GROUNDWATER QUALITY BULLETIN OF INDIA

Pre-monsoon 2024

ABSTRACT

Periodic ground water quality assessment (2020-24) highlighting the findings, significant trends and groundwater contamination status

CGWB, CHQ, Faridabad

1.0 INTRODUCTION

Ground water is an important resource widely used for drinking, irrigation and industrial purpose. Ground Water plays an important role in the sustainable socio-economic development. In regions with scarcity of fresh surface water sources dependence on ground water increases exponentially. They fulfill substantial proportions of irrigation and drinking water needs. However, heightened reliance on groundwater across various sectors has resulted in declining water quality and dwindling water levels. The ground water quality is dependent upon chemical characteristic of rocks and minerals composition of aquifer material. Due to redox reaction, ions can be dissolved from minerals by dissolution and crystallization within aquifer and concentrate beyond permissible limits. Poor ground water quality can also be due to excessive use of fertilizers, urbanization and industrial effluent discharge. According to UNESCO more than 80% of health issues are caused due to consumption of poor-quality water. Inorganic contaminants including Salinity, Fluoride and Nitrate are important in determining the suitability of ground water for drinking purposes.

Therefore, periodic ground water quality assessment is important to alert people who utilize it for domestic and irrigation purpose.

Numerous studies have been carried out on the poor quality of groundwater. Our efforts in the present study are to fulfill the following objectives:

1. To present current parameter wise GW quality scenario with respect to identified trend stations, for each state.
2. To identify present day hot spots of poor-quality ground water through spatial variation analysis of latest 2024 quality data.
3. To assess temporal variation of ground water quality showing improvement / deterioration during the period from 2020 to 2024, providing insights for effective water quality management measures.

2.0 STUDY AREA

India spans between latitudes 8°4' N and 37°6' N, and the longitudes 68°7' E and 97°25' E, covers 3.287 million sq. km, comprising 2 % of world’s total landmass. Based on the hydrogeological characteristics, the entire country has been classified into fourteen Principal Aquifer Systems (Figure 1). Alluvium is the major aquifer system which covers maximum area of around 31% of the entire country and is present in Uttar Pradesh, Bihar, West Bengal, Assam, Odisha and

Rajasthan. The sandstone aquifer covers around 8% area in the country and found in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Gujarat, Karnataka and Rajasthan. The rest of the country is covered with the other formations that cover around 60% of the area. Among these, Basalt aquifer covers maximum of around 17% area of the country and mainly spread over Maharashtra, Madhya Pradesh, Gujarat, Rajasthan and Karnataka. Shale aquifer accounts for around 7% of area in the country and is available mostly in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Rajasthan and in the north-eastern states as well as in the Himalayan terrain. Limestone aquifer covers a very small area of around 2% in the country and mainly available in the states of Chhattisgarh, Andhra Pradesh, Karnataka, and Gujarat and in the Himalayan states. Around 20% of the area of the country is covered by Banded Gneissic Complex (BGC) and Gneiss aquifers which are available almost in all the peninsular states as well as the Himalayan states. The rest 15% of the entire area is covered by aquifers namely; Schist, Granite, Quartzite, Charnockite, Khondalite, Laterites and Intrusive.

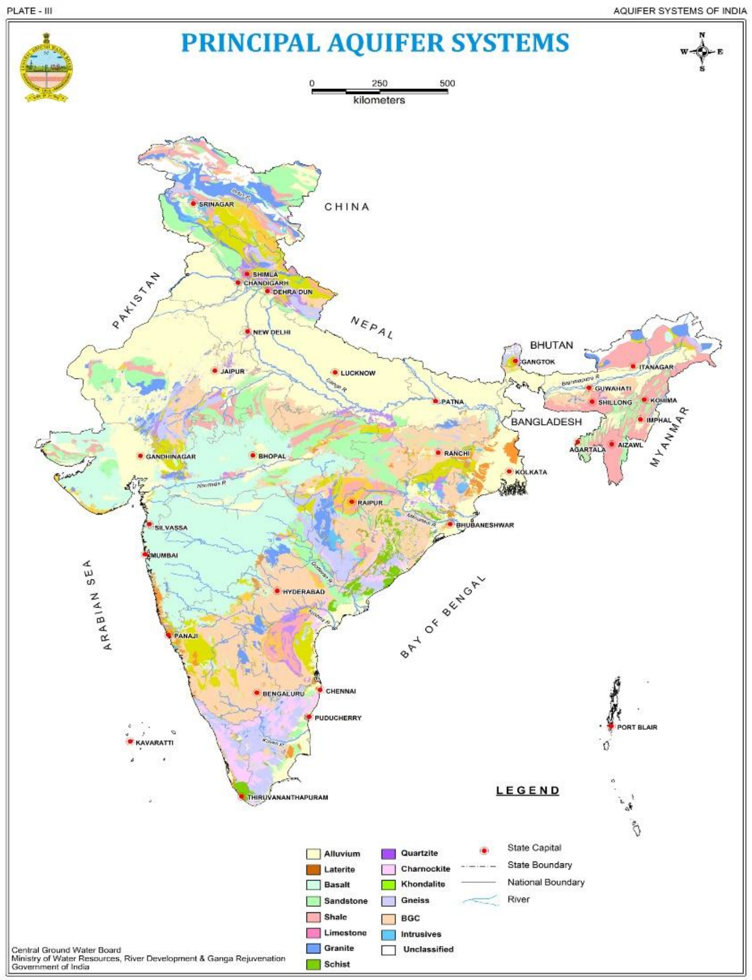

Figure 1: Map showing Principal aquifer systems of India

3.0 GROUND WATER QUALITY MONITORING

Monitoring of ground water quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. The main objective of ground water quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as create a background data bank of different chemical constituents in ground water. Central Ground Water Board has 16 Regional Chemical Labooratories to carry out chemical analysis of water samples. With the objective of safeguarding water from degradation and to establish a basis for improvement in water quality, various standards have been laid down by various national and international organizations such as; Bureau of Indian Standards (BIS), which has laid down the standard specification for drinking water (IS 10500: 2012), which have been revised and updated from time to time. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The present bulletin is based on the changing scenario in water quality during pre-monsoon in network observation wells of CGWB in year 2020 and 2024. To examine the chemical quality of stations identified as vulnerable to contamination based on BIS 10500 standards, at least 25% of the total monitoring stations were chosen as trend stations for detailed analysis. Groundwater quality was sampled at 7281 trend stations located all over the country (Figure 2) during pre-monsoon 2024 to assess the groundwater quality in vulnerable areas. 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.

