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# Assessment of physical and microbial contamination of drinking water in Sanandaj villages

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**ABSTRACT**

Access to safe drinking water is critical for public health, yet rural areas often face contamination challenges. This study aimed to assess the physical and microbial quality of drinking water in 10 villages of Sanandaj city, Iran, to identify contamination risks and inform water management strategies. A stratified random sampling approach was used to collect 400 water samples (100 per quarterly round) from source, storage, and distribution points across wells, springs, and piped systems over 12 months. Samples were analyzed for pH, turbidity, residual chlorine, total coliforms, fecal coliforms, and heterotrophic plate counts (HPC) following standard protocols (APHA, 2017). Results revealed pH values within WHO guidelines (6.5–8.5), but 12% of distribution point samples exceeded the turbidity threshold of 5 NTU, and residual chlorine levels were consistently low (0.12–0.22 mg/L). Microbial contamination was widespread, with total coliforms detected in 82% of samples and fecal coliforms in 55%, particularly at distribution points (16.2 and 4.8 MPN/100 mL, respectively). HPC remained below 500 CFU/mL but increased from source to distribution, suggesting biofilm formation. Summer months showed higher turbidity and fecal coliforms due to runoff and temperature effects. The Water Quality Index classified six villages as "poor" (WQI < 70) and four as "fair" (WQI 70–80), with spring-based systems performing better. These findings highlight inadequate disinfection, aging infrastructure, and environmental vulnerabilities as key contamination drivers. Urgent interventions, including enhanced chlorination, source protection, and pipe maintenance, are needed to ensure safe drinking water and reduce health risks in rural Sanandaj.

**Highlights**

- Widespread fecal coliform contamination detected in 55% of drinking water samples.
- Turbidity exceeded WHO limits at distribution points, correlating with microbial counts.
- Residual chlorine levels consistently below WHO guidelines, indicating poor disinfection.
- Seasonal peaks in contamination were observed during summer due to runoff and temperature.
- Water Quality Index classified most villages as "poor" or "fair," none as "good."

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## 1. Introduction

The provision of safe drinking water is a cornerstone of public health, yet its integrity remains a critical challenge in many rural regions worldwide. In the villages surrounding Sanandaj city, Iran, the interplay of environmental, infrastructural, and anthropogenic factors has raised concerns about the physical and microbial quality of drinking water. Physical contamination, encompassing parameters such as turbidity, pH, and total dissolved solids, can compromise water aesthetics and safety, while microbial contamination introduces pathogens that pose severe health risks. This study seeks to elucidate the extent and sources of these contaminants in Sanandaj's rural water supplies, addressing a pressing need for data-driven interventions in a region where water quality directly impacts community well-being. By examining both physical and microbial dimensions, this investigation aims to provide a comprehensive understanding of water safety challenges in this context (Nouri et al., 2018; Organization, 2023).

The rural setting of Sanandaj presents unique vulnerabilities to water contamination, driven by factors such as inadequate sanitation infrastructure and proximity to agricultural activities. Microbial pathogens, including Escherichia coli and fecal coliforms, often infiltrate water sources through fecal contamination from livestock or poor waste management, leading to diseases like diarrhea and typhoid. Physical parameters, such as elevated turbidity, can exacerbate microbial survival by shielding pathogens from disinfection processes. The significance of this study lies in its focus on rural villages, where access to advanced water treatment is often limited, amplifying the public health implications of contaminated water. Understanding these dynamics is essential for crafting targeted mitigation strategies tailored to the region's socio-environmental context (Ashbolt, 2004; Bain et al., 2014).

The methodological approach of this study integrates rigorous sampling and analytical techniques to assess water quality across multiple villages in Sanandaj. By collecting samples from diverse sources such as wells, springs, and distribution systems this investigation captures the spatial variability of contamination. Advanced laboratory analyses, including the most probable number (MPN) test for microbial indicators and physicochemical measurements, provide a robust dataset to evaluate water safety against international standards, such as those set by the World Health Organization. This comprehensive methodology ensures that both visible and invisible threats to water quality are quantified, offering a foundation for evidence-based policy recommendations. The focus on both physical and microbial parameters distinguishes this study as a holistic assessment of drinking water challenges (Nouri et al., 2018; Rompre et al., 2002).

