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Assessment of the Physical and Chemical Characteristics of Drinking Water with Emphasis on Quality Standards in Shahrood County

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Abstract

Water is a fundamental component of life and one of the most vital natural resources, playing an indispensable role in sustaining human health, supporting agricultural productivity, enabling industrial development, and preserving ecological balance. As global populations expand and urbanization accelerates, ensuring access to safe and clean drinking water has become a significant public health priority. Throughout history, civilizations have recognized the need to monitor water quality to prevent the spread of waterborne diseases and protect community well-being. In modern times, evaluating key physicochemical parameters such as Total Hardness (TH), Potential of Hydrogen (pH), and Total Dissolved Solids (TDS) is essential for assessing the suitability of drinking water. These indicators are directly linked to various health outcomes and are commonly used by national and international agencies to set water quality standards. This study assesses the physical and chemical characteristics of drinking water in Shahrood County to determine potential health risks and ensure compliance with regulatory guidelines. Over nine years (2016–2024), water samples were systematically collected from local drinking water wells and analyzed using standard laboratory protocols. The average values recorded during this time were 7.7 for pH, 239.2 mg/L for TH, and 394.1 mg/L for TDS. When compared with benchmarks set by the Iranian National Standards Organization, the World Health Organization (WHO), and the United States Environmental Protection Agency (EPA), the results confirm that all measured parameters fall within acceptable limits. Thus, it can be concluded that the drinking water in Shahrood County meets health safety standards and poses no significant risks to consumers.

1. Introduction

Drinking water, a fundamental human need, plays a vital role in public health, economic development, and environmental protection. Its primary sources include surface and groundwater.(Ghanbarian et al., 2022). Surface waters, such as rivers and lakes, are the primary sources due to their accessibility; however, they are continually exposed to contaminants, including wastewater, agricultural pesticides, and the effects of climate change. In contrast, groundwater often exhibits higher quality due to natural filtration; however, it is increasingly threatened by overextraction, infiltration of pollutants, and the presence of heavy metals, nitrates, and arsenic. (Rasool et al., 2017).

The quality of groundwater is influenced by hydrogeochemical processes from its formation to extraction, reflecting its history and origin. This quality, especially concerning

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vulnerable populations such as children and pregnant women, can have profound health implications, including gastrointestinal disorders, kidney dysfunction, and neurological disturbances. Additionally, a decline in water quality disrupts aquatic ecosystems and increases water treatment costs (Daud et al., 2017; Miller et al., 2025; Sedaghat, 2008).

From a chemical analysis perspective, water quality is determined by measuring the concentrations of ions such as Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl, and NO_3. Furthermore, parameters like pH, electrical conductivity, and total residue are considered critical indicators. Total Dissolved Solids (TDS), as one of the key parameters, represents the total concentration of dissolved substances in water (excluding sediments, colloids, and gases) and is typically reported in milligrams per liter (mg/L) or parts per million (ppm) (Sadeghat, 2008; Sophocleous, 2002).

The main objectives of this study are to evaluate the quantitative and qualitative status of physical and chemical parameters of groundwater in the region, assess the compliance of contamination levels with national and international standards, investigate potential health risks, particularly for sensitive groups such as children and pregnant women, and identify observable trends or changes in drinking water quality over the study period.

Sheikhi et al. (2014) Conducted a study to assess the water quality of the Kor River for irrigation purposes. Five key parameters, including Electrical Conductivity (EC), sodium (Na), chloride (Cl), Sodium Adsorption Ratio (SAR), and bicarbonate (HCO_3), along with the concentrations of eight heavy metals, were measured at 25 monitoring stations. The Irrigation Water Quality Index (IWQI) was also calculated. The results indicated that in some areas of the river, water quality posed environmental concerns, underscoring the need for continuous monitoring of pollution sources.

Channar et al (2014) investigated Manchar Lake, the largest freshwater lake in Pakistan, which is under threat from industrial wastewater pollution. In this study, water quality was assessed through sampling and laboratory analyses conducted at the University of Sindh. Parameters such as pH, EC, salinity, TDS, DO, nitrate, chlorides, and total hardness were measured and compared with World Health Organization (WHO) standards. The findings demonstrated a significant negative impact of industrial effluents on the lake's water quality.(Channar et al., 2014)

Adams et al (2022) also studied the impact of industrial wastewater discharge on Manchar Lake. Laboratory analyses at the University of Sindh measured pH, EC, salinity, TDS, alkalinity, DO, nitrate, chloride, and total hardness, which were then compared with WHO standards. The results confirmed a deterioration in water quality due to effluent inflows, emphasizing the need for continuous monitoring and improved water resource management in the region(Adams et al., 2022).

Rafiei and Timouri (2023) examined the relationship between groundwater quality and rainfall in the Saveh plain from 2017 to 2019. This study focused on analyzing groundwater chemical quality, delineating high-risk zones, and evaluating its suitability for agricultural and drinking water purposes. The results indicated that optimal water resource management in the region requires greater attention to water availability, adjustments to crop patterns, and reductions in excessive groundwater extraction.