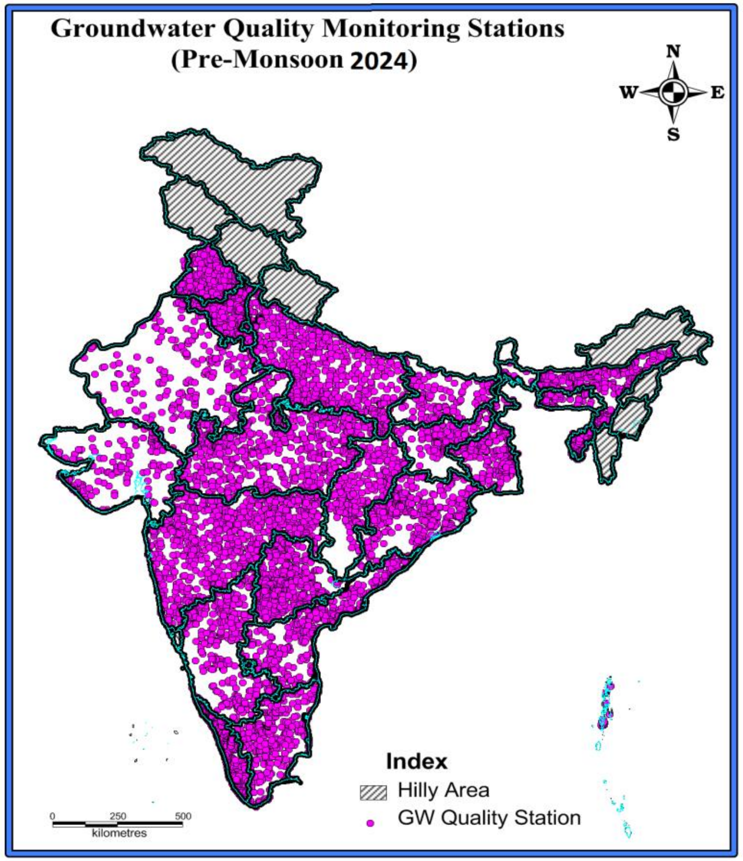

Figure 2: Map showing Spatial Distribution of 7281 Groundwater Quality Monitoring Stations in India based on 2024 Pre-monsoon data

The state-wise distribution of water Quality Monitoring Stations of CGWB is given in Table 1.

S.No.	State/ UT	No. of GW Quality Monitoring Stations				
		2020	2021	2022	2023	2024
1	Andaman & Nicobar Islands	0	110	110	113	29
2	Andhra Pradesh	0	55	940	1149	333
3	Arunachal Pradesh	20	18	18	12	20
4	Assam	174	232	319	155	312
5	Bihar	186	277	661	808	127
6	Chandigarh UT	6	8	0	8	8
7	Chhattisgarh	590	856	801	783	257
8	Dadra And Nagar Haveli	0	0	22	10	0
9	Daman And Diu	0	0	0	7	0
10	Delhi	66	79	95	103	38
11	Goa	0	0	76	10	2
12	Gujarat	601	565	653	632	147
13	Haryana	409	463	463	879	338
14	Himachal Pradesh	90	138	160	171	63
15	Jammu & Kashmir	214	248	250	250	73
16	Jharkhand	150	132	392	397	138
17	Karnataka	146	0	1140	345	317
18	Kerala	0	351	265	342	545
19	Madhya Pradesh	1032	1153	1135	589	614
20	Maharashtra	116	104	1358	1567	753
21	Manipur	0	0	0	0	4
22	Meghalaya	27	44	65	39	75
23	Mizoram	0	0	0	3	2
24	Nagaland	2	0	15	6	117
25	Odisha	781	715	1274	625	459
26	Punjab	323	330	335	922	284
27	Rajasthan	640	774	809	630	224
28	Tamil Nadu	113	620	1197	916	306
29	Telangana	0	139	890	1150	412
30	Tripura	98	90	67	81	90
31	Pondicherry	0	206	16	4	7
32	Uttar Pradesh	217	841	918	1387	670
33	Uttarakhand	198	0	394	207	241
34	West Bengal	771	511	669	959	276
	Total	**6970**	**9059**	**15507**	**15259**	**7281**

Table 1: State wise distribution of water Quality Monitoring Stations of CGWB

4.0 GROUND WATER QUALITY SCENARIO

The main objectives of ground water quality monitoring are to assess the suitability of ground water for drinking purposes as the quality of drinking water is a powerful environmental determinant of the health of a community. Bureau of Indian Standards (BIS) vide its document IS: 10500:2012, Edition 3.2 (2012-15) has recommended the quality standards for drinking water. The ground water samples collected from phreatic aquifers were analysed for all the major inorganic parameters. The types of water found among various general classifications depends on the local variations in hydro-chemical environments due to geogenic conditions and anthropogenic activities. Nevertheless, the occurrence of high concentrations of some water quality parameters such as Salinity (EC), Fluoride, Nitrate and the changes in water quality based on these parameters have been observed in various parts of India.

4.1 QUALITY ASSESSMENT OF GROUNDWATER IN UNCONFINED AQUIFERS

Unconfined aquifers are extensively tapped for water supply and irrigation across the country therefore; its quality is of utmost importance. The chemical parameters like TDS, Fluoride, Nitrate etc. are main constituents defining the quality of ground water in unconfined aquifers. The presence of these parameters and the changes in chemical quality with respect to these in ground water in samples collected during pre-monsoon NHS monitoring 2020 & 2024 are as discussed. Following are the permissible limits for specific parameters as per BIS standard for Drinking water IS: 10500:2012

1. Electrical Conductivity (> 3000 µS/cm)

2 Fluoride (> 1.5 mg/litre)

3. Nitrate (> 45 mg/litre)

4.1.1 THE ELECTRICAL CONDUCTIVITY

Electrical conductivity represents total number of cations and anions present in groundwater, indicating ionic mobility of different ions, total dissolved solids and saline nature of water. 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, quantity of rainfall and above all, the climate of the area. BIS has recommended a drinking water standard for total dissolved solids a limit of 500mg/l (corresponding to EC of about 750 µS/cm at 25°C) that can be extended to a TDS of 2000 mg/l (corresponding to EC of about 3000 µS/cm at 25°C) in case of no alternate source. Water having TDS more than 2000 mg/litre is not suitable for drinking purposes as per IS: 10500:2012 standard.

PRESENT DAY SCENARIO IN INDIA W.R.T ELECTRICAL CONDUCTIVITY (EC)

Distribution of Electrical Conductivity (EC)

The EC value of ground waters in India varies from 14 µS/cm from Meghalaya to 32970 µS/cm from Gujarat at 25°C. Grouping water samples based on EC values, it is found that 43.5 % of them have EC less than 750 µS/cm, 49.1 % have between 750 and 3000 µS/cm and the remaining 7.4 % of the samples have EC above 3000 µS/cm. The Table 2 given below provides for the number of samples analyzed state wise, along with their minimum, maximum, and mean EC values based on NHS 2024 Pre-Monsoon Data. The map (Figure 3) showing aerial distribution of EC (Figure 5) with intervals corresponding to limits as above indicates that less than 750 µS/cm class of water occur throughout the country in patches but in high proportion is in hilly areas. The ground water occurring in the western part of the country comprising of parts of states like, Gujarat, Rajasthan, Haryana, Delhi etc. is mostly saline and is not deemed suitable for drinking purpose in terms of salinity.

