Kukreshwar in the Neemuch district.

The elevated nitrate levels in these samples can be attributed to multiple factors, including excessive use of nitrogen-based fertilizers in agriculture, leaching of fertilizers and animal waste into groundwater, improper disposal of municipal and industrial waste, poorly maintained septic systems, and natural geological sources. Over-extraction of groundwater and waterlogging in some areas may have further aggravated the nitrate concentration by facilitating leaching and accumulation.

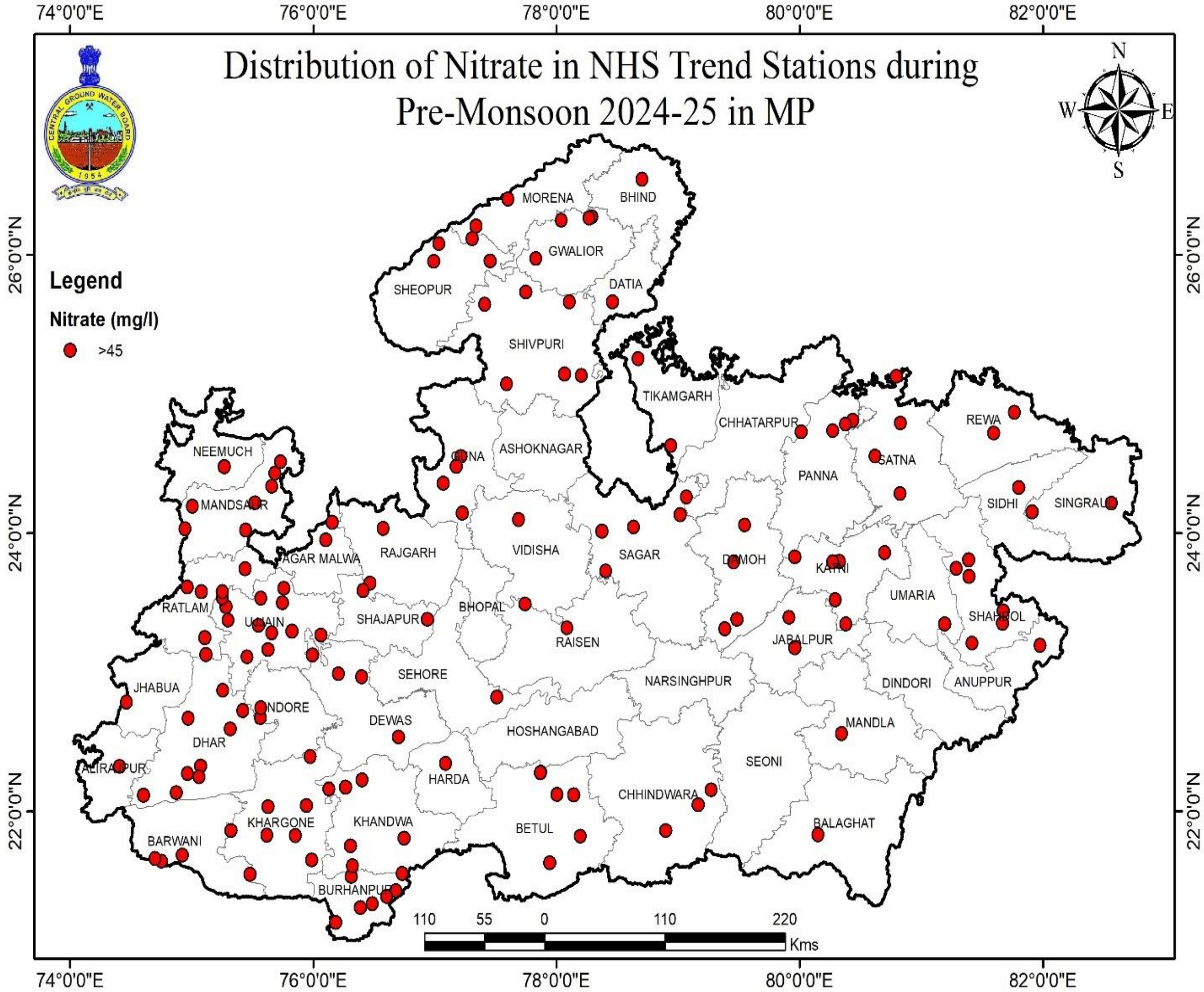


Fig E: Map Showing Distribution of Nitrate in MP during Pre-Monsoon 2024-25.

The table below summarizes the number of samples analyzed per district, along with their minimum, maximum, and average nitrate concentrations, as reported from NHS 2024 Trend Station data.

Table 5: District Wise Range and Distribution of Nitrate in Shallow GW of Madhya Pradesh During Pre-Monsoon 2024.

SL.No	District	Nos. of Samples (Basic)	Permissible limit	Min.	Max.	Mean	S.D.	% of samples	
			mg/l	mg/l				<45	>45
1	AGAR MALWA	13	45	5	69	28	16	85	15
2	ALIRAJPUR	5	45	2	60	21	23	80	20
3	ANUPPUR	14	45	2	45	17	13	100	0
4	ASHOKNAGAR	3	45	5	42	26	15	100	0
5	BALAGHAT	13	45	2	63	10	16	92	8
6	BARWANI	7	45	2	90	42	38	57	43
7	BETUL	17	45	1	200	52	64	65	35
8	BHIND	3	45	12	75	34	29	67	33
9	BHOPAL	9	45	2	35	17	11	100	0
10	BURHANPUR	8	45	29	190	88	55	13	88
11	CHHATARPUR	8	45	3	88	26	27	88	13
12	CHHINDWARA	19	45	2	86	17	25	84	16
13	DAMOH	12	45	6	66	33	20	67	33
14	DATIA	1	45	52	52	52	0	0	100

15	DEWAS	11	45	3	85	36	29	64	36
16	DHAR	17	45	3	120	49	36	47	53
17	DINDORI	13	45	5	25	10	6	100	0
18	GUNA	9	45	2	125	48	33	56	44
19	GWALIOR	10	45	10	112	47	33	60	40
20	HARDA	5	45	6	140	46	48	80	20
21	HOSHANGABAD	9	45	3	40	16	13	100	0
22	INDORE	8	45	2	94	26	30	75	25
23	JABALPUR	18	45	2	85	23	23	89	11
24	JHABUA	5	45	3	112	32	41	80	20
25	KATNI	9	45	11	144	70	51	44	56
26	KHANDWA	17	45	6	89	43	28	59	41
27	KHARGONE	10	45	9	88	63	25	20	80
28	MANDLA	20	45	1	46	10	13	95	5
29	MANDSAUR	15	45	5	123	53	33	53	47
30	MORENA	4	45	32	123	68	36	50	50
31	NARSINGHPUR	3	45	3	4	4	0	100	0
32	NEEMUCH	10	45	4	287	39	83	90	10
33	PANNA	30	45	1	132	20	32	87	13
34	RAISEN	9	45	3	134	36	38	78	22
35	RAJGARH	10	45	3	56	24	19	80	20
36	RATLAM	15	45	5	88	38	25	53	47
37	REWA	21	45	0	71	14	18	90	10
38	SAGAR	21	45	3	168	32	39	76	24
39	SATNA	19	45	1	93	26	30	79	21
40	SEHORE	10	45	16	55	29	12	90	10
41	SEONI	16	45	3	41	14	11	100	0
42	SHAHDOL	24	45	0	111	27	31	75	25
43	SHAJAPUR	8	45	16	68	39	16	75	25
44	SHEOPUR	10	45	8	187	63	68	60	40
45	SHIVPURI	15	45	4	244	52	64	60	40
46	SIDHI	23	45	1	199	18	40	96	4
47	SINGRAULI	10	45	0	66	19	21	80	20
48	TIKAMGARH	7	45	12	71	33	21	71	29
49	UJJAIN	23	45	15	98	46	25	57	43
50	UMARIA	8	45	9	55	29	15	88	13
51	VIDISHA	10	45	2	63	20	18	90	10

Temporal Variation of Nitrate in groundwater over the period 2020-2024

Table 6: Comparative Change in Number of Locations Having Nitrate>45 Mg/L in Various Districts .

S.No	***District***	**2020**	**2021**	**2022**	**2023**	**2024**
1	*AGAR MALWA*	6	8	3	3	2
2	*ALIRAJPUR*	5	5	3		1
3	*ANUPPUR*		1		2	
4	*ASHOK NAGAR*	3	3	3		
5	*BALAGHAT*	10	8	7	2	1
6	*BARWANI*	7	3	13	3	3
7	*BETUL*	11	1	5		6
8	*BHIND*	2	3	6	2	1
9	*BHOPAL*		2	2		
10	*BURHANPUR*	7	3	7	3	7
11	*CHHATARPUR*	9	12	7		1
12	*CHHINDWARA*	11	19	17	6	3
13	*DAMOH*	7	5	7	1	4
14	*DATIA*	3	3		1	1
15	*DEWAS*	10	8	10	3	4
16	*DHAR*	10	9	6	5	9
17	*DINDORI*	1				
18	*GUNA*				1	4
19	*GWALIOR*	5	5	9	5	4
20	*HARDA*	4	4	8	1	1
21	*HOSHANGABAD*	4	2	2		

22	INDORE	2	10	3	1	2
23	JABALPUR	2	3	4	3	2
24	JHABUA	5	5	4	2	1
25	KATNI	4	6	4	5	5
26	KHANDWA	12	10	13	9	7
27	KHARGONE	16	7	15	6	8
28	MANDLA	3	3	4	1	1
29	MANDSAUR	15	11	6	11	7
30	MORENA	4	3	1	2	2
31	NARSINGHPUR	2	4	5	2	
32	NEEMUCH	12	6		1	1
33	PANNA	5	4	2	1	4
34	RAISEN	5	5	4		2
35	RAJGARH	6	8	6	1	2
36	RATLAM	17	5	2	5	7
37	REWA	6	3	3	1	2
38	SAGAR	15	14	1	5	5
39	SATNA	7	7	2	1	4
40	SEHORE	11	2	8		1
41	SEONI	6	10	7		
42	SHAHDOL	4	4	2	7	6
43	SHAJAPUR	12	5	5	3	2
44	SHEOPUR	11	7	9	8	4
45	SHIVPURI	20	15	21	8	6
46	SIDHI	1		3	1	1
47	SINGRAULI	4	1			2
48	TIKAMGARH	10	10	4	3	2
49	UJJAIN	16	7	4	10	10
50	UMARIA	3	4	4	3	1
51	VIDISHA	11	8	10		1
	Total	362	291	271	138	150

The analysis reveals a significant reduction in the number of locations across various districts with high nitrate concentrations (exceeding 45 mg/l) in groundwater, decreasing from 362 in 2020 to 150 in 2024. This trend indicates an overall improvement in groundwater quality over the years. However, it is important to note that there has been a slight increase in the number of such locations compared to 2023, suggesting localized factors or activities that may have contributed to this increment. These observations underscore the need for continuous monitoring and targeted mitigation measures to sustain and further enhance groundwater quality (*See* **Tables 5, 6 &7; Chart C & D; Fig E**).

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Table 7: Periodic Variation in Nitrate Suitability Classes in Groundwater of Madhya Pradesh

Parameter	Class	Percentage of Samples					Periodic Variation 2020-24
		2020 (n=1037)	2021 (n=1149)	2022 (n=1139)	2023 (n=589)	2024 (n=614)	
Nitrate	< 45	64.32	74.41	75.77	76.20	75.6	0.24
	> 45	35.68	25.59	24.23	23.80	24.4	-0.24

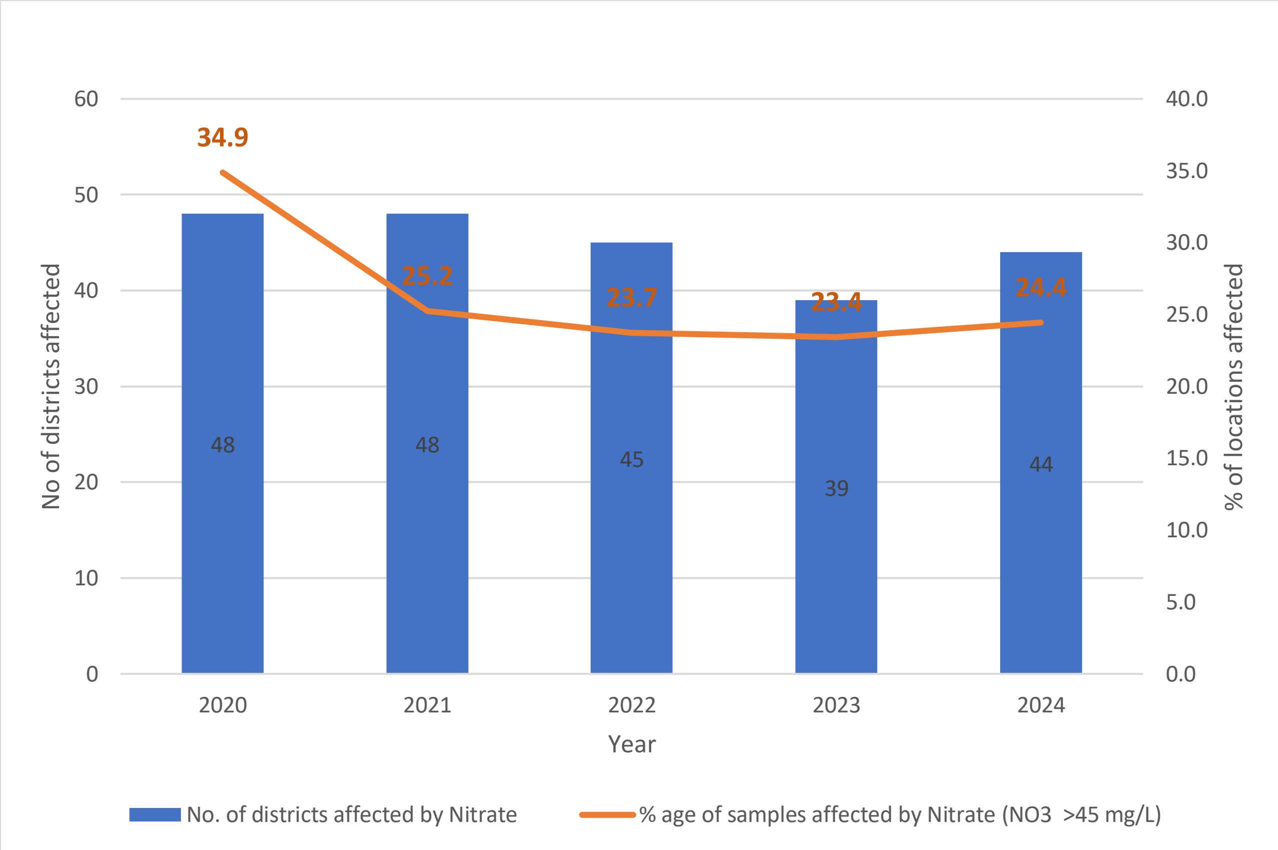


Chart D: Trend of Nitrate Occurrence in Madhya Pradesh from 2020-24.

4.3 FLUORIDE

Fluorine does not occur in its elemental state in nature due to its high reactivity. Instead, it exists as fluorides in various minerals, with Fluorspar, Cryolite, Fluorite, and Fluorapatite being the most common. Most of the fluoride in groundwater originates from the natural breakdown of rocks and soils, or from the weathering and deposition of atmospheric particles. Fluorides are generally sparingly soluble and present in small amounts in groundwater. The occurrence of fluoride in natural water is influenced by the type of rocks, climatic conditions, nature of hydrogeological strata, and the duration of contact between the rock and circulating groundwater. The Bureau of Indian Standards (BIS) has recommended a desirable limit of 1.0 mg/l of fluoride concentration in drinking water, with a maximum permissible limit of 1.5 mg/l when no alternative source is available. It is well known that small amounts of fluoride (up to 1.0 mg/l) can help reduce tooth decay. However, high concentrations (>1.5 mg/l) can lead to staining of tooth enamel, and even higher levels (>5.0 mg/l) can cause more severe issues, such as bone stiffness. Water with fluoride concentrations above 1.5 mg/l is not suitable for drinking. High fluoride levels (>1.5 mg/l) are mainly due to geogenic conditions. In most observation wells across the state, the fluoride content in groundwater is found to be less than 1.0 mg/l.

Fluoride (F) Levels in Madhya Pradesh: Current Year Overview

The fluoride concentrations in the samples collected during the pre-monsoon period of 2023 varied from 0 to 2.7 mg/l. The chart below illustrates the distribution of fluoride levels across the samples during this period. Notably, a significant majority of the samples (92%) exhibited fluoride concentrations ranging between 0 and 1 mg/l, indicating that most of the groundwater in the region contained fluoride within lower levels. This suggests that fluoride concentrations in the majority of the sampled areas fall within safe or acceptable limits.

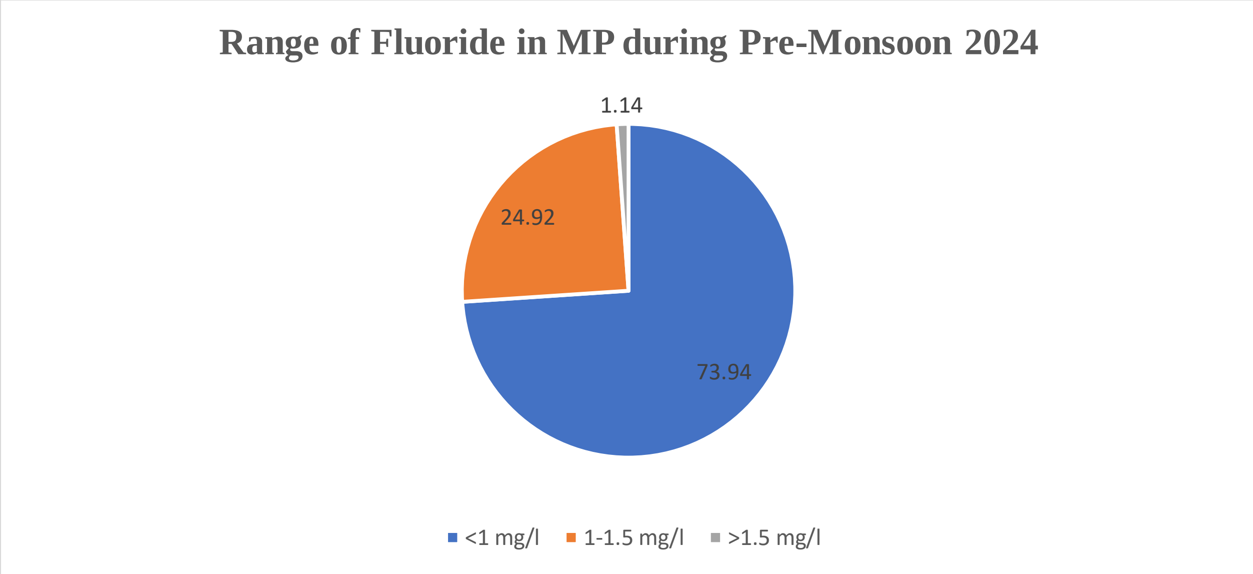


Chart E: Range of F in MP during Pre-monsoon 2024.

Fluoride concentrations exceeding 1.5 mg/l were detected at 7 locations across the districts of Betul, Dewas, Dindori, Harda, Seoni, and Sidhi, out of the 614 samples analysed, highlighting a fluoride concern in these areas. The highest fluoride concentration, 2.65 mg/l, was recorded at Gorakhpur Kala village in Seoni.

