International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
SJIF (2025): 8.036

Assessment of Physicochemical Characteristics and Fluoride Distribution in Groundwater of the Vidarbha Region

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Abstract: ***Groundwater serves as a primary source of drinking water in many parts of the Vidarbha region of Maharashtra; however, its quality is influenced by natural geochemical processes and localized anthropogenic activities. The present study evaluates the physicochemical characteristics of groundwater samples collected from twenty locations across the region, with particular emphasis on fluoride contamination. Parameters including pH, fluoride, sulphate, nitrate, phosphate, calcium, turbidity, total hardness (TH), electrical conductivity (EC), and total dissolved solids (TDS) were analyzed using standard analytical procedures. The groundwater was found to be neutral to slightly alkaline, with fluoride concentrations showing spatial variability. While most samples were within recommended drinking water limits, a few locations exhibited elevated fluoride levels, indicating localized geogenic enrichment due to prolonged water–rock interaction. Several samples also showed high TDS, EC, and hardness values, suggesting significant mineralization and dissolution of aquifer materials. The turbidity–TDS relationship indicated that suspended particles, rather than dissolved ions, largely governed turbidity variations. The overall assessment highlights the need for regular groundwater monitoring and the implementation of effective, region-specific treatment strategies, particularly in fluoride-affected areas.***

Keywords: Groundwater quality; Fluoride contamination; Vidarbha region; Physicochemical parameters; Hydrogeochemistry; Total dissolved solids; Water quality assessment; Defluoridation

1.Introduction

The scarcity of safe drinking water has become a global concern, affecting both rural and urban populations across many nations. Each year, millions of individuals are exposed to waterborne diseases that are largely preventable but persist due to poor sanitation and lack of access to clean water. [1] Ensuring safe drinking water is therefore recognized as one of the major challenges of the twenty-first century. Water resources are increasingly burdened by a wide spectrum of contaminants including organic, inorganic, and microbial pollutants that infiltrate aquifers from multiple sources, thereby intensifying the drinking water crisis. [2] Rapid growth in population and the pace of industrial development have further contributed to environmental degradation on a large scale. Among these pollutants, fluoride ions (F^-) are a significant concern because they are commonly detected in both groundwater and surface water.[3] Their occurrence arises from natural geological processes as well as human activities.

Excessive intake of fluoride through drinking water has been identified as a serious public health risk, leading to disorders collectively known as fluorosis. [4] This condition, caused by prolonged exposure, affects teeth, bones, and in severe cases other vital organs, thereby creating a widespread environmental and health hazard. Consequently, the development of effective materials such as modified activated alumina for the removal of fluoride has become an essential area of research.[5]

Fluorine (F), belonging to the halogen group, has an atomic number of 9 and an atomic mass of 18.998 amu. In its elemental form, it occurs as a pale-yellow diatomic gas (F_2) with a melting point of -219.67 °C, a boiling point of -188.11 °C, and a density of 1.696 g/L at 0 °C and standard pressure (101.32 kPa). [6] Being the most electronegative element, fluorine exhibits extremely strong oxidizing behavior in its molecular state. Owing to this high reactivity, it is rarely found in nature in elemental form and is instead commonly present as the fluoride ion (F^-).[7]

Fluoride contamination of groundwater has emerged as an important environmental and public health concern in the Vidarbha region of Maharashtra. Several hydrogeochemical investigations have reported elevated fluoride concentrations in districts such as Nagpur, Amravati, Yavatmal, Chandrapur, and Buldhana, particularly in rural areas that depend heavily on groundwater for drinking purposes.[8] The occurrence of fluoride in this region is primarily attributed to natural geogenic sources, where prolonged interaction between groundwater and fluoride-bearing minerals in the host rocks leads to its dissolution. Variations in fluoride levels are influenced by factors such as lithology, groundwater residence time, pH, and climatic conditions. In many villages, measured concentrations exceed recommended drinking water limits, increasing the risk of dental and skeletal fluorosis among local populations.[9]

Public health surveys conducted in fluoride-affected parts of Vidarbha have documented noticeable cases of dental fluorosis among children and early symptoms of skeletal fluorosis in adults exposed to contaminated water over long periods. Although monitoring programs by state agencies have helped identify high-risk zones, access to safe and sustainable defluoridation systems remains limited in several rural communities. Existing mitigation strategies include the development of alternative water sources, installation of small-scale treatment units, and public awareness initiatives. However, the literature emphasizes the need for improved groundwater monitoring, village-level mapping of contamination, and the adoption of cost-effective treatment technologies that are suitable for long-term use under local conditions.