Perera (2023) investigated the impact of water hardness on human health. Water hardness, primarily due to calcium and magnesium ions, can affect the body's absorption of these minerals. Evidence suggests a negative correlation between water hardness and the incidence of cardiovascular disease and cancer.

Perveen (2023) analyzed the status of drinking water quality in Pakistan. This study aimed to assess global challenges in water supply systems and evaluate the current situation in Pakistan, drawing on governmental and non-governmental reports. The study covered aspects such as water safety planning, environmental impact assessments, and independent monitoring of water quality. The findings highlight that improving access to safe drinking water can have significant positive effects on the country's socio-economic conditions.

Heidari Motlagh and Veysi (2024) investigated the groundwater quality in the Alishtar plain using data from 17 wells collected over 31 years (1987–2018). Parameters such as pH, EC, Total Dissolved Solids (TDS), sodium (Na), Total Hardness (TH), and SAR were analyzed. The findings revealed that some parameters exhibited increasing trends, while others showed declining patterns. A strong correlation was observed between TDS and EC (r = 0.98). GIS-based mapping and interpretations using Wilcox and Schoeller diagrams confirmed that the region's groundwater is suitable for both drinking and agricultural use.

Homayounejad et al. (2024) conducted a one-year seasonal sampling campaign from October 2020 to October 2021 at eight stations to evaluate the quality of "Chah-Nimeh I" wells recognized as the primary source of drinking and agricultural water in the Sistan region. The water quality index was calculated based on factors such as nitrate, nitrite, dissolved oxygen (DO), EC, hardness, and pH. The results showed that the water quality remained within the "good" category, with central lake zones exhibiting better quality than peripheral areas. The study emphasized the necessity of continuous monitoring of these water resources.

Nawaz et al. (2023) assessed the water quality of 50 tap water samples from the Gulshan-e-Ravi and Samanabad regions. Physicochemical parameters, including pH, TDS, dissolved oxygen (DO), and hardness, were measured and compared with WHO standards. Results revealed that TDS and magnesium hardness in Samanabad exceeded permissible limits, with water quality in Gulshan-e-Ravi and Samanabad classified as "poor" and "very poor," respectively. The primary causes of low water quality were identified as aging pipelines and poor waste management.

Jurczynski et al. (2024) identified hazardous chemical pollutants, including arsenic, nitrate, and fluoride, in various countries, attributing their presence to industrial sources, agricultural runoff, and improper waste disposal. The study emphasizes the importance of enhanced monitoring and stricter regulations to mitigate health risks.

Lwin et al. (2024) investigated the physicochemical properties and elemental composition of groundwater in the campus area of Sagaing University in January 2023. Three samples were collected from different locations, and parameters such as pH, turbidity, EC, TDS, hardness, alkalinity, chloride, calcium, sodium, and heavy metals (arsenic and lead) were measured. The results were compared to WHO standards, indicating that water quality in some instances requires monitoring and improvement.

John et al. (2025) evaluated the physical and chemical parameters of wells and groundwater in Nigeria. Measurements included electrical conductivity (EC), pH, total dissolved solids (TDS), total hardness (TH), total suspended solids (TSS), and turbidity. Results showed that TDS and turbidity levels exceeded the NSDWQ and WHO standards, indicating risks of salinity and microbial contamination, while water hardness surpassed acceptable limits in some areas. The study highlights the importance of regularly monitoring and treating water sources.

Prifti et al. (2025) conducted a study in March 2022 on the water quality of the Shkumbin River, measuring and analyzing physical-chemical parameters and nutrients. The results indicated that geographical factors, urbanization, and human activities played a primary role in altering water quality. The water quality at all sampling stations was classified as "good" ($71 < WQI < 90$), a status attributed to the low water temperature and rainy conditions. The study effectively used the Water Quality Index (WQI), and the model used to assess water quality proved reliable.

Talpur et al. (2025) analyzed 57 groundwater samples for fluoride, turbidity, iron, and total dissolved solids, and found that 47% exceeded the WHO limit of 1.5 mg/L. Spatial analysis revealed higher pollution levels in the northern and southern regions compared to other areas. Health risk assessments indicated that children, particularly girls, were at the most significant risk of developing fluorosis.

This research is of paramount importance, as the quality of drinking water directly impacts public health. The sources of drinking water, especially groundwater, face numerous threats, including excessive extraction, industrial and agricultural pollution, and climate change.

Given the vital role of groundwater in supplying drinking water to Shahrood County, continuous monitoring of the physical and chemical parameters of these sources is essential to assess water quality and prevent potential threats. This study, which analyzes nine years of data, provides an opportunity to identify gradual changes in water quality that can serve as a foundation for informed management decisions and health policy-making.

Moreover, the standards set by reputable international organizations, such as the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA), indicate that any fluctuations in water quality parameters can have adverse effects on human health. Consequently, this study's findings emphasize the need for periodic monitoring and the implementation of control and preventive measures to maintain optimal water quality.

Ultimately, the findings of this research can serve as a valuable scientific resource for other regions with similar climatic conditions, playing a crucial role in the development of management strategies and in health and environmental planning.