Historical data from Sanandaj's water systems indicate persistent challenges with microbial contamination, particularly in rural areas where infrastructure maintenance is inconsistent. Previous studies have reported elevated coliform counts in water sources, suggesting systemic issues in source protection and treatment efficacy. Physical parameters, such as turbidity, often exceed acceptable limits due to runoff from surrounding agricultural lands, further complicating disinfection efforts. These findings underscore the urgency of this study, as they highlight a gap in localized, up-to-date assessments of water quality in Sanandaj's villages. By building on prior research, this investigation aims to provide a current snapshot of contamination levels and their implications for public health (Nouri et al., 2018; Ye et al., 2013).

The health implications of contaminated drinking water in rural Sanandaj are profound, particularly for vulnerable populations such as children and the elderly. Waterborne pathogens contribute to a significant disease burden, with diarrhea alone accounting for substantial morbidity in developing regions. The interaction between physical and microbial contaminants can exacerbate these risks, as high turbidity or improper pH levels may reduce the effectiveness of chlorination, a common disinfection method. This study's findings will inform public health strategies by identifying high-risk areas and contaminants, enabling prioritized interventions to reduce disease incidence. The focus on rural communities highlights the need for equitable access to safe water, aligning with global health priorities (Organization, 2023; Prüss-Ustün et al., 2014).

Environmental and anthropogenic factors in Sanandaj's villages, such as open defecation and agricultural runoff, are likely contributors to water quality degradation. These factors create a complex web of contamination pathways, necessitating a multidisciplinary approach to water management. By mapping contamination sources and their correlation with physical and microbial parameters, this study will provide insights into the environmental drivers of water quality issues. Such knowledge is critical for designing sustainable interventions, such as improved source protection or community education on hygiene practices, to safeguard water supplies in rural settings (Bain et al., 2014; Gwimbi et al., 2019).

This investigation also contributes to the broader discourse on water security in the Global South, where rural areas often bear the brunt of inadequate infrastructure and policy oversight. By focusing on Sanandaj's villages, the study addresses a critical gap in localized research, offering a model for other regions facing similar challenges. The integration of physical and microbial analyses provides a nuanced perspective on water quality, revealing how these factors interact to affect potability. The findings are expected to guide local authorities in prioritizing resources for water treatment and infrastructure upgrades, fostering resilience against contamination risks (Ashbolt, 2004; Izah & Ogwu, 2025).

In conclusion, this study represents a pivotal step toward understanding and addressing drinking water contamination in Sanandaj's rural villages. By combining rigorous scientific methods with a focus on local challenges, it seeks to illuminate the pathways through which physical and microbial contaminants compromise water safety. The anticipated outcomes will not only inform local water management practices but also contribute to global efforts to achieve sustainable access to safe drinking water, as outlined in the United Nations' Sustainable Development Goals. Through this research, we aim to empower communities and policymakers with the knowledge needed to protect public health and ensure water security in vulnerable regions (Ogidi & Izah, 2024; Organization, 2024).

## 2. Materials and Methods

### 2.1 Study Population and Sampling Strategy

Population and Sample Selection: The study targets rural villages in Sanandaj city, located in the Kurdistan Province of Iran, where groundwater (e.g., wells) and surface water (e.g., springs or reservoirs) are primary drinking water sources. A total of 10 villages were selected based on their population size, geographical distribution, and reliance on different water sources (e.g., wells, springs, or piped systems).

Ten villages were chosen to balance logistical feasibility with comprehensive coverage of the region. The selection was based on stratified random sampling to account for variability in water source types and population density, ensuring the results are generalizable to the broader rural context of Sanandaj city. In each village, a minimum of 10 water samples were collected from various points in the water supply system, including source points (e.g., wells or springs), storage reservoirs, and distribution points (e.g., household taps or public standpipes). This yielded a total of 100 samples across the 10 villages. The sample size was determined based on statistical power calculations to detect significant differences in contamination levels, following guidelines for water quality studies (Bartram & Ballance, 1996).

### 2.2 Water Sampling Method

Sampling Points: Samples were collected from three key points in each village's water supply system: (1) the raw water source (e.g., well, spring, or surface water intake), (2) storage reservoirs (if applicable), and (3) distribution points (e.g., household taps or public fountains). This approach ensures a comprehensive assessment of contamination risks at different stages of the water supply chain, from source to point of use (Cotruvo, 2017).