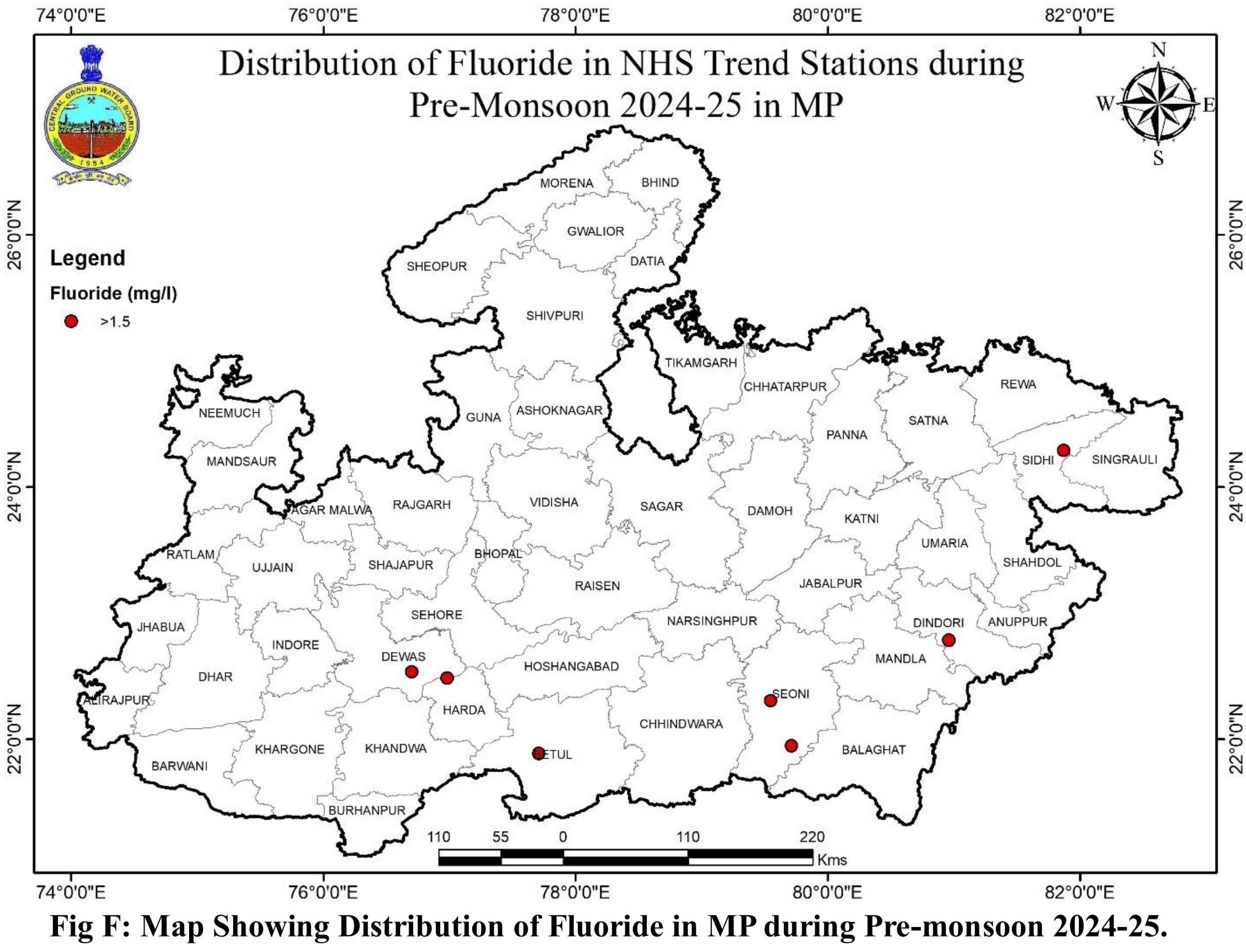


Fig F: Map Showing Distribution of Fluoride in MP during Pre-monsoon 2024-25.

The table below presents the number of samples analyzed per district, along with their minimum, maximum, and average fluoride values, based on NHS 2024 Trend Stations data.

Table 8 : District-Wise Range and Distribution of Fluoride in Shallow Groundwater of Madhya Pradesh During Pre-Monsoon 2024									
Fluoride Concentrations(mg/l)									
SL.No	***District***	***Nos. of Samples (Basic)***	***Permissible limit***	***Min.***	***Max.***	***Mean***	***S.D.***	***percentage of samples (%)***	
			mg/l	***mg/l***				***<=1.5***	***>1.5***
1	AGAR MALWA	13	1.5	0.05	1.10	0.54	0.28	100	0
2	ALIRAJPUR	5	1.5	0.54	1.42	0.96	0.32	100	0
3	ANUPPUR	14	1.5	0.17	1.47	0.46	0.34	100	0
4	ASHOKNAGAR	3	1.5	0.29	0.65	0.45	0.15	100	0
5	BALAGHAT	13	1.5	0.05	1.12	0.33	0.29	100	0
6	BARWANI	7	1.5	0.17	0.26	0.22	0.03	100	0
7	BETUL	17	1.5	0.18	2.70	0.57	0.58	94	6
8	BHIND	3	1.5	0.4	0.45	0.42	0.02	100	0
9	BHOPAL	9	1.5	0.26	0.84	0.47	0.16	100	0
10	BURHANPUR	8	1.5	0.22	0.88	0.54	0.21	100	0
11	CHHATARPUR	8	1.5	0.23	1.41	0.81	0.40	100	0
12	CHHINDWARA	19	1.5	0.05	1.12	0.36	0.28	100	0
13	DAMOH	12	1.5	0.11	0.88	0.50	0.20	100	0
14	DATIA	1	1.5	0.65	0.65	0.65	0.00	100	0
15	DEWAS	11	1.5	0.29	1.59	0.77	0.40	91	9
16	DHAR	17	1.5	0.05	1.46	0.45	0.35	100	0
17	DINDORI	13	1.5	0.07	1.56	0.39	0.37	92	8
18	GUNA	9	1.5	0.28	0.89	0.60	0.22	100	0
19	GWALIOR	10	1.5	0.32	1.12	0.60	0.21	100	0
20	HARDA	5	1.5	0.12	1.98	0.69	0.69	80	20
21	HOSHANGABAD	9	1.5	0.09	0.65	0.32	0.20	100	0
22	INDORE	8	1.5	0.43	1.44	0.64	0.31	100	0
23	JABALPUR	18	1.5	0.14	0.89	0.45	0.20	100	0
24	JHABUA	5	1.5	0.05	1.06	0.68	0.36	100	0
25	KATNI	9	1.5	0.36	1.29	0.69	0.35	100	0
26	KHANDWA	17	1.5	0.13	0.70	0.31	0.13	100	0
27	KHARGONE	10	1.5	0.05	0.62	0.32	0.15	100	0
28	MANDLA	20	1.5	0.05	0.86	0.21	0.21	100	0
29	MANDSAUR	15	1.5	0.02	1.38	0.26	0.36	100	0
30	MORENA	4	1.5	0.32	0.65	0.48	0.12	100	0
31	NARSINGHPUR	3	1.5	0.18	0.36	0.24	0.08	100	0
32	NEEMUCH	10	1.5	0.31	0.89	0.55	0.18	100	0
33	PANNA	30	1.5	0.26	1.27	0.77	0.28	100	0
34	RAISEN	9	1.5	0.23	0.70	0.40	0.14	100	0
35	RAJGARH	10	1.5	0.21	1.32	0.54	0.33	100	0
36	RATLAM	15	1.5	0.05	0.47	0.20	0.12	100	0
37	REWA	21	1.5	0.25	1.03	0.61	0.22	100	0
38	SAGAR	21	1.5	0.18	1.07	0.42	0.23	100	0
39	SATNA	19	1.5	0.11	1.12	0.54	0.31	100	0
40	SEHORE	10	1.5	0.19	0.75	0.37	0.19	100	0
41	SEONI	16	1.5	0.29	2.65	0.73	0.61	88	13
42	SHAHDOL	24	1.5	0	0.78	0.22	0.27	100	0
43	SHAJAPUR	8	1.5	0.22	1.12	0.54	0.29	100	0
44	SHEOPUR	10	1.5	0.21	0.97	0.44	0.28	100	0
45	SHIVPURI	15	1.5	0.12	1.29	0.71	0.32	100	0
46	SIDHI	23	1.5	0.01	1.58	0.44	0.36	96	4
47	SINGRAULI	10	1.5	0.14	0.99	0.37	0.26	100	0
48	TIKAMGARH	7	1.5	0.36	1.23	0.82	0.31	100	0
49	UJJAIN	23	1.5	0.25	0.94	0.52	0.19	100	0
50	UMARIA	8	1.5	0.1	1.01	0.48	0.30	100	0
51	VIDISHA	10	1.5	0.22	1.42	0.46	0.33	100	0

Temporal Variation of Fluoride Levels in Groundwater over the Period 2020–2024

Table 9 : Comparative Change in the Number of Locations with Fluoride Levels Greater than 1.5 mg/l Across Various Districts.

S.No	District	2020	2021	2022	2023	2024
1	AGAR MALWA					
2	ALIRAJPUR				1	
3	ANUPPUR		1	1		
4	ASHOK NAGAR					
5	BALAGHAT					
6	BARWANI					
7	BETUL		3			1
8	BHIND		3			
9	BHOPAL					
10	BURHANPUR					
11	CHHATARPUR		2	1		
12	CHHINDWARA	3			1	
13	DAMOH					
14	DATIA	2	2	1		
15	DEWAS	2			1	1
16	DHAR		1		2	
17	DINDORI	3		1		1
18	GUNA					
19	GWALIOR					
20	HARDA		1			1
21	HOSHANGABAD					
22	INDORE					
23	JABALPUR		1			
24	JHABUA					
25	KATNI		1		1	
26	KHANDWA	1				
27	KHARGONE		1			
28	MANDLA				1	
29	MANDSAUR	1				
30	MORENA	1	1			
31	NARSINGHPUR					
32	NEEMUCH	2	1	2		
33	PANNA					
34	RAISEN					
35	RAJGARH					
36	RATLAM	1				
37	REWA					
38	SAGAR					
39	SATNA					
40	SEHORE	1				
41	SEONI			5		2
42	SHAHDOL					
43	SHAJAPUR		1	3		
44	SHEOPUR					
45	SHIVPURI					
46	SIDHI					1
47	SINGRAULI		2	1		
48	TIKAMGARH	1				
49	UJJAIN		2			
50	UMARIA	1				
51	VIDISHA		1			
	Total	19	24	15	7	7

It has been observed that the number of districts experiencing high fluoride levels in groundwater has significantly decreased over the past few years. In 2020, 19 districts were identified with fluoride concentrations exceeding safe limits, posing potential health risks to the local populations. However, by 2024, this number has reduced to just 7 districts, indicating a substantial improvement in managing fluoride contamination. While the reduction is encouraging, continued monitoring and targeted efforts are still required to address fluoride contamination in the remaining affected districts (*See* **Tables 8, 9 &10; Chart E & F; Fig F**).

Table 10: Periodic Variation in Fluoride Suitability Classes in Madhya Pradesh's Groundwater							
Parameter	**Class**	**Percentage of Samples**					**Periodic Variation 2020-24**
		2020 (n=1037)	**2021 (n=1149)**	**2022 (n=1139)**	**2023 (n=589)**	**2024 (n=614)**	
Fluoride	***<1.5***	98.17	97.91	98.68	98.56	98.9	3.3
	>1.5	1.83	2.09	1.32	1.44	1.1	-3.3

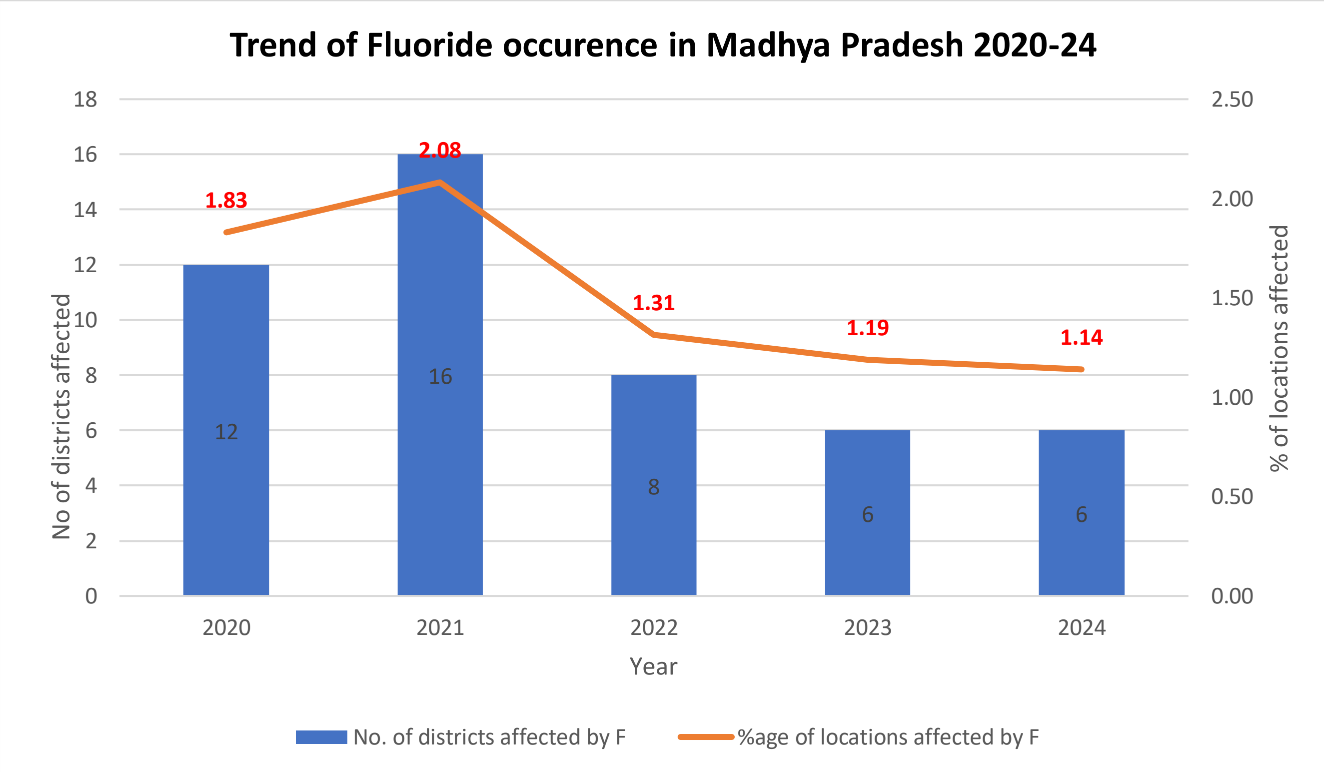


Chart F: Trend of Fluoride Occurrence in Madhya Pradesh from 2020-24

4.4 ARSENIC

Arsenic, a naturally occurring element, is widely distributed in the Earth's crust and can be found in water, air, food, and soil. It exists in two main forms: organic and inorganic. Natural processes such as biological activities, weathering, and volcanic emissions contribute to arsenic's release, but human activities also significantly impact its distribution. Anthropogenic sources include mining, fossil fuel combustion, and the use of arsenic-containing pesticides, herbicides, and crop desiccants, as well as arsenic additives in livestock feed, particularly poultry feed. While the use of arsenical pesticides and herbicides has decreased in recent decades, their use in wood preservation remains prevalent. The Bureau of Indian Standards (BIS) sets the maximum permissible limit for arsenic at 10 parts per billion (ppb).

Current Status of Arsenic across Madhya Pradesh: A Yearly Perspective

The arsenic concentrations in the samples collected during the pre-monsoon period of 2023 ranged from 0 to 78.2 ppb. During the pre-monsoon period of 2024-25, eight locations in Madhya Pradesh were found to have arsenic levels exceeding the BIS-prescribed permissible limit of 0.01 mg/l (10 ppb). This indicates a concern for arsenic contamination in these areas, with elevated levels posing potential health risks to local populations. The highest arsenic concentration, 78.2 ppb, was recorded at Kharotia village in Ujjain district, highlighting a critical point of concern for further investigation and remediation.

Table 11: District-Wise Range and Distribution of Arsenic in Shallow Groundwater of Madhya Pradesh During Pre-Monsoon 2024

Arsenic Concentrations(µg/l)									
Sl.No.	***District***	***Total sample s=614***	***Permissible Limit***	***Min.***	***Max***	***Mean***	***S.D.***	***Number of Samples (%)***	
								< 10	***> 10***
1	AGAR MALWA	13	10	0.0	1.30	0.32	0.46	100	0
2	ALIRAJPUR	5	10	0.0	0.30	0.12	0.10	100	0
3	ANUPPUR	14	10	0.1	1.50	0.46	0.45	100	0
4	ASHOKNAGAR	3	10	0.7	6.50	2.77	2.64	100	0
5	BALAGHAT	13	10	0.0	2.80	0.46	0.72	100	0
6	BARWANI	7	10	0.1	0.30	0.20	0.08	100	0
7	BETUL	17	10	0.1	0.70	0.15	0.15	100	0
8	BHIND	3	10	0.4	2.30	1.23	0.79	100	0
9	BHOPAL	9	10	0.1	3.40	0.83	1.01	100	0
10	BURHANPUR	8	10	0.1	1.10	0.35	0.34	100	0
11	CHHATARPUR	8	10	0.1	4.60	1.08	1.39	100	0
12	CHHINDWARA	19	10	0.0	0.40	0.21	0.13	100	0
13	DAMOH	12	10	0.0	3.10	0.47	0.84	100	0
14	DATIA	1	10	0.2	0.20	0.20	0.00	100	0
15	DEWAS	11	10	0.2	0.90	0.38	0.23	100	0
16	DHAR	17	10	0.1	12.0	0.96	2.77	94	6
17	DINDORI	13	10	0.0	0.50	0.17	0.11	100	0
18	GUNA	9	10	0.4	1.40	0.68	0.31	100	0
19	GWALIOR	10	10	0.2	18.0	2.80	5.19	90	10
20	HARDA	5	10	0.0	0.20	0.10	0.06	100	0
21	HOSHANGABAD	9	10	0.0	0.20	0.10	0.05	100	0
22	INDORE	8	10	0.1	0.30	0.19	0.06	100	0
23	JABALPUR	18	10	0.2	66.8	5.26	15.47	89	11
24	JHABUA	5	10	0.2	0.60	0.38	0.16	100	0
25	KATNI	9	10	0.1	3.30	0.76	0.95	100	0
26	KHANDWA	17	10	0.1	1.00	0.35	0.23	100	0
27	KHARGONE	10	10	0.1	1.90	0.42	0.50	100	0
28	MANDLA	20	10	0.1	1.90	0.48	0.47	100	0
29	MANDSAUR	15	10	0.0	0.90	0.11	0.23	100	0
30	MORENA	4	10	0.2	1.20	0.65	0.42	100	0
31	NARSINGHPUR	3	10	0.2	0.60	0.40	0.16	100	0
32	NEEMUCH	10	10	0.1	0.90	0.37	0.28	100	0
33	PANNA	30	10	0.1	7.60	0.88	1.38	100	0
34	RAISEN	9	10	0.1	1.40	0.48	0.38	100	0
35	RAJGARH	10	10	0.2	0.70	0.34	0.16	100	0
36	RATLAM	15	10	0.1	1.00	0.37	0.27	100	0
37	REWA	21	10	0.1	1.10	0.47	0.29	100	0
38	SAGAR	21	10	0.0	18.9	1.19	3.98	95	5
39	SATNA	19	10	0.1	6.80	0.59	1.48	100	0
40	SEHORE	10	10	0.1	2.00	0.47	0.56	100	0
41	SEONI	16	10	0.2	10.1	0.98	2.36	94	6

42	SHAHDOL	24	10	0.1	2.30	0.43	0.53	100	0
43	SHAJAPUR	8	10	0.0	0.50	0.10	0.18	100	0
44	SHEOPUR	10	10	0.0	7.90	1.73	2.45	100	0
45	SHIVPURI	15	10	0.1	1.90	0.33	0.44	100	0
46	SIDHI	23	10	0.1	19.3	1.14	3.88	96	4
47	SINGRAULI	10	10	0.0	0.70	0.22	0.19	100	0
48	TIKAMGARH	7	10	0.0	1.30	0.27	0.45	100	0
49	UJJAIN	23	10	0.1	78.2	3.87	15.85	96	4
50	UMARIA	8	10	0.0	0.30	0.14	0.09	100	0
51	VIDISHA	10	10	0.0	6.30	1.05	1.78	100	0

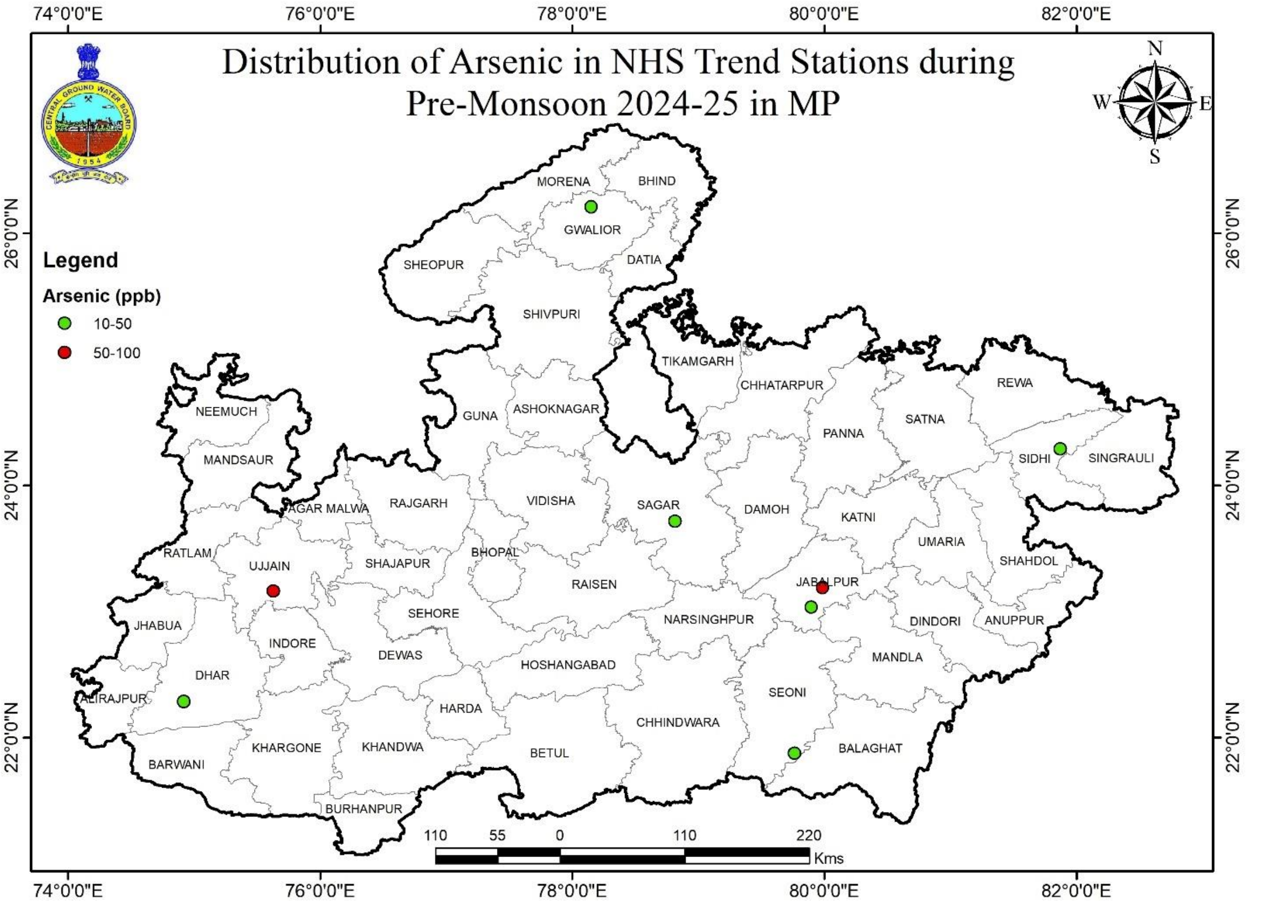


Fig G: Distribution of Arsenic in Madhya Pradesh during Pre-Monsoon 2024-25

Temporal Variation of Arsenic Levels in Groundwater Over the Period 2020–2024

Table 12: Comparative Change in the Number of Locations with Arsenic Levels Exceeding 10 ppb Across Various Districts.

