Microbial and Chemical Assessment of Drinking Water Quality and Its Public Health Implications in Shkodra, Albania

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Abstract: ***Access to clean drinking water remains fundamental to public health, especially in preventing waterborne diseases. This study evaluates the relationship between drinking water quality and disease incidence in Shkodra, Albania, based on microbiological and physicochemical assessments conducted throughout 2023. Residual chlorine levels and Escherichia coli contamination were central indicators. Results showed 42.18% of samples had 0 mg/L chlorine, while 4.3% tested positive for E. coli findings that coincided with higher disease rates in August. The study highlights chlorination failures as a critical factor in microbial contamination and calls for stronger disinfection protocols and continuous monitoring to reduce health risks associated with unsafe water.***

Keywords: drinking water quality, residual chlorine, *Escherichia coli,* public health, waterborne diseases

1. Introduction

The assessment of drinking water quality plays a crucial role in preventing waterborne epidemic outbreaks, which can lead to a rapid increase in morbidity within affected populations. This highlights the critical importance of ensuring drinking water quality at the point of consumption. The supply of safe drinking water is a fundamental public health requirement. Waterborne diseases, such as diarrhea and gastroenteritis remain a global concern, especially in regions where water treatment processes are unstable or inadequate (Centers for Disease control and prevention, 2023).

This study aims to assess the association between residual chlorine levels and the incidence of waterborne diseases in the Municipality of Shkodra, using microbiological and physicochemical indicators collected over a one-year period. Among the various water treatment methods, disinfection is considered the final and most critical step in safeguarding public health. This process employs chemical agents such as chlorine, chloramines, or ozone, as well as non-chemical methods like ultraviolet (UV) light or advanced oxidation processes (AOPs), to inactivate pathogenic bacteria, viruses, and protozoa [1]. Once treated, water enters the Drinking Water Distribution System (DWDS), where maintaining its chemical and biological integrity is essential. Residual disinfectants, such as free chlorine or monochloramine, are maintained throughout the distribution network to prevent microbial regrowth and recontamination [2]. Chlorination remains one of the most widely adopted and cost-effective disinfection methods globally.

Among chlorine-based strategies, residual chlorine control is the most commonly applied, where chlorine is continuously dosed into the water supply [3]. This dosage is regulated using signals from a chlorine analyzer system, which adjusts dosing levels to maintain the target residual concentration. In systems with consistent water quality, either constant-rate control (fixed chlorine dose) or proportional flow control (dose adjusted based on real-time water flow) may be used, the latter governed by signals from flow sensors [4], [5]. Despite its effectiveness, chlorination presents significant monitoring challenges. If not properly managed, it may fail to provide adequate microbial protection. To ensure the microbiological safety of water intended for human consumption, it is essential to maintain appropriate residual chlorine levels at the consumer's tap, in accordance with recommendations [6]. Numerous studies have demonstrated a strong correlation between insufficient residual chlorine and outbreaks of waterborne pathogens such as *Escherichia coli*, *Giardia lamblia*, and *Cryptosporidium parvum*. These organisms can cause severe gastrointestinal illnesses, especially in vulnerable populations including children, the elderly, and immunocompromised individuals. However, the use of chlorine is not without drawbacks. When chlorine interacts with natural organic matter present in the water, it can form disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). Long-term exposure to elevated levels of these DBPs poses additional health risks.

Recognizing these concerns, the U.S. Environmental Protection Agency established the Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules (DBPRs) to regulate these compounds. These rules set maximum contaminant levels (MCLs) for THMs and HAAs, ensuring that the benefits of disinfection are balanced against the potential risks posed by DBPs [7], [8] The effectiveness of chlorine as a disinfectant is also influenced by various physical and chemical factors, including water pH, temperature, and the presence of organic or inorganic materials. High levels of organic matter, in particular, not only reduce chlorine's disinfection efficiency but also increase the likelihood of DBP formation, adding another layer of complexity to water quality management [9].

This research contributes to public health by providing region-specific evidence on the role of residual chlorine in waterborne disease prevention, offering a replicable model for similar settings.

2. Materials and Methods

The Municipality of Shkodra is supplied by groundwater sources. Water is extracted from deep, confined aquifers, which are typically microbiologically safe and chemically stable in the absence of direct contamination [10]. This cross-sectional study aimed to evaluate the relationship between drinking water quality, determining the level of contamination, residual chlorine levels and the incidence of waterborne diseases over a one-year period, with an emphasis on maintaining an effective balance between disinfection and risk minimization.