S. No.	State	Number of Samples Analysed (2024-25)	Min	Max	Mean	Percentage of samples showing EC value		
						<750 µS/cm	750-3000 µS/cm	>3000 µS/cm
1	A&N Islands	29	230	6134	945	65.5	31.0	3.4
2	Andhra Pradesh	333	154	10920	1991	7.8	77.2	15.0
3	Arunachal Pradesh	20	27	429	151	100.0	0.0	0.0
4	Assam	312	19	1940	314	94.9	5.1	0.0
5	Bihar	127	237	4269	1170	27.6	70.1	2.4
6	Chandigarh	8	260	1165	484	87.5	12.5	0.0
7	Chhattisgarh	257	50	4280	669	67.3	32.3	0.4
8	Delhi	38	243	10940	4054	7.9	39.5	52.6
9	Goa	2	290	700	495	100.0	0.0	0.0
10	Gujarat	147	632	32970	3920	1.4	49.0	49.7
11	Haryana	338	252	25800	3018	21.3	45.6	33.1
12	Himachal Pradesh	63	63	1923	623	74.6	25.4	0.0
13	Jammu & Kashmir	73	294	2051	960	30.1	69.9	0.0
14	Jharkhand	138	140	2728	956	36.2	63.8	0.0
15	Karnataka	317	60	10100	1937	12.3	72.9	14.8
16	Kerala	545	29	2366	273	93.9	6.1	0.0
17	Madhya Pradesh	614	160	3700	980	34.4	65.0	0.7
18	Maharashtra	753	42	11040	1181	32.3	63.9	3.9
19	Manipur	4	111	415	258	100.0	0.0	0.0
20	Meghalaya	75	14	510	107	100.0	0.0	0.0
21	Mizoram	2	353	602	477	100.0	0.0	0.0
22	Nagaland	117	23	1382	289	95.7	4.3	0.0
23	Odisha	459	57	4647	981	41.2	57.5	1.3
24	Punjab	284	273	9945	1526	27.1	62.0	10.9
25	Rajasthan	224	268	20000	3203	11.6	49.1	39.3
26	Tamil Nadu	306	155	25300	2012	12.4	73.2	14.4
27	Telangana	412	270	19840	1370	15.0	82.3	2.7
28	Tripura	90	61	809	271	98.9	1.1	0.0
29	UT of Puducherry	7	821	2590	1429	0.0	100.0	0.0
30	Uttar Pradesh	670	193	10560	840	56.7	41.9	1.3
31	Uttarakhand	241	72	2515	446	90.0	10.0	0.0
32	West Bengal	276	90	5453	991	44.2	52.9	2.9
	Total	**7281**	**14**	**32970**	**1259**	**43.5**	**49.1**	**7.4**

Table 2: State wise Range and distribution of EC in shallow GW of India

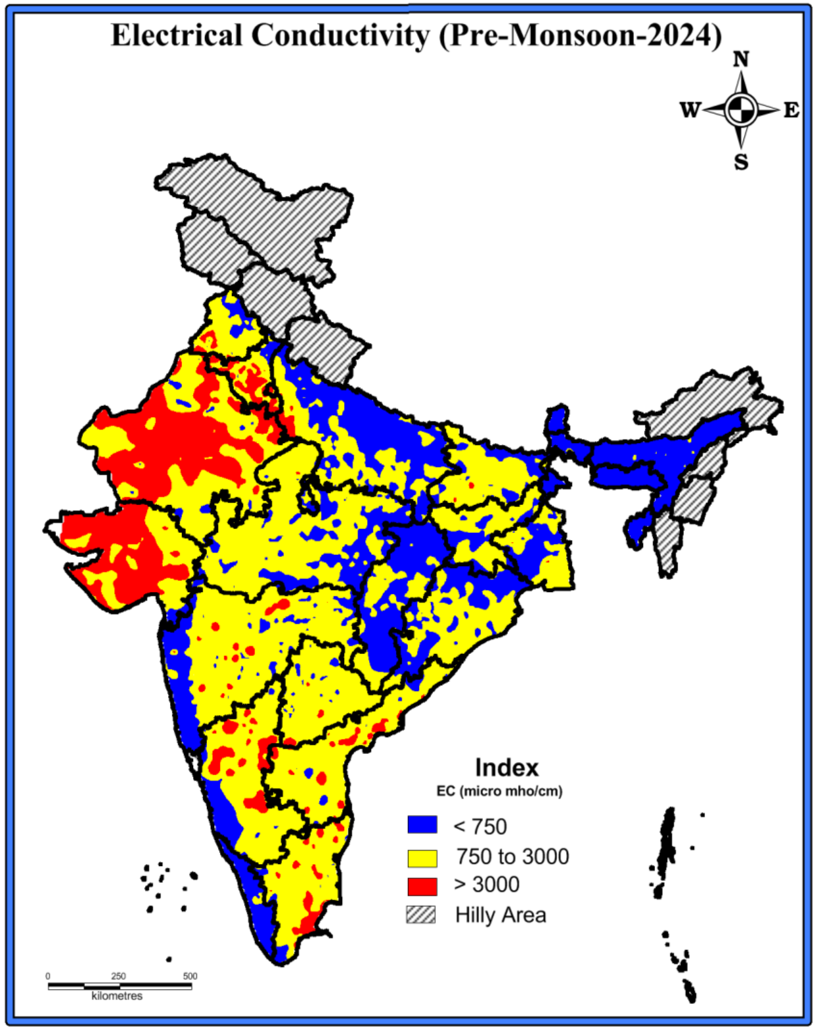

Figure 3: Map showing distribution of Electrical Conductivity in India based on Pre-monsoon NHS 2024 Data

TEMPORAL VARIATION OF EC IN GROUND WATER DURING THE PERIOD FROM 2020 TO 2024

In comparison to 2020 (Table 3), it has been observed that there is an increase in the no. of locations having EC more than 3000 µS/cm in 2024 which is further depicted as an increasing trend in Figure 4.

