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Comprehensive Evaluation of Drinking Water Quality in Sironcha Tehsil, Maharashtra: Physico-Chemical Characterization and Health Risk Assessment

[1]S.T. Peddiwar; [2]S.B. Lonare*; [3]D.K. Ingole; [4]R.M. Yerojwar; [5]S.V. Pusala; [6]P.P. Patre; [7]G.R. Nimbarte and [8]P.S. Ganvir

[1]Department of Chemistry, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[2]Department of Maths, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[3]Department of Physics, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[4]Department of Physics, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[5]Department of Zoology, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[6]Department of Microbiology, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[7]Department of Chemistry, Mohsinbhai Zaweri Mahavidyalaya, Desaiganj (Wadsa), Dist. - Gadchiroli. Maharashtra, India.
[8]Department of Geology, M. G. Arts, Science & Late N. P. Commerce College, Armori, Dist. - Gadchiroli. Maharashtra, India.

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Abstract: The easy access to the clean drinking water is a requisite for the health of dependent population. However drinking water quality degradation remains a significant challenge, especially in the regions, where groundwater acts as a key source. The groundwater regimes are more vulnerable to the contamination, because of its physical setup. Hence, thoughtful efforts are certainly needed to take over groundwater contamination issues. This study evaluates the physico-chemical quality of drinking water from Sironcha Tehsil of Gadchiroli District in the state of Maharashtra, India, by analysing the parameters such as pH, EC, TDS, Total Hardness, Nitrate, Chloride, Fluoride, and Iron. The results were then compared with the standards prescribed by WHO, to depict the contamination patterns. Apart of the pH and fluoride, rest of the parameters comprising TDS, nitrate, and iron were exceeding the safe thresholds in several samples. The elevated nitrate levels could be attributed to the agricultural runoff; whereas, the geo-genic sources could be held accountable for the high iron concentrations. These apexes pose an undisputed health risk to the dependent population. The correlations among parameters were also measured to sort out the probable contamination sources. In comprehensive picture, the findings underscore the need for targeted water treatment and sustainable management strategies for the study area. This study provides critical insights for the policymakers and public health officials, emphasizing regular monitoring and region specific interventions to ensure safe drinking water.

***Keywords**: Groundwater Quality, Physico-Chemical Analysis, Nitrate Pollution, Drinking Water Safety, Health Risks.*

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I. INTRODUCTION

Water quality is a critical determinant of public health, environmental sustainability, and economic development. Access to clean and safe drinking water is essential for human well-being, yet contamination from natural and anthropogenic sources poses significant challenges globally [1]. In India, where groundwater serves as the primary source of drinking water for millions, the degradation of water quality due to industrial discharge, agricultural runoff, and inadequate waste management is particularly alarming [2-6].

Recent studies have highlighted the presence of harmful contaminants such as fluoride, nitrate, total dissolved solids (TDS), and iron in groundwater, often exceeding permissible limits. For instance, a study over the Gangetic Plains revealed that 35% of groundwater samples exceeded the WHO limit for nitrate, primarily due to excessive fertilizer use and poor sanitation practices [7]. Similarly, another significant study reported the elevated fluoride levels in groundwater across semi-arid regions of Rajasthan, with concentrations reaching up to 4.2 mg/L, far above the limit prescribed by WHO [8]. These contaminations are associated with various health risks, like the methemoglobinemia and increased cancer risks is associated with nitrate contamination, the over intake of fluoride is associated with dental and skeletal fluorosis and many more are associations are there, which are critical in view of public health [9-11].

The variability in terms of seasonal and regional further complicates the task of water quality management. A study conducted a spatio-temporal analysis of groundwater in Telangana, exhibited significant fluctuations in nitrate and hardness levels during monsoon and post-monsoon seasons, emphasizing the need for continuous monitoring [12]. Despite of the guidelines from the WHO and the Bureau of Indian Standards (BIS), many regions in India continues to face the water quality challenges [1, 13]. A nationwide study found that 30% of groundwater samples in rural India exceeded safe limits for fluoride and nitrate, with contamination hotspots in states like Uttar Pradesh, Bihar, and Rajasthan [14].