S.No	*District*	2020	2021	2022	2023	2024
1	*AGAR MALWA*	**0**	**0**	**0**	**0**	0
2	*ALIRAJPUR*	**0**	**0**	**0**	**0**	0
3	*ANUPPUR*	**0**	**0**	**0**	**0**	0
4	*ASHOK NAGAR*	**0**	**0**	**0**	**0**	0
5	*BALAGHAT*	**0**	**0**	**0**	**0**	0
6	*BARWANI*	**0**	**0**	**0**	**0**	0
7	*BETUL*	**0**	**0**	**0**	**0**	0
8	*BHIND*	**0**	**0**	**0**	**0**	0
9	*BHOPAL*	**0**	**0**	**0**	**0**	0
10	*BURHANPUR*	**0**	**0**	**0**	**0**	0
11	*CHHATARPUR*	**0**	**0**	**0**	**0**	0
12	*CHHINDWARA*	**0**	**0**	**0**	**0**	0
13	*DAMOH*	**0**	**0**	**0**	**0**	0
14	*DATIA*	**0**	**0**	**0**	**0**	0
15	*DEWAS*	**0**	**0**	**0**	**0**	0

16	DHAR	0	0	0	0	1
17	DINDORI	0	0	0	0	0
18	GUNA	0	0	0	0	0
19	GWALIOR	0	0	0	0	1
20	HARDA	0	0	0	0	0
21	HOSHANGABAD	0	0	0	0	0
22	INDORE	0	0	0	0	0
23	JABALPUR	0	0	0	0	2
24	JHABUA	0	0	0	0	0
25	KATNI	0	0	0	0	0
26	KHANDWA	0	0	0	0	0
27	KHARGONE	0	0	0	0	0
28	MANDLA	0	0	0	0	0
29	MANDSAUR	0	0	0	0	0
30	MORENA	0	0	0	0	0
31	NARSINGHPUR	0	0	0	0	0
32	NEEMUCH	0	0	0	0	0
33	PANNA	0	0	0	0	0
34	RAISEN	0	0	0	0	0
35	RAJGARH	0	0	0	0	0
36	RATLAM	0	0	0	0	0
37	REWA	0	0	0	0	0
38	SAGAR	0	0	0	0	1
39	SATNA	0	0	0	0	0
40	SEHORE	0	0	0	0	0
41	SEONI	0	0	0	0	1
42	SHAHDOL	0	0	0	0	0
43	SHAJAPUR	0	0	0	0	0
44	SHEOPUR	0	0	0	0	0
45	SHIVPURI	0	0	0	0	0
46	SIDHI	0	0	0	0	1
47	SINGRAULI	0	0	0	0	0
48	TIKAMGARH	0	0	0	0	0
49	UJJAIN	0	0	0	0	1
50	UMARIA	0	0	0	0	0
51	VIDISHA	0	0	0	0	0
	Total	**0**	**0**	**0**	**0**	**7**

In 2024, seven locations in Madhya Pradesh were identified with arsenic concentrations exceeding the Bureau of Indian Standards (BIS) permissible limit of 0.01 mg/l (10 ppb) in groundwater samples. The highest arsenic concentration, 78.2 ppb, was recorded at Kharotia village in Ujjain district(*See* **Tables 11, 12 &13; Fig G**).

Table 13: Periodic Variation in Arsenic Suitability Classes in Madhya Pradesh's Groundwater

Parameter	Class	Percentage of Samples					Periodic Variation 2020-24
		2020	2021	2022	2023	2024	
		(n =1033)	(n = 0)	(n = 0)	(n =1064)	(n=614)	
Arsenic	**<10 ppb**	100	0	0	100	98.7	0.01
	>10 ppb	0	0	0	0	1.3	1.92

4.5 IRON

Iron is commonly found in soil and groundwater, existing either as soluble ferrous iron or insoluble ferric iron. Water with ferrous iron is clear and colourless due to its complete dissolution. However, when exposed to air, it turns cloudy as ferrous iron oxidizes to reddish-brown ferric oxide. The iron concentration in natural water is influenced by both physical-chemical and microbiological factors. Groundwater typically gains iron from the weathering of ferruginous minerals in igneous rocks, such as hematite and magnetite, as well as from sulphide ores in sedimentary and metamorphic rocks. According to BIS standards for drinking water, the permissible iron concentration in groundwater is less than 1.0 mg/litre.

Current Status of Iron across Madhya Pradesh: A Yearly Perspective

During the pre-monsoon season of 2024, iron concentrations in the collected groundwater samples ranged from 0 to 17.88 mg/L. Iron levels exceeding the BIS permissible limit of 1 mg/l were identified at 39 locations across the districts of Agar-Malwa, Balaghat, Betul, Burhanpur, Chhatarpur, Chhindwara, Dewas, Gwalior, Jabalpur, Khandwa, Mandsaur, Neemuch, Rajgarh, Ratlam, Sagar, Sehore, Seoni, Shahdol, Sidhi, and Ujjain. Out of 614 samples analyzed, the highest concentration of 17.88 mg/L was observed in Rehpura, Sagar district.

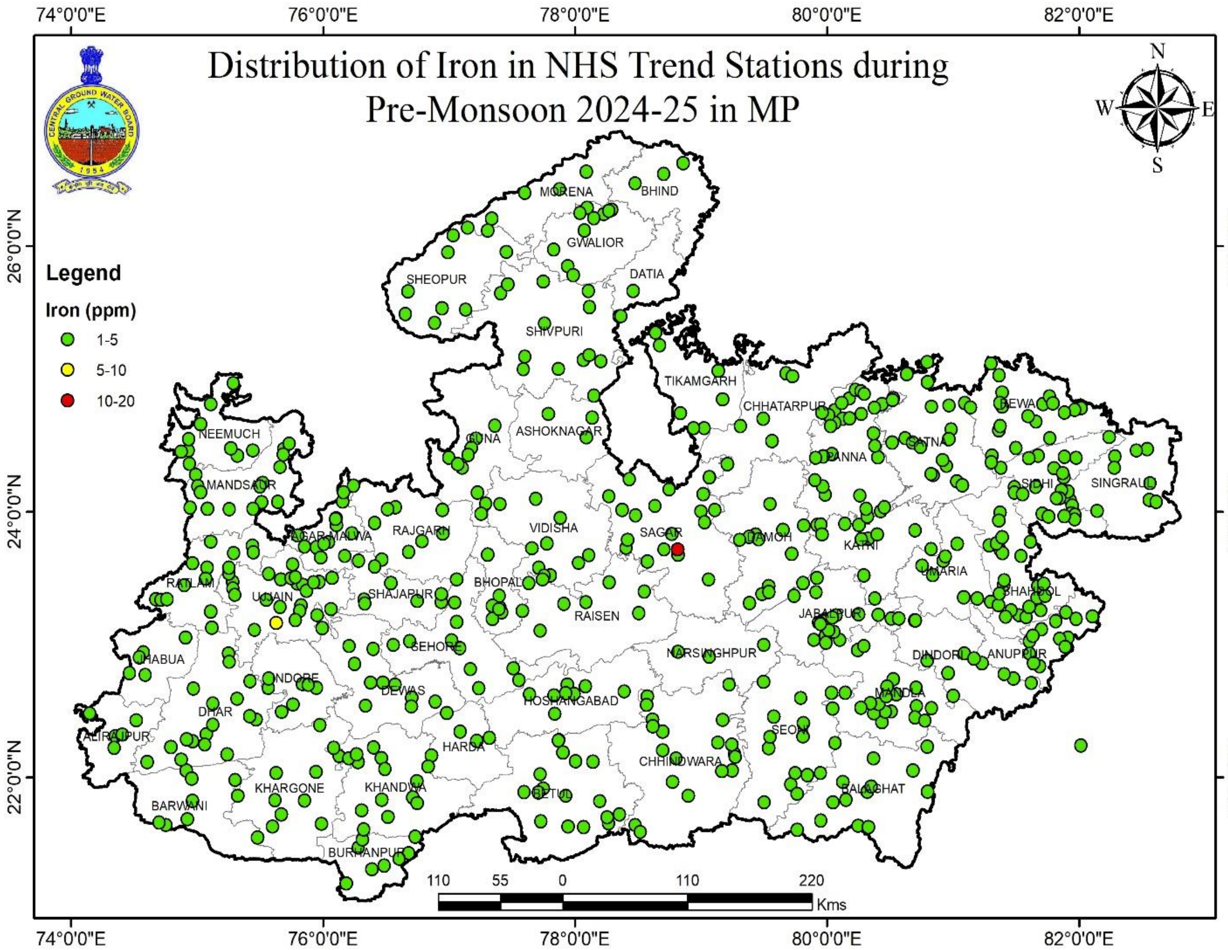


Fig H: Map Depicting Iron Hotspot Locations in Madhya Pradesh during Pre-Monsoon 2024-25

The table below presents the number of samples analysed for each district, along with their minimum, maximum, and average iron values, derived from the NHS 2024 Trend Stations data (Pre-monsoon).

Table 14 : District-Wise Range and Distribution of Iron in Shallow Groundwater of Madhya Pradesh During Pre-Monsoon 2024										
Iron Concentrations(mg/l)										
S. No.	*District*	*Nos of Samples analysed (N=614)*	*Permissible Limit*	*Min.*	*Max.*	*Mean*	*S.D.*	*Percentage of Samples (%)*	
								<1.0	*>1.0*
1	AGAR MALWA	13	1	0.000	2.341	0.193	0.621	77	23
2	ALIRAJPUR	5	1	0.000	0.036	0.007	0.014	100	0
3	ANUPPUR	14	1	0.036	0.472	0.147	0.122	79	21
4	ASHOKNAGAR	3	1	0.000	1.369	0.456	0.645	33	67
5	BALAGHAT	13	1	0.033	2.312	0.315	0.588	92	8
6	BARWANI	7	1	0.000	0.250	0.083	0.084	100	0
7	BETUL	17	1	0.004	1.377	0.310	0.340	100	0
8	BHIND	3	1	0.000	0.000	0.000	0.000	33	67
9	BHOPAL	9	1	0.000	0.103	0.031	0.036	78	22
10	BURHANPUR	8	1	0.023	1.042	0.237	0.312	88	13
11	CHHATARPUR	8	1	0.000	1.062	0.254	0.332	75	25
12	CHHINDWARA	19	1	0.000	2.203	0.446	0.565	100	0
13	DAMOH	12	1	0.000	0.089	0.046	0.032	92	8
14	DATIA	1	1	0.000	0.000	0.000	0.000	100	0
15	DEWAS	11	1	0.004	1.864	0.364	0.659	100	0
16	DHAR	17	1	0.000	0.543	0.163	0.160	94	6
17	DINDORI	13	1	0.070	0.683	0.292	0.181	100	0
18	GUNA	9	1	0.000	0.454	0.091	0.148	89	11
19	GWALIOR	10	1	0.000	1.859	0.286	0.585	70	30
20	HARDA	5	1	0.001	0.085	0.028	0.033	100	0
21	HOSHANGABAD	9	1	0.005	0.825	0.240	0.265	100	0
22	INDORE	8	1	0.017	0.232	0.095	0.085	100	0
23	JABALPUR	18	1	0.016	2.300	0.397	0.566	72	28
24	JHABUA	5	1	0.015	0.119	0.050	0.036	100	0
25	KATNI	9	1	0.000	0.347	0.146	0.102	78	22
26	KHANDWA	17	1	0.000	1.114	0.169	0.275	94	6
27	KHARGONE	10	1	0.000	0.044	0.017	0.015	90	10
28	MANDLA	20	1	0.071	0.993	0.314	0.271	85	15
29	MANDSAUR	15	1	0.028	1.254	0.342	0.359	100	0
30	MORENA	4	1	0.005	0.529	0.155	0.217	75	25
31	NARSINGHPUR	3	1	0.052	0.111	0.079	0.024	100	0
32	NEEMUCH	10	1	0.068	2.529	0.552	0.737	100	0
33	PANNA	30	1	0.018	0.907	0.238	0.234	83	17
34	RAISEN	9	1	0.000	0.217	0.096	0.096	89	11
35	RAJGARH	10	1	0.020	1.707	0.433	0.589	100	0
36	RATLAM	15	1	0.000	2.566	0.729	0.886	87	13
37	REWA	21	1	0.025	1.637	0.201	0.329	86	14
38	SAGAR	21	1	0.000	17.87	1.220	3.792	90	10
39	SATNA	19	1	0.012	0.088	0.043	0.022	95	5
40	SEHORE	10	1	0.025	1.964	0.300	0.562	90	10
41	SEONI	16	1	0.033	1.968	0.341	0.509	94	6
42	SHAHDOL	24	1	0.092	2.362	0.319	0.452	92	8
43	SHAJAPUR	8	1	0.000	0.444	0.138	0.166	100	0
44	SHEOPUR	10	1	0.000	0.854	0.138	0.286	60	40
45	SHIVPURI	15	1	0.000	0.669	0.113	0.174	93	7
46	SIDHI	23	1	0.026	1.803	0.228	0.373	91	9
47	SINGRAULI	10	1	0.031	0.872	0.262	0.243	100	0
48	TIKAMGARH	7	1	0.020	0.224	0.119	0.066	86	14
49	UJJAIN	23	1	0.029	9.144	1.413	2.084	83	17
50	UMARIA	8	1	0.008	0.079	0.050	0.020	100	0
51	VIDISHA	10	1	0.000	0.396	0.078	0.115	100	0.00
	Total	**1064**							

Temporal Variation of Iron Levels in Groundwater over the Period 2020–2024

Table 15: Comparative Change in the Number of Locations with Iron Levels Exceeding 1 mg/l Across Various Districts.

S.No	District	2020	2021	2022	2023	2024
1	AGAR MALWA	0	0	0	0	3
2	ALIRAJPUR	0	0	0	0	0
3	ANUPPUR	0	0	0	0	3
4	ASHOK NAGAR	0	0	0	2	2
5	BALAGHAT	0	0	0	6	1
6	BARWANI	0	0	0	0	0
7	BETUL	0	0	0	0	0
8	BHIND	0	0	0	0	2
9	BHOPAL	0	0	0	0	2
10	BURHANPUR	0	0	0	0	1
11	CHHATARPUR	0	0	0	0	2
12	CHHINDWARA	0	0	0	0	0
13	DAMOH	0	0	0	1	1
14	DATIA	0	0	0	0	0
15	DEWAS	0	0	0	0	0
16	DHAR	0	0	0	0	1
17	DINDORI	0	0	0	0	0
18	GUNA	0	0	0	0	1
19	GWALIOR	0	0	0	1	3
20	HARDA	0	0	0	0	0
21	HOSHANGABAD	0	0	0	0	0
22	INDORE	0	0	0	0	0
23	JABALPUR	0	0	0	0	5
24	JHABUA	0	0	0	0	0
25	KATNI	0	0	0	0	2
26	KHANDWA	0	0	0	1	1
27	KHARGONE	0	0	0	0	1
28	MANDLA	0	0	0	0	3
29	MANDSAUR	0	0	0	0	0
30	MORENA	0	0	0	0	1
31	NARSINGHPUR	0	0	0	0	0
32	NEEMUCH	0	0	0	1	0
33	PANNA	0	0	0	1	5
34	RAISEN	0	0	0	0	1
35	RAJGARH	0	0	0	0	0
36	RATLAM	0	0	0	0	2
37	REWA	0	0	0	0	3
38	SAGAR	0	0	0	3	2
39	SATNA	0	0	0	0	1
40	SEHORE	0	0	0	1	1
41	SEONI	0	0	0	0	1
42	SHAHDOL	0	0	0	0	2
43	SHAJAPUR	0	0	0	1	0
44	SHEOPUR	0	0	0	0	4
45	SHIVPURI	0	0	0	0	1
46	SIDHI	0	0	0	0	2
47	SINGRAULI	0	0	0	0	0
48	TIKAMGARH	0	0	0	2	1
49	UJJAIN	0	0	0	0	4
50	UMARIA	0	0	0	0	0
51	VIDISHA	0	0	0	0	1
	Total	0	0	0	20	66

Note: Iron (Fe) analysis was not conducted on the samples collected in 2020, 2021, and 2022 at the Regional Chemical Laboratory, Bhopal.

Table 16: Periodic Variation in Iron Suitability Classes in Groundwater of Madhya Pradesh							
Parameter	Class	Percentage of Samples					Periodic Variation 2020-24
		2020 (n=0)	2021 (n=0)	2022 (n=0)	2023 (n=1064)	2024 (n=614)	
Iron	***<1 mg/l***	0	0	0	98.44	89.3	0.03
	>1 mg/l	0	0	0	1.56	10.7	0.26

4.6 URANIUM

Uranium occurs naturally in groundwater and surface water. Being naturally occurring uranium in groundwater and surface water poses health risks due to its radioactive properties. Sources include natural deposits, nuclear industry emissions, coal combustion, and phosphate fertilizers. Human exposure occurs mainly through drinking water, food, air, and occupational hazards. Concentrations exceeding 30 ppb, according to BIS standards, can cause damage to internal organs with prolonged intake, necessitating caution in consumption.

Current Status of Uranium across Madhya Pradesh: A Yearly Perspective

In the pre-monsoon period of 2023, uranium concentrations in the samples collected ranged from 0 to 322.6 ppb. Notably, uranium levels surpassing the permissible limit set by the Bureau of Indian Standards (BIS), which is 0.03 mg/l (or 30 ppb), were identified at five locations across various districts: Gwalior, Panna, Shivpuri, Ujjain, and Umaria. This was observed in a total of 614 samples analyzed. Among these, the highest uranium concentration was recorded at Kharotia village in Ujjain district, where it reached 322.6 ppb.