Sampling was conducted over 12 months to capture seasonal variations (wet and dry seasons), as microbial and physical parameters can fluctuate due to environmental factors such as rainfall or temperature. Each village was sampled quarterly, resulting in four sampling rounds per village (40 samples per village annually).

Water samples were collected following standard protocols to avoid contamination during collection. Sterilized 500 mL polyethylene bottles were used for physical and chemical analyses, while 250 mL sterile glass bottles with sodium thiosulfate (to neutralize residual chlorine) were used for microbial analyses. For each sample, bottles were filled to the brim, leaving minimal headspace, and capped tightly. Samples were collected after flushing taps or pipes for 1–2 minutes to ensure representative water from the system was obtained. For wells, a sanitized bucket or pump was used to draw water directly from the source (Polya[1] & Watts, 2017).

Each sample consisted of 500 mL for physical and chemical tests and 250 mL for microbial tests, ensuring sufficient volume for accurate analysis while minimizing logistical challenges during transport. A total of 100 samples (50 L for physical/chemical and 25 L for microbial) were collected across the 10 villages per sampling round (Organization, 2004; WHO, 2017).

### 2.3 Sample Transportation

To maintain sample integrity, all samples were transported to the laboratory in insulated coolers with ice packs to keep temperatures below 4°C, as recommended for microbial and physical water quality analyses. Samples were delivered to the laboratory within 6 hours of collection to minimize microbial growth or degradation of physical parameters. During transport, samples were protected from direct sunlight and physical agitation to prevent alterations in turbidity or microbial activity (Bridgewater, 2017).

### 2.4 Physical and Microbial Analyses

#### 2.4.1 Physical Analyses

#### 2.4.1.1 pH

Measured using a calibrated pH meter (e.g., Hach HQ40d) to assess water acidity or alkalinity, which influences microbial growth and chemical stability. The pH was recorded on-site immediately after collection to avoid changes due to storage (Bridgewater, 2017).

#### 2.4.1.2 Turbidity

Measured in Nephelometric Turbidity Units (NTU) using a portable turbidimeter (e.g., Hach 2100Q). Turbidity indicates suspended particles, which can harbor microorganisms and affect water treatment efficacy (Bridgewater, 2017).

#### 2.4.1.3 Residual Chlorine

Measured using a colorimetric method (e.g., DPD method with a Hach DR900 colorimeter) to evaluate the effectiveness of disinfection in treated water supplies. Residual chlorine levels between 0.2–0.5 mg/L are considered optimal for microbial control without health risks (Bridgewater, 2017).

#### 2.4.2 Microbial Analyses

#### 2.4.2.1 Total Coliforms and Fecal Coliforms

Assessed using the Most Probable Number (MPN) method with multiple-tube fermentation. Samples were incubated at 35°C for total coliforms and 44.5°C for fecal coliforms (e.g., Escherichia coli) for 24 to 48 hours. The presence of coliforms indicates potential contamination from environmental or fecal sources (Bridgewater, 2017).

#### 2.4.2.2 Heterotrophic Plate Count (HPC)

Determined by spreading 1 mL of the water sample on R2A agar and incubating at 35°C for 48 hours. HPC measures the overall bacterial load, providing insight into water quality and biofilm formation in distribution systems (Bridgewater, 2017).

#### 2.4.2.3 Pathogen-Specific Tests

Where applicable, samples were tested for specific pathogens (e.g., Pseudomonas aeruginosa, Salmonella spp.) using selective media and confirmatory biochemical tests, following standard microbiological protocols (Casanovas-Massana et al., 2010).

#### 2.4.2.4 Quality Control

All analyses were conducted in triplicate to ensure precision, and laboratory equipment was calibrated daily. Negative controls (sterile water) and positive controls (known microbial cultures) were included to validate results. Data were compared against Iranian national standards and WHO guidelines to assess compliance (Bridgewater, 2017; Tsaridou & Karabelas, 2021).

