

STATISTICAL PROFILING OF GROUNDWATER: UNVEILING PATTERNS AND QUALITY INDICATORS FOR SAFE DRINKING

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Abstract

This study uses physicochemical analysis to assess groundwater samples for drinking water quality. Samples of groundwater were taken from rural regions of Tharad taluka [Banaskantha district of Gujarat state of India]. The evaluation encompassed a comprehensive analysis of various parameters to assess drinking water quality in the specified region. Parameters such as temperature, color, odor, turbidity, electrical conductivity (E.C.), pH, total dissolved solids (TDS), total alkalinity (T.A.), and concentrations of ions including fluoride, chloride, calcium, magnesium, sodium, and potassium were thoroughly examined. This approach provides a detailed understanding of the overall water quality profile in the designated area. The results obtained were judged against the drinking water guidelines given by Indian Council of Medical Research (ICMR). Total dissolved solids measurements in the samples indicate that the water is unsuitable for consumption. So, water needs to be adequately treated before being used for drinking. For statistical analysis, Pearson Correlation Coefficient was used to analyze physico-chemical parameters. It indicates that turbidity is strongly related to several parameters, including total dissolved solids, electrical conductivity, and fluoride concentration.

Keywords: Analysis; Drinking water; Groundwater; ICMR; Samples; TDS

Introduction

Groundwater is a valuable source for drinking water, particularly in areas where surface water resources are limited or unstable due of erratic weather patterns. Communities are depending more and more on groundwater to meet their potable water needs as surface water sources like lakes and rivers grow less dependable (Dinka, 2022; Ghalhari *et al.*, 2022; Thomas, 2023). Similar situation is also found in rural areas such as Tharad taluka of Banaskantha district of Gujarat state of India, where rainfall is scarce and water management

is insufficient, local residents rely on groundwater for dual purposes:

- 1) For irrigation
- 2) For drinking.

Hence, the quantity and quality of groundwater becomes a critical concern. The scarcity of rainfall emphasizes the need to evaluate whether the groundwater is suitable for drinking purposes. With this objective in mind, this humble study was undertaken to determine the adequacy and safety of

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the groundwater in meeting the essential criteria for consumption.

Materials and Methods

The outline of the present work is shown in Figure 1.

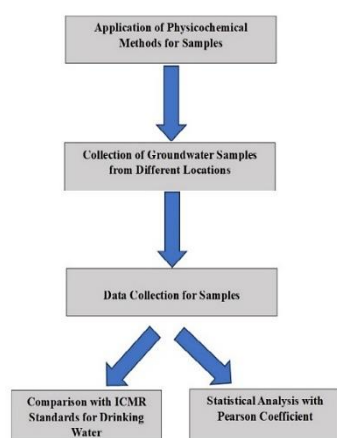


Figure 1. Outline of work

The present study is focused to the groundwater quality of some places of the Tharad Taluka which is situated in Banaskantha district (23.33° to 24.25° north latitude and 71.03° to 73.02° east longitude) of the Gujarat state of India. The district lies on the north-west side of the Gujarat State. The climate in the Tharad taluka is characterized by hot and dry conditions. Tharad serves as the principal town in this taluka, which predominantly features rural landscapes within the district. The primary economic activities in this region revolve around agriculture and milk

production. Groundwater samples were collected from bore/tube wells in pre-cleaned one-liter plastic containers during the months of January and February 2022. These samples were extracted from various locations within the taluka: (a) Arantwa, (b) Bhadodar, (c) Chotapa, (d) Didarda, (e) Tharad, and (f) Karbu.

At the time of sample collection, observations were made for temperature, color, and odor. The physicochemical properties of the samples were subsequently analyzed using established titrimetric and instrumental procedures (Trivedi and Goel, 1986; FAO, 1997; Aghazadeh and Mogaddam, 2010; Ackah *et al.*, 2011; Mohamed *et al.*, 2014). Various physical parameters, including pH, Electrical Conductivity (E.C.), Turbidity, and Total Dissolved Solids (TDS), were determined using a pH meter, E.C. meter, Turbidity meter, and TDS meter, respectively. Chemical parameters such as the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) were assessed through standard EDTA titration. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) levels were estimated by titrating with H_2SO_4 . Chloride (Cl^{-}) content was determined through argentometric titration. Sodium (Na^{+}) and potassium (K^{+}) concentrations were measured using the flame photometric method. Fluoride (F^{-}) levels were quantified using an ion-selective electrode.