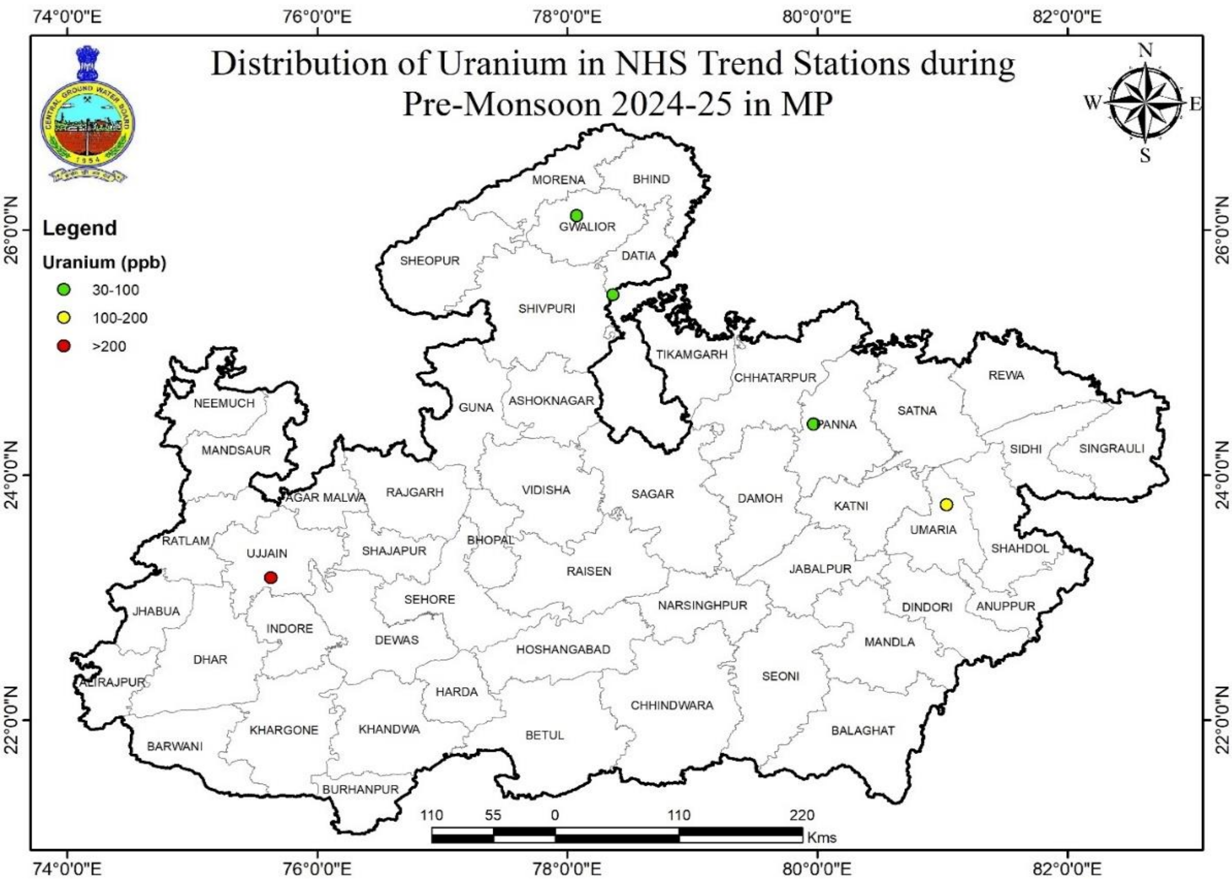


Fig I: Map Showing Location of Uranium Hotspots in MP during Pre-monsoon 2024-25.

The table below presents the number of samples analysed per district, along with their minimum, maximum, and average uranium values, based on NHS 2024 Trend Stations Pre-Monsoon data.

Table 17 : District-Wise Range and Distribution of Uranium in Shallow Groundwater of Madhya Pradesh During Pre-Monsoon 2024

Uranium Concentrations(µg/l)									
Sl.No	***District***	***Nos of samples analysed (N=1064)***	***Permissible Limit***	***Min.***	***Max.***	***Mean***	***S.D.***	***Number of Samples (%)***	
								<10	***>10***
1	AGAR MALWA	13	30	0.0	4.3	1.2	1.3	100	0
2	ALIRAJPUR	5	30	0.1	1.2	0.7	0.4	100	0
3	ANUPPUR	14	30	0.2	2.6	0.9	0.6	100	0
4	ASHOKNAGAR	3	30	0.2	0.8	0.4	0.3	100	0
5	BALAGHAT	13	30	0.0	7.9	1.7	2.3	100	0
6	BARWANI	7	30	0.1	0.3	0.2	0.1	100	0
7	BETUL	17	30	0.0	4.6	0.7	1.4	100	0
8	BHIND	3	30	0.0	15.3	7.5	6.2	100	0
9	BHOPAL	9	30	0.0	3.4	1.3	1.2	100	0
10	BURHANPUR	8	30	0.1	0.5	0.2	0.1	100	0
11	CHHATARPUR	8	30	0.2	18.8	5.2	6.9	100	0
12	CHHINDWARA	19	30	0.0	4.0	1.1	1.0	100	0
13	DAMOH	12	30	0.2	4.4	2.3	1.4	100	0
14	DATIA	1	30	5.7	5.7	5.7	0.0	100	0
15	DEWAS	11	30	0.5	13.7	2.6	3.6	100	0
16	DHAR	17	30	0.0	0.5	0.3	0.2	100	0
17	DINDORI	13	30	0.2	1.0	0.6	0.2	100	0
18	GUNA	9	30	0.0	1.0	0.4	0.4	100	0
19	GWALIOR	10	30	0.4	81.9	16.4	23.4	90	10
20	HARDA	5	30	0.1	0.9	0.5	0.3	100	0
21	HOSHANGABAD	9	30	0.2	9.8	1.9	2.9	100	0
22	INDORE	8	30	0.1	1.0	0.4	0.3	100	0
23	JABALPUR	18	30	0.1	8.5	1.9	2.0	100	0
24	JHABUA	5	30	0.1	0.4	0.2	0.1	100	0
25	KATNI	9	30	0.5	17.9	6.2	6.1	100	0
26	KHANDWA	17	30	0.0	4.6	0.6	1.1	100	0
27	KHARGONE	10	30	0.0	0.6	0.1	0.2	100	0
28	MANDLA	20	30	0.1	2.2	0.7	0.6	100	0
29	MANDSAUR	15	30	0.1	13.1	1.9	3.0	100	0
30	MORENA	4	30	3.7	17.2	10.0	5.7	100	0
31	NARSINGHPUR	3	30	0.1	0.7	0.4	0.2	100	0
32	NEEMUCH	10	30	0.5	17.1	5.6	5.3	100	0
33	PANNA	30	30	0.5	58.4	7.2	10.2	97	3
34	RAISEN	9	30	0.0	2.5	0.7	0.7	100	0
35	RAJGARH	10	30	0.4	2.8	1.1	0.7	100	0
36	RATLAM	15	30	0.3	2.4	1.2	0.6	100	0
37	REWA	21	30	0.3	9.7	2.9	2.3	100	0
38	SAGAR	21	30	0.3	5.8	2.0	1.4	100	0
39	SATNA	19	30	0.1	2.2	0.9	0.7	100	0
40	SEHORE	10	30	0.2	2.1	1.2	0.7	100	0
41	SEONI	16	30	0.2	12.1	2.3	3.5	100	0
42	SHAHDOL	24	30	0.2	14.3	2.6	3.3	100	0
43	SHAJAPUR	8	30	0.0	3.6	1.4	1.3	100	0
44	SHEOPUR	10	30	0.0	5.3	1.6	1.8	100	0
45	SHIVPURI	15	30	0.3	30.2	6.0	8.6	93	7
46	SIDHI	23	30	0.2	5.7	1.6	1.6	100	0
47	SINGRAULI	10	30	0.4	3.4	1.3	0.9	100	0
48	TIKAMGARH	7	30	1.9	10.4	4.8	3.1	100	0
49	UJJAIN	23	30	0.4	322.6	16.0	65.4	96	4
50	UMARIA	8	30	0.0	170.0	22.4	55.8	88	13
51	VIDISHA	10	30	0.1	4.6	1.3	1.4	100	0

Temporal Variation of Uranium in Groundwater over the Period 2020–2024

Table 18: **Comparative Change in the Number of Locations with Uranium Levels Exceeding 30 ppb Across Various Districts**

S.No	District	2020	2021	2022	2023	2024
1	AGAR MALWA					
2	ALIRAJPUR			1		
3	ANUPPUR					
4	ASHOK NAGAR					
5	BALAGHAT		1			
6	BARWANI					
7	BETUL					
8	BHIND		1	1		
9	BHOPAL					
10	BURHANPUR					
11	CHHATARPUR		1		1	
12	CHHINDWARA					
13	DAMOH					
14	DATIA	1	5	1	1	
15	DEWAS					
16	DHAR					
17	DINDORI					
18	GUNA					
19	GWALIOR	1	3	3	3	1
20	HARDA					
21	HOSHANGABAD					
22	INDORE					
23	JABALPUR					
24	JHABUA					
25	KATNI					
26	KHANDWA					
27	KHARGONE					
28	MANDLA			1		
29	MANDSAUR					
30	MORENA					
31	NARSINGHPUR					
32	NEEMUCH					
33	PANNA					1
34	RAISEN			1		
35	RAJGARH					
36	RATLAM					
37	REWA					
38	SAGAR		1			
39	SATNA					
40	SEHORE					
41	SEONI					
42	SHAHDOL			1		
43	SHAJAPUR					
44	SHEOPUR					
45	SHIVPURI	1	3	2		1
46	SIDHI					
47	SINGRAULI					
48	TIKAMGARH					
49	UJJAIN					1
50	UMARIA					1
51	VIDISHA					
	Total	3	15	11	5	5

It has been noted that the number of districts experiencing elevated uranium levels has shown a modest increase, rising from three districts in 2020 to five districts in 2024.

Table 19: Periodic Variation in Suitability Classes of Uranium in Groundwater of MP.							
Parameter	**Class**	**Percentage of Samples**					**Periodic Variation 2020-24**
		2020 (n=1037)	**2021 (n=1142)**	**2022 (n=1136)**	**2023 (n=1064)**	**2024 (n=614)**	
Uranium	***<30 ppb***	99.71	98.69	99.03	99.46	99.2	**-0.41**
	>30 ppb	0.29	1.31	0.97	0.54	0.8	**0.41**

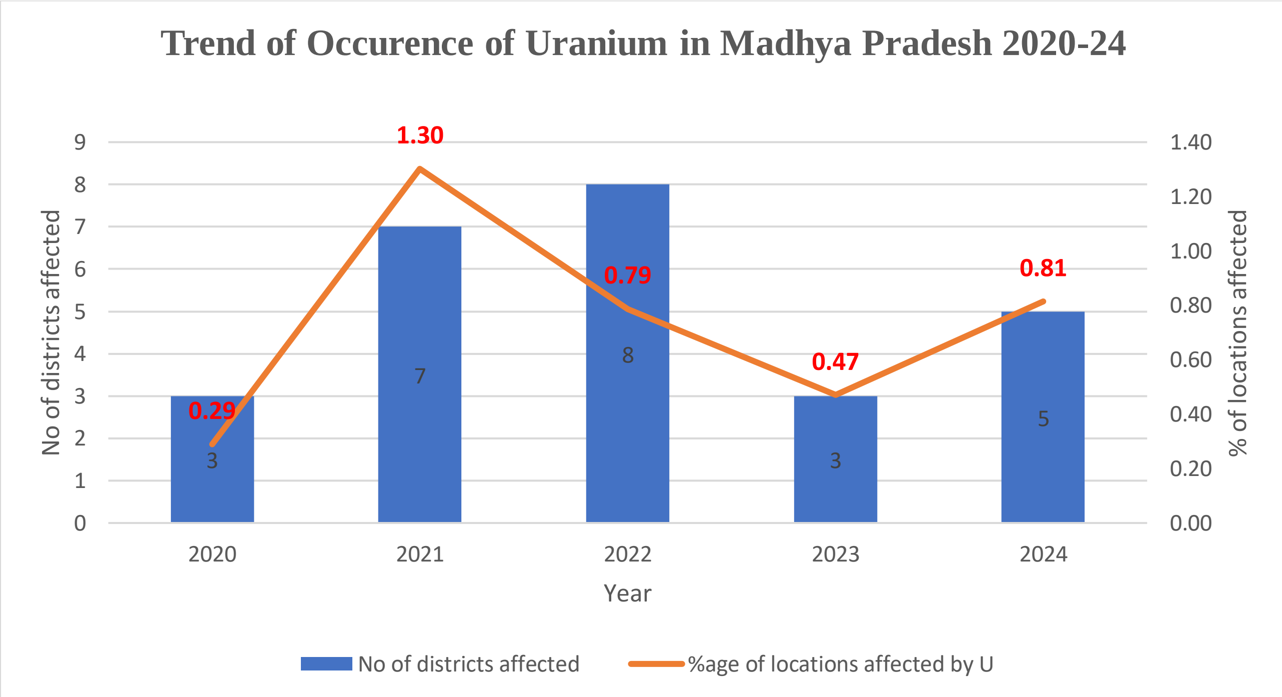


Chart G: Trend of Occurrence of Uranium in Madhya Pradesh from 2020-2024.

4.7 Other Major Findings:

- The pH levels of all analyzed samples ranged from 6.62 to 8.82, with all samples falling within the BIS permissible range, except for those from four locations.
- For the pre-monsoon 2024 Trend stations samples, chloride levels varied from 5 to 844 mg/l, and no samples exceeded the BIS permissible limit of 1000 mg/l.
- Calcium levels in the pre-monsoon 2024 Trend stations samples ranged from 8 to 318 mg/l, with 97.2% of the samples having calcium levels below the BIS permissible limit of 200 mg/l.
- Magnesium concentrations ranged from 2 to 153 mg/l. Only three locations out of 614 samples analyzed had magnesium levels exceeding the BIS permissible limit of 100 mg/l.
- Sodium levels ranged from 7 to 419 mg/l. Sodium concentrations above the WHO permissible limit of 200 mg/l were observed at 21 locations out of 614 samples analyzed. The highest sodium concentration was found at Methwada, Indore (419 mg/l).

- Potassium levels ranged from 0.1 to 189.5 mg/l. Potassium concentrations exceeding the WHO permissible limit of 10 mg/l were detected in 80 locations out of 614 samples analyzed. The highest potassium concentration was recorded at Patwara, Satna (189.5 mg/l).
- Hardness levels exceeding the BIS permissible limit of 600 mg/l were observed at 50 locations out of 614 samples analyzed, indicating very hard water at these locations. The highest hardness was recorded in Gwalior Urban (1093 mg/l).
- Manganese levels exceeding the BIS permissible limit of 0.3 mg/l were found at 30 locations out of 614 samples analyzed. The highest manganese concentration was found at Banjari, Chhindwara (1.57 mg/l).
- Lead concentrations above the BIS permissible limit of 0.01 mg/l were observed at 35 locations out of 614 samples analyzed. The highest lead concentration was found at Kharotia village, Ujjain (0.347 mg/l).
- No samples collected during the pre-monsoon 2023-24 season had copper or zinc levels exceeding the BIS permissible values.

5. Water Quality Scenario in Special Purpose Monitoring Stations

5.1 Arsenic

Arsenic, a naturally occurring metalloid element, exists in three primary forms: inorganic arsenic, organic arsenic, and arsine gas. This element and its compounds are found widely in the environment, including rocks (particularly igneous and sedimentary rocks rich in sulfide ores), soil, water, air, and biological tissues in plants and animals. The release of arsenic into groundwater is influenced by its chemical form, the geochemical conditions of the aquifer, and various biogeochemical processes.

In aquatic ecosystems, inorganic arsenic is primarily derived from arsenic-bearing minerals such as arsenic trioxide (As_2O_3), orpiment (As_2S_3), arsenopyrite (AsFeS), and realgar (As_4S_4), which are the most prevalent sources. Additionally, human activities such as mining, industrial processes, use in animal feed, wood preservation, and pesticide application significantly contribute to the release of arsenic into the environment.

Arsenic contamination in drinking water is particularly concerning due to its toxicity at even low concentrations and its classification as a known carcinogen. Recognizing the health risks, the Bureau of Indian Standards (BIS) revised the permissible limit for arsenic in public water supplies in 2012, reducing it from 50 µg/L to 10 µg/L. This stricter standard reflects a stronger commitment to public health and safety, aligning India with international guidelines to mitigate the adverse health impacts associated with arsenic exposure.

As part of the Special Purpose Monitoring program conducted in Madhya Pradesh, a total of 544 groundwater samples were collected for the analysis of trace metals, including arsenic. The analyses were carried out using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Central Ground Water Board (CGWB), North Eastern Region (NER), Guwahati.

The results revealed that arsenic concentrations exceeding the safe limit of 10 parts per billion (ppb) were detected at six locations across Madhya Pradesh (*See* **Table 20**). Among these, the highest arsenic concentration was recorded at Takiya ka Pura in Gwalior, with a level of 112.9 ppb. This finding underscores the need for targeted groundwater quality monitoring and mitigation measures in the affected areas to address potential health risks associated with arsenic contamination.

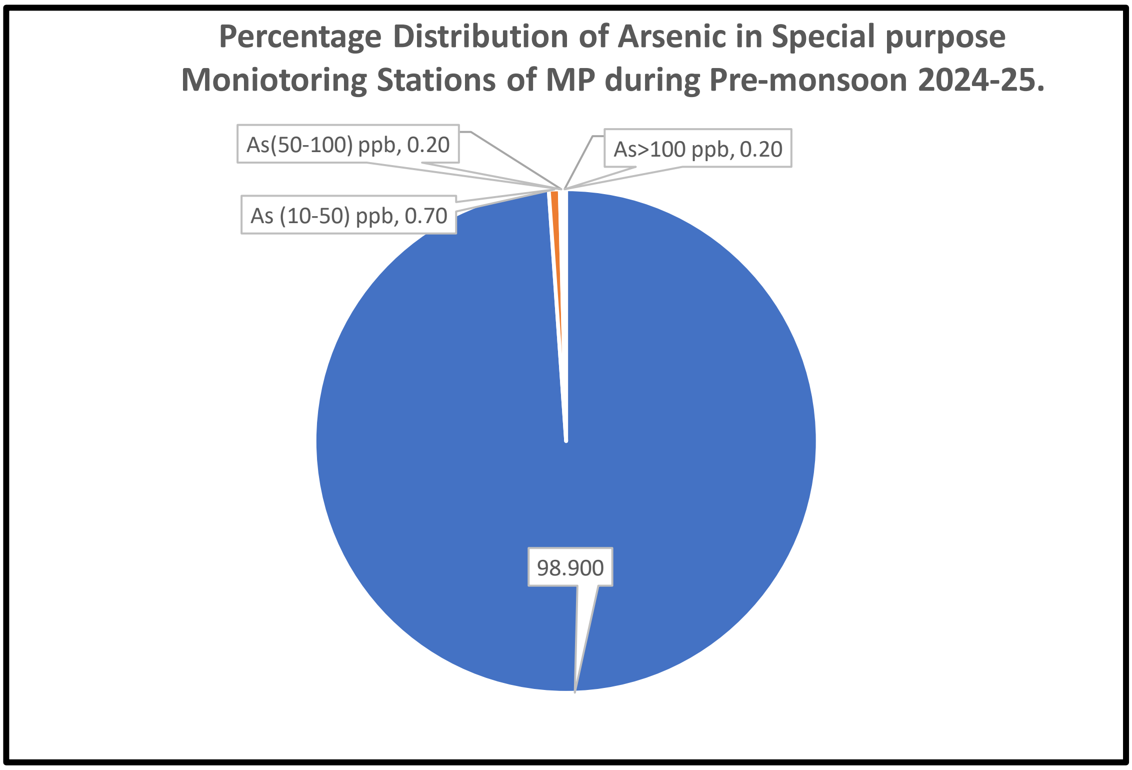


Chart H: Percentage Distribution of Arsenic in Madhya Pradesh During Pre-Monsoon 2024-25 (Special Purpose Monitoring Samples).

As depicted in the chart above, the majority of the analysed samples—538 out of a total of 544, accounting for 98.9%—had arsenic concentrations within the permissible limit of 10 parts per billion (ppb) as specified by the Bureau of Indian Standards (BIS). Elevated arsenic levels exceeding the BIS guideline were identified in only 1.1% of the samples collected from the Special Purpose Monitoring Stations across Madhya Pradesh during the pre-monsoon period of 2024-25.
The specific locations where arsenic concentrations were found to exceed 10 ppb are detailed below for further review and targeted intervention.

Table 20: Locations in Madhya Pradesh with Arsenic Levels Exceeding 10 ppb (Special Purpose Monitoring, Pre-Monsoon 2024-25)

Sl. No.	District	Block	Location	Longitude	Latitude	Source	As (ppb)
1	Gwalior	Ghatigaon	Takiya Ka Pura	77.8804	26.0644	HP	112.9
2	Gwalior	Gwalior	Mounch	78.0851	26.04986	BW	62.9
3	Singrauli	Deosar	Karda	82.0392	24.2415	DW	42.9
4	Gwalior	Gwalior	Mounch	78.0851	26.05126	BW	40.8
5	Gwalior	Ghatigaon	Jhakodha	77.8394	26.06194	BW	30.9
6	Damoh	Pathariya	Rajwas	79.2057	23.908	BW	15.6

The map below illustrates the spatial distribution of arsenic concentrations across the Special Purpose Monitoring Stations in Madhya Pradesh during the pre-monsoon period of 2024-25. It provides a visual representation of the arsenic levels detected at various monitoring locations, highlighting areas of concern where concentrations may exceed permissible limits. This distribution map serves as a valuable tool for identifying regions requiring focused attention and potential remedial measures to address arsenic contamination in groundwater resources.