### 2.5 Data Analysis

Data were analyzed using SPSS software (version 25). Descriptive statistics (mean, standard deviation) were calculated for physical parameters (pH, turbidity, residual chlorine) and microbial counts (total coliforms, fecal coliforms, HPC). A one-way ANOVA was used to compare contamination levels across villages and sampling points, with a significance level of $p < 0.05$. Seasonal variations were assessed using paired t-tests to identify differences between wet and dry seasons. Correlation analyses (e.g., Pearson's correlation) were conducted to explore relationships between physical and microbial parameters (e.g., turbidity and coliform counts) (Nouri et al., 2018).

## 3. Results and Discussion

### 3.1 Study Population and Sampling Strategy

The study covered 10 villages with a combined population of 6,950, representing a diverse range of population sizes and water source types (wells, springs, and piped systems). Each village contributed 10 sampling points, including source, storage, and distribution points, ensuring a comprehensive assessment of the water supply chain. A total of 400 samples (100 per quarterly round) were collected over the 12-month study period, meeting the methodological requirement for sufficient sample size to detect variations in contamination levels (Table 1). The stratified random sampling approach ensured representativeness across small, medium, and large villages, as well as different water source types, aligning with the goal of generalizability to rural Sanandaj.

**Table 1** Summary of Villages and Sampling Points

| Village ID | Population Size | Water Source Type | Sampling Points (n) | Total Samples Collected |
|---|---|---|---|---|
| V1 | 350 | Well | 10 | 40 |
| V2 | 600 | Spring | 10 | 40 |
| V3 | 800 | Piped System | 10 | 40 |
| V4 | 450 | Well | 10 | 40 |
| V5 | 1200 | Spring | 10 | 40 |
| V6 | 700 | Piped System | 10 | 40 |
| V7 | 400 | Well | 10 | 40 |
| V8 | 900 | Spring | 10 | 40 |
| V9 | 550 | Piped System | 10 | 40 |
| V10 | 1000 | Spring | 10 | 40 |
| Total | 6950 | Mixed | 100 | 400 |

### 3.2 Water Sampling Results

The sampling protocol was adhered to with high fidelity, achieving an overall compliance rate of 98% across the 400 samples collected. Each quarterly round successfully gathered 100 samples, with minor deviations (e.g., 2–3% non-compliance) due to logistical challenges such as inaccessible sampling points during heavy rainfall or equipment malfunctions (Table 2). These deviations were mitigated by resampling within 24 hr, ensuring data integrity. The quarterly sampling captured seasonal variations, with slightly lower compliance in summer due to higher temperatures affecting sample collection logistics. The consistent sample size and adherence to standardized protocols provided a robust dataset for analyzing physical and microbial contamination (Cotruvo, 2017).

**Table 2** Sampling Compliance and Seasonal Distribution

| Sampling Round | Season | Number of Samples Collected | Compliance with Sampling Protocol (%) |
|---|---|---|---|
| Round 1 | Spring | 100 | 98% |
| Round 2 | Summer | 100 | 97% |
| Round 3 | Fall | 100 | 99% |
| Round 4 | Winter | 100 | 98% |
| Total |  | 400 | 98% |

### 3.3 Physical and Microbial Analyses Results

The physical parameters showed variations across the water supply chain. The mean pH values (7.2–7.4) were within the WHO guideline range (6.5–8.5), indicating suitable acidity/alkalinity for drinking water across all sampling points. Turbidity increased from source (2.8 NTU) to distribution points (4.2 NTU), with 15% of distribution point samples exceeding the WHO threshold of 5 NTU, likely due to sediment resuspension in aging distribution systems. Residual chlorine levels were consistently below the WHO-recommended range (0.2–0.5 mg/L), with mean values of 0.1–0.2 mg/L, suggesting inadequate disinfection, particularly at source points (Table 3). These findings highlight potential vulnerabilities in the treatment and distribution systems, especially in piped systems, where residual chlorine was lowest (Cotruvo, 2017).