S.No.	State/ UT	% of No. of Locations having EC > 3000 µS/cm				
		2020	2021	2022	2023	2024
1	Andaman & Nicobar Islands	0.0	0.0	0.9	0.0	3.4
2	Andhra Pradesh	0.0	1.8	10.2	9.7	15.0
3	Arunachal Pradesh	0.0	0.0	0.0	0.0	0.0
4	Assam	0.0	0.0	0.6	0.6	0.0
5	Bihar	1.6	0.0	1.1	0.9	2.4
6	Chandigarh UT	0.0	0.0	0.0	0.0	0.0
7	Chhattisgarh	0.0	0.0	0.0	0.3	0.4
8	Dadra And Nagar Haveli	0.0	0.0	4.5	0.0	0.0
9	Daman And Diu	0.0	0.0	0.0	14.3	0.0
10	Delhi	33.3	27.8	25.3	23.3	52.6
11	Goa	0.0	0.0	0.0	0.0	0.0
12	Gujarat	15.8	18.6	17.2	19.6	49.7
13	Haryana	21.5	21.8	20.7	21.0	33.1
14	Himachal Pradesh	0.0	0.0	0.0	0.0	0.0
15	Jammu & Kashmir	0.0	0.0	0.0	0.0	0.0
16	Jharkhand	0.0	0.0	0.0	0.0	0.0
17	Karnataka	5.5	0.0	4.5	14.5	14.8
18	Kerala	0.0	0.0	0.0	0.0	0.0
19	Madhya Pradesh	0.8	0.7	1.1	1.2	0.7
20	Maharashtra	0.0	0.0	2.2	3.6	3.9
21	Manipur	0.0	0.0	0.0	0.0	0.0
22	Meghalaya	0.0	0.0	0.0	0.0	0.0
23	Mizoram	0.0	0.0	0.0	0.0	0.0
24	Nagaland	0.0	0.0	0.0	0.0	0.0
25	Odisha	0.5	0.3	0.2	1.1	1.3
26	Punjab	9.0	7.9	7.8	6.7	10.9
27	Rajasthan	27.5	25.2	30.0	48.6	39.3
28	Tamil Nadu	9.7	12.6	12.4	9.2	14.4
29	Telangana	0.0	2.2	3.5	3.0	2.7
30	Tripura	0.0	0.0	0.0	0.0	0.0
31	Pondicherry	0.0	0.0	0.0	0.0	0.0
32	Uttar Pradesh	3.7	2.0	4.0	2.7	1.3
33	Uttarakhand	0.5	0.0	0.5	0.0	0.0
34	West Bengal	0.6	1.0	1.2	0.8	2.9
	Total	**6.6**	**6.2**	**6.0**	**7.3**	**7.4**

Table 3: Comparative change in percentage of locations having EC > 3000 µS/cm in various States from 2020-2024.

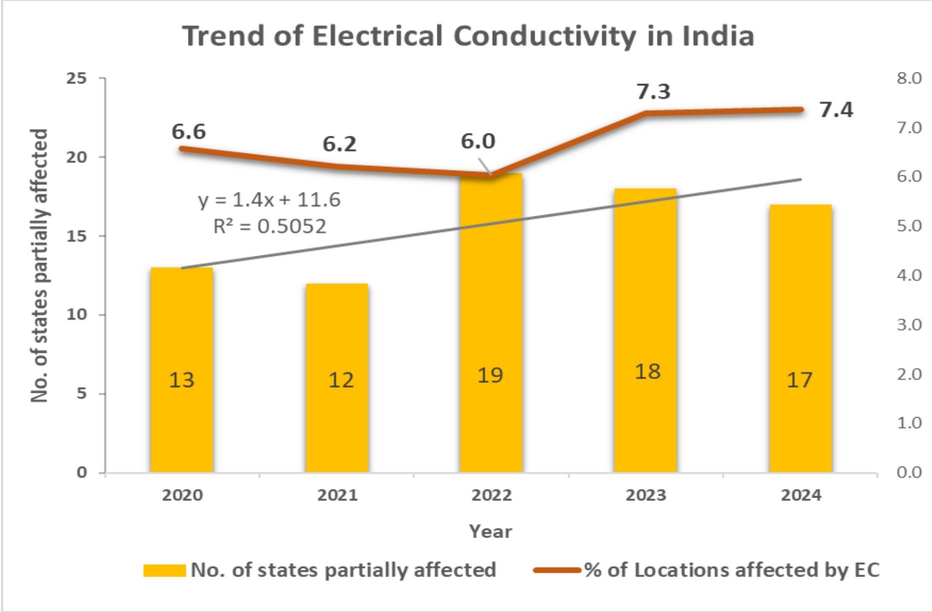

Figure 4: Periodic variation in Electrical Conductivity (EC) values of groundwater in India.

4.1.2 NITRATE

Naturally occurring nitrate forms when nitrogen and oxygen combine in soil, primarily sourced from atmospheric nitrogen. Groundwater nitrate mainly comes from chemical fertilizers, animal manure leaching, and sewage discharge. Identifying natural vs. man-made sources is challenging. Chemical and microbiological processes like nitrification and denitrification also affect groundwater nitrate levels.

As per the BIS standard for drinking water the maximum desirable limit of nitrate concentration in groundwater is 45 mg/l. Though nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water is an environmental health concern arising from increased risks of methaemoglobonaemia particularly to infants. Adults can tolerate little higher concentration.

PRESENT DAY SCENARIO IN INDIA W.R.T NITRATE (NO_3)

Distribution of Nitrate (NO_3)

The probable sources of nitrate contamination of ground water are through excessive application of fertilizers, bacterial nitrification of organic nitrogen, and seepage from animal and human wastes and atmospheric inputs. In the State, nitrate in ground water samples varies from 0 to 2070 mg/L. BIS permits a maximum concentration of 45 mg/L nitrate in drinking water. Considering this limit, it is found that 75.8 % of the samples, spread over the entire country, have nitrate below 45 and 24.2 % have concentration more than 45 mg/L. Spatial distribution of nitrate (Figure 5) indicates parts of the country having nitrate concentration exceeding 45 mg/L.

The Table 4 given below provides for the number of samples analyzed per state, along with their minimum, maximum, and mean Nitrate values based on pre monsoon 2024 Data.