Water sampling was carried out throughout the year 2023, with samples collected monthly from 23 designated points within the city of Shkodra. The number and distribution of these sampling points were selected to provide representative coverage of the urban area, taking into account population density, potential contamination sources, and accessibility. To ensure the accuracy and reliability of microbiological testing, periodic quality control measures were implemented. These included parallel analyses performed in two local laboratories in Shkodra and in a national reference laboratory, enabling inter laboratory comparison and validation of results. Both microbiological and physicochemical parameters, as well as residual chlorine concentrations, were analyzed. The measured parameters included Escherichia coli, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), turbidity, pH, color, and odor. Residual chlorine and water temperature were measured on site using calibrated portable instruments. Laboratory analyses followed certified international protocols. Detection of *E. coli* was performed in accordance with ISO standards, and all instruments were regularly calibrated. The overall sampling methodology complied with ISO standards, ensuring proper sampling techniques and strict adherence to transportation conditions to preserve sample integrity [11], [12]. *Escherichia coli* was the primary microbiological indicator used to detect potential fecal contamination within the distribution network [13].

Many residual chlorine measurements revealed inadequate disinfection. Epidemiological data including morbidity rates, demographic distribution, and clinical symptoms were obtained from the Shkodra Local Health Care Unit. These data were collected and processed in compliance with guidelines for the protection of public health information. Statistical analysis was performed using Excel and SPSS. Fisher's exact test was applied to identify significant associations between water quality indicators and reported cases of gastroenteritis and other waterborne diseases throughout the study period [14].

3. Results and Discussion

The results of the study indicate microbiological contamination in 4.3% of water samples, corresponding to 235 out of 5460 samples, with a distinct peak observed in August. The assessment of residual chlorine levels revealed that 42.18% of the measurements recorded 0 mg/L, raising serious concerns regarding the effectiveness of disinfection [15]. Water temperature exceeded standard limits in 72.74% of the samples, in accordance with Health Canada guidelines [16]. *Escherichia coli* contamination, peaking in August, further supports the correlation between inadequate chlorination and microbial contamination [17]. Morbidity data showed that 95.1% of reported waterborne illnesses were gastroenteritis cases, with the highest incidence also recorded in August the month with the highest number of samples showing 0 mg/L residual chlorine. The gender distribution of cases was nearly equal, with 50.6% male (1,779/3,474) and 49.3% female (1,715/3,474) cases.

These findings support the hypothesis that failures in the chlorination process are directly associated with microbiological contamination within the distribution system, significantly increasing the risk of waterborne disease outbreaks [18]. Notably, the highest number of gastroenteritis cases recorded in August coincided with the presence of *Escherichia coli* in water samples [19].

Statistical analyses results. To evaluate the impact of residual chlorine on microbial water safety, 5459 water samples were analyzed for chlorine concentration and 5460 samples were tested for the presence of *Escherichia coli* during the 2023 monitoring period. Among the chlorine measurements, 2303 samples (42.18%) recorded 0 mg/L of residual chlorine. Microbiological analysis identified 235 *E. coli*-positive samples (4.30%), all of which originated from the group with 0 mg/L residual chlorine. Fisher's exact test was applied to determine the strength of association between the absence of residual chlorine and the presence of microbial contamination. The analysis revealed a statistically significant association ($p < 0.001$), indicating a strong correlation between the lack of residual chlorine and *Escherichia coli* contamination.

This study provides a comprehensive and integrated assessment of the relationship between water quality and public health outcomes. Unlike previous research limited to epidemiological trends or small datasets, this investigation combines microbiological and physicochemical analyses of water samples with morbidity data reported throughout 2023. It offers a detailed seasonal and demographic evaluation of residual chlorine levels, microbial contamination, and the incidence of waterborne diseases, highlighting chlorination as a key determinant of drinking water safety. Notably, this represents a systematic, year-long assessment within the Albanian context that links laboratory-based water quality monitoring with real-time public health surveillance. Other regions facing similar challenges could benefit from this integrated approach providing valuable insights for evidence based public health decision making. The seasonal increase in gastroenteritis cases, coinciding with low residual chlorine concentrations and elevated water temperatures in August, underscores the need for more robust disinfection protocols within the distribution system. The repeated detection of

Escherichia coli during this period reinforces the vulnerability of the network when chlorination fails. Although other factors such as hygiene and nutrition may also influence disease patterns, the consistent correlation observed during the months of highest risk highlights the need for enhanced surveillance and increased investment in water treatment infrastructure. Furthermore, comprehensive assessments of the health burden associated with all routes of exposure (ingestion, contact, and inhalation) and all water sources (drinking, recreational, and environmental) are still needed [20], [21], [22]. Future studies should also investigate additional causative agents of diarrhea and gastroenteritis, as overlapping etiologies may obscure diagnosis and complicate source attribution.