2. Materials and Methods

2.1. Study area

The study area is located in Shahrood County, Semnan Province, in northeastern Iran. Covering approximately 405.43 square kilometers, it is one of the largest counties in Semnan Province. The center of the county, Shahrood city, is situated on the northern edge of the Kavir Desert and the southern slopes of the Alborz Mountain range. The geographic coordinates of Shahrood city are 36°25' North latitude and 54°58' East longitude, with an elevation of 1,380 meters above sea level. This county is bordered to the north by Golestan Province, to the east by North Khorasan Province, to the west by Damghan County, and to the south by Isfahan Province. The study area is shown in Figure 1. For this research, data collected by the Shahrood Water and Wastewater Department were utilized. The sampling sites are groundwater wells used for water supply in Shahrood County.

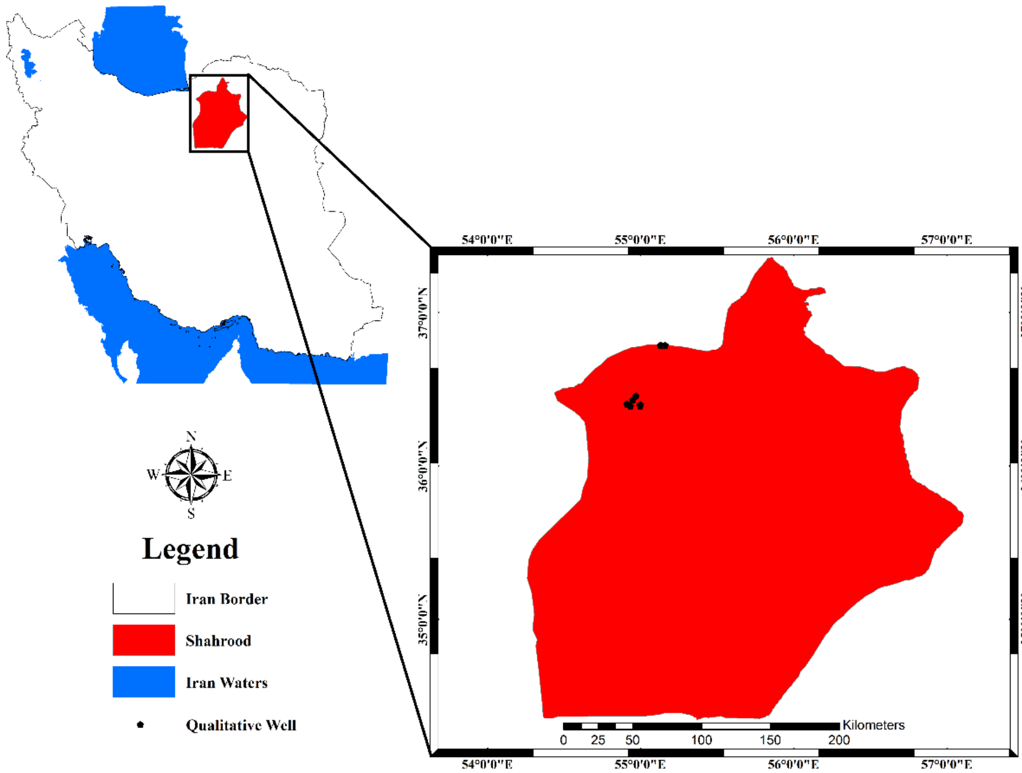

Figure1. The locations of wells

2.2.Mann-Kendall Method

To examine temporal trends in the physical and chemical parameters of drinking water in Shahrood County (TH, pH, and TDS) from 2016 to 2024, the nonparametric Mann-Kendall test was used. This test is applied to analyze trends in time series data and does not require the assumption of normality.

Since one of the test's prerequisites is data independence, the time-series data were first examined for autocorrelation. If significant autocorrelation was observed, the Trend-Free Pre-Whitening (TFPW) method was applied to remove this effect. This process enhances the accuracy of trend analysis in dependent data. Finally, the Mann-Kendall test was applied to the adjusted data.

2.3.Trend-Free Pre-Whitening (TFPW)

In this study, the Trend-Free Pre-Whitening (TFPW) method was used to identify trends in time series data with autocorrelation. The technique involves the following steps:

The time series data were analyzed using the TSA method (Mann & Kendall, 1996), and the trend slope (b) was estimated as follows:

$$b = Median\left(\frac{X_j - X_l}{j - l}\right) \quad \forall l < j \qquad (1)$$

In this equation, Xl and Xj represent the data values at times l and j, respectively. If the estimated slope is approximately zero, no significant trend is detected in the data, and the Mann-Kendall test can be directly applied. Otherwise, a linear trend is removed from the time series using the following formula:

$$X_t' = X_t - T_t = X_t - bt \qquad (2)$$

Where Tt represents the predicted trend at time t.

The autocorrelation coefficient of the new time series Xt′, after detrending, is calculated using the following equation:

$$r_k = \frac{\frac{1}{n-k}\sum_{t=1}^{n-k}[X'_t - E(X'_t)][X_{t+k} - E(X'_t)]}{\frac{1}{n}\sum_{t=1}^{n}[X'_t - E(X'_t)]^2} E(X'_t) = \frac{1}{n}\sum_{1}^{n} X'_t \quad (3)$$

Where E(X) is the mean of the time series data, and K is the time lag used to calculate autocorrelation.