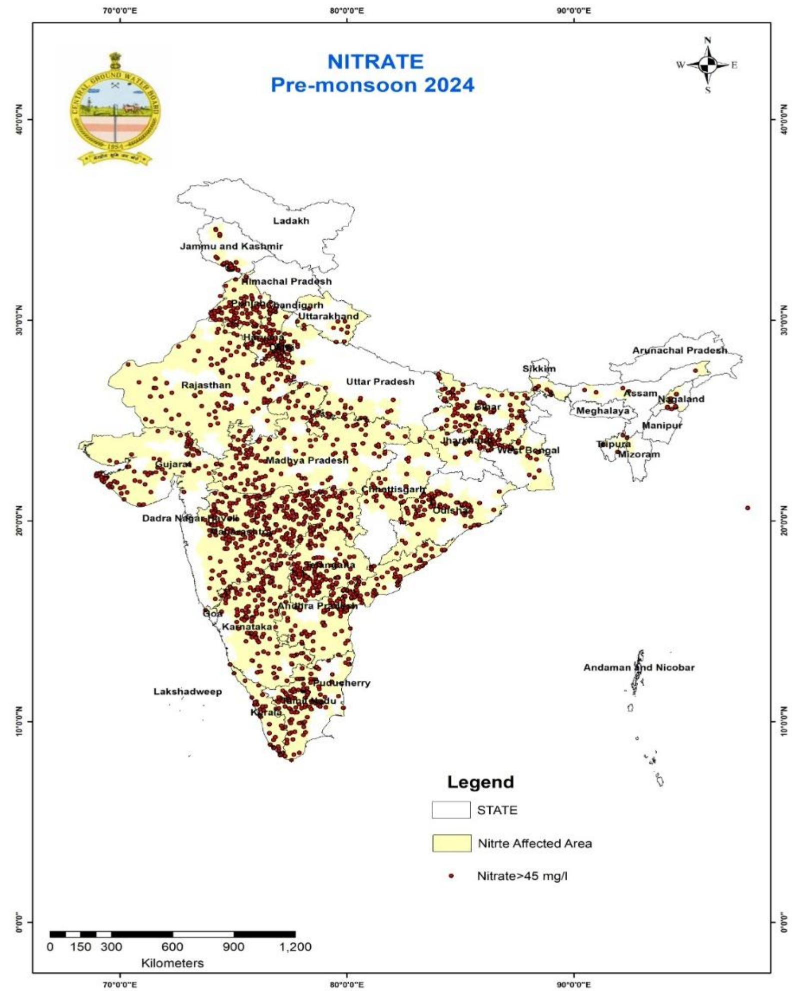

Figure 5: Map showing distribution of Nitrate in India based on NHS 2024 Pre-monsoon Data

S. No.	State	Number of Samples Analysed (2024-25)	Min	Max	Mean	Percentage of samples showing Nitrate value	
						≤ 45 mg/L	> 45 mg/L
1	A&N Islands	29	0	35	5	100.0	0.0
2	Andhra Pradesh	333	0	2070	57	58.9	41.1
3	Arunachal Pradesh	20	0	21	5	100.0	0.0
4	Assam	312	0	111	6	98.4	1.6
5	Bihar	127	2	195	61	37.8	62.2
6	Chandigarh	8	0	3	2	100.0	0.0
7	Chhattisgarh	257	0	61	18	87.5	12.5
8	Delhi	38	2	290	50	63.2	36.8
9	Goa	2	34	96	65	50.0	50.0
10	Gujarat	147	0	866	87	46.9	53.1
11	Haryana	338	0	1185	51	74.9	25.1
12	Himachal Pradesh	63	0	5	1	100.0	0.0
13	Jammu & Kashmir	73	8	205	47	64.4	35.6
14	Jharkhand	138	0	105	37	60.1	39.9
15	Karnataka	317	0	909	66	55.8	44.2
16	Kerala	545	0	148	14	94.1	5.9
17	Madhya Pradesh	614	0	287	32	75.6	24.4
18	Maharashtra	753	0	466	39	59.0	41.0
19	Manipur	4	0	4	2	100.0	0.0
20	Meghalaya	75	0	38	7	100.0	0.0
21	Mizoram	2	2	56	29	50.0	50.0
22	Nagaland	117	0	62	12	88.0	12.0
23	Odisha	459	0	214	28	81.7	18.3
24	Punjab	284	0	440	41	72.2	27.8
25	Rajasthan	224	0	1202	94	57.1	42.9
26	Tamil Nadu	306	1	331	47	62.7	37.3
27	Telangana	412	0	250	43	65.3	34.7
28	Tripura	90	0	56	8	95.6	4.4
29	UT of Puducherry	7	1	28	8	100.0	0.0
30	Uttar Pradesh	670	0	181	16	93.3	6.7
31	Uttarakhand	241	0	72	8	95.4	4.6
32	West Bengal	276	0	138	13	89.1	10.9
	Total	**7281**	**0**	**2070**	**34**	**75.8**	**24.2**

Table 4: State wise Range and distribution of Nitrate in shallow GW of India

TEMPORAL VARIATION OF NO_3 IN GROUND WATER DURING THE PERIOD FROM 2020 TO 2024

S.No.	State/ UT	% of No. of Locations having Nitrate > 45 mg/ L				
		2020	2021	2022	2023	2024
1	Andaman & Nicobar Islands	0.0	0.0	0.0	0.0	0.0
2	Andhra Pradesh	0.0	30.9	31.4	23.5	41.1
3	Arunachal Pradesh	0.0	0.0	0.0	0.0	0.0
4	Assam	0.0	0.0	0.0	0.0	1.6
5	Bihar	41.4	13.4	1.1	2.4	62.2
6	Chandigarh UT	0.0	0.0	0.0	0.0	0.0
7	Chhattisgarh	21.7	16.2	14.1	11.5	12.5
8	Dadra And Nagar Haveli	0.0	0.0	4.5	0.0	0.0
9	Daman And Diu	0.0	0.0	0.0	0.0	0.0
10	Delhi	15.2	21.5	34.7	20.4	36.8
11	Goa	0.0	0.0	5.3	0.0	50.0
12	Gujarat	32.1	28.5	24.7	18.0	53.1
13	Haryana	23.0	18.6	16.0	14.6	25.1
14	Himachal Pradesh	7.8	10.1	7.5	9.4	0.0
15	Jammu & Kashmir	14.5	11.3	10.0	9.2	35.6
16	Jharkhand	36.0	56.8	12.8	5.8	39.9
17	Karnataka	44.5	0.0	25.4	49.0	44.2
18	Kerala	0.0	8.3	8.7	6.7	5.9
19	Madhya Pradesh	34.9	25.2	23.8	22.6	24.4
20	Maharashtra	28.4	7.7	37.6	35.7	41.0
21	Manipur	0.0	0.0	0.0	0.0	0.0
22	Meghalaya	0.0	0.0	0.0	0.0	0.0
23	Mizoram	0.0	0.0	0.0	0.0	50.0
24	Nagaland	0.0	0.0	6.7	0.0	12.0
25	Odisha	16.3	6.3	6.3	14.4	18.3
26	Punjab	26.9	22.4	19.4	12.6	27.8
27	Rajasthan	39.5	35.9	41.7	49.5	42.9
28	Tamil Nadu	39.8	38.4	37.5	37.8	37.3
29	Telangana	0.0	59.7	39.3	27.5	34.7
30	Tripura	0.0	0.0	0.0	2.5	4.4
31	Pondicherry	0.0	0.0	56.3	25.0	0.0
32	Uttar Pradesh	8.3	8.4	9.2	9.4	6.7
33	Uttarakhand	3.5	3.4	2.0	17.4	4.6
34	West Bengal	7.8	11.2	10.0	8.7	10.9
	Total	**23.7**	**19.4**	**21.4**	**19.8**	**24.2**

Table 5: Comparative change in percentage of locations having Nitrate > 45 mg/l

It has been observed (Table 5) that percentage of number of locations in various districts having high Nitrate (more than 45 mg/l) content in ground water has slightly increased from 23.7% in year 2020 to 24.2% in the year 2024, and an overall increasing trend has been observed (Figure 6).