Looking at this scenario, present study aims to address similar issues by conducting a comprehensive physico-chemical analysis of drinking water samples from Sironcha Tehsil, Gadchiroli District, Maharashtra, India. The focus is on evaluating key parameters such as pH, TDS, hardness, nitrate, fluoride, and iron, along with the comparison with WHO and BIS standards. Additionally, the study explores correlations between the parameters like nitrate and alkalinity to identify contamination patterns. The findings will provide critical insights for policymakers and public health officials, aiding in the development of targeted water treatment and sustainable management strategies.

II. MATERIALS AND METHODS

- *Study Area and Sampling Procedure*

The study focused on the bore well water quality, indirectly taking over the groundwater quality. 20 water samples were collected from active borewells serving as primary drinking water sources during April 2024. The samples were collected in pre-cleaned, sterilized 1L polyethylene bottles, rinsed with sample water to avoid contamination. Each sample was then labelled with location, date, and time, and transported to the laboratory in a cold bath for an immediate analysis [15].

- *Physico-Chemical Analysis*

The physico-chemical parameters of water, including turbidity, pH, electrical conductivity (EC), TDS, alkalinity, fluoride, chloride, nitrate, total hardness, and iron, were analysed following standard methods [1, 15]. The techniques and instruments used are summarized below [16-24]:

Table 1: Techniques and Instruments used for Measurement of Physico-Chemical Parameters

Parameter	Technique and Instrument
pH	Measured using a calibrated digital pH meter (buffer solutions: pH 4.0, 7.0, 9.2)
EC and TDS	Determined using a digital conductometer and TDS meter, respectively
Total Hardness	Estimated by EDTA titration using Eriochrome Black T as an indicator
Nitrate (NO_3^-)	Quantified using the Phenol Disulphonic Acid Method (absorbance measured at 410 nm)
Chloride (Cl^-)	Analysed by Argentometric Titration with potassium chromate as an indicator
Fluoride (F^-)	Estimated using the SPADNS method (spectrophotometric measurement)
Iron (Fe)	Determined by the 1,10-Phenanthroline Method (absorbance measured at 510 nm)
Alkalinity	Measured by acid-base titration using 0.02N H_2SO_4 and phenolphthalein as an indicator

The results were statistically analysed and compared with permissible limits set by the WHO and BIS to assess water suitability for human consumption [1, 13].

III. RESULTS AND DISCUSSION

The groundwater samples collected from the villages in study area were analysed for key parameters, including temperature, pH, electrical conductivity, total dissolved solids (TDS), turbidity, total hardness, alkalinity, chloride, fluoride, nitrate, and iron. These parameters are essential for assessing the suitability of water for drinking and other domestic uses. This analysis interprets the data in the

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context of established water quality standards and findings from recent research studies. The summarized data is presented in Tables 1 and 2.

A. Analysis of Physico-chemical parameters:

- *Temperature*

The temperature of the water samples ranged from 21°C to 27°C. It influences the solubility of gases, chemical reaction rates, and microbial activity in water. Elevated temperatures can also affect the taste and odour of water, making it less palatable [25]. The observed range is typical for surface and groundwater in tropical and subtropical regions.

- *Turbidity (NTU)*

Turbidity levels in the sampled water ranged from 0.36 to 2.28 NTU. Turbidity is a measure of water clarity and is influenced by suspended particles such as clay, silt, and organic matter. High turbidity can interfere with disinfection processes and may indicate the presence of pathogens [26]. The World Health Organization (WHO) recommends a turbidity level of less than 5 NTU for drinking water [1]. All samples are within this limit, but higher values (e.g., 2.28 NTU) may still pose aesthetic concerns.

- *pH*

The pH values in the sampled water ranged from 7.22 to 8.27, indicating slightly alkaline conditions. pH is a critical parameter that affects the solubility and bioavailability of nutrients and contaminants. The optimal pH range for drinking water, as per WHO guidelines, is 6.5–8.5 [1]. All samples fall within this range, suggesting that the water is neither too acidic nor too alkaline for consumption.

- *Electrical Conductivity (EC) and Total Dissolved Solids (TDS)*

EC values in the sampled water ranged from 548 to 1854 µS/cm, and TDS levels ranged from 304 to 946 mg/L. High TDS levels can affect the taste of water and may indicate the presence of dissolved salts, minerals, and organic matter [27]. The WHO recommends a TDS level of less than 600 mg/L for drinking water [1]. Several samples exceed this limit, suggesting potential issues with water quality, possibly due to geological factors or anthropogenic activities such as agricultural runoff [28].