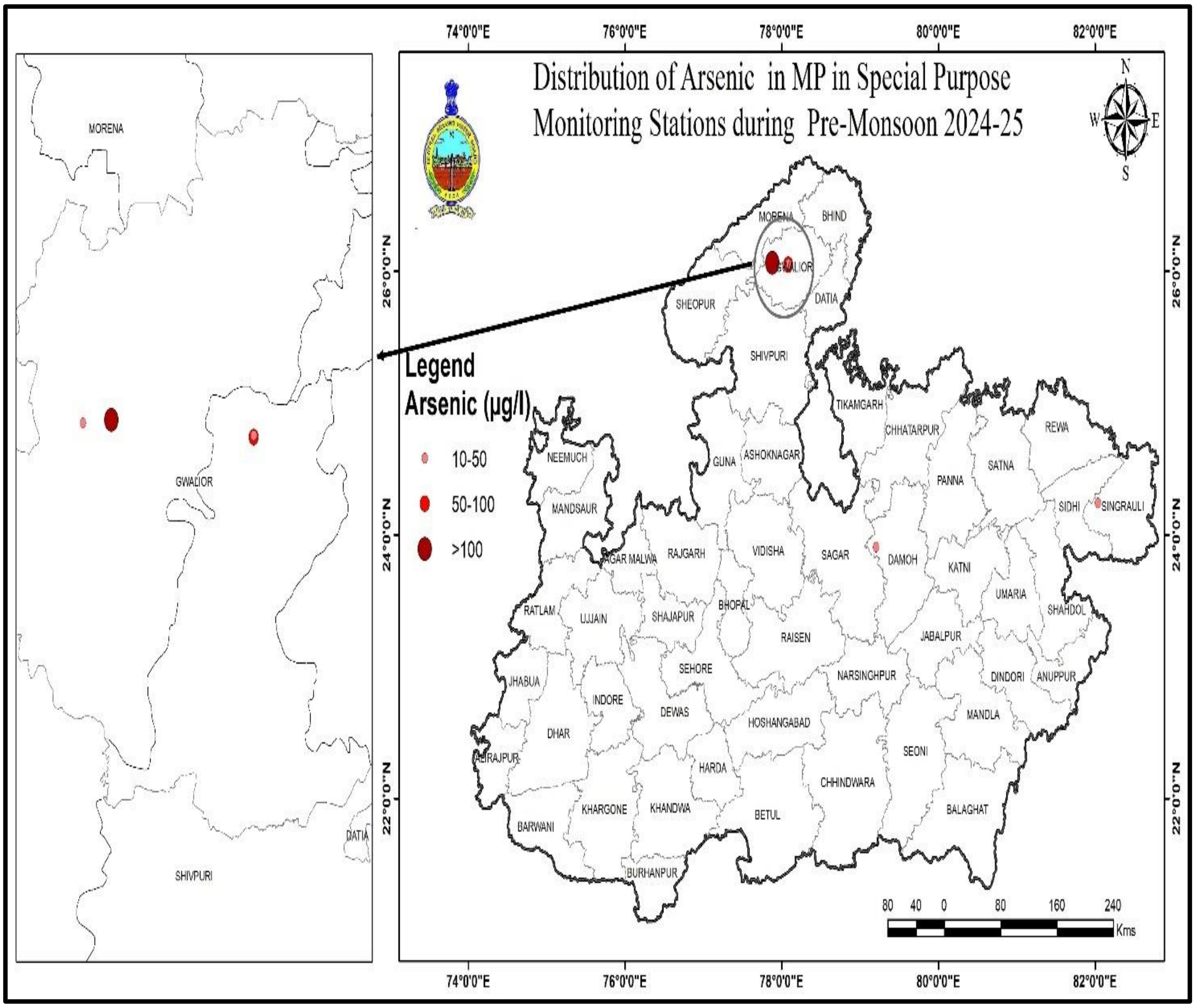


Fig J: Map Showing Distribution of Arsenic in Special purpose Monitoring Stations of MP during Pre-monsoon 2024-25.

5.2 Lead

Lead (Latin: plumbum) is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. Lead is used in building construction, lead-acid batteries, bullets and shots, weights, as part of solders, fusible alloys, and as a radiation shield. Lead is most likely transported in ground water by mobile *particulate matter* **(McDowell- Boyerand others, 1986; Wells et. al. 1989).** Otherwise movement of lead into groundwater is unlikely unless the water is acidic. Lead is deposited on the land surface by atmospheric deposition (industrial sources of lead), infiltrates through soils attached to colloids in soil moisture films, including iron (Fe)-hydroxides and large organic molecules such as humic-material **(Ereland Patterson, 1994). Erel et. al. (1990)** estimated that up to15 percent of the industrial lead deposited from atmospheric deposition is incorporated in water that infiltrates through soils to ground water.

Lead can cause a variety of adverse health effects when people are exposed to it at elevated levels. Children under the age of 6, pregnant women, and nursing mothers are considered to be most at risk. Water is rarely an important source of lead exposure except where lead pipes, for instance in old buildings, are common.The BIS has set the maximum permissible limit for Lead as 10µg/l.

During the Special Purpose Monitoring conducted in Madhya Pradesh during the pre-monsoon period of 2024-25, elevated lead (Pb) concentrations exceeding 10 parts per billion (ppb) were detected in 95 out of the 544 groundwater samples analyzed (refer to Annexure 5).

The highest lead concentration was recorded in Daroli (New) village, Damoh, with a remarkably high level of 4,068.5 ppb. Notably elevated concentrations were also observed in Nohta village, Damoh (1,355.6 ppb) and Luhari, Damoh (948.4 ppb), indicating localized areas of significant contamination. The observed range of lead concentrations across the state is summarized in the table below, providing a comprehensive overview of lead levels detected during the monitoring program.

Table 21: Range of Lead in MP during Pre-Monsoon 24-25 (Special Purpose Monitoring Samples)

Range of Lead(ppb)	No. of Samples	% of Samples
< 10 ppb	449	82.5
10-100 ppb	50	9.2
100-500 ppb	42	7.7
500-1000 ppb	1	0.2
1000-2000 ppb	1	0.2
2000-5000 ppb	1	0.2

Map Showing the Distribution of Lead in Special Purpose Monitoring Stations in Madhya Pradesh During Pre-Monsoon 2024-25

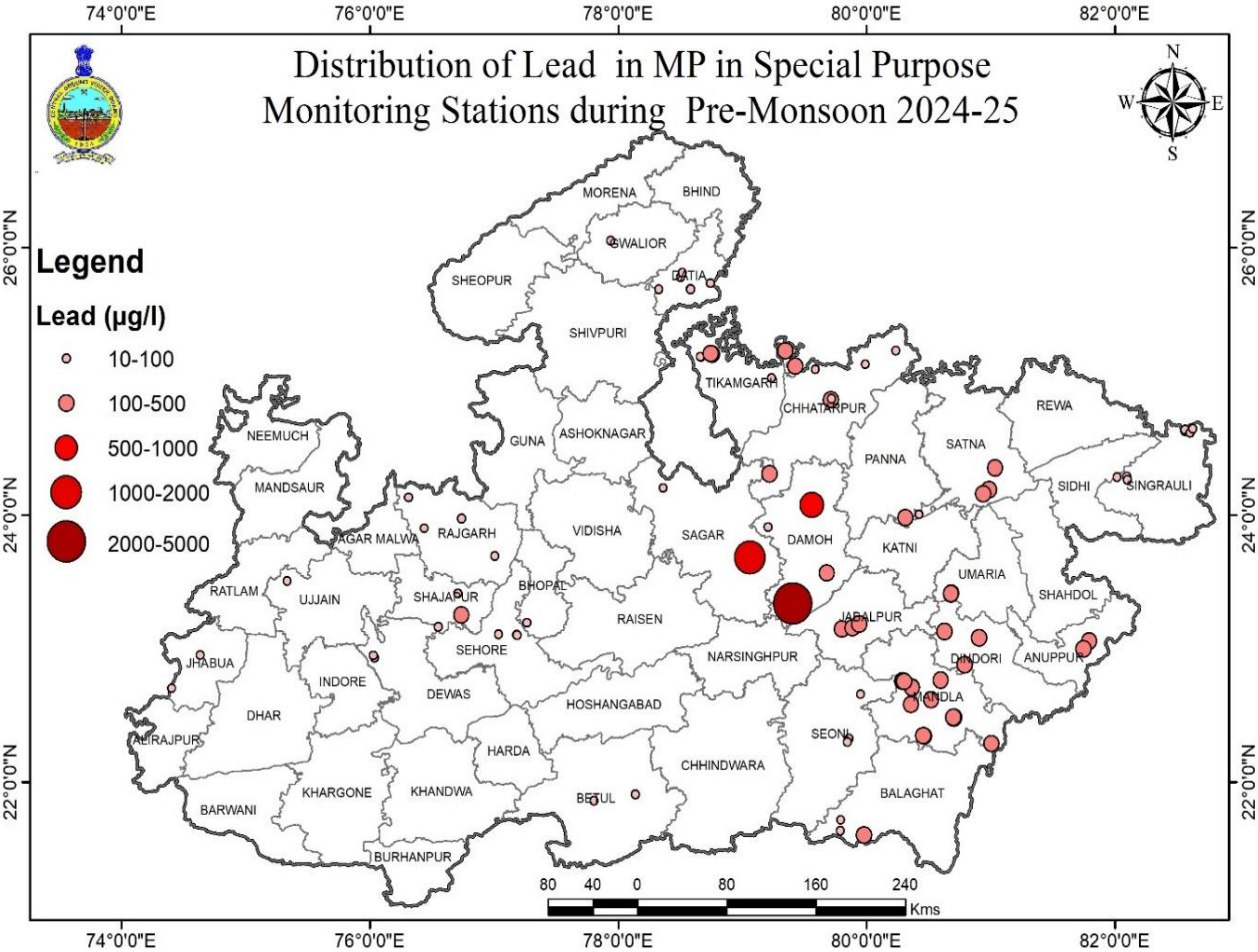


Fig K: Map Showing Distribution of Lead in Special purpose Monitoring Stations of MP during Pre-monsoon 2024-25.

5.3 Iron

Iron is a common constituent in soils and groundwater. Iron is reactive and readily reflects changes in surrounding Eh/pH conditions. In groundwater systems, iron occurs mainly in two forms :either soluble ferrous iron or insoluble ferric iron .Water containing ferrous iron is clear and colourless because the iron is completely dissolved .Although present in drinking water, iron is seldom found at concentrations greater than 10 milligrams per litre, however, as little as 0.3 mg/l can cause water to turn a reddish-brown colour [Ferric-Hydroxide; $Fe(OH)_3$]. According to BIS, the maximum desirable allowable concentration for iron in drinking water is 1.0 mg/l with no relaxation.

As part of the Special Purpose Monitoring conducted in Madhya Pradesh during the pre-monsoon period of 2024-25, iron (Fe) concentrations exceeding the permissible limit of 1 mg/L were detected in 160 out of the 544 groundwater samples analyzed (*See* **Annexure 6**).

The highest iron concentration was recorded in Jowa, Satna, at an extraordinary level of 76.06 mg/L. Additionally, significantly elevated iron levels were observed at various locations within the districts of Mandla, Anuppur, Dindori, Jabalpur, and Umaria. These findings point to potential localized sources of iron contamination that may require further investigation and targeted management strategies.The range of iron concentrations across Madhya Pradesh is summarized in the table below, providing a detailed overview of the extent and distribution of iron contamination identified during the monitoring program.

Table 22: Range of Iron in MP during Pre-Monsoon-24-25 (Special Purpose Monitoring Samples)

Range of Iron	No. of Samples	% of Samples
Fe <1.0 mg/L	384	70.6
Fe (1-10) mg/L	106	19.5
Fe (10-50) mg/L	33	6.1
Fe(50-100) mg/L	21	3.9

The distribution of Iron in SPM stations in MP during Pre-Monsoon 2024-25 is depicted in the Map below:

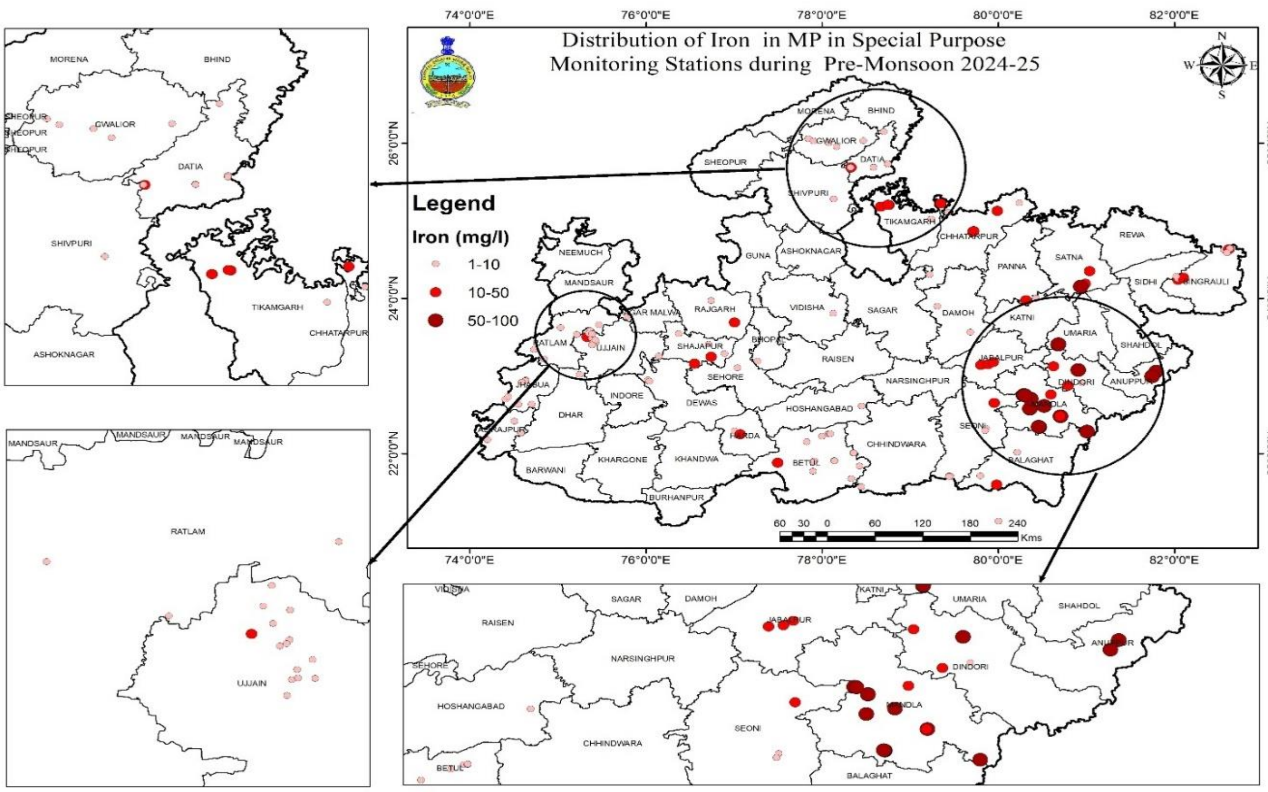


Fig L: Map Showing Distribution of Iron in Special purpose Monitoring Stations of MP during Pre-monsoon 2024-25.

5.4 Manganese

Manganese is an essential trace element for human health. The daily nutritional requirement is 30–50 µg/kg)ppb(of body weight)WHO, 1993(. At excessive concentrations, manganese can be detrimental to health. Evidence from occupational exposure indicates that manganese can affect neurological function. Miners and welders exposed through airborne contamination for long periods have developed neurological disorders such as Parkinson's disease)Takeda, 2003(. Some links have been made between exposure to manganese and a form of motor neuron disease found in the Pacific region, known as Guamian Amyotrophic Lateral Sclerosis)Foster, 1992(. Manganese occurs in several oxidation states, from –III to VII, but usually in the forms II or IV in the environment. The BIS has set health-based desirable and permissible guideline values for manganese in drinking water as 0.1 mg/l and 0.3 mg/l respectively to ensure protection against manganese toxicity.

During the Special Purpose Monitoring conducted in Madhya Pradesh during the pre-monsoon period of 2024-25, manganese (Mn) concentrations exceeding the permissible limit of 0.3 mg/L were detected at 20 locations out of the 544 groundwater samples analyzed (refer to Table 23).

The highest manganese concentration was recorded in Kurri, Chhatarpur, at a significantly elevated level of 8.27 mg/L. This observation highlights localized areas with unusually high manganese levels, necessitating further investigation into potential sources of contamination and their impact on groundwater quality.

Table 23: Locations with Mn > 0.3 mg/L in Madhya Pradesh (Special purpose Monitoring, 2024-25, Pre-Monsoon)

SL. No	District	Block	Location	Longitude	Latitude	Source	Mn (mg/l)
1	Chhatarpur	Chhatarpur	Kurri 2	79.713	24.86	BW	8.275
2	Seoni	Kurai	Litrita	79.4664	21.7047	HP	2.24
3	Chhatarpur	Chhatarpur	Kurri	79.7163	24.865	BW	1.71
4	Seoni	Keolari	Pandiachhapara	80.0004	21.1272	DW	1.439
5	Dewas	Dewas	Industrial area (Jonson Tiles)	76.0344	22.936	TW	1.159
6	Chhatarpur	Nowgaon	Kukrel	79.3458	25.226	DW	0.833
7	Chhatarpur	Buxwaha	Gadhoi	79.2197	24.308	DW	0.794
8	Ujjain	Nagda	Geedgarh	75.3858	23.4927	Chambal River	0.653
9	Singrauli	Deosar	Kundwar	82.0953	24.2848	DW	0.626
10	Ujjain	Nagda	Divel	75.3423	23.5243	DW	0.513
11	Alirajpur	Kathiwada	Panala	74.3274	22.4066	BW	0.492
12	Betul	Ghoradongri	Jholi No-1(I)	77.0726	22.2498	HP	0.435
13	Ujjain	Nagda	Juna Nagada	75.4046	23.4757	Chambal River	0.423
14	Satna	Ramnagar	Jowa	80.9372	24.156	DW	0.42
15	Anuppur	Pushprajgarh	Padri Key Well 2	81.7456	22.995	DW	0.401
16	Ujjain	Nagda	Atalavada	75.3554	23.5239	Chambal River	0.375
17	Damoh	Jabera	Bichiya	79.6814	23.565	BW	0.343
18	Betul	Amla	Bordehi-2	78.3527	22.0064	HP	0.326
19	Anuppur	Jaithari	Murra Tola	81.793	23.056	DW	0.314
20	Dewas	Dewas	Industrial area(Madhumilan Square)	76.0264	22.946	DW	0.309

The percentage distribution of Manganese concentration observed in MP is illustrated in chart below:

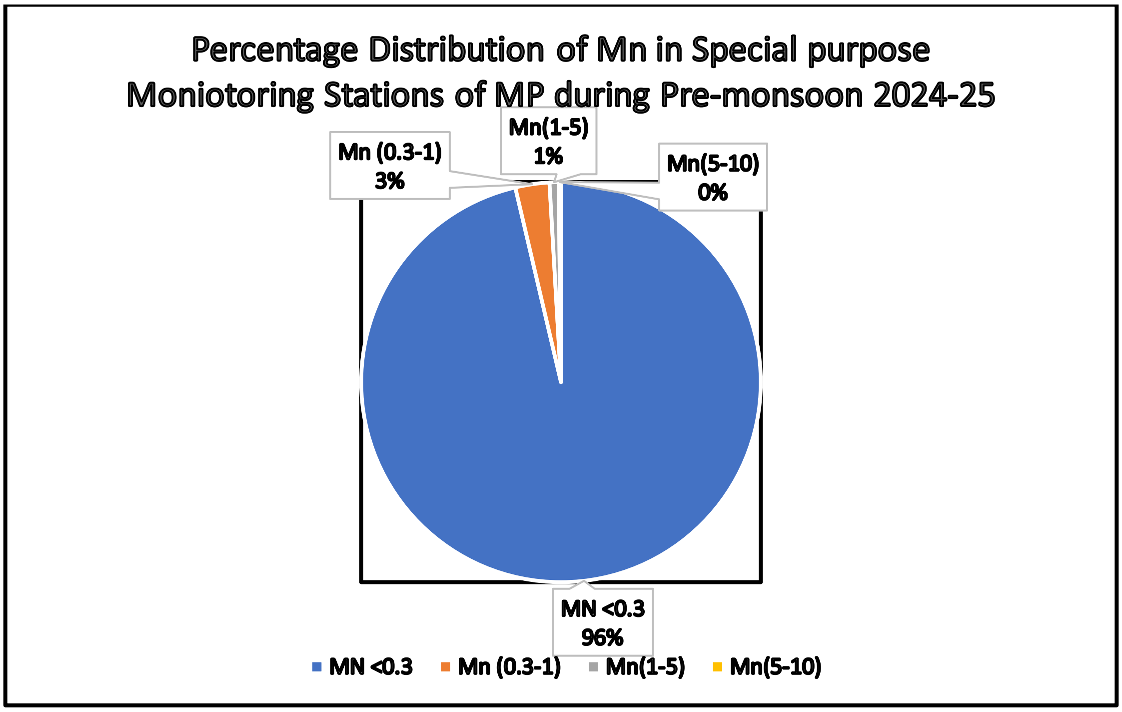


Chart I: Percent Distribution of Mn in MP during Pre-Monsoon 24-25 (Special Purpose Monitoring Samples)

The map below illustrates the distribution of manganese (Mn) in Madhya Pradesh at SPM stations during the pre-monsoon period of 2024-25.