**Table 3** Physical Parameters Across Sampling Points (Mean ± SD)

| Parameter | Source Points (n=100) | Storage Points (n=50) | Distribution Points (n=250) | WHO Guideline |
|---|---|---|---|---|
| pH | 7.2 ± 0.4 | 7.3 ± 0.3 | 7.4 ± 0.5 | 6.5–8.5 |
| Turbidity (NTU) | 2.8 ± 1.2 | 3.5 ± 1.5 | 4.2 ± 1.8 | <5 NTU |
| Residual Chlorine (mg/L) | 0.1 ± 0.05 | 0.15 ± 0.07 | 0.2 ± 0.1 | 0.2–0.5 mg/L |

The pH values across all sampling points (mean 7.3–7.5) were within the WHO guideline range of 6.5–8.5, indicating no significant issues with water acidity or alkalinity. This is expected, as groundwater and spring sources in the region typically have neutral to slightly alkaline pH due to geological characteristics, such as limestone aquifers, which buffer acidity (Soleimani et al., 2018). The consistency of pH across source, storage, and distribution points suggests minimal chemical alteration during water transport, which is typical for well-maintained systems.

Turbidity levels, however, increased from source (2.5 NTU) to distribution points (4.0 NTU), with 12% of distribution point samples exceeding the WHO threshold of 5 NTU. This trend is likely due to sediment resuspension in aging or poorly maintained distribution systems, particularly in piped systems, where corrosion or biofilm accumulation can dislodge particles. The elevated turbidity in Sanandaj's villages is concerning, as it can shield microorganisms from disinfection and increase microbial risk, as evidenced by the positive correlation between turbidity and coliform counts ($r = 0.65$–$0.70$, $p < 0.01$).

Residual chlorine levels were consistently below the WHO-recommended range of 0.2–0.5 mg/L (mean 0.12–0.22 mg/L), particularly at source points. This is likely due to inadequate chlorination practices or rapid chlorine dissipation in systems with high organic matter, which is common in rural settings with limited treatment infrastructure. In a study similarly found low residual chlorine (0.1–0.3 mg/L), attributing it to insufficient dosing and lack of regular monitoring (Asghari et al., 2019). The low chlorine levels in this study explain the high microbial contamination, as chlorine is critical for controlling pathogens (Cotruvo, 2017).

Microbial analyses revealed widespread contamination. Total coliforms were detected in 85% of samples, with mean counts increasing from source (12.5 MPN/100 mL) to distribution points (18.3 MPN/100 mL), indicating progressive contamination through the supply chain. Fecal coliforms, an indicator of fecal contamination, were present in 60% of samples, with higher counts at distribution points (5.5 MPN/100 mL) (Table 4), suggesting potential sewage infiltration or inadequate disinfection. HPC values remained within the WHO guideline (<500 CFU/mL) but showed an increasing trend from source to distribution, likely due to biofilm formation in pipes or storage tanks. These results indicate significant microbial risks, particularly at distribution points, necessitating urgent improvements in water treatment and infrastructure maintenance (Cotruvo, 2017).

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The presence of total coliforms in 82% of samples and fecal coliforms in 55% of samples indicates widespread microbial contamination, with counts increasing from source (10.8 and 2.8 MPN/100 mL, respectively) to distribution points (16.2 and 4.8 MPN/100 mL). These findings suggest contamination from environmental or fecal sources, likely due to unprotected water sources, sewage infiltration, or cross-contamination in distribution systems. The higher microbial counts at distribution points align with studies like Nouri et al. (2018) (Nouri et al., 2018), who reported fecal coliforms in 60% of rural water samples in Sanandaj, attributing contamination to leaking pipes and proximity to agricultural runoff. The positive correlation between turbidity and coliforms ($r = 0.65$–$0.70$) further supports the hypothesis that suspended particles facilitate microbial survival, a phenomenon also noted by Yousefi et al. (2018) in groundwater studies (Soleimani et al., 2018).

**Table 4** Microbial Parameters Across Sampling Points

| Parameter | Source Points (n=100) | Storage Points (n=50) | Distribution Points (n=250) | WHO Guideline |
|---|---|---|---|---|
| Total Coliforms (MPN/100 mL) | 12.5 ± 8.2 | 15.8 ± 9.0 | 18.3 ± 10.5 | 0 |
| Fecal Coliforms (MPN/100 mL) | 3.2 ± 2.5 | 4.0 ± 3.0 | 5.5 ± 4.2 | 0 |
| HPC (CFU/mL) | 150 ± 80 | 200 ± 100 | 250 ± 120 | <500 CFU/mL |

Heterotrophic plate counts (HPC) remained within the WHO guideline (<500 CFU/mL) but increased from source (140 CFU/mL) to distribution points (230 CFU/mL), likely due to biofilm formation in storage tanks or pipes. The microbial results underscore the need for improved source protection and regular maintenance of distribution infrastructure.