Results and Discussion

Table 1 unfolds the diverse characteristics exhibited by the water samples, offering a captivating insight into their qualities. The excellence of these samples is meticulously assessed against the esteemed drinking water standards set forth by the Indian

Table 1. Physicochemical Profiles of Water Samples

Sr. No. of Para.	Parameter	a	b	c	d	e	f	Mean	Median	S. D.
1	Temp.°C	24.2	24.5	24.4	24.2	24.5	24.4	24.367	24.4	0.0596
2	Colour	Cl	Cl	Cl	Cl	Cl	Cl	-	-	-
3	Odour	Ol	Ol	Ol	Ol	Ol	Ol	-	-	-
4	Tur.(NTU)	2.50	2.00	2.10	2.50	2.75	1.75	2.2583	2.3	0.4116
5	TDS(mg/l)	1400	1560	1440	1380	1025	1130	1341.6667	1410.0	203.8489
6	pH	8.10	8.15	7.90	8.40	8.50	7.80	8.241	8.175	0.2343
7	E.C. ($\mu\text{S cm}^{-1}$)	1725	1800	1690	1500	1230	1450	1608.3	1595.0	224.3670
8	T. A. (mg/l)	331.40	330.10	315.70	280.10	400.60	350.20	322.65	325.45	48.4662
9	F^{-} (mg/l)	1.90	0.80	1.20	1.30	0.90	0.80	1.3167	1.15	0.4071
10	Cl^{-} (mg/l)	150.15	210.40	166.40	170.90	140.55	110	152.8067	158.775	35.0775
11	Na^{+} (mg/l)	180	204.26	209.80	210.30	190.80	220.70	203.6417	205.13	13.128
12	K^{+} (mg/l)	2.40	4.80	5.18	4.10	3.50	3.27	3.7917	3.9	0.7563
13	Ca^{2+} (mg/l)	13.25	11.80	10.75	14.20	12.60	15.45	13.6083	12.925	1.5606
14	Mg^{2+} (mg/l)	6.10	4.85	6.33	7.80	5.47	6.11	6.11	6.105	0.8799

Council of Medical Research (ICMR) (Chatterjee and Raziuddin, 2007; Etim *et al.*, 2013)., ensuring a benchmark of quality that aligns with global health guidelines. This analysis aims to gauge the conformity of the water samples to the prescribed benchmarks, ensuring that they meet the necessary criteria for safe consumption.

All the samples exhibited a lack of color upon examination. A direct assessment of the samples for odor revealed the absence of any distinct smell. Turbidity, representing the cloudiness of water, indicates water quality, with clear water having low turbidity and murky water having high turbidity. In this study, all samples showed turbidity levels within the range of 1.75 to 2.75 Nephelometric Turbidity Units (NTU).

Total Dissolved Solids (TDS) in the samples ranged from 1025 to 1560 mg/l. The Indian Council of Medical Research (ICMR) suggests a desirable TDS limit of 500 mg/l and a maximum permissible limit of 1500-3000 mg/l. However, all samples (a to f) exceeded the desirable limit, and elevated TDS levels can adversely impact drinking water quality.

The pH values of the samples fell within the range of 7.80 to 8.50, meeting the recommended pH range of 7.0 to 8.5 by ICMR. Electrical conductivity (E.C.), reflecting the presence of dissolved salts, ranged from 1230 to 1800 $\mu\text{S cm}^{-1}$, with a standard deviation of 224.3670 $\mu\text{S cm}^{-1}$. High E.C. values render water unsuitable for consumption.