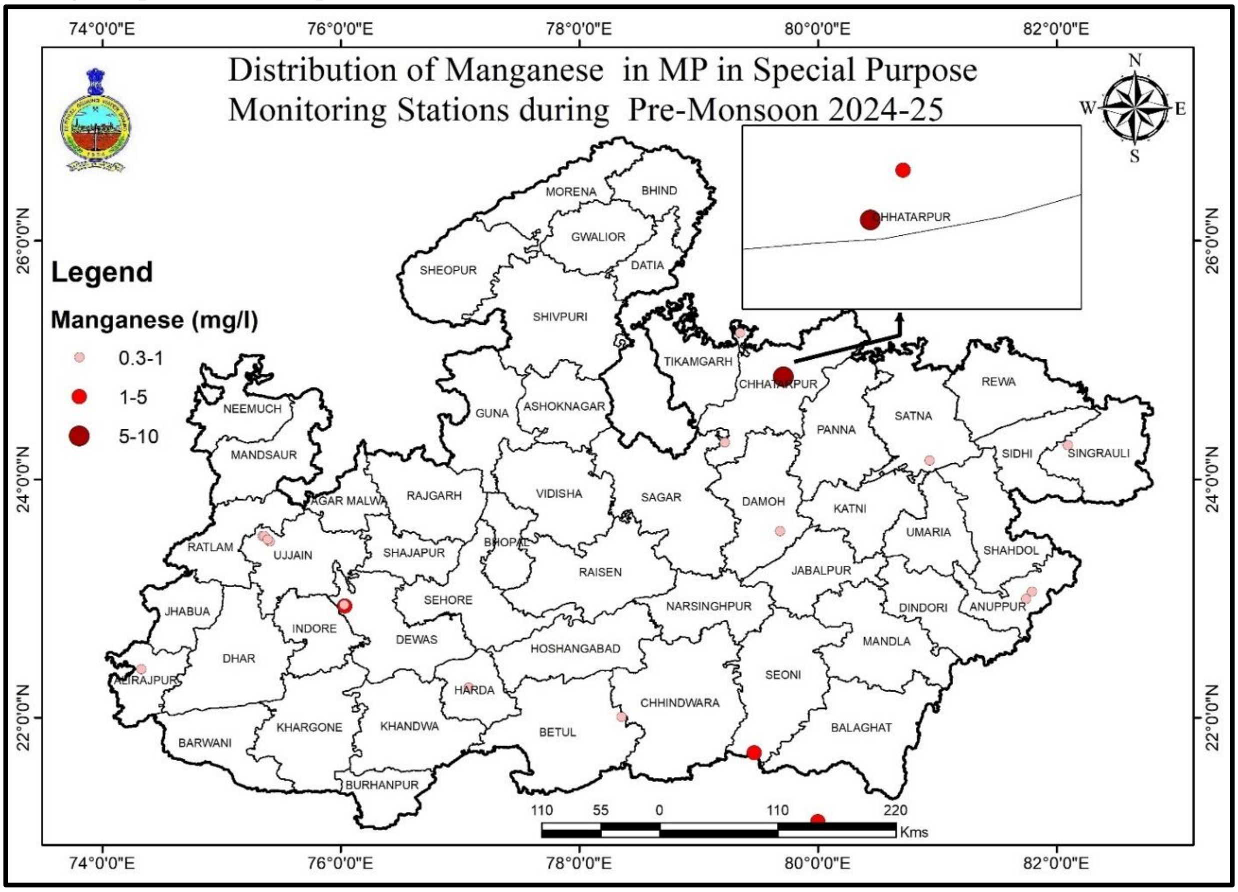


Fig M: Map Showing Distribution of Manganese in Special purpose Monitoring Stations of MP during Pre-monsoon 2024-25.

5.5 Uranium

The natural isotopic composition Uranium of consists of three isotopes: ^{238}U (99.28%), ^{235}U (0.71%) and ^{234}U, all of them are radioactive. There are only three known primary uranium ore minerals {uraninite (UO_2), pitchblende (U_3O_8) and davidite ((Fe, Ce, U)2 (Ti, Fe, V, Cr)5O12)}. Uranium is disseminated throughout the crust of the earth in trace quantities in various rock types. Its average concentration in the Earth's crust is 2.8 µg/g **(USGS,1997)**. The levels of uranium in natural igneous rocks and sedimentary rocks may vary from 0.5 to 4.7 µg/gm and in carbonate rocks, the average level is 2.0 µg/gm **(CGWB, 2014).** Uranium can be found in minute quantities in igneous (granites, syenites), metamorphic, or sedimentary rocks, soils, and in waters including terrestrial and ocean waters **(Sasaki et al., 2016)**. The occurrence of higher Uranium in ground water is reported to be more in sedimentary formation followed by Granites. Generally siliceous igneous rocks contain higher Uranium which increases further with the silica content. Sedimentary rocks like black shales, phosphate rocks and coal also contain very high Uranium.

In addition to being toxic heavy metal, it is also a radioactive element and can cause several adverse health effects ranging from renal failure, diminished bone growth, and damage to the DNA when consumed in high quantities **(Brugge et al., 2005)**. BIS has recommended 0.03 mg/l as acceptable limit of 'U' to be implemented with further No-relaxation. The drinking water sources having above 0.03 mg/l uranium shall have to be rejected.

During the Special Purpose Monitoring (SPM) conducted in Madhya Pradesh during the pre-monsoon period of 2024-25, it was observed that uranium (U) concentrations exceeded 30 ppb at 104 locations out of the 544 samples analysed (*See* **Annexure 7**). The highest uranium concentration, recorded at Mounch in Gwalior district, reached 2554 ppb.

In addition to Mounch, significantly elevated uranium concentrations were detected at several other locations within Gwalior district as well as in the districts of Datia, Seoni, and Betul, among others. These findings indicate localized areas of concern where uranium levels are considerably higher than the threshold.

The observed range of uranium concentrations across Madhya Pradesh is summarized in the table below for further reference and analysis.

Table 24: Uranium Concentration Range in Madhya Pradesh During Pre-Monsoon 2024-25 (Special Purpose Monitoring)

Range of Uranium (ppb)	No. of Samples	% of Samples
U<30	440	80.9
U (30-100)	68	12.5
U (100-500)	26	4.8
U (500-1000)	5	0.9

The map below illustrates the distribution of uranium at SPM stations in Madhya Pradesh during the pre-monsoon period of 2024-25.

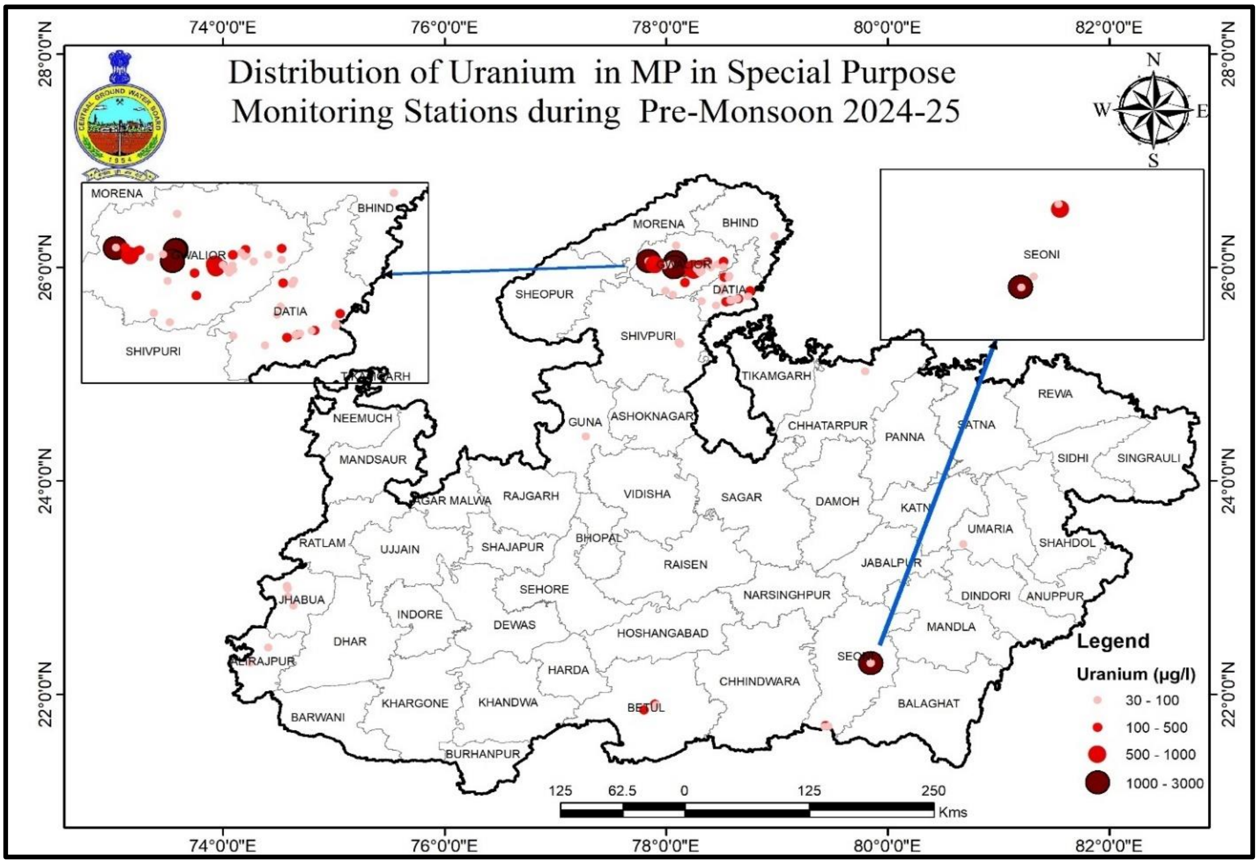


Fig N: Map Showing Distribution of Uranium in Special purpose Monitoring Stations of MP during Pre-monsoon 2024-25.

5.6 Salinity, F, Hardness and Nitrate

The samples collected for Special Purpose Monitoring (SPM) were analyzed for basic parameters. The analysis revealed that the primary contaminants included high salinity, fluoride, nitrate, and total hardness. The range of electrical conductivity (EC), nitrate, fluoride (F), and total hardness (TH) observed at SPM stations in Madhya Pradesh during the pre-monsoon period of 2024-25 is presented in the chart below.

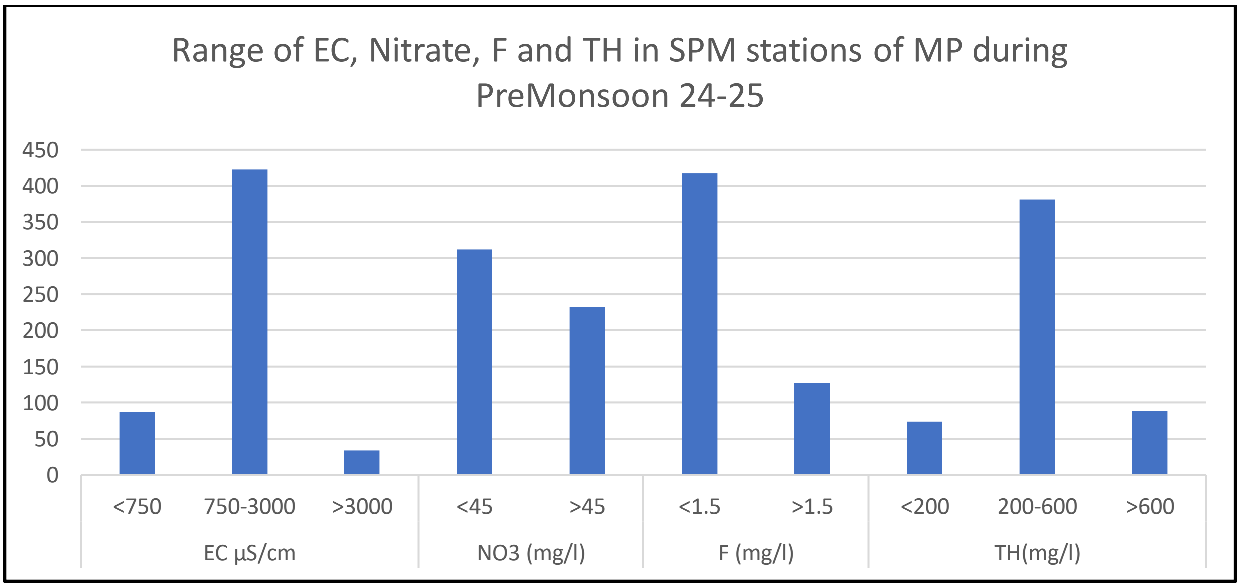


Chart J: Range of EC, Nitrate, Fluoride, and Total Hardness in Madhya Pradesh During Pre-Monsoon 2024-25 (Special Purpose Monitoring Samples).

The map below illustrates the distribution of EC, Nitrate, Fluoride, and Total Hardness at SPM stations in Madhya Pradesh during the pre-monsoon period of 2024-25.

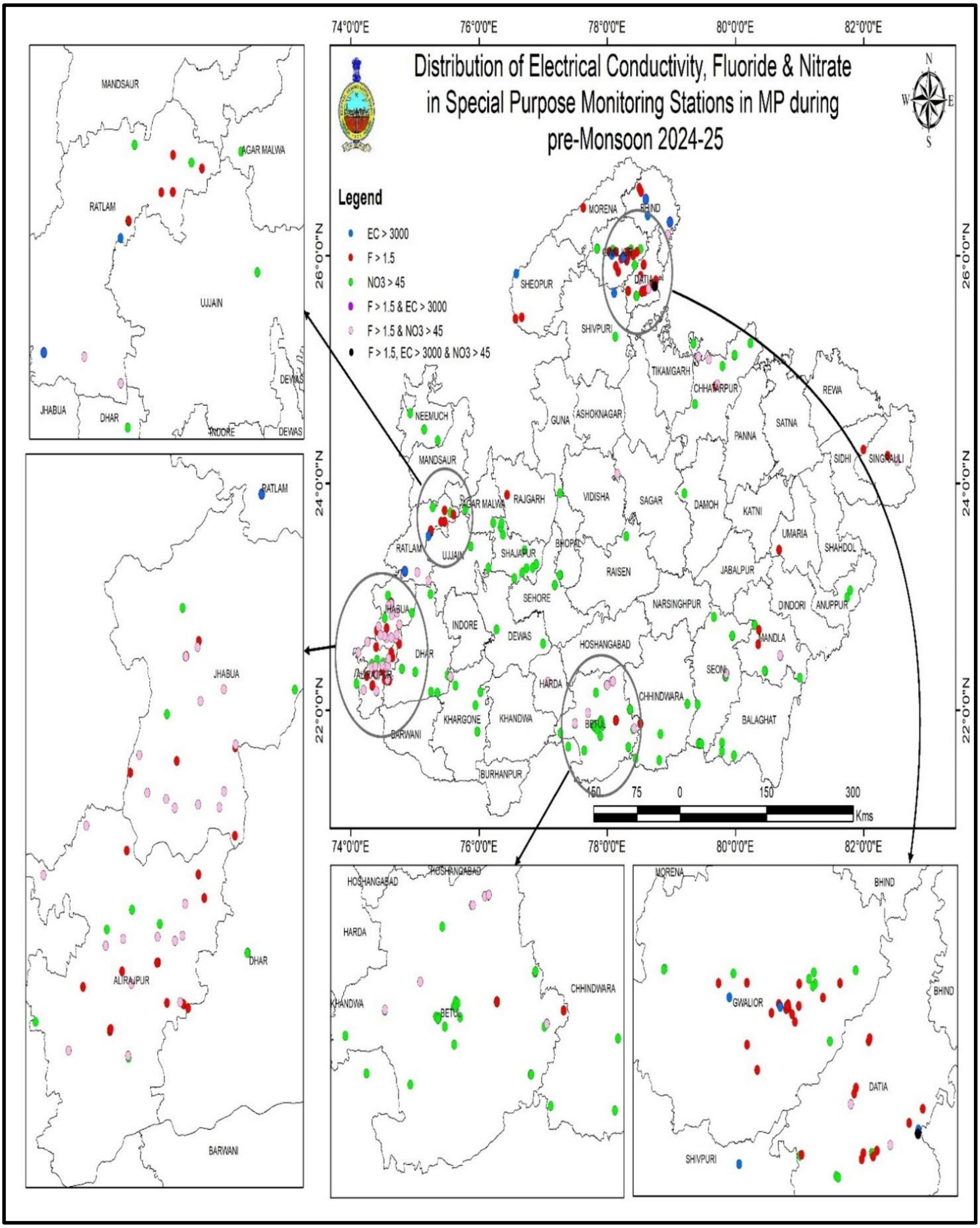


Fig O: Map Depicting the Distribution of EC, Fluoride, Total Hardness, and Nitrate at Special Purpose Monitoring Stations in Madhya Pradesh During Pre-Monsoon 2024-25.

5.7 Dewas Industrial Area

Dewas, Madhya Pradesh is an industrial city with many small and mid-sized industries. It's known as the Soya capital of India and is a major player in the country's soya bean processing industry. Some of the largest companies in Dewas include Tatas, Kirloskers, Arvind Mills, S Kumars, Tata - Cummins, Gajra Gears, Gabriel India Ltd, Ranbaxy Labs, and Steel Tubes. Dewas has many manufacturing companies, including those that produce audio and video equipment, cement, glass, and more. It has industrial machinery manufacturers.

Dewas is located in the West-central part of Madhya Pradesh, on the Malwa plateau, about 160 km southwest of Bhopal. It's an important district for the state's industrial and agricultural contributions. Dewas, like most of Madhya Pradesh, has a transitional climate between a "tropical savanna and a humid subtropical climate. In the study area and around Dewas town is covered by a large number of basaltic lava flows of Cretaceous to Eocene age.

According to the Standard Operating Procedure (SOP) for groundwater sample collection, industrial clusters must also be monitored and assessed for groundwater quality. Accordingly, the Dewas Industrial Area was selected for sample collection under the Special Purpose Monitoring (SPM) stations. The location of sampling points of Dewas Industrial area is depicted in map below:

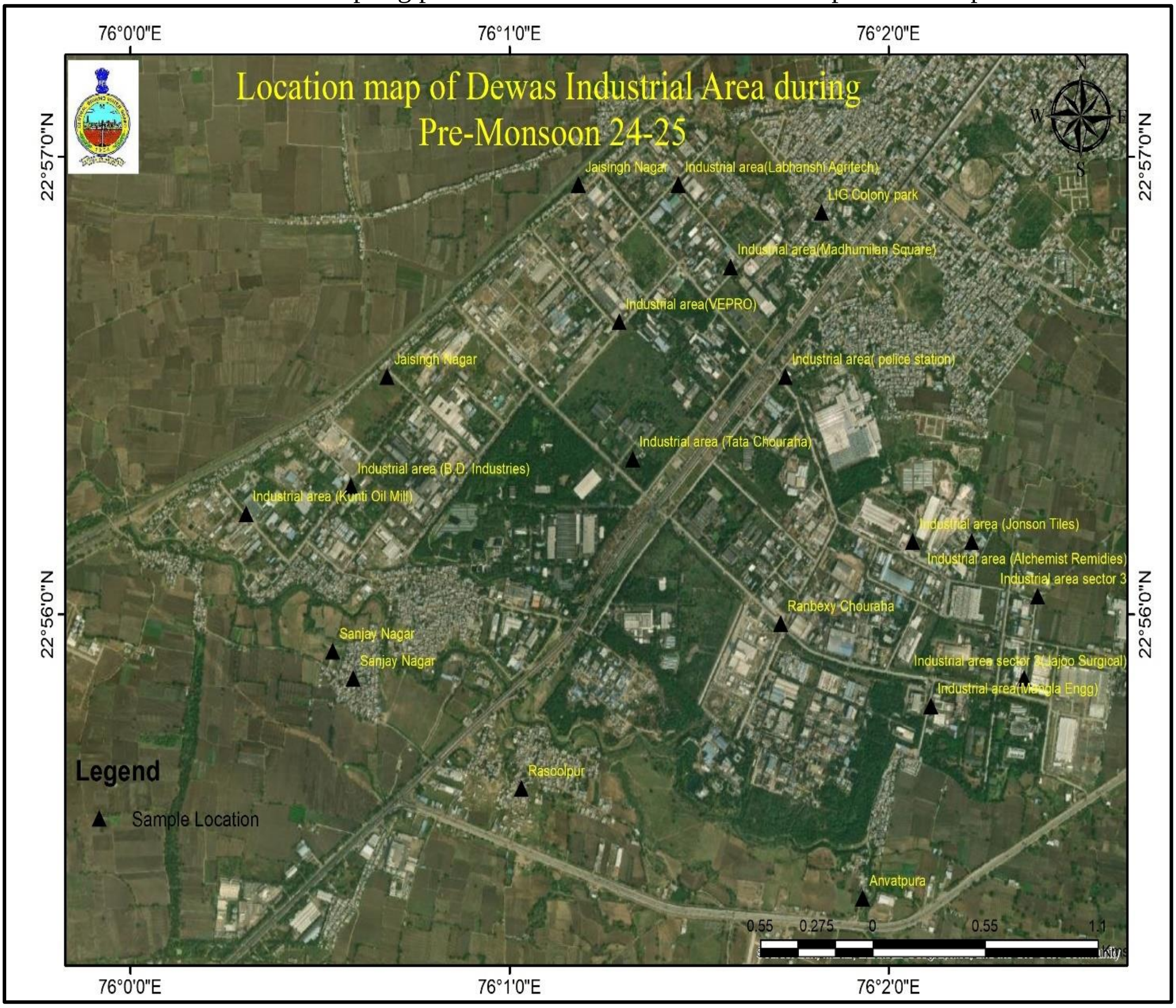


Fig P: Map Indicating Sampling Locations in the Dewas Industrial Area, Madhya Pradesh, During Pre-Monsoon 2024-25.