4. Conclusion

The findings of this study highlight the essential role of effective water disinfection particularly, the continuous monitoring of residual chlorine in ensuring microbiological safety. A statistically significant association was observed between inadequate residual chlorine levels and an increased incidence of waterborne illnesses, especially gastroenteritis. To strengthen public health protection and improve water safety, the following actions are recommended:

- Regular *in situ* monitoring of residual chlorine throughout the distribution system.
- Seasonal adjustment of disinfection strategies in response to temperature variations.
- Routine integration of epidemiological data with water quality monitoring to enable early warning and rapid response.

Residual chlorine should be regarded as a critical barrier against microbial contamination and must be continuously monitored across the entire water supply network. Strengthening disinfection practices particularly in zones with recurring deficiencies is essential for preventing disease transmission and maintaining public confidence in drinking water systems.

By providing robust, data driven insights, this study offers actionable guidance for policymakers, water system operators, and public health authorities aiming to reduce the burden of waterborne diseases within the population.

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Figures

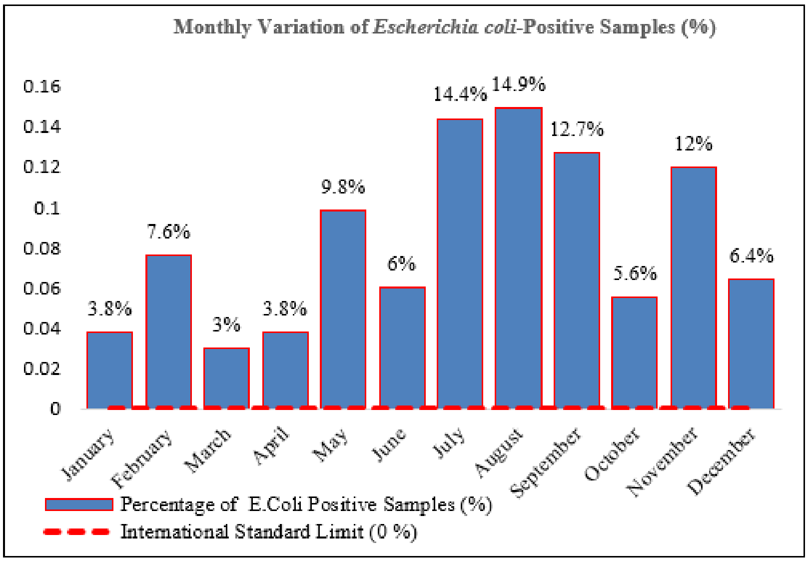

Figure 1: Monthly variation in the percentage of *Escherichia coli*-positive water samples

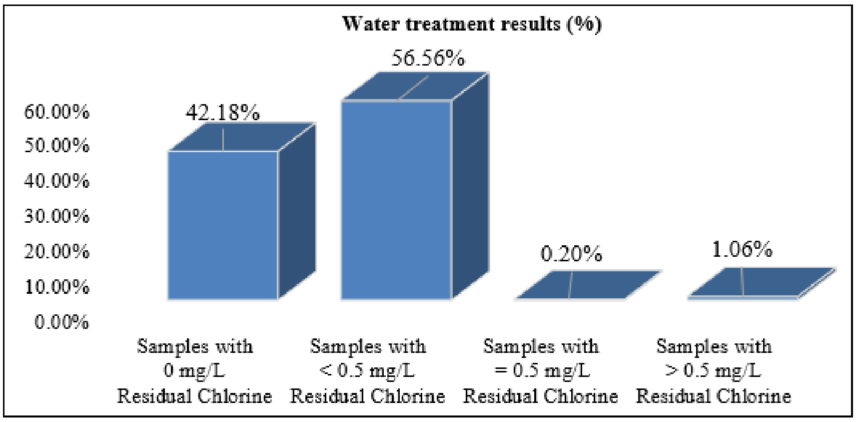

Figure 2: Residual chlorine levels measured in the water distribution network of Shkodra Municipality

Table 1: Results of physicochemical analysis of drinking water

Month	Samples Analyzed for Physicochemical Indicators	Ammonium (NH_4^+)	Nitrite (NO_2^-)	Nitrate (NO_3^-)	Turbidity (NTU)	Odor	Temperature (°C)	pH
January	467	22	5	5	446	445	445	13
February	460	35	10	13	464	453	453	13
March	466	26	1	3	467	466	466	5
April	378	28	1	3	379	378	378	4
May	488	26	1	1	489	488	488	5
June	465	26	1	1	466	465	465	4
July	466	28	1	1	467	466	466	6
August	510	19	11	11	531	520	520	14
September	444	2	0	0	445	444	444	4
October	471	26	1	1	490	489	498	5
November	422	27	24	23	424	422	422	4
December	422	26	23	23	423	422	422	26
Annual Total	5459	291	79	85	5491	5458	5467	103

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