To eliminate significant autocorrelation from the data, an AR(1) (first-order autoregressive) model is applied. The adjusted time series data are defined as follows:

$$Y'_t = X'_t - r_1 X'_{t-1} \quad (4)$$

After this process, the resulting time series Yt is free of autocorrelation, allowing the application of the Mann-Kendall test.

2. Mann-Kendall Test

The Mann-Kendall test is one of the most widely used non-parametric methods for trend analysis in time-series data. It is particularly effective in hydrological, climatological, and water quality studies.

In this test:

- The null hypothesis H0: there is no trend in the data (i.e., the observations are independent and identically distributed).
- The alternative hypothesis H1: there is a monotonic (increasing or decreasing) trend over time.

To perform the test, the S statistic is calculated using the following formula:

$$\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (5)$$

Where xj is the value of the data at time j, n is the number of observations, and sgn(θ) is the sign function, defined by the following equation:

$$\begin{cases} 1 & \text{if} \quad \theta > 0 \\ 1 & \text{if} \quad \theta = 0 \\ -1 & \text{if} \quad \theta < 0 \end{cases} \quad (6)$$

2.3.1. Properties of the Mann-Kendall Statistic (S)

The S statistic is the sum of ranks calculated based on changes in values across the time series. Each time a newer observation differs from a previous one, a rank is assigned, and these ranks are summed to obtain the S value.

According to Kendall (1975), if the number of observations n≥8 and the data are not normally distributed, the mean and variance of the S statistic can be calculated as follows:

$$if\ E(S) = 0 \rightarrow \mathrm{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{m=1}^{n} t_m(t_m - 1)(2t_m + 5)}{18} \quad (7)$$

Where mi is the number of tied data points in the i category. The Mann-Kendall test statistic (Z) is calculated using the following formula:

2.3.2. Z (Normal Test)

It indicates the normality of the data distribution, which is typically assessed using the Mann-Kendall test. This helps determine whether the obtained trend is unlikely to be due to random chance.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var(S)}}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var(S)}}} & S < 0 \end{cases} \quad (8)$$

The probability of the MK test statistic Z can be calculated using the cumulative normal distribution.

Then, to obtain the p-value

$$p = 2 \times P(Z > |z|) \quad (9)$$

2.3.3. P-value

The probability of observing similar or more extreme results assuming no trend exists in the data. If the p-value is less than 0.05, the trend is considered statistically significant.

$$\tau = \frac{C - D}{n(n-1)\frac{1}{2}} \quad (10)$$

Kendall's Tau (τ): It is a coefficient that measures the relationship and correlation between two variables based on their changes and trends.

In this study, the physical and chemical parameters of water, including TH, pH, TDS, Mg, Ca, Na, Cl, SO_4, and HCO_3, were examined.

2.4.Total Hardness

Total hardness refers to the amount of calcium, magnesium, and other dissolved mineral compounds in water, which affect soap's foaming ability and the formation of deposits in containers and pipes. Water containing a relatively high concentration of these minerals does not foam well with soap. Total hardness is usually expressed as the sum of the concentrations of Ca^{2+} and Mg^{2+} ions, equivalent to calcium carbonate, in units of ppm (parts per million) or mg/L.

On the other hand, total hardness is one of the main factors influencing the corrosion and degradation of pipes, especially in water distribution and storage systems. Laboratory studies have shown that in most natural waters with a pH between 6.5 and 8.0, the likelihood of crevice corrosion in L304 stainless steel is minimal, with a rate of 3.4 at chloride concentrations below 200 mg/L. Additionally, in 316 and L316 stainless steels, crevice corrosion has been observed only rarely, typically at chloride concentrations below 1000 mg/L within the same pH range. Therefore, total hardness is expressed as the sum of the concentrations of Ca^{2+} and Mg^{2+} ions in ppm or mg/L, equivalent to the amount of calcium carbonate, and is referred to as total hardness (Reza & Reza, 2009).

$$TH = Ca \times \frac{CaCO3}{Ca} + Mg\frac{CaCO3}{Mg} \tag{11}$$

Equivalency Ratio in Terms of Equivalent Weights (Sadeghat, 2013).

2.5. pH

The pH of water is a primary indicator of water quality, with significant impacts on aquatic ecosystems and the health of living organisms. Water with a pH between 6.0 and 9.0 is suitable for drinking. Changes outside this range can disrupt the functioning of enzymes and proteins, potentially leading to the death of living organisms. A decrease in pH can also accelerate the release of toxic metals from soil and sediments, increasing the risk of toxicity. Meanwhile, alkalinity plays a vital role in maintaining water quality by serving as an indicator of the water's ability to resist acidity (Long et al., 2025).

2.6.Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is a key indicator of water quality, representing the total concentration of dissolved ions, including cations (such as sodium, calcium, magnesium, and potassium) and anions (such as chloride, sulfate, bicarbonate, and nitrate). Various factors, including geological sources, human activities, agriculture, industrial wastewater, and water treatment processes influence this parameter. An increase in TDS in water can alter its physical and chemical properties, including electrical conductivity, taste, clarity, and total hardness. Furthermore, high TDS levels may have adverse effects on human health, water supply and distribution systems, the efficiency of industrial equipment, and plant growth (Shakeri et al., 2025).