The table below summarizes the major contaminants identified in the analysis of basic parameters and trace metals in the Dewas Industrial Area.

Table 25: Contaminants Detected in Dewas Industrial Area (Special Purpose Monitoring, Pre-Monsoon 2024-25)

Parameter	Permissible Limit	Unit	No. of Locations	% of Locations
EC	>3000	(µS/cm at 25 ^{O} C)	1	4.8
F	>1.5	mg/L	0	0.0
Nitrate	>45	mg/L	5	23.8
TH	>600	mg/L	10	47.6
Fe	>1.0	mg/L	2	9.5
Mn	>0.3	mg/L	2	9.5
Cr	>50	ppb	2	9.5
Pb	>10	ppb	2	9.5

The chart below provides a detailed range of various key parameters observed during the monitoring process. These parameters are critical for assessing the overall groundwater quality and environmental conditions in the study area.

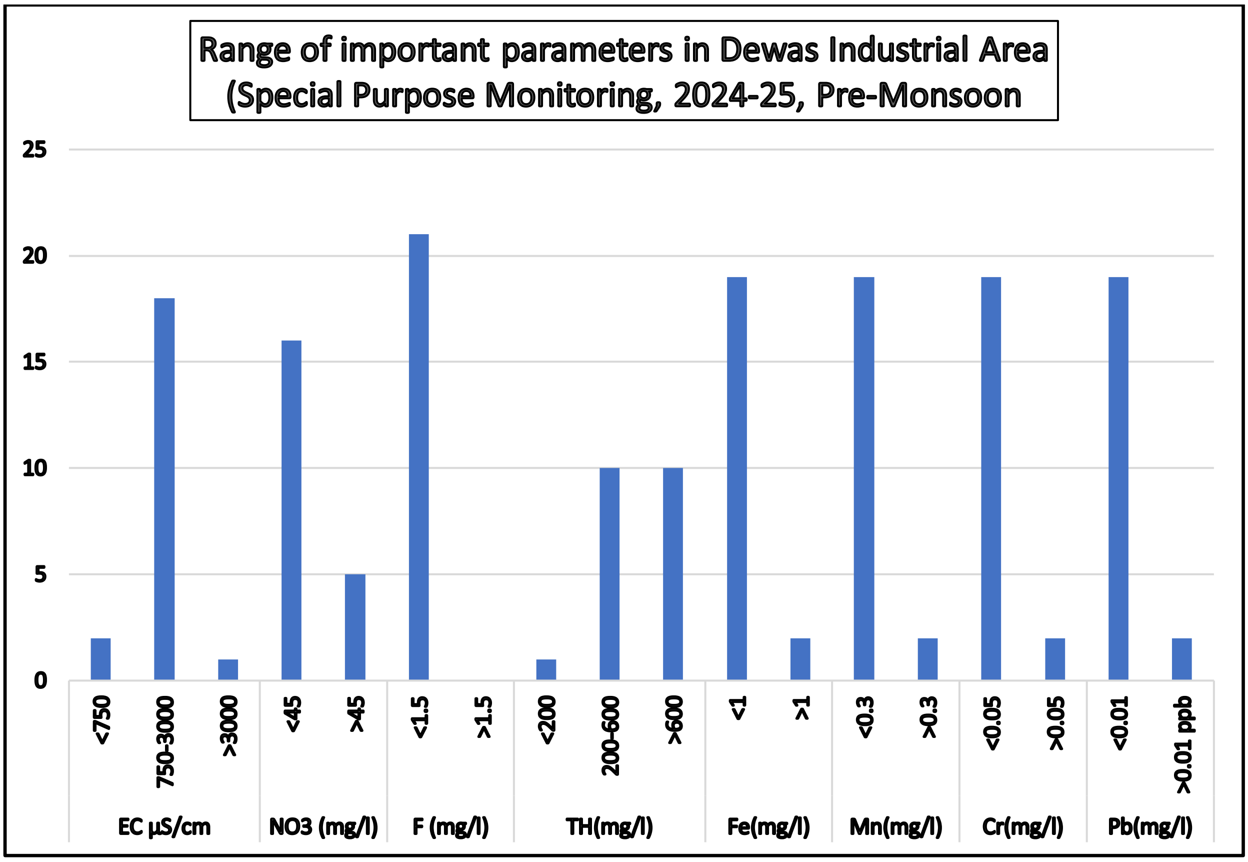


Chart K: Range of important parameters in Dewas Industrial Area (Special Purpose Monitoring, 2024-25, Pre-Monsoon)

The map below illustrates the distribution of EC, Nitrate, Total Hardness, and Fluoride in the Dewas Industrial Area.

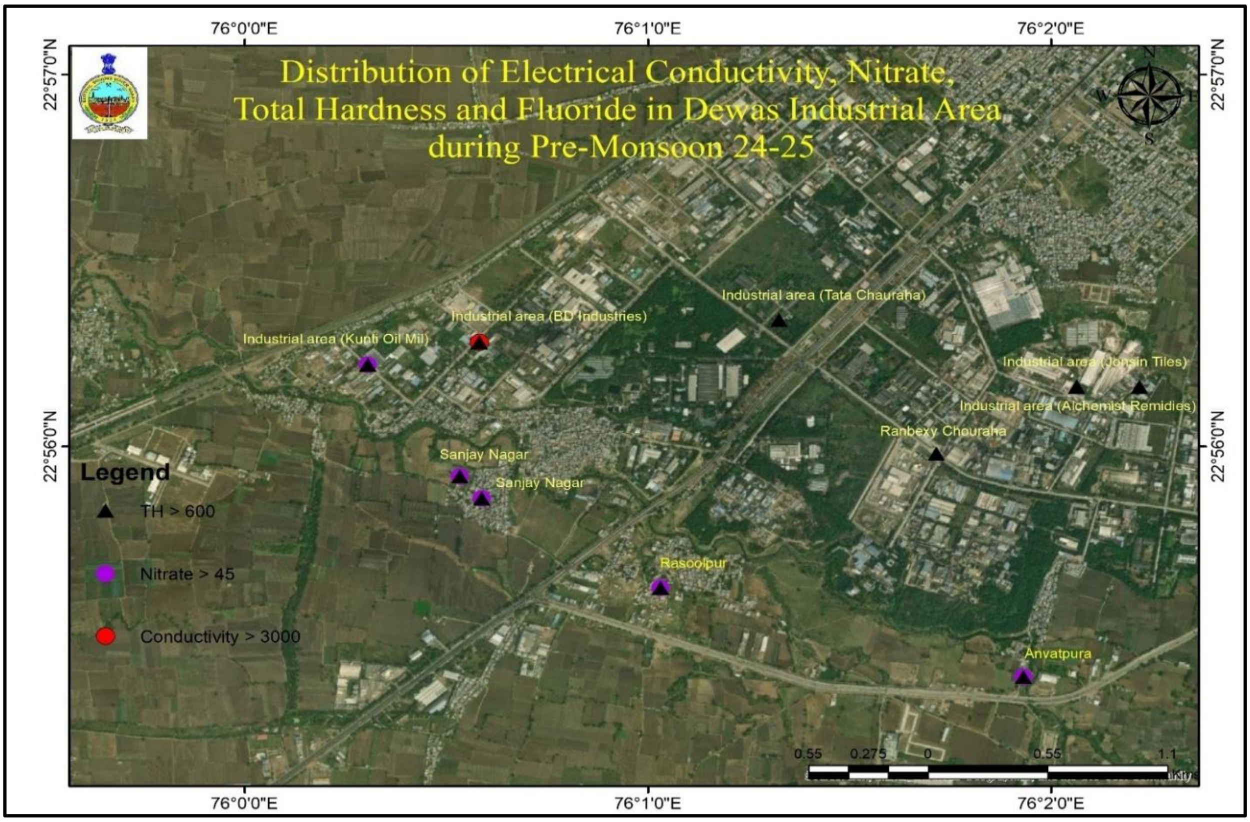


Fig Q: Map Showing Distribution of EC, F, TH & NO3 in Dewas Industrial area of MP during Pre-monsoon 2024-25.

The distribution of various trace metals in dewas industrial area is depicted in map below:

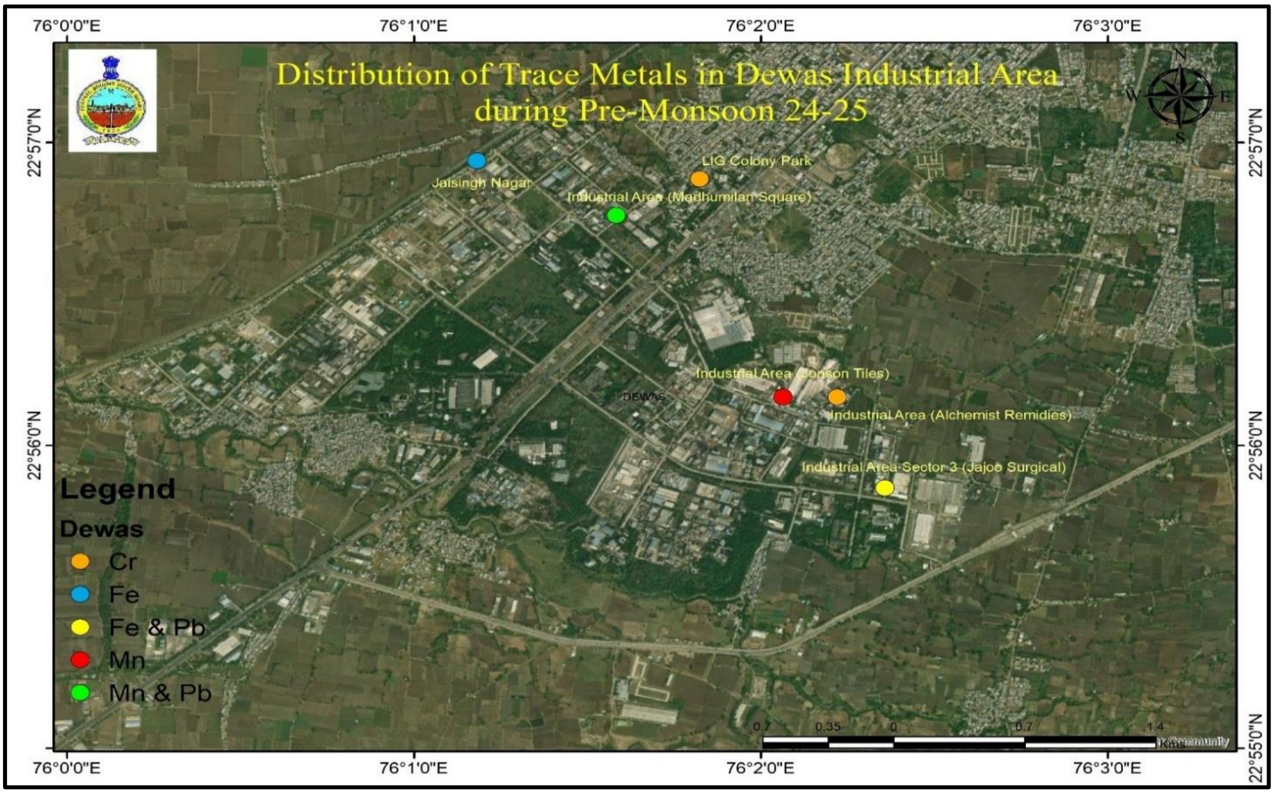


Fig R: Map Showing Distribution of Trace Metals in Dewas Industrial area of MP during Pre-monsoon 2024-25.

5.8 Nagda Industrial Area

Nagda is an industrial town situated 40 km away from Ujjain district of M.P. It lies in the Malwa region of western Madhya Pradesh and on the bank of Chambal River. Nagda has a big industrial complex developed by Birla group, the major Grasim industry located on the north- west of Nagda town; which manufactures a variety of products including viscous rayon, polyesterised yarn, caustic soda, liquid chlorine, carbon disulfide and, etc. The other subsidiaries industries are Gwalior chemicals, Lanxess, Arcil Catalyst, Sunity Chemicals etc. All these industrial units discharge effluents to Chambal River near Khachrod Naka.Nagda city areas have been identified as one of country's most severely polluted areas by Central Pollution Control Board. Industrial activities had resulted considerable deterioration of groundwater and surface water quality in these areas. The main purpose of the study was to assess the impact of industrialization on the chemical quality of ground water as well as Chambal River water in and around Nagda town and surrounding villages.

The study area is located in Nagda town of Kachrod block of Ujjain district, Madhya Pradesh and is covered by Survey of India Toposheet (46 M/ 6 and 7 on 1:50,000 scale). The area lies in between latitudes 23°24'24″ N to 23°35'31″ N and longitudes 75°18'40″ E to 75°27'23″ E. An Anicut is constructed on river Chambal near industrial area. The water from Anicut is used for drinking and industrial requirement. An area extending about 16 km downstream upto Rajgarh village and about 5 km upstream upto Tumni Village from the Anicut constructed on river Chambal near industrial area and about 2.5 km either side of Chambal river in and around the industrial area is taken for study.

In accordance with the Standard Operating Procedure (SOP) for groundwater sample collection, it is essential to monitor and assess the groundwater quality in industrial clusters as part of the broader environmental monitoring framework. Consequently, the Nagda Industrial Area was chosen as a designated site for sample collection under the Special Purpose Monitoring (SPM) stations. This selection ensures that the groundwater quality in this industrial hub is thoroughly evaluated to identify any potential contaminants or concerns related to industrial activities.

The analysis of basic parameters and trace metals during the pre-monsoon period of 2024-25 revealed the presence of several significant contaminants. These contaminants, which have implications for both environmental and public health, were identified across various monitoring stations. The following are the major contaminants that were reported based on the analysis:

Table 26: Contaminants Found in Ujjain Industrial Area (Special Purpose Monitoring, Pre-Monsoon 2024-25).

Parameter	Permissible Limit	Unit	No. of Locations	% of Locations
EC	>3000	(µS/cm at 25 °C)	19	41.3
F	>1.5	mg/L	3	6.5
Nitrate	>45	mg/L	18	39.1
TH	>600	mg/L	26	56.5
Fe	>1.0	mg/L	14	30.4
Mn	>0.3	mg/L	4	8.7
Cr	>50	ppb	0	0.0
Pb	>10	ppb	1	2.2

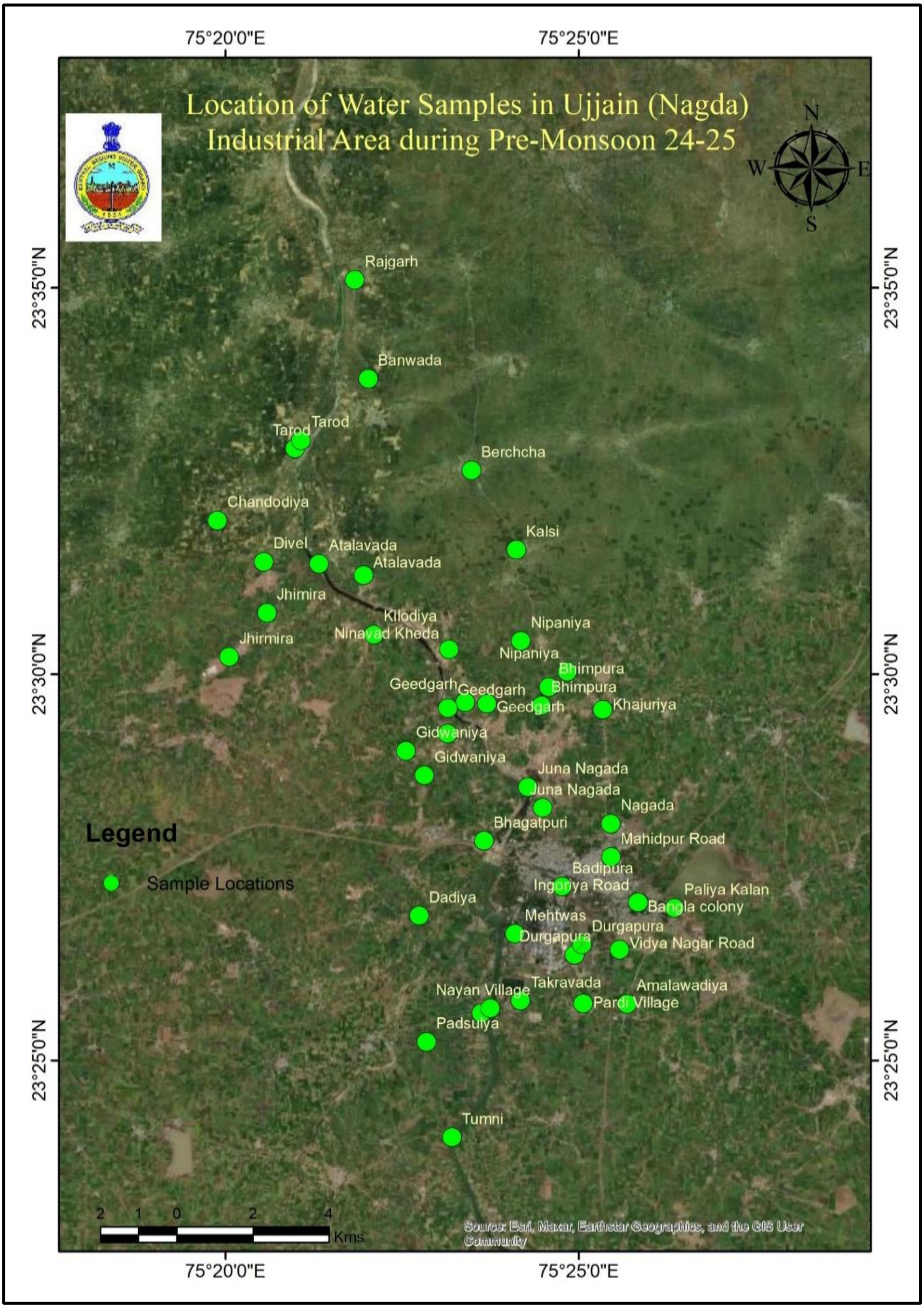
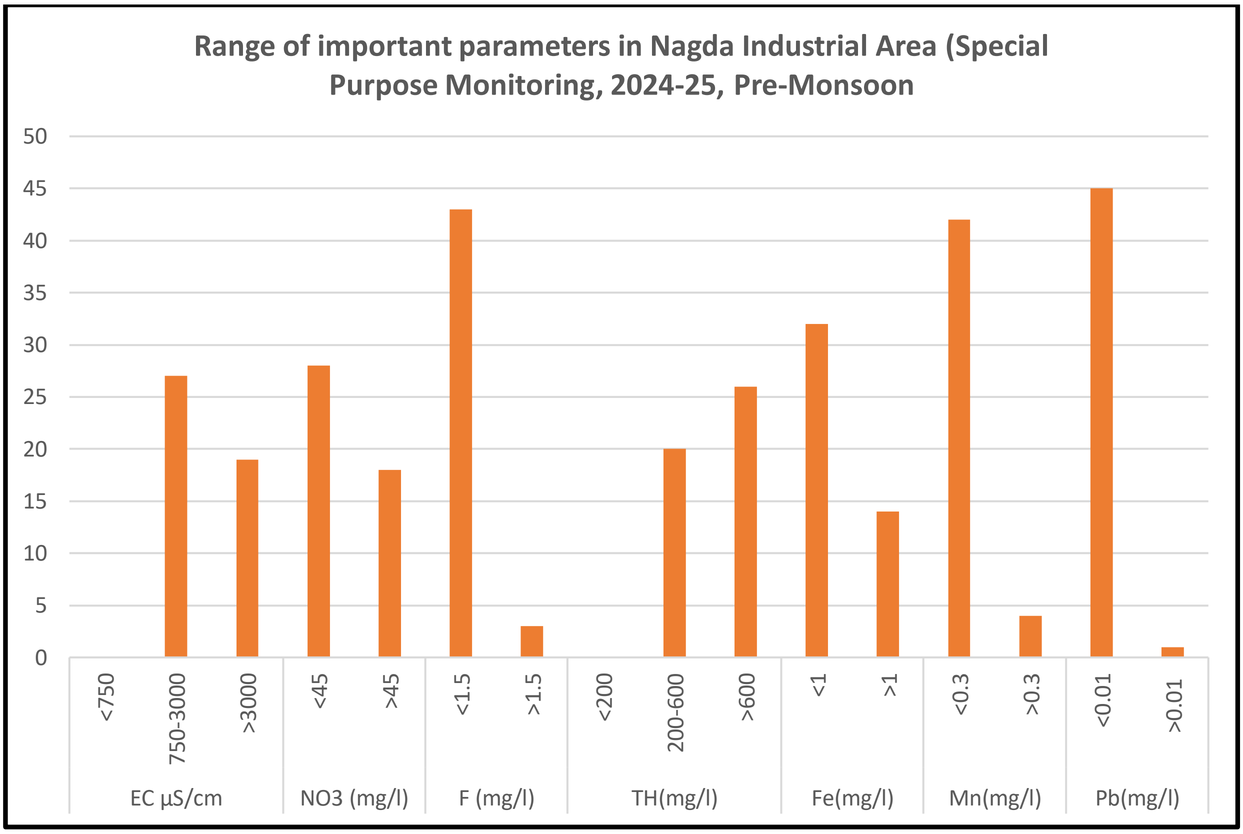


Fig S: Map Indicating Sampling Locations in the Nagda Industrial Area, Ujjain, Madhya Pradesh, During Pre-Monsoon 2024-25.