Groundwater and surface water resources are increasingly threatened by the presence of various contaminants, including organic, inorganic, and microbiological pollutants originating from natural and anthropogenic activities. Rapid population growth and accelerating industrial development have further intensified environmental pressures, contributing to widespread water quality deterioration. Among the inorganic pollutants of concern, fluoride (F^-) is particularly significant because it can contaminate both groundwater and surface water through geological processes as well as human activities. Prolonged consumption of water containing excessive fluoride levels poses serious health risks and can lead to fluorosis, making fluoride contamination a major global public health concern.

Several field investigations in India have documented the occurrence of fluoride and arsenic in groundwater. Researchers in the Vidarbha region of Maharashtra reported elevated fluoride levels in borewell water, linking the problem to leaching of fluorite- and apatite-bearing minerals. Similarly, arsenic has been detected in trace to toxic levels in aquifers influenced by sedimentary deposits and geochemical processes. These studies underline the urgent need for low-cost, locally applicable defluoridation and decontamination technologies. The present study illustrates the fluoride concentration in water sources located in Vidarbha region.

2.Water Sample Collection Protocol for Fluoride, TDS, Conductivity and Total Hardness

Water samples were collected following standard procedures to ensure representative sampling and to prevent contamination or alteration of water quality parameters. Clean, high-density polyethylene (HDPE) bottles (500-1000 mL capacity) were used for sample collection. Prior to sampling, the bottles were washed with laboratory detergent, rinsed thoroughly with distilled water, soaked in dilute nitric acid, and finally rinsed with deionized water. At the sampling site, each bottle was rinsed two to three times with the water to be sampled before final collection.

For groundwater sampling, the source (hand pump or borewell) was allowed to run for 3-5 minutes to flush stagnant water and obtain a representative sample. The bottles were filled without trapping air bubbles and tightly sealed. Samples intended for fluoride, total dissolved solids (TDS), electrical conductivity (EC), and total hardness (TH) analysis were stored in insulated containers and transported to the laboratory as soon as possible. During transport, samples were kept at approximately 4 °C to minimize chemical and biological changes.

Measurements of TDS and electrical conductivity were preferably carried out on-site using calibrated portable meters to avoid changes during storage. Fluoride and total hardness analyses were performed in the laboratory within 24-48 hours of collection. All instruments were calibrated using standard solutions prior to analysis. Proper labeling, including sampling location, date, time, and sample code, was maintained to ensure traceability.

Table 1: Locations of the water samples collection sites in Vidarbha Region

Sample Code	Village	Latitude	Longitude	Source
4001	Suradevi	21.246616 N	79.120806 E	HP
4002	Mhasala	21.213573 N	79.125103 E	BW
4003	Gadchiroli	20.111023 N	80.001981 E	HP
4004	Kawatha	21.230101 N	79.143506 E	HP
4005	Yawatmal	20.14 1425 N	78.042423 E	HP
4006	Waregaon	21.245869 N	79.154677 E	HP
4007	Kanhan River	21.220934 N	79.150091 E	BW
4008	Bidbina	21.260832 N	79.152913 E	HP
4009	Samata Nagar	21.204167 N	79.106329 E	HP
4010	Khairy	21.216942 N	79.153971 E	HP
4011	New Khasala	21.20628 N	79.128217 E	BW
4012	Nara	21.215274 N	79.09116 E	BW
4013	Bidbina	21.244346 N	79.143233 E	HP
4014	Mahadula	21.231754 N	79.112863 E	BW
4015	Samata Nagar	21.229844 N	79.083394 E	BW
4016	Karanja (Ghadge)	20.481377 N	77.482109 E	BW
4017	Amravati	20.553312 N	77.455376 E	BW
4018	Chandrapur	19.570012 N	79.171749 E	BW
4019	Bhandara	21.113240 N	79.392122 E	HP
4020	Gondia	21.273511 N	80.114223 E	HP