2.7.Global Standards for Drinking Water Quality Assessment

Drinking water, as one of the primary sources of public health, must have an optimal and suitable quality. For this purpose, various standards are used to assess water quality, including national standards of Iran as well as international standards such as those from WHO and EPA (Shayan et al., 2019).

Table 1. Information on standards

Parameter	Iran National Standard	World Health Organization (WHO)	United States Environmental Protection Agency (EPA)
pH	7 to 8.5	6.5 to 8.5	6.5 to 8.5
Total Hardness	200 to 400 mg/L	100 to 500 mg/L	100 to 500 mg/L
TDS	Less than 1500 mg/L	Less than 1000 mg/L	Less than 500 mg/L

2.8. Schoeller Diagram

The Schoeller diagram is one of the standard methods for evaluating the quality of drinking water, determining its suitability for human consumption based on its physical and chemical parameters.

The Schoeller diagram is a valuable tool for evaluating and monitoring water quality, with numerous applications in water-related research. One of its primary uses is to assess the quality of drinking water in various regions. This diagram can help identify changes in water quality over different periods and monitor water sources to support decisions on water treatment and resource management. Additionally, the Schoeller diagram can be used to compare water quality across regions and to identify solutions to improve it. These features make the Schoeller diagram an efficient tool in water studies and water resource management.

This diagram focuses explicitly on key indicators such as TDS, TH, chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), and other chemical compounds.

In this method, the measured values for each parameter are classified within a specified range, and the water under investigation is categorized as "very good," "good," "acceptable," "unsuitable," or "unfit for use." Water with a TDS of less than 500 mg/L is considered "very good" for drinking according to standards. A TDS between 500 and 1000 mg/L is considered acceptable, while a TDS range of 1000 to 1500 mg/L is permissible for drinking. Water with a TDS higher than 1500 mg/L is not suitable for drinking. The Schoeller diagram is typically plotted as a semi-logarithmic chart that graphically displays the different quality ranges (Choramin et al., 2015; Dindarloo et al., 2006).

3. Results and Discussion:

Based on data collected from drinking water sources in Shahrood County from 2016 to 2024, the evaluation of the physical and chemical characteristics of pH, TH, and TDS was conducted within the drinking water range of the study area. The results of the analysis of these parameters are presented below. Additionally, the quality of drinking water was assessed in accordance with the standards of the National Iranian Standard Organization, the World Health Organization (WHO), and the United States Environmental Protection Agency (EPA).

The total hardness in the study area, Shahrood County, ranged from 236.58 to 244.7 mg/L (Figure 2). This parameter indicates the concentration of mineral salts, such as calcium and magnesium, in water and is one of the key indicators of drinking water quality. According to the National Iranian Standard, the permissible range for total hardness in drinking water is 200-400 milligrams per liter (mg/L). In contrast, the World Health Organization and the United States Environmental Protection Agency recommend a range of 100 to 500 mg/L as the optimal level for this parameter. Based on these standards, the results indicate that the drinking water in Shahrood County from 2016 to 2024 is within an acceptable and suitable range for total hardness, with negligible annual fluctuations. Therefore, it does not pose a threat to the health of the residents of Shahrood County.

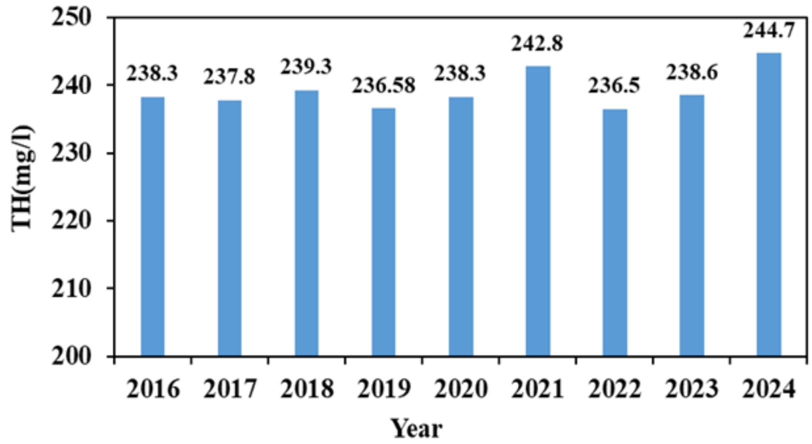

Figure 2. Standards for TH (2016-2024)

Based on the analysis of recorded data from water sources in Shahrood County from 2016 to 2024, the pH values of drinking water in the region ranged from 7.67 to 7.78 (Figure 3). This parameter, which indicates the acidity or alkalinity of water, is considered an essential indicator of drinking water quality. According to the Iranian national standard, the acceptable pH range is 7.0-8.5. At the same time, the World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) recommend a desirable range of 6.5-8.5. The analysis of available data reveals that the pH of Shahrood's drinking water has consistently remained within standard limits, with minimal annual fluctuations, indicating relative stability in water quality and no significant health risk to consumers in the region.