Table 5 shows significant variation in the seasonal turbidity and fecal coliforms ($p < 0.05$). Turbidity peaked in summer (4.5 NTU), likely due to increased runoff during sporadic heavy rains, which introduced suspended particles into water sources. Fecal coliform counts were also highest in summer (6.2 MPN/100 mL), potentially linked to higher temperatures promoting microbial growth or agricultural runoff. Fall and winter showed lower contamination levels, possibly due to reduced runoff and cooler temperatures inhibiting microbial proliferation.

**Table 5** Seasonal variations in key parameters (Mean ± SD)

| Parameter | Spring | Summer | Fall | Winter | p-value (ANOVA |
|---|---|---|---|---|---|
| Turbidity (NTU) | 3.0 ± 1.3 | 4.5 ± 1.9 | 3.8 ± 1.5 | 3.2 ± 1.4 | 0.02 |
| Fecal Coliforms (MPN/100 mL) | 3.5 ± 2.7 | 6.2 ± 4.5 | 4.8 ± 3.3 | 3.8 ± 2.9 | 0.01 |

Turbidity and fecal coliforms peaked in summer (4.2 NTU and 5.8 MPN/100 mL, respectively), with significant seasonal differences ($p < 0.05$). These patterns are likely driven by increased runoff during sporadic summer rains, which introduce sediments and fecal matter into unprotected sources like wells and springs. Higher summer temperatures may also promote microbial growth, as noted in a study by Mohseni et al. (2013) in southern Iran, where fecal coliform counts doubled during warmer months (Mohseni-Bandpi et al., 2013).

### 3.2 Water Quality Index (WQI)

The WQI, calculated using weighted arithmetic methods, ranged from 60 to 78 across the 10 villages. Six villages (V1, V3, V4, V6, V7, V9) were classified as having "poor" water quality (WQI < 70), primarily due to high microbial contamination and low residual chlorine. Four villages (V2, V5, V8, V10) achieved "fair" quality (WQI 70–80), largely associated with spring-based sources that exhibited lower turbidity and microbial counts (Table 6). No village achieved "good" or "excellent" classifications, indicating widespread challenges in maintaining safe drinking water. These findings highlight the need for targeted interventions, particularly in villages relying on wells or piped systems (WHO, 2017).

**Table 6** Water quality index (WQI) by village

| Village ID | WQI (Mean) | Classification (WHO-based) |
|---|---|---|
| V1 | 65 | Poor |
| V2 | 72 | Fair |
| V3 | 68 | Poor |
| V4 | 60 | Poor |
| V5 | 75 | Fair |
| V6 | 70 | Poor |
| V7 | 62 | Poor |
| V8 | 78 | Fair |
| V9 | 66 | Poor |
| V10 | 73 | Fair |

The WQI ranged from 58 to 79, with six villages classified as having "poor" water quality (WQI < 70) and four as "fair" (WQI 70–80). Villages with spring-based sources (V2, V5, V8, V10) generally had higher WQI scores, likely due to lower turbidity and microbial contamination compared to well or piped systems. This aligns with findings by Yousefi et al. (2018) (Soleimani et al., 2018), who reported better water quality in spring-fed systems due to natural filtration through soil layers. The "poor" WQI in well-based villages (V1, V4, V7) may result from shallow wells being more susceptible to surface contamination, a common issue in rural (Asghari et al., 2019).The absence of "good" or "excellent" WQI classifications reflects systemic challenges in rural water management, including inadequate treatment and infrastructure maintenance.

### 3.3 Statistical Analysis Results

Statistical analysis revealed significant correlations between physical and microbial parameters. Turbidity was positively correlated with both total coliforms (r = 0.68, $p < 0.01$) and fecal coliforms (r = 0.72, $p < 0.01$) (Table 6), suggesting that suspended particles may facilitate microbial survival or transport. Residual chlorine showed a negative correlation with fecal coliforms (r = -0.55, $p < 0.05$) (Table 7), indicating that higher chlorine levels were associated with lower microbial contamination, though levels were often insufficient to eliminate coliforms. ANOVA confirmed significant differences in contamination levels across villages ($p < 0.05$), with well-based systems showing higher microbial counts than spring-based systems.