HP- Hand Pump, BW- Bore well

3.Physicochemical Characteristics of Groundwater Samples from Vidarbha Region

The physicochemical properties of groundwater samples collected from various locations in the Vidarbha region are presented in Table 1. The parameters analyzed include fluoride, sulphate, nitrate, phosphate, calcium, turbidity, pH, total hardness (TH), electrical conductivity (EC), and total dissolved solids (TDS). Together, these parameters offer a comprehensive understanding of the hydrogeochemical characteristics of the groundwater and help assess its suitability for drinking purposes. [10-12]

The pH of the groundwater samples ranged from 7.0 to 7.9, indicating a neutral to slightly alkaline nature of the aquifer system.[13] Such pH conditions are typical of groundwater circulating through basaltic formations of the Deccan Trap and play a significant role in controlling fluoride mobility and adsorption behavior. Slightly alkaline conditions are known to favor the dissolution of fluoride-bearing minerals, thereby influencing fluoride concentration in groundwater.[14]

Fluoride concentrations showed noticeable spatial variation across the study area (figure 2). Most groundwater samples exhibited fluoride levels below the BIS guideline limit of 1.0 mg/L, indicating generally safe conditions for drinking.[15] However, samples 4007 (Kanhan) and 4003 (Gadchiroli) recorded fluoride concentrations of approximately 1.983 mg/L and 1.673 mg/L, respectively, exceeding the permissible limit. These elevated values suggest localized geogenic enrichment, possibly due to prolonged water–rock interaction and the presence of fluoride-bearing minerals in the aquifer matrix.[16] Prolonged consumption of such water may pose a risk of dental fluorosis, emphasizing the need for targeted mitigation measures in these locations.[17]

Sulphate concentrations varied widely among the samples, ranging from moderate to high values. Elevated sulphate levels observed in some samples may be attributed to mineral dissolution, agricultural runoff, or localized anthropogenic inputs.[18] Nitrate concentrations were generally within acceptable limits, indicating limited impact from agricultural fertilizers or sewage contamination. [19] Similarly, phosphate levels remained low to moderate, suggesting minimal nutrient pollution in the groundwater system.

Calcium concentrations ranged from moderate to high, contributing significantly to the observed total hardness values, which varied from 30 to 523 mg/L. The presence of high hardness in several samples indicates dominance of alkaline earth metals, particularly calcium, which is consistent with groundwater interaction with carbonate and silicate minerals.[20] High hardness, although not a direct health concern, affects water palatability and domestic usability.[21]

Electrical conductivity values showed a strong positive correlation with total dissolved solids, confirming that EC is a reliable indicator of ionic strength and salinity of groundwater.[22] TDS values ranged from 783 to 2621 mg/L, with several samples exceeding the recommended drinking water limits.[23] Elevated TDS indicates high mineralization, which may arise from prolonged residence time of groundwater, evaporation effects, and dissolution of soluble salts. Such conditions can adversely affect the suitability of groundwater for drinking and domestic use.[24]

Table 2: Chemical Characteristics of Groundwater Samples from Vidarbha Region

Sample Code	F (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	Ca (mg/L)
4001	1.322	31.33	10.9	3.73	303.2
4002	0.342	315.78	11.23	1.27	90.82
4003	1.673	35.873	9.83	4.33	102.34
4004	1.632	56.98	15.84	3.55	209.88
4005	0.378	415.98	12.34	6.83	515.88
4006	0.893	412.98	12.34	2.83	233.44
4007	1.983	80.873	6.78	1.73	70.92
4008	0.675	651.87	13.83	4.23	452.92
4009	0.986	54.983	9.76	3.44	502.9
4010	1.123	167.98	9.34	2.43	289.92
4011	0.879	713.88	10.22	3.44	216.22
4012	1.245	90.833	9.83	1.4	356.72
4013	1.452	811.98	17.22	3.63	380.32
4014	1.456	367.98	21.72	0.73	345.83
4015	1.234	302.98	15.82	2.73	309.33
4016	1.433	405.94	17.92	3.42	305.93
4017	1.233	512.93	12.32	4.92	307.55
4018	0.322	432.33	17.92	5.34	412.37
4019	1.23	512.74	18.45	6.12	523.98
4020	0.78	440.5	17.45	7.23	330.84