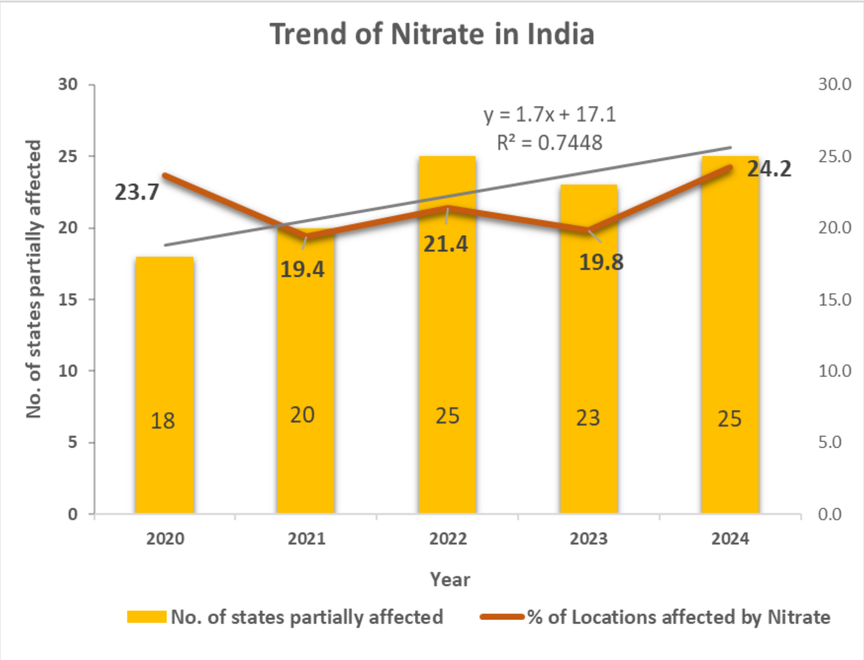

Figure 6: Periodic variation in Nitrate contaminated sites in groundwater of India

4.1.3 FLUORIDE

Fluorine does not occur in the elemental state in nature because of its high reactivity. It exists in the form of fluorides in a number of minerals of which Fluorspar, Cryolite, Fluorite & Fluorapatite are the most common.

Most of the fluoride found in groundwater is naturally occurring from the breakdown of rocks and soils or weathering and deposition of atmospheric particles. Most of the fluorides are sparingly soluble and are present in groundwater in small amount. The type of rocks, climatic conditions, nature of hydro geological strata and time of contact between rock and the circulating groundwater affect the occurrence of fluoride in natural water.

BIS has recommended a desirable limit of 1.0 mg/l of fluoride concentration in drinking water and maximum permissible limit of 1.5 mg/l in case no alternative source of drinking water is available. It is well known that small amount of fluoride (up to 1.0 mg/l) have proven to be beneficial in reducing tooth decay. However, high concentrations (>1.5mg/l) have resulted in staining of tooth enamel while at still higher levels of fluoride (> 5.0 mg/l) further critical problems such as stiffness of bones occur. Water having fluoride concentration more than 1.5 mg/L is not suitable for drinking purposes. High Fluoride (> 1.5mg/L) is mainly attributed due to geogenic conditions.

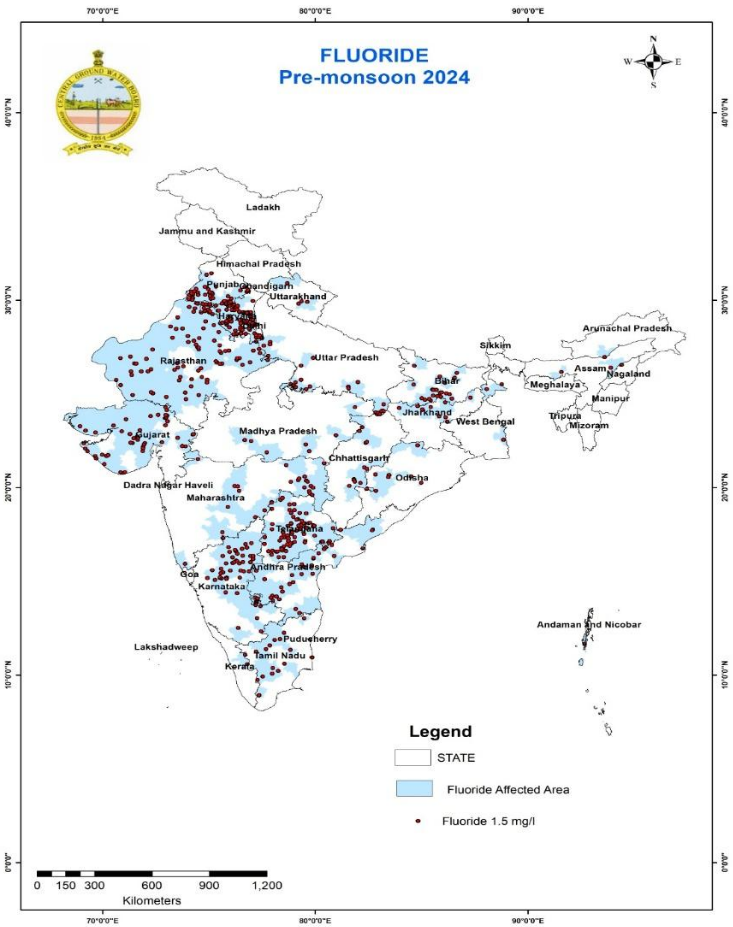

Figure 7: Map showing distribution of Fluoride in India based on NHS 2024 Pre-monsoon Data

Distribution of Fluoride (F)

The fluoride content in ground water ranges from 0.0 to 14.0 mg/L As per above mentioned BIS limits, it is found that 92.4 % samples have fluoride under the permissible limit, while the remaining 7.6 % have fluoride concentration above 1.50 mg/L. Map showing spatial distribution (Figure 7) of fluoride contents in ground water indicates the Fluoride affected parts of the country. It is worth mentioning that high fluoride waters are encountered in areas where high salinity is encountered. The Table 6 given below provides for the number of samples analyzed per state, along with their minimum, maximum, and mean Fluoride values based on NHS 2024 Pre-monsoon trend stations data.