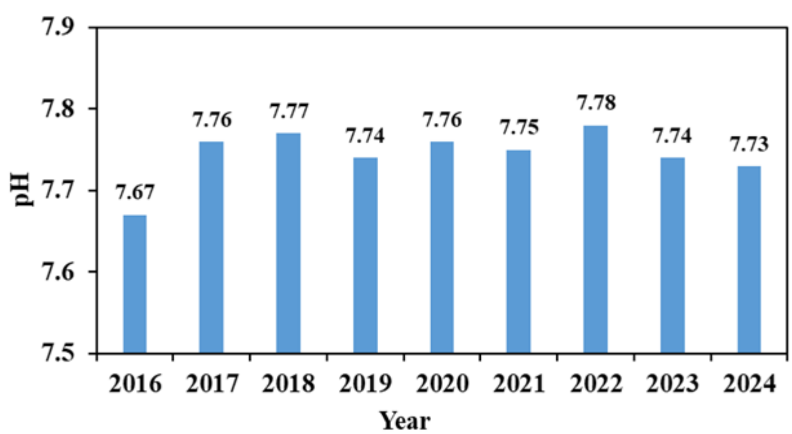

Figure 3. Standards for Drinking Water pH in Shahrood (2016-2024)

The total dissolved solids (TDS) content of drinking water in this region ranges from 374 to 402 mg/L (Figure 4). This parameter reflects the overall concentration of dissolved ions and salts in water and serves as a key indicator of drinking water quality. Specifically, the Iranian national standard sets the maximum permissible TDS limit at 1500 mg/L. In contrast, the World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) recommend levels below 1000 mg/L and 500 mg/L, respectively. Periodic water quality monitoring from 2016 to 2024 indicates that TDS levels in this region remain well below the maximum thresholds established by the authorities above.

Accordingly, the drinking water in Shahrood County can be classified as acceptable in terms of TDS, with minimal annual variations observed throughout the study period.

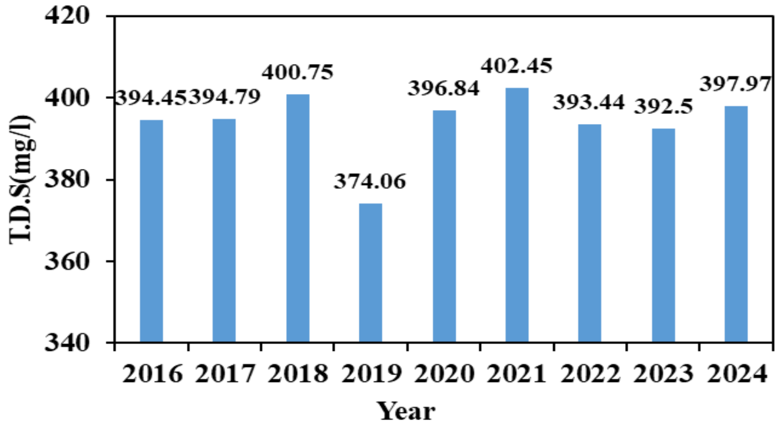

Figure 4. Standards for Drinking Water TDS in Shahrood (2016-2024)

Based on quality parameter data collected for Shahrood City's drinking water over five years (2020–2024), it is possible to analyze trends and assess overall water quality. These data include concentrations of calcium (Ca), magnesium (Mg), sodium (Na), total dissolved solids (TDS), chloride (Cl), sulfate (SO_4), and bicarbonate (HCO_3). A detailed breakdown of each parameter is presented in Table 2.

Table 2: Analysis of Drinking Water Quality Parameters (2020–2024)

Year	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	TDS (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)
2020	60	25	42	238	97	78	176
2021	59	26	41	243	96	78	176
2022	60	26	41	236	96	79	175
2023	57	27	42	239	98	78	176
2024	59	27	41	245	95	78	176

Calcium concentrations in the drinking water of Shahrood ranged between 57 and 60 mg/L over the five years. A slight decline to 57 mg/L was observed in 2023, followed by an increase to 59 mg/L in 2024. These minor fluctuations indicate a relatively stable calcium content. As a principal contributor to total hardness, calcium levels remained well within the internationally accepted limits for drinking water (typically <200 mg/L), posing no public health concerns.

Magnesium levels increased gradually from 25 to 27 mg/L, representing an approximate 8% increase over 5 years. This mild upward trend may be attributed to natural variations in groundwater sources or soil erosion. Because magnesium also contributes to total hardness, its concentration remains within acceptable limits (generally <150 mg/L). Although the increase is not alarming, continued monitoring is recommended to detect any long-term trends that may emerge.

Sodium concentrations remained stable at 41-42 mg/L throughout the study period, exhibiting no significant variations. Sodium is an essential parameter for individuals with hypertension; however, the recorded values are considerably lower than the maximum permissible level (typically <200 mg/L), and thus pose no public health risks.

Chloride concentrations fluctuated slightly between 95 and 98 mg/L. Elevated chloride levels can increase water salinity and cause corrosion of plumbing systems; however, the observed values are well below the recommended threshold (generally <250 mg/L). Consequently, there is no concern regarding salinity or corrosion based on the current data.