Table 3: Physical Characteristics of Groundwater Samples from Vidarbha Region

Sample Code	Turbidity (NTU)	pH	Total Hardness (mg/L)	EC (mS/cm)	TDS (mg/L)
4001	7.8	7.4	321	1.763	783
4002	5.6	7.8	345	1.983	2544
4003	12.43	7.2	564	2.021	1802
4004	5.6	7.9	321	1.872	1672
4005	9.76	7.4	478	1.567	1452
4006	32.33	7.6	876	2.982	1892
4007	23.45	7.9	234	2.287	1892
4008	70.85	7.1	454	1.873	1892
4009	66.76	7.2	463	1.352	1520
4010	34.56	7.4	512	2.383	1522
4011	23.45	7.5	324	0.971	1892
4012	9.32	7.8	186	2.367	2621
4013	8.23	7.9	498	2.378	2367
4014	5.6	7.1	387	2.3892	2102
4015	4.5	7.5	467	1.983	2378
4016	6.4	7.0	572	1.29	1890
4017	7.3	7.6	623	1.75	1550
4018	7.9	7.5	640	1.88	2110
4019	8.2	6.9	550	1.88	1850
4020	7.7	6.8	340	2.45	2118

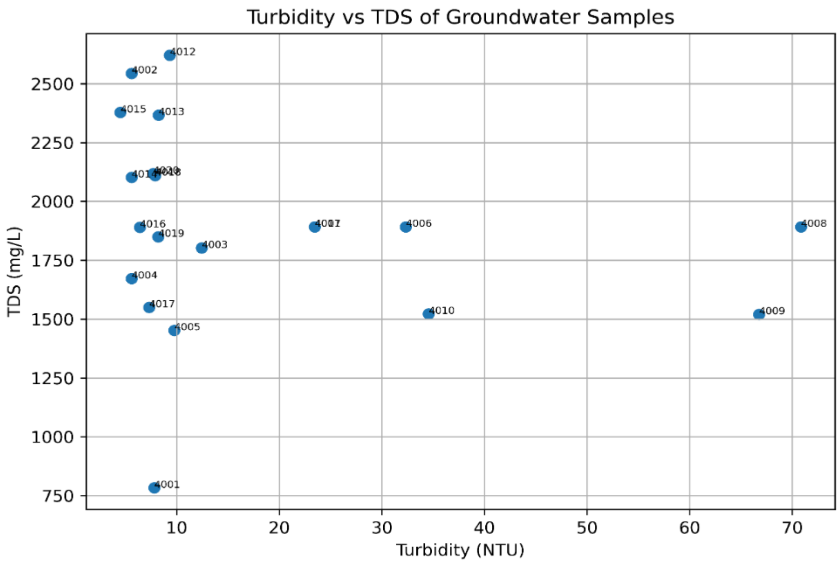

Figure 1: Turbidity Vs TDS plot for ground water samples

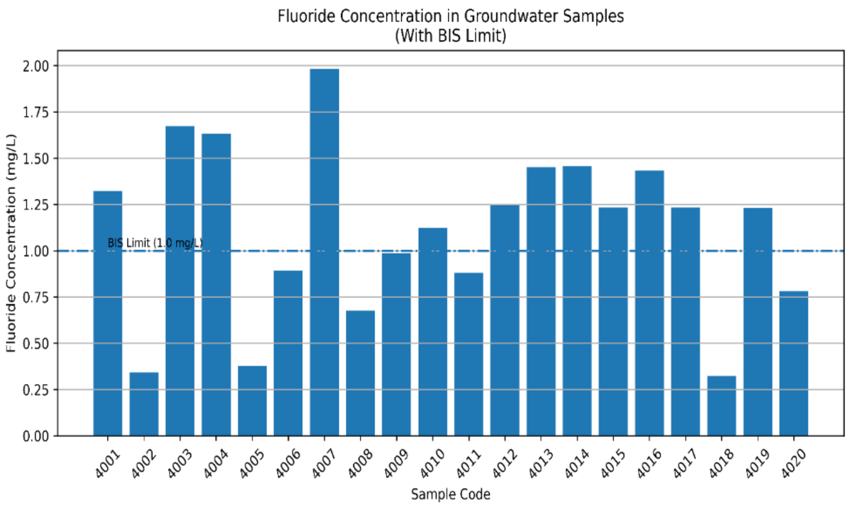

Figure 2: Fluoride concentrations in ground water samples

Turbidity values exhibited significant variation, with some samples (Figure 1) showing elevated turbidity levels. The scatter plot of turbidity versus TDS reveals an inverse trend, where higher turbidity is often associated with relatively lower TDS values. This behavior suggests that turbidity is mainly influenced by suspended particulates rather than dissolved ions. [25] Samples such as 4008 and 4009 showed notably high turbidity, possibly due to fine colloidal particles, poor well construction, or surface water intrusion during sampling.

Overall, the integrated assessment of physicochemical parameters indicates that groundwater quality in the Vidarbha region is generally characterized by neutral to slightly alkaline pH, low to moderate fluoride levels, and variable salinity and hardness. While fluoride contamination is limited to specific pockets, several locations exhibit high TDS and hardness, underscoring the need for continuous monitoring and site-specific water treatment strategies. The identification of fluoride-affected locations provides a strong justification for the development and application of efficient defluoridation materials, such as the Ca- and Mg-modified activated alumina investigated in the present study.

4.Discussion

The physicochemical analysis of groundwater samples collected from various locations in the Vidarbha region reveals considerable spatial variation in water quality parameters, reflecting differences in local hydrogeochemical conditions. The groundwater is predominantly neutral to slightly alkaline (pH 6.8-7.9), a condition that favors the mobility of fluoride through enhanced dissolution of fluoride-bearing minerals present in the host basaltic formations. Fluoride concentrations ranged from 0.322 to 1.983 mg/L, with most samples falling within acceptable drinking limits; however, a few locations exceeded the desirable limit, indicating localized geogenic enrichment and prolonged water–rock