S. No.	State	Number of Samples Analysed (2024-25)	Min	Max	Mean	Percentage of samples showing Fluoride value	
						≤ 1.5 mg/L	> 1.5 mg/L
1	A&N Islands	29	0.0	1.8	0.3	96.6	3.4
2	Andhra Pradesh	333	0.0	5.7	0.8	89.8	10.2
3	Arunachal Pradesh	20	0.1	1.5	0.8	95.0	5.0
4	Assam	312	0.0	2.4	0.4	99.4	0.6
5	Bihar	127	0.2	2.4	1.0	81.9	18.1
6	Chandigarh	8	0.3	1.1	0.6	100.0	0.0
7	Chhattisgarh	257	0.0	3.5	0.7	95.3	4.7
8	Delhi	38	0.2	3.2	1.1	76.3	23.7
9	Goa	2	0.1	0.1	0.1	100.0	0.0
10	Gujarat	147	0.0	9.1	1.4	68.7	31.3
11	Haryana	338	0.1	14.0	1.4	76.0	24.0
12	Himachal Pradesh	63	0.0	0.6	0.2	100.0	0.0
13	Jammu & Kashmir	73	0.1	1.1	0.3	100.0	0.0
14	Jharkhand	138	0.0	2.5	0.7	93.5	6.5
15	Karnataka	317	0.0	4.6	0.9	83.3	16.7
16	Kerala	545	0.0	2.0	0.1	99.6	0.4
17	Madhya Pradesh	614	0.0	2.7	0.5	98.9	1.1
18	Maharashtra	753	0.0	4.9	0.5	96.9	3.1
19	Manipur	4	0.0	0.9	0.2	100.0	0.0
20	Meghalaya	75	0.0	0.9	0.1	100.0	0.0
21	Mizoram	2	0.0	0.0	0.0	100.0	0.0
22	Nagaland	117	0.0	1.7	0.2	99.1	0.9
23	Odisha	459	0.0	2.8	0.5	98.5	1.5
24	Punjab	284	0.2	10.4	1.0	85.2	14.8
25	Rajasthan	224	0.0	13.5	1.6	67.0	33.0
26	Tamil Nadu	306	0.0	4.0	0.6	95.1	4.9
27	Telangana	412	0.0	5.8	1.0	80.3	19.7
28	Tripura	90	0.0	1.3	0.4	100.0	0.0
29	UT of Puducherry	7	0.2	1.7	0.5	85.7	14.3
30	Uttar Pradesh	670	0.0	6.7	0.6	96.6	3.4
31	Uttarakhand	241	0.0	2.4	0.2	98.3	1.7
32	West Bengal	276	0.0	2.0	0.3	98.9	1.1
	Total	**7281**	**0.0**	**14.0**	**0.6**	**92.4**	**7.6**

Table 6: State wise Range and distribution of Fluoride in GW of India

TEMPORAL VARIATION OF FLUORIDE IN GROUND WATER DURING THE PERIOD FROM 2020 TO 2024

It has been observed (Table 7) that total percentage of locations affected by high fluoride values has increased from 6.8 % in 2020 to 7.6 % in 2024.

S.No.	State/ UT	% of No. of Locations having Fluoride > 1.5 mg/ L				
		2020	2021	2022	2023	2024
1	Andaman & Nicobar Islands	0.0	0.0	0.0	0.0	3.4
2	Andhra Pradesh	0.0	5.5	9.8	11.3	10.2
3	Arunachal Pradesh	0.0	0.0	0.0	0.0	5.0
4	Assam	1.1	1.7	0.0	0.0	0.6
5	Bihar	0.0	0.7	3.8	4.6	18.1
6	Chandigarh UT	0.0	0.0	0.0	0.0	0.0
7	Chhattisgarh	2.0	1.3	1.4	1.8	4.7
8	Dadra And Nagar Haveli	0.0	0.0	4.5	0.0	0.0
9	Daman And Diu	0.0	0.0	0.0	0.0	0.0
10	Delhi	9.1	16.5	15.8	16.5	23.7
11	Goa	0.0	0.0	3.9	0.0	0.0
12	Gujarat	13.8	8.8	11.6	13.9	31.3
13	Haryana	13.9	17.7	11.0	23.7	24.0
14	Himachal Pradesh	1.1	1.4	4.4	1.2	0.0
15	Jammu & Kashmir	0.9	2.0	0.4	0.0	0.0
16	Jharkhand	3.3	0.8	2.8	2.8	6.5
17	Karnataka	11.6	0.0	7.2	17.7	16.7
18	Kerala	0.0	0.3	0.4	0.3	0.4
19	Madhya Pradesh	1.7	2.1	1.3	1.0	1.1
20	Maharashtra	1.7	0.0	2.8	1.9	3.1
21	Manipur	0.0	0.0	0.0	0.0	0.0
22	Meghalaya	3.7	0.0	0.0	0.0	0.0
23	Mizoram	0.0	0.0	0.0	0.0	0.0
24	Nagaland	0.0	0.0	0.0	0.0	0.9
25	Odisha	3.8	2.0	2.4	4.5	1.5
26	Punjab	8.4	8.8	8.7	13.8	14.8
27	Rajasthan	27.5	19.5	26.0	43.2	33.0
28	Tamil Nadu	2.7	8.2	10.0	9.7	4.9
29	Telangana	0.0	15.1	18.7	14.9	19.7
30	Tripura	0.0	0.0	0.0	0.0	0.0
31	Pondicherry	0.0	0.0	0.0	0.0	14.3
32	Uttar Pradesh	1.4	4.2	3.9	5.7	3.4
33	Uttarakhand	0.0	0.0	0.5	0.5	1.7
34	West Bengal	3.6	1.2	0.6	0.7	1.1
	Total	**6.8**	**5.6**	**6.6**	**9.0**	**7.6**

Table 7: Comparative change in percentage of Locations having F > 1.5 mg/l

Overall, the values are showing an increasing trendline (Figure 8).

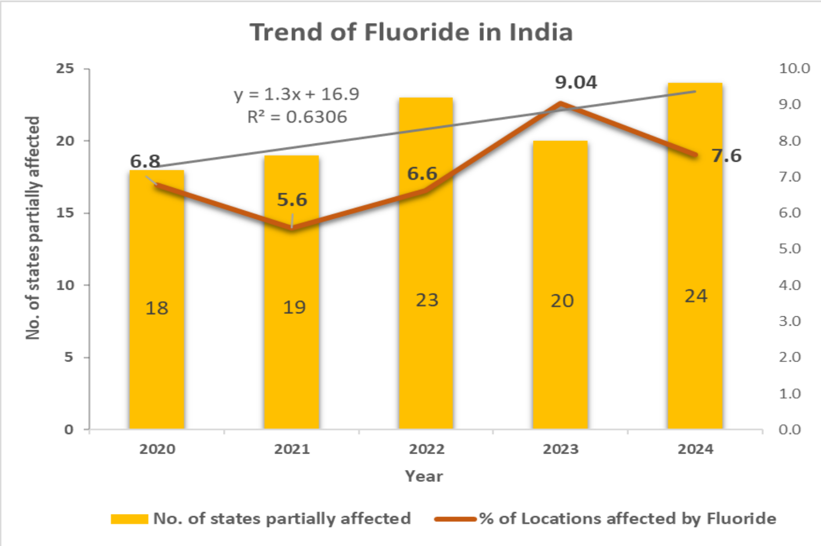

Figure 8: Periodic variation in Fluoride contaminated sites in groundwater of India

5. SUMMARY

The analytical results of 7281 Groundwater samples spanning all over the country, show a concerning trend and this decline in water quality may stem from geogenic or anthropogenic sources. While most samples from Central Ground Water Board observation wells meet drinking water standards for basic parameters, some of them exceed permissible limits, posing health risks with prolonged use. The Table 8 provides a detailed summary of groundwater quality across various states in India, focusing on basic parameters namely electrical conductivity, nitrate and fluoride.