Sulfate concentrations remained consistently around 78 mg/L throughout the five-year monitoring period. At elevated levels, sulfate can impart an unpleasant taste and exhibit laxative effects. However, the recorded levels of drinking water in Shahrood are significantly below the maximum permissible limit (typically <250 mg/L). The stability of this parameter suggests that no new industrial or agricultural pollutant sources are entering the local water systems.

Bicarbonate levels were steady, ranging from 175 to 176 mg/L. Bicarbonate plays a critical role in buffering capacity, pH regulation, and reducing water corrosivity. The reported concentrations indicate a balanced alkalinity in Shahrood's drinking water, with negligible annual variation.

The Schoeller diagram is a graphical tool used for classifying water types based on the relative concentrations of major cations and anions, including calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. By plotting the ion concentrations in milliequivalents per liter (meq/L), the diagram helps determine the hydrochemical facies and infer the potential origin of the water (Figure 5).

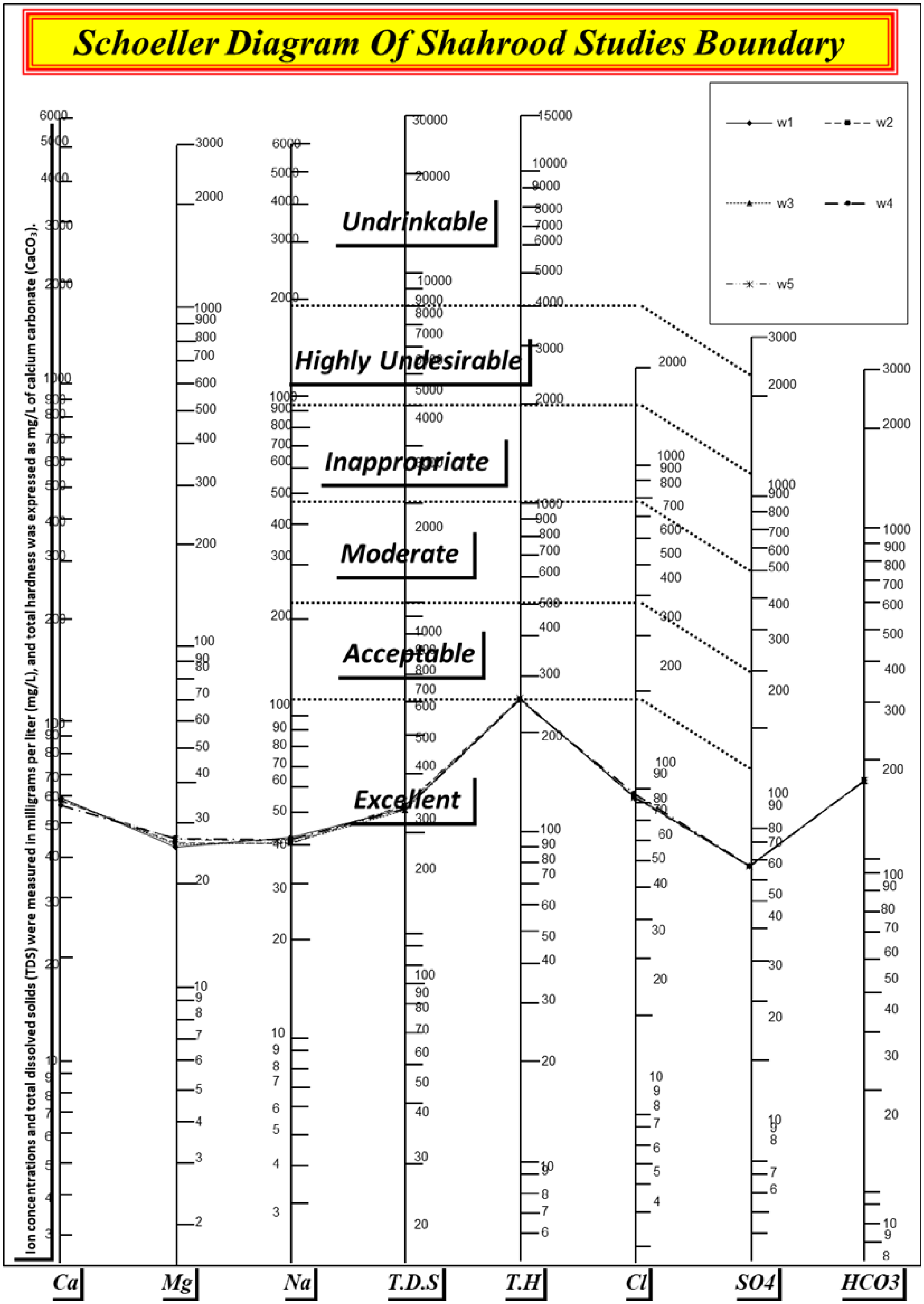

Figure 5. Schoeller Diagram – Changes in Drinking Water Quality (2020–2024)

The groundwater in Shahrood primarily originates from the dissolution of carbonate rocks (limestone and dolomite). This is confirmed by the high concentrations of Ca^{2+} and HCO_3^- ions, as well as a Ca/(Na+K) ratio greater than 1. For drinking water, the total hardness, based on calcium and magnesium concentrations, falls within the moderate range of 200–250 mg/L as $CaCO_3$, which is suitable for general consumption.