- *Alkalinity*

Alkalinity levels in the sampled water ranged from 106 to 482 mg/L. Alkalinity is a measure of the water's capacity to neutralize acids and is primarily influenced by the presence of carbonates, bicarbonates, and hydroxides. High alkalinity can affect the taste of water and may indicate the presence of dissolved minerals [29]. The observed levels are within the typical range for natural waters but may require monitoring to prevent scaling in pipes and appliances.

- *Chloride*

Chloride concentrations ranged from 30 to 228 mg/L in the sampled water. Chloride is a common anion in water and can originate from natural sources or anthropogenic activities such as industrial discharge and road salt application. High chloride levels can affect the taste of water and may indicate contamination [30]. The WHO recommends a chloride concentration of less than 250 mg/L for drinking water [1]. All samples are within this limit.

- *Fluoride*

Fluoride levels in the sampled water ranged from 0.1 to 0.6 mg/L. Fluoride is essential for dental health, but excessive levels can cause dental and skeletal fluorosis [31]. The WHO recommends a fluoride concentration of 1.5 mg/L as the maximum allowable limit [1]. All samples are within safe limits, indicating no significant risk of fluorosis.

- *Nitrate*

Nitrate levels in the sampled water ranged from 18 to 50 mg/L. High nitrate levels can be harmful, especially to infants, causing methemoglobinemia (blue baby syndrome) [32]. The WHO recommends a nitrate concentration of less than 50 mg/L [1]. While all samples are within this limit, the upper range (50 mg/L) suggests potential contamination from agricultural runoff or sewage.

- *Total Hardness*

Total hardness ranged from 152 to 524 mg/L. Hardness is primarily due to the presence of calcium and magnesium ions. While hard water is not harmful to health, it can cause scaling in pipes and appliances. The WHO does not set a specific limit for hardness but suggests that levels below 500 mg/L are acceptable [1]. Most samples are within this range, but some exceed it, indicating the need for water softening in affected areas.

- *Iron*

Iron concentrations ranged from 0.02 to 1.28 mg/L. High iron levels can cause aesthetic issues such as staining, metallic taste, and discoloration of water [33]. The WHO recommends an iron concentration of less than 0.3 mg/L [1]. Several samples exceed this limit, indicating potential issues with iron contamination, possibly due to natural geological sources or corrosion of pipes [28].

B. Discussion

The analysis reveals significant variability in water quality across the sampled habitations. While parameters such as pH, fluoride, and chloride are within acceptable limits, others like TDS, turbidity, and iron exceed recommended levels in several samples. This variability may be attributed to natural geological conditions, agricultural practices, or industrial activities [5]. For example, high TDS and nitrate levels in some samples suggest potential contamination from agricultural runoff, while elevated iron levels may indicate natural geological sources or pipe corrosion [28].

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Table 1: Physicochemical Parameters of Water Samples

Sr. No.	Sample No.	Name of Habitation	Temp.	Tur. (NTU)	pH	EC	TDS (mg/L)	Alkalinity (mg/L)
1.	S1	Waddam	22	0.7	7.52	868	492	214
2.	S2	Waddam	26	0.62	7.56	1154	642	208
3.	S3	Waddam	22	0.48	7.46	988	696	138
4.	S4	Chittur	27	0.36	8.12	1854	946	202
5.	S5	Chittur	22	0.54	7.98	1164	702	184
6.	S6	Chittur	23	0.52	7.26	1158	642	204
7.	S7	Chittur	21	0.76	7.68	1214	720	226
8.	S8	Kotapalli	21	0.43	7.28	1302	712	346
9.	S9	Kotapalli	22	0.48	7.69	1352	716	448
10.	S10	Pochampalli	23	0.9	7.26	1124	652	482
11.	S11	Pochampalli	22	0.54	8.27	1354	724	328
12.	S12	Rangdhampetha chek	22	0.76	7.22	548	304	136
13.	S13	Rangdhampetha chek	23	0.7	7.36	598	332	166
14.	S14	Rangdhampetha chek	25.2	0.42	8.22	656	364	132
15.	S15	Rangdhampetha Mal	24	0.88	7.42	586	326	118
16.	S16	Ganjirampetha	21	2.28	7.38	556	309	184
17.	S17	Ganjirampetha	22	0.42	8.22	572	318	106
18.	S18	Laxmidevipetha Ry	23	0.36	7.30	686	382	112
19.	S19	Laxmidevipetha Ry	22.2	0.48	7.68	640	356	118
20.	S20	Laxmidevipetha Ry	22.5	0.54	7.52	724	402	124
21.	S21	Ankisa Mal	22	1.20	7.26	1124	438	460
22.	S22	Ankisa Mal	22	1.24	7.88	1325	784	404
23.	S23	Ankisa Mal	23	1.01	8.14	1356	752	**676**
24.	S24	Ankisa Mal	22	1.52	7.44	1154	632	460
25.	S25	Balmutyampalli	23.2	0.62	7.54	1124	624	408