The fluoride concentration (F^{1-}) in the samples ranged from 0.80 to 1.90 mg/l. Samples (a, c, d) surpassed the desirable limit (1.0 mg/l) set by ICMR, posing risks of dental and skeletal fluorosis.

Chloride (Cl^{1-}) values ranged from 110 to 210.40. Sample (b) violated the ICMR limit of 200 mg/l for chloride. Elevated sodium (Na^{1+}) levels, ranging from 180 to 220.70, indicate excessive salinity. Potassium (K^{1+}) values ranged from 2.40 to 5.18, with a mean of 3.9 and a standard deviation of 0.7563.

Water hardness, primarily caused by multivalent cations like Ca^{2+} and Mg^{2+} , saw Ca^{2+} values ranging from 10.75 to 15.45, within the

desirable limit of 75 mg/l as suggested by ICMR. Mg^{2+} values ranged from 4.85 to 7.80.

Statistical analysis

Statistical analysis in water assessment involves calculating the mean, median, and standard deviation (S.D.) for various parameters, as presented in Table 1 as an initial step. It provides a summary of the central tendency, spread, and distribution of key parameters in the groundwater samples. Correlation, a comprehensive statistical method for assessing relationships between multiple variables, is employed to gauge the strength and statistical significance of connections among different water quality parameters. The goal was to determine the correlation between the concentrations of two parameters in relation to one another. This method of analysis is highly significant because it uses a correlation regression equation to show how changes in one water quality or physico-chemical parameter affect other parameters in a scientifically meaningful way. Pearson Correlation Coefficients examines the relationships between different water quality parameters, highlighting potential dependencies or associations. The Pearson correlation coefficients (r) were computed, resulting in a correlation matrix (Hao *et al.*, 2022; Burgund *et al.*, 2023).

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (1)$$

Where;

r = correlation coefficient,
 x_i and y_i = for a sample, values of x – variable and y – variable consecutively,
 $\bar{x}$ and $\bar{y}$ = mean values of x and y variables consecutively

The dimensionless index, r , ranges from -1.0 to +1.0, with 0 indicating no correlation. Table 2 provides the correlation coefficients for different variables.

Table 2. Pearson Correlation Matrix Among Physicochemical Parameters in Water Samples

P	4	5	6	7	8	9	10	11	12	13	14
4	1.0000										
5	-0.8666	1.0000									
6	0.8347	-0.9361	1.0000								
7	0.9180	-0.9664	0.9264	1.0000							
8	-0.7611	0.8925	-0.8716	-0.8946	1.0000						
9	0.8270	-0.9612	0.8927	0.9366	-0.9103	1.0000					
10	-0.9781	0.8554	-0.7987	-0.8642	0.7275	-0.8426	1.0000				
11	-0.9397	0.9521	-0.8678	-0.9291	0.8065	-0.9144	0.9860	1.0000			
12	0.5978	-0.8943	-0.7677	0.7819	-0.7435	0.8690	-0.6518	-0.7804	1.0000		
13	0.5385	-0.9166	0.7817	0.7890	-0.7320	0.8837	-0.5897	-0.8102	0.9809	1.0000	
14	-0.5290	0.9102	-0.7809	-0.7447	0.8377	-0.8025	0.6161	0.7495	-0.8338	-0.9107	1.0000

Interpretation of the results involves analyzing the Pearson correlation matrix to uncover relationships and dependencies among the various physicochemical parameters in the water samples. The correlation coefficients indicate the strength and direction of associations, offering insights into how changes in one parameter may influence another. Identifying significant correlations is crucial for understanding the interconnected nature of these parameters and their potential implications for water quality. The Pearson correlation matrix provides insights into the linear relationships between pairs of variables in the dataset. Here are some key observations from the correlation matrix:

Turbidity (NTU): Strong negative correlation with TDS (mg/l), indicating that as turbidity increases, TDS tends to decrease. Strong positive correlation with pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), F^{-1} (mg/l), Cl^{-1} (mg/l), and Mg^{2+} (mg/l). Negative correlation with some ion concentrations (Na^{1+} , K^{1+} , Ca^{2+}).