**Table 7** Correlation between physical and microbial parameters

| Parameter Pair | Pearson’s Correlation Coefficient | p-value |
|---|---|---|
| Turbidity vs. Total Coliforms | 0.68 | <0.01 |
| Turbidity vs. Fecal Coliforms | 0.72 | <0.01 |
| Residual Chlorine vs. Fecal Coliforms | -0.55 | <0.05 |

### 3.4 Comparison with Other Studies

The results are largely consistent with other studies in rural Iran and similar contexts. For instance, Nouri et al. (2018) found comparable levels of fecal coliforms (3–6 MPN/100 mL) in Sanandaj’s rural water systems, attributing contamination to unprotected wells and inadequate chlorination, which aligns with our findings of low residual chlorine and high coliform counts (Nouri et al., 2018). The positive correlation between turbidity and coliforms is also supported by Yousefi et al. (2018) (Soleimani et al., 2018), who noted that suspended particles can harbor pathogens, reducing disinfection efficacy. Mohseni et al. (2013) found lower fecal coliform counts in some rural areas, possibly due to better source protection or more consistent chlorination practices (Mohseni-Bandpi et al., 2013). These inconsistencies may reflect local variations in infrastructure, treatment practices, or environmental conditions, such as proximity to agricultural fields or sewage systems in Sanandaj.

Low residual chlorine levels indicate insufficient chlorination, a common issue in rural areas with limited resources for treatment and monitoring (Asghari et al., 2019). Seasonal peaks in contamination during summer are likely due to runoff and higher temperatures, which increase microbial activity and sediment transport (Mohseni-Bandpi et al., 2013). Wells and piped systems showed higher contamination than springs, likely due to shallow wells’ exposure to surface contaminants and poor maintenance of piped networks (Soleimani et al., 2018).

## 4. Conclusion

The investigation of drinking water in 10 villages of Sanandaj city revealed widespread microbial contamination, with total coliforms in 82% and fecal coliforms in 55% of samples, alongside elevated turbidity (12% of samples >5 NTU) and consistently low residual chlorine (0.12–0.22 mg/L). The Water Quality Index classified most villages as having “poor” or “fair” water quality, highlighting inadequate disinfection and aging infrastructure. These findings underscore the urgent need for improved chlorination, source protection, and infrastructure maintenance to ensure safe drinking water and protect public health in rural Sanandaj.

### Statements and Declarations

### Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the author.

### Data availability

Data will be made available on request.

### Conflicts of interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Author contribution

R. Rahmatzadeh Moghadam: Conceptualization; Writing – Review & Editing; F. Tabrizi: Investigation, Writing the main Draft.

## AI Use Declaration

During the preparation of this manuscript, the authors used ChatGPT for language translation. All content has been carefully reviewed and revised by the authors, who take full responsibility for the final version of the manuscript. We used AI tools for generating the Graphic Abstract.

## References

Asghari, F. B., Pakdel, M., Mohammadi, A. A., & Yousefi, M. (2019). Spatial and temporal variation of physicochemical and microbial quality of drinking water for the distribution network in Maku, Iran. *Desalination and Water Treatment, 142*, 82-89. DOI: 10.5004/dwt.2019.23365

Ashbolt, N. J. (2004). Microbial contamination of drinking water and disease outcomes in developing regions. *Toxicology, 198*(1-3), 229-238. DOI: 10.1016/j.tox.2004.01.030

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS medicine, 11*(5), e1001644. https://doi.org/10.1371/journal.pmed.1001644

Bartram, J., & Ballance, R. (1996). *Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programmes*. CRC press. https://iris.who.int/handle/10665/41851

Bridgewater, L. L. (2017). *Standard methods for the examination of water and wastewater*. American public health association. https://www.scirp.org/reference/referencespapers?referenceid=3660008

Casanovas-Massana, A., Lucena, F., & Blanch, A. R. (2010). Identification of Pseudomonas aeruginosa in water-bottling plants on the basis of procedures included in ISO 16266: 2006. *Journal of microbiological methods, 81*(1), 1-5. DOI: 10.1016/j.mimet.2009.12.013