Table 2: Physicochemical Parameters of Water Samples

Sr. no.	Sample No.	Name of Habitation	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Total Hardness (mg/L)	Iron (mg/L)
1.	S1	Waddam	81	0.1	32	310	0.2
2.	S2	Waddam	222	0.1	**46**	244	0.15
3.	S3	Waddam	228	0.1	34	342	0.15
4.	S4	Chittur	92	0.1	**50**	402	0.15
5.	S5	Chittur	68	0.1	24	362	0.2
6.	S6	Chittur	82	0.1	**47**	244	0.2
7.	S7	Chittur	120	0.1	**46**	218	0.2
8.	S8	Kotapalli	110	0.1	41	524	0.26
9.	S9	Kotapalli	78	0.1	41	322	0.22
10.	S10	Pochampalli	83	0.1	**48**	478	0.22
11.	S11	Pochampalli	87	0.1	42	464	0.24
12.	S12	Rangdhampetha chek	37	0.3	39	224	**1.28**
13.	S13	Rangdhampetha chek	60	0.4	21	198	0.02
14.	S14	Rangdhampetha chek	103	0.3	38	214	**1.16**
15.	S15	Rangdhampetha Mal	48	0.2	42	172	0.02
16.	S16	Ganjirampetha	34	0.2	38	188	0.4
17.	S17	Ganjirampetha	30	0.4	37	164	0.21
18.	S18	Laxmidevipetha Ry	67	0.6	42	168	0.18
19.	S19	Laxmidevipetha Ry	65	0.2	40	186	0.16
20.	S20	Laxmidevipetha Ry	66	0.1	42	152	0.17
21.	S21	Ankisa Mal	38	0.2	18	234	0.15
22.	S22	Ankisa Mal	98	0.2	18	266	0.1
23.	S23	Ankisa Mal	64	0.2	22	248	0.18
24.	S24	Ankisa Mal	48	0.2	18	244	0.1
25.	S25	Balmutyampalli	56	0.2	26	244	0.1

The analyzed parameters has been manifested by the graphical methods represented in figure 1, which aids in understanding the obtained data with high accuracy [34].