TDS (mg/l): Strong negative correlation with turbidity, indicating an inverse relationship. Strong positive correlation with pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), and Cl^{-1} (mg/l). Negative correlation with some ion concentrations (Na^{1+} , K^{1+} , Ca^{2+} , Mg^{2+}).

pH: Positive correlation with turbidity, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), and F^{-1} (mg/l). Negative correlation with TDS, Cl^{-1} , Na^{1+} , K^{1+} , Ca^{2+} , and Mg^{2+} .

E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$): Strong positive correlation with turbidity, indicating a direct relationship. Positive correlation with pH, T.A. (mg/l), F^{-1} (mg/l), Cl^{-1} (mg/l), Na^{1+} , K^{1+} and Mg^{2+} . Negative correlation with TDS and Ca^{2+} .

T.A. (mg/l): Positive correlation with turbidity, pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), and F^{-1} (mg/l). Negative correlation with TDS, Cl^{-1} , Na^{1+} , K^{1+} , Ca^{2+} and Mg^{2+} .

F^{-1} (mg/l): Positive correlation with turbidity, pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), and T.A. (mg/l). Negative correlation with TDS, Cl^{-1} , Na^{1+} , K^{1+} , Ca^{2+} , and Mg^{2+} .

Cl^{-1} (mg/l): Strong negative correlation with turbidity. Positive correlation with TDS (mg/l), pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), and F^{-1} (mg/l). Negative correlation with some ion concentrations (Na^{1+} , K^{1+} , Ca^{2+} , Mg^{2+}).

Na^{1+} (mg/l): Positive correlation with turbidity, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), F^{-1} (mg/l), and

Mg^{2+} (mg/l). Negative correlation with TDS (mg/l), pH, Cl^{-1} (mg/l), and Ca^{2+} (mg/l).

K^{1+} (mg/l): Positive correlation with turbidity, pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), and F^{-1} (mg/l). Negative correlation with TDS, Cl^{-1} , Na^{1+} , Ca^{2+} and Mg^{2+} .

Ca^{2+} (mg/l): Negative correlation with turbidity, pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), F^{-1} (mg/l), Cl^{-1} (mg/l), Na^{1+} , and K^{1+} (mg/l). Positive correlation with TDS and Mg^{2+} .

Mg^{2+} (mg/l): Negative correlation with turbidity, pH, E.C. ($\mu\text{S}\cdot\text{cm}^{-1}$), T.A. (mg/l), F^{-1} (mg/l), Cl^{-1} (mg/l), Na^{1+} , and K^{1+} (mg/l). Positive correlation with TDS (mg/l) and Ca^{2+} (mg/l).

These interpretations are based on the strength and direction of the correlation coefficients. Positive values indicate a positive correlation (as one variable increases, the other tends to increase), while negative values indicate a negative correlation (as one variable increases, the other tends to decrease). The closer the coefficient is to +1 or -1, the stronger the correlation.

Conclusions

Statistical analysis indicates that turbidity is strongly related to several parameters, including total dissolved solids, electrical conductivity, and fluoride concentration. Total dissolved solids are inversely related to pH and fluoride concentration. pH is positively correlated with electrical conductivity but negatively correlated with fluoride concentration. Electrical conductivity and total alkalinity exhibit a strong negative correlation. The concentrations of specific ions, such as sodium and potassium, show a strong positive correlation.

These observations provide valuable insights into the interdependencies of water quality parameters and can be crucial for making informed decisions about water treatment and management.

The high total dissolved solids (TDS) values (1130 to 1560 mg/l) in the samples indicate that the water is unsuitable for consumption. While certain physicochemical parameters in the studied water samples met acceptable standards, the chloride (Cl^{-1}) for sample b, and fluoride (F^{-1}) for samples (a, c, d), exceeded the recommended limits set by ICMR. Therefore, it is imperative to treat the water before using it for drinking purposes. Remedial actions need to be implemented, and public awareness about drinking water quality standards should be raised.

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