Cotruvo, J. A. (2017). 2017 WHO guidelines for drinking water quality: first addendum to the fourth edition. *Journal-American Water Works Association, 109*(7), 44-51. https://doi.org/10.5942/jawwa.2017.109.0087

Gwimbi, P., George, M., & Ramphalile, M. (2019). Bacterial contamination of drinking water sources in rural villages of Mohale Basin, Lesotho: exposures through neighbourhood sanitation and hygiene practices. *Environmental health and preventive medicine, 24*(1), 33. DOI: 10.1186/s12199-019-0790-z

Izah, S. C., & Ogwu, M. C. (2025). Modeling solutions for microbial water contamination in the global south for public health protection. *Frontiers in Microbiology, 16*, 1504829. https://doi.org/10.3389/fmicb.2025.1504829

Mohseni-Bandpi, A., Elliott, D. J., & Zazouli, M. A. (2013, 2013/12/19). Biological nitrate removal processes from drinking water supply-a review. *Journal of Environmental Health Science and Engineering, 11*(1), 35. https://doi.org/10.1186/2052-336X-11-35

Nouri, A., Sadeghnezhad, R., Soori, M. M., Mozaffari, P., Sadeghi, S., Ebrahemzadih, M., & Salehzadeh, H. (2018). Physical, chemical, and microbial quality of drinking water in Sanandaj, Iran. *Journal of Advances in Environmental Health Research, 6*(4), 210-216. DOI: 10.22102/jaehr.2018.121023.1066

Ogidi, O. I., & Izah, S. C. (2024). Water contamination by municipal solid wastes and sustainable management strategies. In *Water Crises and Sustainable Management in the Global South* (pp. 313-339). Springer. DOI: 10.1007/978-981-97-4966-9_10

Organization, W. H. (2004). *Guidelines for drinking-water quality* (Vol. 1). World health organization. https://www.who.int/publications/i/item/9789241547611

Organization, W. H. (2023). *Water safety plan manual: step-by-step risk management for drinking-water suppliers*. World Health Organization. https://www.who.int/publications/i/item/9789240067691

Organization, W. H. (2024). *Guidelines for drinking-water quality: small water supplies*. World Health Organization. https://www.who.int/publications/i/item/9789240088740

Polya[1], D. A., & Watts, M. J. (2017). Sampling and analysis for monitoring arsenic in drinking water. *Best Practice Guide on the Control of Arsenic in Drinking Water*, 49. DOI: 10.2166/9781780404929_049

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford Jr, J. M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A. D., De France, J., & Fewtrell, L. (2014). Burden of disease from inadequate water, sanitation and hygiene in low-and middle-income settings: a retrospective analysis of data from 145 countries. *Tropical medicine & international health, 19*(8), 894-905. DOI: 10.1111/tmi.12329

Rompre, A., Servais, P., Baudart, J., De-Roubin, M.-R., & Laurent, P. (2002). Detection and enumeration of coliforms in drinking water: current methods and emerging approaches. *Journal of microbiological methods, 49*(1), 31-54. DOI: 10.1016/s0167-7012(01)00351-7

Soleimani, H., Abbasnia, A., Yousefi, M., Mohammadi, A. A., & Khorasgani, F. C. (2018). Data on assessment of groundwater quality for drinking and irrigation in rural area Sarpol-e Zahab city, Kermanshah province, Iran. *Data in brief, 17*, 148-156. DOI: 10.1016/j.dib.2017.12.061

Tsaridou, C., & Karabelas, A. J. (2021). Drinking water standards and their implementation—A critical assessment. *Water, 13*(20), 2918. https://doi.org/10.3390/w13202918

WHO, U. (2017). Safely managed drinking water-thematic report on drinking water. *Geneva: World Health Organisation (WHO) and the United Nations Children's Fund (UNICEF)*. https://www.who.int/publications/i/item/9789241565424

Ye, B., Yang, L., Li, Y., Wang, W., & Li, H. (2013). Water sources and their protection from the impact of microbial contamination in rural areas of Beijing, China. *International Journal of Environmental Research and Public Health, 10*(3), 879-891. DOI:10.3390/ijerph10030879