All the calculated parameters complied with the World Health Organization (WHO) standards and Iran's Standard 1053. The low concentrations of sulfate and chloride ions also remained within the permissible limits, ensuring that the water did not have any undesirable tastes or odors. The stability of most parameters over the five years indicates a relatively stable quality of the groundwater resources and an absence of new contamination sources. All measured chemical parameters were within the acceptable range of both national (Standard 1053 of Iran) and international (WHO) standards, confirming that the drinking water is chemically safe and satisfactory.

Based on the Schoeller diagram, the water in Shahrood is classified hydrochemically as calcium-bicarbonate hard water with a natural origin (carbonate rocks). The water quality has remained stable over the five years, with no signs of severe contamination or sudden changes in its chemical composition. The water is currently suitable for drinking, agricultural, and industrial uses.

To investigate trends in physicochemical parameters from 2016 to 2024, the Mann-Kendall nonparametric test was applied. The test results indicated that the pH parameter showed a slight decreasing trend with a Kendall coefficient of -0.149 and a p-value of 0.624, which was not statistically significant, suggesting that the changes were oscillatory. Similarly, the TDS parameter showed no significant trend, with a Kendall coefficient of 0.056 and a p-value of 0.919, indicating that the changes were random. Regarding total hardness, although the Kendall coefficient was 0.254, indicating a relative increase, the p-value of 0.345 was not statistically significant. Therefore, it can be concluded that none of the three parameters examined showed a clear and statistically significant trend during this period (Table 3).

Table 3. Mann-Kendall Test Results for pH, Total Hardness, and TDS Parameters

Parameter	Average	S	Z	Kendall's Tau (τ)	P-value	Observed Trend	Statistical Significance
pH	7.7	-25	-0.322	-0.149	0.624	Slight decreasing trend	Not significant
TDS	394.1	2	0.057	0.056	0.919	Very weak increasing trend	Not significant
TH (Total Hardness)	239.2	8	1.291	0.254	0.345	Relatively noticeable increasing trend	Not significant

4. Conclusions

This study examined trends in drinking water quality parameters in Shahrood County from 2016 to 2024. Based on the collected data, the values of TDS, total hardness, and pH fall within the standards of Iran's national regulations, the World Health Organization (WHO), and the United States Environmental Protection Agency (EPA). In none of the years examined did the values of these parameters exceed the allowable limits.

The trend in total hardness shows that it has fluctuated between 236.5 and 344.7 mg/L. An analysis of these fluctuations over the study period revealed that total hardness has varied, but overall no significant increase or decrease has been observed. TDS values also varied between 374.1 and 402.5 mg/L, with these changes mainly attributed to variations in water supply sources and groundwater extraction rates. The pH of Shahrood's drinking water ranged from 7.7 to 7.8, consistently within the standard range across all years.

A regional analysis of these parameters revealed that TDS levels in areas such as Abshar and Chamran were slightly higher than in other places, which could be attributed to the geological composition of the water source or human activities. In contrast, total hardness levels in certain years were reported to be lower in areas such as Shahrood Cultural Town and Mahdiabad than in other regions.

Statistical trend analysis of the data reveals that between 2016 and 2024, changes in TDS, total hardness, and pH did not exhibit any clear trend of significant increase or decrease, mainly remaining within a stable range. These findings suggest that drinking water quality in Shahrood County has remained relatively stable and poses no significant threat to public health.

However, given population growth, land-use changes, and groundwater extraction, it is recommended that continuous water-quality monitoring at the district level be maintained. Additionally, more detailed analyses of chemical compounds, such as heavy metals, nitrates, and other potential pollutants, can complement water quality data and enhance water resource management programs. Based on the results of this study on drinking water quality parameters, it is recommended that continuous monitoring of water resources, particularly magnesium levels and total dissolved solids (TDS), be conducted to identify long-term trends. Identifying potential sources of increased magnesium, such as the erosion of magnesium-rich rocks within the aquifer area, is crucial for a more accurate analysis of changes. When water hardness needs to be reduced for specific industrial or domestic uses, water softening systems are recommended. Moreover, continuous monitoring of water sources for potential changes in ion ratios, particularly chloride (Cl^-) and sulfate (SO_4^{2-}), is essential. Finally, given the possibility of increased water hardness in the future, being prepared to use filtration and softening systems would be a practical step to maintain drinking water quality. This analysis indicates that Shahrood's water has maintained good quality throughout the study period, with no significant concerns regarding its chemical quality.

According to the available data provided by the Shahrood Water and Sewerage Department, the values for the parameters of total hardness (TH), TDS, and pH from 2016 to 2024 have fluctuated as follows: TH between 236.5 and 344.7 mg/L, TDS between 374.1 and 402.5 mg/L, and pH between 7.7 and 7.8. These figures were reported as averages. Given the importance of water quality in maintaining public health, this study emphasizes the need for continuous monitoring of water resources. It recommends periodic inspections to identify potential changes in water quality indicators in a timely manner and to implement appropriate control and preventive measures. The findings of this study can serve as a scientific reference for other regions with similar climatic conditions.

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