The Chart below presents the range of several critical parameters that were analysed.

Chart L: Range of important parameters in Nagda Industrial Area (Special Purpose Monitoring, 2024-25, Pre-Monsoon)



The map below illustrates the spatial distribution of key parameters, including electrical conductivity (EC), nitrate, total hardness, and fluoride, within the Nagda Industrial Area. This mapping provides a visual representation of the variation in these parameters across the region.

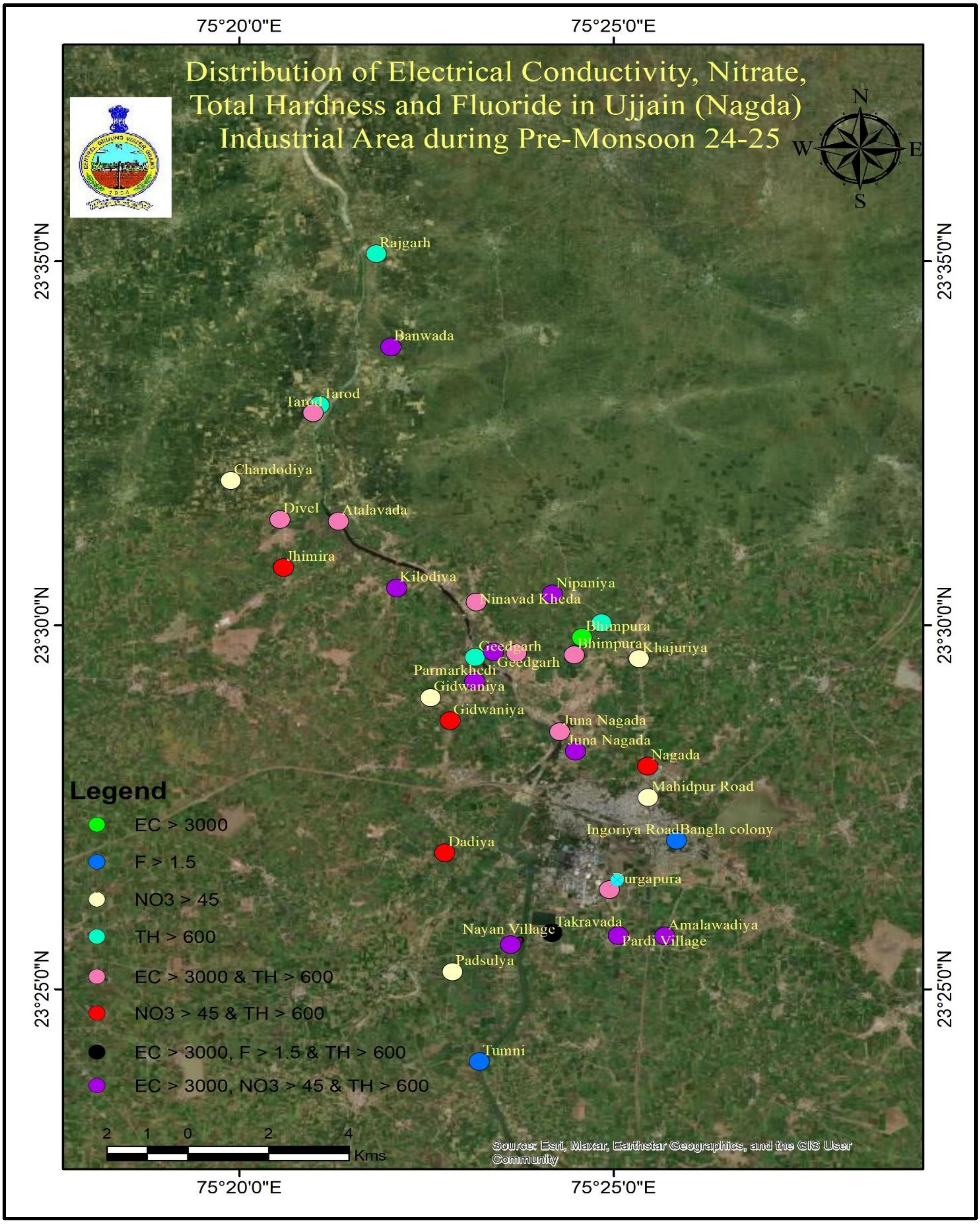


Fig T: Map Showing Distribution of EC, F, TH & NO_3 in Nagda Industrial area of Ujjain, MP during Pre-monsoon 2024-25.

The map below illustrates the distribution of various trace metals within the Dewas Industrial Area. This map provides a comprehensive view of how these trace metals are spread across the region, highlighting areas where their concentrations are recorded higher.

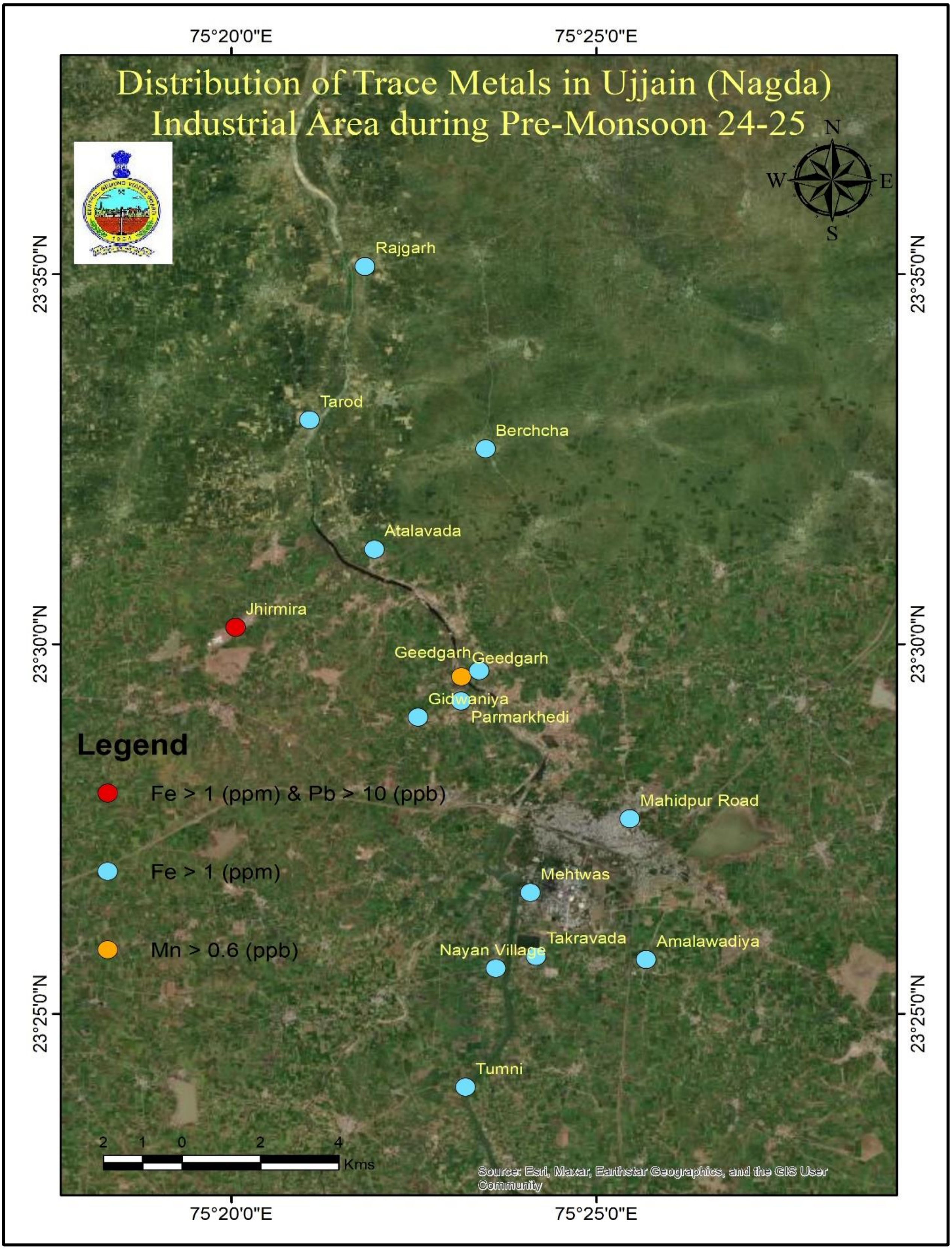


Fig U: Map Showing Distribution of Trace Metals in Nagda Industrial area of Ujjain, MP during Pre-monsoon 2024-25.

6. Summary

The analytical results reveal a concerning trend. More districts in Madhya Pradesh had groundwater samples exceeding permissible limits for nitrate, fluoride, arsenic, uranium, and iron compared to 2023. This deterioration in water quality may be attributed to anthropogenic activities. While most samples from the Central Ground Water Board's observation wells comply with drinking water standards for basic parameters and heavy metals, some specific locations exceed permissible limits, potentially posing health risks with prolonged use.

NHS Trend Stations:

- **EC (Electrical Conductivity):** Only 4 locations exceed permissible limits at Gwalior, Indore, Narmadapuram, and Shivpuri districts, out of the 614 samples analyzed.
- **NO_3 (Nitrate):** 24.4% of samples surpass permissible limits, with significant levels at 150 locations across various districts of Madhya Pradesh.
- **F (Fluoride):** Overall, 1.1% of samples (7 locations) across the districts of Betul, Dewas, Dindori, Harda, Seoni, and Sidhi, out of the 614 samples analysed
- **Fe (Iron):** Iron levels exceeding the BIS permissible limit of 1 mg/l were identified at 39 locations (10.7% of samples) across the districts of Agar-Malwa, Balaghat, Betul, Burhanpur, Chhatarpur, Chhindwara, Dewas, Gwalior, Jabalpur, Khandwa, Mandsaur, Neemuch, Rajgarh, Ratlam, Sagar, Sehore, Seoni, Shahdol, Sidhi, and Ujjain
- **As (Arsenic):** 1.3% samples, (8 locations) in Madhya Pradesh were found to have arsenic levels exceeding the BIS-prescribed permissible limit of 0.01 mg/l (10 ppb).
- **U (Uranium):** Present in 0.8% of samples (5 locations) with slightly elevated levels in certain districts like Gwalior, Panna, Shivpuri, Ujjain, and Umaria

Special purpose Monitoring Stations:

- **EC (Electrical Conductivity):** 33 out of 544 samples exceed permissible limits.(EC>3000 µS/cm)
- **NO_3 (Nitrate):** 232 out of 544 samples exceed permissible limits (NO3>45 mg/l)
- **F (Fluoride):** 125 out of 544 samples exceed permissible limits (F>1.5 mg/l)
- **TH(Total Hardness):** 88 out of 544 samples exceed permissible limits (TH>600 mg/l)
- **Fe (Iron):** Fe concentrations exceeding the permissible limit of 1 mg/L were detected in 160 out of the 544 groundwater samples analyzed . Additionally, significantly elevated iron levels were observed at various locations within the districts of Mandla, Anuppur, Dindori, Jabalpur, and Umaria.
- **Mn**: Elevated manganese concentration (>0.3 mg/l) detected at 20 locations out of the 544 groundwater samples analyzed.
- **As (Arsenic):** Elevated arsenic levels exceeding the BIS guideline were identified in only 1.1% of the samples (6 locations) out of 544 samples analyzed.
- **Lead:** Elevated lead (Pb) concentrations exceeding 10 parts per billion (ppb) were detected in 95 out of the 544 groundwater samples analyzed in SPM stations.

- **U (Uranium):** uranium (U) concentrations exceeded 30 ppb at 104 locations out of the 544 samples analysed. Notably higher concentrations observed at districts of Gwalior Datia, Seoni, and Betul etc
- Dewas Industrial Area: Contaminants like EC, F, NO3, TH, Fe, Mn, Cr and Pb were detected at few locations in the Industrial area.
- Nagda Industrial Area: Contaminants like EC, F, NO3, TH, Fe, Mn and Pb were detected at several locations in the Industrial area.

State Summary

The table below summarises the number of contaminated samples observed throughout the state of MP during Pre-Monsoon 2024-25 in both NHS trend Stations and Special Purpose Monitoring (SPM) Stations i.e. Hotspot samples.

Parameter	Trend Stations (n=614)		SPM Stations (n=544)		Total	
	No.	%	No.	%	No.	%
EC	4	0.65	33	6.1	37	3.2
NO3	150	24.43	232	42.6	382	33
F	7	1.14	125	23.0	132	11
TH	50	8.14	88	16.2	138	12
Fe	39	6.35	160	29.4	199	17
Mn	30	4.89	20	3.7	50	4.3
As	8	1.30	6	1.1	14	1.2
U	5	0.81	104	19.1	109	9.4
Pb	35	5.70	95	17.5	130	11

Table 27: Summary of No of Samples Contaminated (%) in MP.

The graphical representation is shown below:

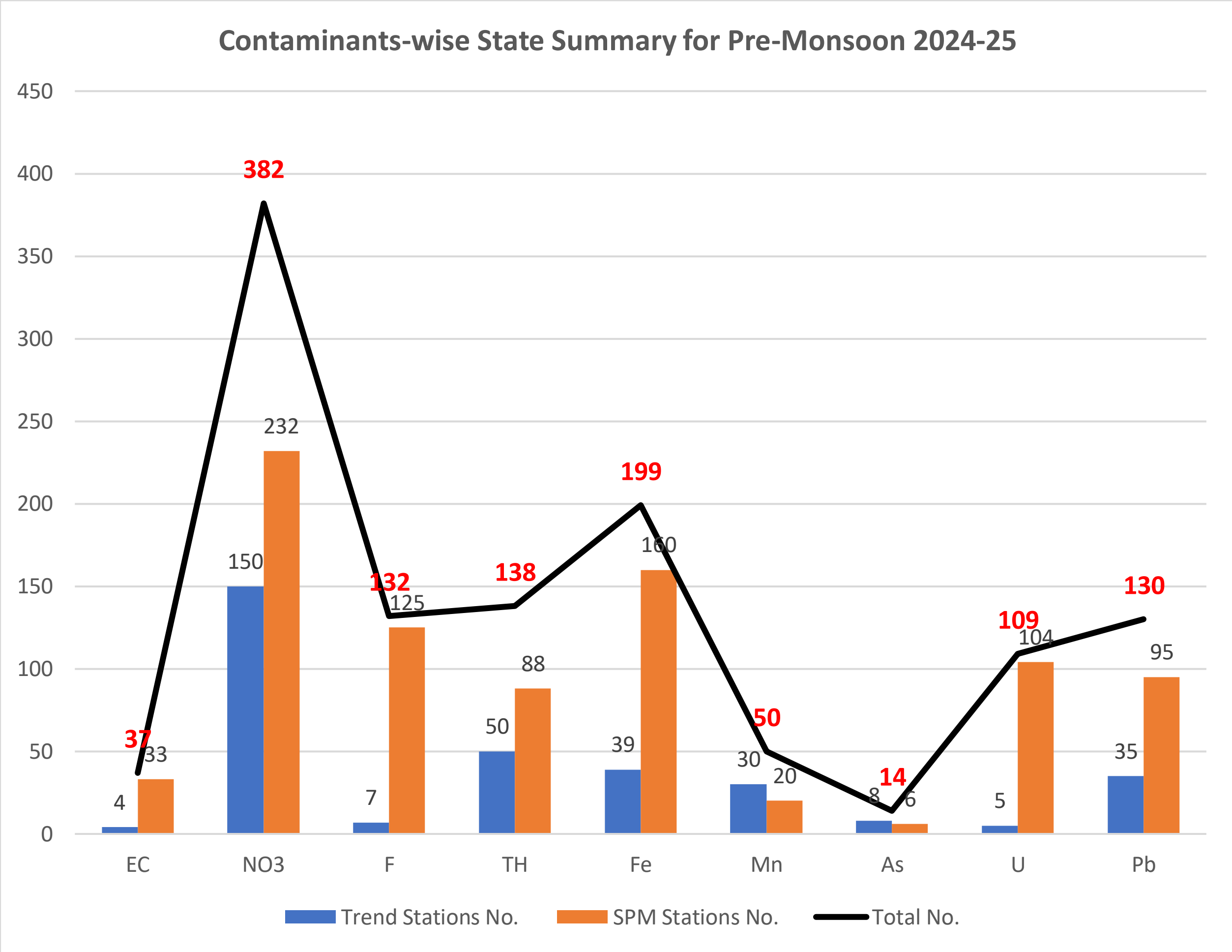


Chart M: Contaminants Wise State Summary.

The groundwater quality assessment in Madhya Pradesh revealed significant contamination across various parameters. Nitrate (NO_3) was the predominant contaminant, with 33% of samples exceeding permissible limits, followed by Iron (Fe) at 17% and Hardness (TH) at 12%.

F and Pb contamination was observed in 11% samples , 9.4% samples were found contaminated with Uranium and 4.3% with manganese during pre-Monsoon 2024-25. Electrical conductivity (EC) contamination was observed in 3.2 % of samples, while Arsenic contamination was lower, with 1.2 % of samples exceeding permissible limits.

6.0 Remediation & Conclusion

Overall, the state of Madhya Pradesh generally has good quality water according to drinking and domestic water standards. However, in a few localized areas, contaminants are found in the groundwater. The primary concern in Madhya Pradesh is the high nitrate levels present in almost all districts, likely due to the use of pesticides in agriculture, sewage, and other anthropogenic sources. Additionally, certain locations exhibit contamination from iron, manganese, and uranium, which can be attributed to geogenic origins.

Recommendation for Mitigation

- **Nitrate:** For removal of nitrate both non-treatment techniques like blending and treatment processes such as ion exchange, reverse osmosis, biological denitrification and chemical reduction are useful. The most important thing is that neither of these methods is completely effective in removing all the nitrogen from the water.

  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)

Complex biogeochemical processes govern the mechanism of nitrate pollution in subsurface porous unconfined/confined aquifer. Apart from recharge conditions, groundwater chemistry may be impacted by the mineral kinetics of water-rock interactions. Consequently, suitable nitrate removal technologies should be selected. Nitrate is a very soluble ion with limited potential for co-precipitation or adsorption. This makes it difficult to remove by processes such as chemical coagulation, lime softening and filtration, which are commonly used for removing most of the chemical pollutants such as fluoride, arsenic and heavy metals. According to King et al., 2012 nitrate treatment technologies can be classified in two categories in two categories, i.e. nitrate reduction and nitrate removal options. Nitrate removal technologies involve physical processes that does not necessarily involve any alteration of the chemical state of nitrate ions. Bio-chemical reduction options aim to reduce nitrate ions to other states of nitrogen, e.g. ammonia, or a more innocuous form as nitrogen gas. In-situ bioremediation is also effectively used in used in nitrate treatment of contaminated groundwater. Reverse Osmosis, catalytic reduction and blending are effective methods for nitrate removal from groundwater.

- **Fluoride:** The fluoride remedial measures broadly adopted are ex-situ techniques. They can be classified into three major categories.

✓ Adsorption and ion exchange

- ✓ Ion-Exchange resins
- ✓ Coagulation-precipitation
- ✓ Nalgonda Technique

- **Total Hardness, Calcium and Magnesium**

A few methods to remove hardness from water are,

- ✓ Chemical Process of Boiling Hard Water.
- ✓ Adding Slaked Lime (Clark's Process)
- ✓ Adding Washing Soda.
- ✓ Calgon Process.
- ✓ Ion Exchange Process.
- ✓ Using Ion Exchange Resins.

Carbonate (Temporary) Hardness also known as Ca Bicarbonate
Removal by Boiling or adding Lime
Non-Carbonate (Permanent) Hardness Removal by Lime-soda, Zeolite or Demineralization Processes

- **Manganese:** Treating the water at its source, filtration system and water treatment method.
- **Lead:** Reverse osmosis systems, water distillers and carbon filters.
- **Iron:** Oxygenation of groundwater followed by precipitation
- **Arsenic:** Methods for removing arsenic from water include adsorptive media, reverse osmosis, distillation, and anion exchange.
- **Salinity:** Rainwater Harvesting, MAR(Managed Aquifer Recharge), Artificial Recharge, Groundwater abstraction optimization, growing salt tolerant species, increasing groundwater level , reducing the evaporation rates, reducing water consumption etc

The choice of method depends quantum of water to be treated i.e domestic level or community level or large scale and implementation**.** It also depends on factors such as the level of contamination, water quality standards, and available resources. Combination approaches may also be necessary for effective contamination removal in some cases. In present day scenario, **Reverse Osmosis (RO) Method using controlled TDS** (TDS not less than 500 mg/l as per BIS acceptable value) seems economically and practically more feasible than other methods. Additionally, piped treated water supply in affected locations and method of **dilution by employing Rainwater Harvesting method also seems effective.**

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