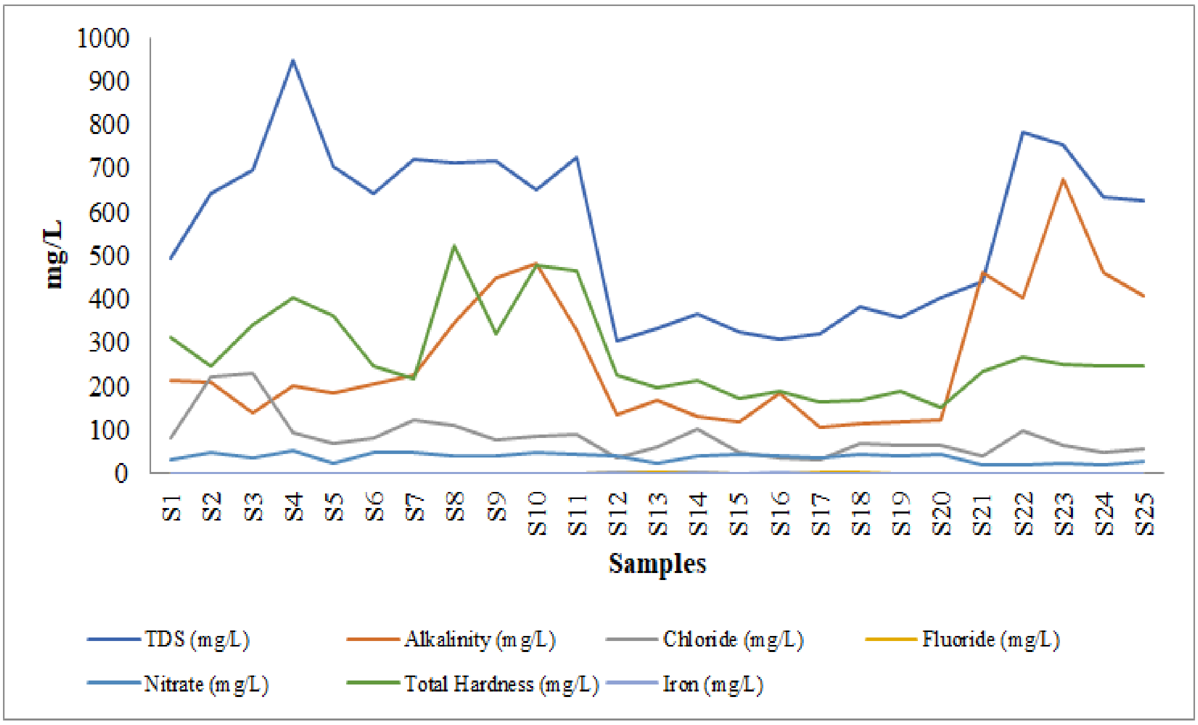

Fig 1: Graphical representations of the analyzed parameters [TDS, Alkalinity, Chloride, Fluoride, Nitrate, Total Hardness, and Iron]

C. Correlation matrix of various physicochemical parameters

The correlation coefficient measures the strength and direction of a linear relationship between two variables. The value ranges from -1 to 1, where 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation [35]. The positive correlation between EC and TDS is evident from the value of 0.95 and certainly it is obvious to have it [Table 3]. The Total Hardness shows moderate positive correlations with EC and TDS, suggesting association of higher hardness levels with higher EC and TDS. The correlation values manifested a weak positive association between pH and Total Hardness. The Iron shows weak correlations with most of the variables.

Table No. 3: Correlation Matrix of Various Physicochemical Parameters

	Tem.	Tur.	pH	EC	TDS	Alkal.	Cl^{-1}	F^{-1}	Nitrate	TH	Iron
Tem.	1.00										
Tur.	-0.12	1.00									
pH	0.14	-0.15	1.00								
EC	0.08	-0.10	0.20	1.00							
TDS	0.07	-0.09	0.18	0.95	1.00						
Alkal.	-0.10	0.12	-0.05	0.10	0.08	1.00					
Cl^{-1}	0.05	-0.07	0.12	0.30	0.28	0.15	1.00				
F^{-1}	-0.03	0.04	-0.08	-0.05	-0.04	0.02	-0.03	1.00			
Nitrate	-0.08	0.10	-0.10	0.12	0.10	0.05	0.08	0.05	1.00		
TH	-0.04	0.08	0.15	0.40	0.38	0.20	0.25	-0.10	0.12	1.00	
Iron	-0.10	0.15	-0.12	-0.08	-0.07	0.10	-0.05	0.03	0.08	-0.04	1.00

IV. CONCLUSION AND RECOMMENDATIONS

The analysis of the groundwater samples from the study area reveals significant water quality challenges. While pH and fluoride levels comply with WHO standards, elevated TDS, nitrate, and iron concentrations in several samples pose serious health risks. The nitrate contamination could be attributed to the agricultural runoff, and high iron levels to the geo-genic sources. Correlations between parameters, such as nitrate and alkalinity, further elucidate associations. To address these issues, regular monitoring, cost effective water treatment solutions, community awareness campaigns, and sustainable agricultural practices are essential. Strengthening regulations to control pollution and implementing region specific strategies will ensure long term protection of water resources. This study provides

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critical insights for policymakers and public health officials, emphasizing the need for immediate action to safeguard public health and promote environmental sustainability.

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