interaction. Elevated total dissolved solids (TDS) and electrical conductivity (EC) values in several samples suggest significant mineralization, likely resulting from extended groundwater residence time and dissolution of soluble salts. High total hardness and calcium concentrations further confirm the dominance of alkaline earth metals derived from carbonate and silicate weathering. Sulphate levels exhibited wide variation, possibly influenced by mineral dissolution and anthropogenic inputs, whereas nitrate and phosphate concentrations remained comparatively moderate, indicating limited agricultural or sewage contamination. The turbidity-TDS relationship demonstrates that suspended particulates, rather than dissolved ionic species, largely govern turbidity fluctuations in certain samples. Overall, the findings highlight that although widespread severe fluoride contamination is not evident, specific pockets require attention, and the presence of high salinity and hardness underscores the necessity for continuous monitoring and the implementation of suitable, region-specific water treatment strategies.

5.Conclusions

The present investigation provides a comprehensive assessment of the physicochemical characteristics of groundwater in selected locations of the Vidarbha region. The analysis indicates that groundwater in the study area is generally neutral to slightly alkaline, a condition that facilitates the dissolution and mobility of fluoride from host rock formations. Although most samples exhibited fluoride concentrations within permissible limits, a few locations recorded elevated levels that may pose potential health risks if consumed over prolonged periods. The spatial variation in fluoride concentration highlights the influence of localized geological and hydrogeochemical conditions. In addition to fluoride, several samples showed high total dissolved solids, electrical conductivity, and total hardness, indicating significant mineralization and the dominance of calcium and other alkaline earth metals. While these parameters do not always present immediate health hazards, they affect water palatability and long-term suitability for domestic use. The variability observed in sulphate and turbidity further reflects differences in groundwater–rock interaction, aquifer characteristics, and possible minor anthropogenic influences. Overall, the study underscores the need for periodic monitoring of groundwater quality in the region, particularly in fluoride-prone zones. The identification of affected locations provides a scientific basis for implementing appropriate defluoridation and water treatment strategies. The findings also support the development and application of efficient, low-cost treatment materials to ensure safe and sustainable drinking water for rural communities in Vidarbha.

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