S. No.	State/ UT	Number of Samples Analysed (2024-25)	EC >3000 µS/cm		Nitrate > 45 mg/L		Fluoride > 1.5 mg/L	
			No. of samples	% of samples	No. of samples	% of samples	No. of samples	% of samples
1	A&N Islands	29	1	3.4	0	0.0	1	3.4
2	Andhra Pradesh	333	50	15.0	137	41.1	34	10.2
3	Arunachal Pradesh	20	0	0.0	0	0.0	1	5.0
4	Assam	312	0	0.0	5	1.6	2	0.6
5	Bihar	127	3	2.4	79	62.2	23	18.1
6	Chandigarh	8	0	0.0	0	0.0	0	0.0
7	Chhattisgarh	257	1	0.4	32	12.5	12	4.7
8	Delhi	38	20	52.6	14	36.8	9	23.7
9	Goa	2	0	0.0	1	50.0	0	0.0
10	Gujarat	147	73	49.7	78	53.1	46	31.3
11	Haryana	338	112	33.1	85	25.1	81	24.0
12	Himachal Pradesh	63	0	0.0	0	0.0	0	0.0
13	Jammu & Kashmir	73	0	0.0	26	35.6	0	0.0
14	Jharkhand	138	0	0.0	55	39.9	9	6.5
15	Karnataka	317	47	14.8	140	44.2	53	16.7
16	Kerala	545	0	0.0	32	5.9	2	0.4
17	Madhya Pradesh	614	4	0.7	150	24.4	7	1.1
18	Maharashtra	753	29	3.9	309	41.0	23	3.1
19	Manipur	4	0	0.0	0	0.0	0	0.0
20	Meghalaya	75	0	0.0	0	0.0	0	0.0
21	Mizoram	2	0	0.0	1	50.0	0	0.0
22	Nagaland	117	0	0.0	14	12.0	1	0.9
23	Odisha	459	6	1.3	84	18.3	7	1.5
24	Punjab	284	31	10.9	79	27.8	42	14.8
25	Rajasthan	224	88	39.3	96	42.9	74	33.0
26	Tamil Nadu	306	44	14.4	114	37.3	15	4.9
27	Telangana	412	11	2.7	143	34.7	81	19.7
28	Tripura	90	0	0.0	4	4.4	0	0.0
29	UT of Puducherry	7	0	0.0	0	0.0	1	14.3
30	Uttar Pradesh	670	9	1.3	45	6.7	23	3.4
31	Uttarakhand	241	0	0.0	11	4.6	4	1.7
32	West Bengal	276	8	2.9	30	10.9	3	1.1
	Total	**7281**	**537**	**7.4**	**1764**	**24.2**	**554**	**7.6**

Table 8: Summary of Groundwater Quality in India: Samples Collected and Contamination Percentage

- EC (Electrical Conductivity): 7.4 % of samples exceed permissible limits, with higher occurrences in states/UTs like Rajasthan (39.3 %), Gujarat (49.7 %), Haryana (33.1 %) and Delhi (52.6 %) This high percentage may also be attributed to the fact that the data collected was for trend stations, which were already vulnerable to parameter specific contamination.
- NO_3 (Nitrate): 24.2 % of the samples exceed permissible limit, with varying percentages across states.
- F (Fluoride): Overall 7.6 % of samples surpass permissible levels, with varying percentages across states.

Graphical representation of the same is depicted hereunder:

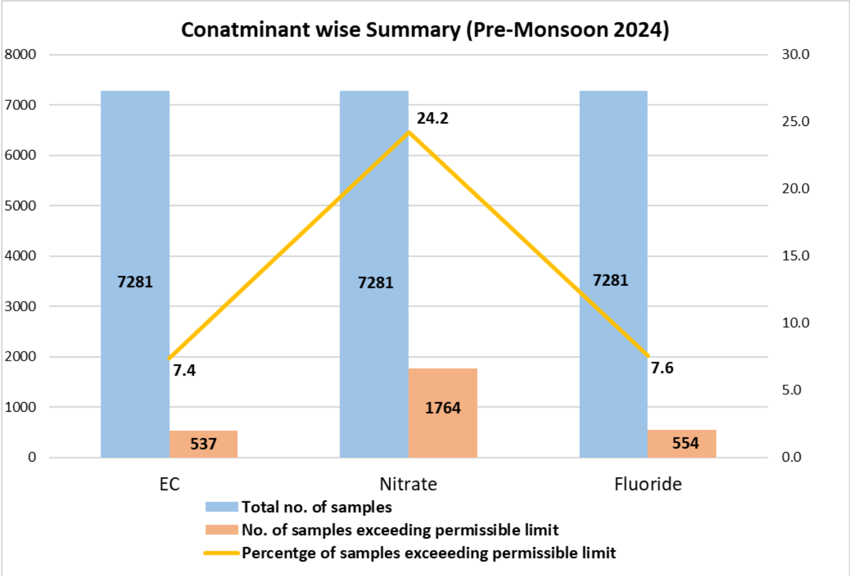

Figure 9: Graph showing contaminant wise state summary

6. RECOMMENDATIONS & MITIGATION MEASURES

Overall, the ground water in India is generally of good quality according to drinking and domestic water standards. However, in a few localized areas, contaminants are found in the groundwater. The primary concern across India is the high nitrate levels detected in various parts of the country which is likely due to the use of pesticides in agriculture, sewage, and other anthropogenic sources. The following points are recommended for proper planning and management of Ground water in India for dealing with ground water quality related issues.

- **Monitoring and Surveillance:** Enduring a robust groundwater monitoring and surveillance system to regularly assess water quality and detect changes over time.

- **Reduce dependency on groundwater:** Initiation of Surface water-based water supply scheme in Fluoride and Arsenic endemic villages. Affected wells should be avoided and alternative contamination free water source should be identified.

- **Prior consumption Treatment:** Water treatment is essential before using it in hot spot areas to ensure its safety and suitability for various purposes.

- **Participatory Ground water management:** Encourage and foster public engagement in groundwater management is essential to implement a comprehensive strategy that involves and empowers individuals and protect the source.

- **Promoting the 3 R's (Reduce, Reuse, Recycle):** Promoting the 3 R's (Reduce, Reuse, Recycle) in the context of groundwater protection is crucial for sustainable water management.

In addition to these practices, some mitigation measures are introduced below to curb the parameter specific contamination in affected areas:

- **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.

- **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)

- **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

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.**