DRINKING WATER QUALITY –AN ASSESSMENT OF RESIDUAL CHLORINE AND IT´S HEALTH EFFECTS

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ABSTRACT

Drinking water chlorination is a critical public health intervention used to eliminate bacteria, viruses, and parasites that can cause waterborne diseases. According to data from the World Health Organization (WHO), approximately one million people die each year from diarrheal diseases associated with unsafe drinking water, inadequate sanitation, and poor hygiene. This study aims to assess the levels of residual chlorine in drinking water and evaluate their public health implications. The analytical methods employed conform to European Standard 80/778 and the Albanian standard STASH 3904:1997. Between January and May 2023, a total of 1,963 drinking water samples were collected and analysed from 13 monitoring points within the Barbulloja water supply system, which serves the city of Lezha—a coastal urban centre in north-western Albania. Between 28 and 31 samples were collected each month, depending on the number of days in the month. The results indicate that residual chlorine concentrations ranged from 0.2 to 0.4 mg/L, remaining within the permissible limits set by the aforementioned standards. The presence of residual chlorine at these levels confirms both the efficacy of the disinfection process and the continued microbiological safety of the drinking water supplied to the population.

Keywords: quality of drinking water, residual chlorine

1. INTRODUCTION

In 2022, at least 1.7 billion people globally relied on drinking water sources contaminated with microbial pathogens, posing a substantial threat to public health and water safety (UN 2021; WHO 2024). Such contamination facilitates the transmission of a range of waterborne diseases, including hepatitis A, diarrhea, dysentery, typhoid, polio, and cholera (UN 2021; WHO 2024). According to World Health Organization estimates, approximately one million deaths occur annually due to diarrheal diseases resulting from unsafe drinking water, inadequate sanitation, and poor hand hygiene (UN 2021). WHO (2023) emphasizes that access to safe drinking water is a fundamental human right, essential for all individuals regardless of their social or economic circumstances or stage of development.

Contaminated drinking water remains a major source of infectious pathogens; however, many waterborne diseases can also be transmitted through alternative routes, including person-to-person contact, contaminated food, droplets, and aerosols (WHO 2022). Consequently, effective disinfection of drinking water is critical to protecting public health. The elimination of pathogenic microorganisms is essential and is most commonly achieved through the application of reactive chemical agents such as chlorine. Disinfection—particularly effective against bacterial pathogens—acts as a vital barrier in the treatment of drinking water and is routinely applied to both surface and groundwater sources that are susceptible to faecal contamination.

When a drinking water supply is contaminated with fecal matter, chemical disinfection becomes a critical measure to mitigate the risk of disease transmission. However, disinfection alone does not ensure complete microbiological safety. Chlorine, the most commonly used disinfectant, has limited efficacy against certain protozoan pathogens—particularly *Cryptosporidium*—as well as some viruses (UN 2021; WHO 2022; 2023). The effectiveness of disinfection can also be compromised when pathogens are embedded within flocs or suspended particles, which shield them from contact with the disinfectant. Additionally, elevated turbidity levels may reduce disinfection efficiency by protecting microorganisms, facilitating bacterial regrowth, and increasing the overall chlorine demand (UN 2021; WHO 2022; 2023).

To ensure the safety of drinking water, a comprehensive water quality management strategy is essential. This strategy should encompass multiple barriers, including source water protection, appropriate treatment processes, and safeguards during storage and distribution—supplemented by effective disinfection—to eliminate or prevent microbial contamination. The use of chemical disinfectants in water treatment commonly results in the formation of disinfection by-products (DBPs). However, the health risks posed by inadequate disinfection significantly outweigh the potential risks associated with DBPs. Therefore, efforts to reduce DBP formation must not compromise the efficacy of disinfection. Chlorine remains the most widely used disinfectant due to its proven effectiveness, ease of application, and straightforward monitoring and control, making it especially suitable for drinking water treatment. In systems where chlorination is applied, regular monitoring is strongly recommended (Zyara *et al*., 2016; WHO 2022; 2023). Most chemicals found in drinking water pose health concerns only after long-term exposure, generally over years rather than months (WHO 2022). In some cases, groups of related chemicals may originate from common sources—for instance, DBPs—making it unnecessary to establish guideline values for each compound. Instead, monitoring key indicator compounds may suffice. In chlorinated systems, the principal DBPs of concern are trihalomethanes (THMs) and haloacetic acids (HAAs). Effective control of these and other by-products requires managing the concentration of precursor compounds to ensure that THM and HAA levels remain below their respective guideline values (WHO 2022). Chlorine is typically present in disinfected drinking water at concentrations ranging from 0.2 to 1.0 mg/L (WHO 2003).

Climate change poses a persistent and unpredictable challenge to drinking water quality. Due to the inherent difficulties in forecasting climate-driven impacts, risks to water safety are expected to be ongoing and recurrent (Ma *et al*., 2022; Swinamer *et al*., 2024). These risks become particularly pronounced during extreme weather events, such as heavy rainfall, flooding, or harmful algal blooms (e.g., red tides). In such cases, authorities may be forced to temporarily shut down water treatment plants to manage resulting emergencies (Swinamer *et al*., 2024). Ensuring the safety of drinking water in the context of climate change demands increased vigilance and strengthened collaboration among governments, research institutions, and water utilities (see Figure 1). Efforts should prioritize adaptive strategies and proactive water quality management (Ma *et al*., 2022; Swinamer *et al*., 2024). A low-level concentration of chlorine remaining in drinking water after a specified contact period is termed free residual chlorine (FRC). This residual chlorine acts as a critical safeguard against post-treatment microbial contamination, offering a unique and vital benefit for public health.

There are three forms of residual chlorine in water treatment: i) free - residual chlorine, which consists of dissolved hypochlorite ions (OCl^-), hypochlorous acid (HOCl), and chlorine gas (Cl_2); ii) combined - residual chlorine, primarily in the form of chloramines, which possess bactericidal properties and are capable of oxidizing organic matter, and iii) total residual, which is the sum of both free and combined residual chlorine (Ma *et.al*., 2022; Swinamer *et.al*, 2024).

2. MATERIALS AND METHODS

The present study aims to assess the concentration of residual chlorine in drinking water and its potential health effects. The analytical methods employed comply with European Standard 80/778 and Albanian Standard STASH 3904:1997. From January to December 2023, a total of 4,745 drinking water samples were analyzed—one sample per day (28 to 31 samples depending on the month)—collected from 13 monitoring points. These points are part of the Barbulloja water supply system, which serves the population of Lezha, a coastal city in northwestern Albania (Nezaj and Puto, 2013). Free chlorine concentrations within the range of 0.1–10 mg/L were determined using a colorimetric method. Additionally, to measure free chlorine, chloramines, and total chlorine concentrations up to 5 mg/L, other analytical techniques were applied, as detailed in the following sections. The minimum detectable chlorine concentration using these methods is approximately 0.02 mg/L (APHA 1989; WHO 2003).

Disinfection of drinking water

Disinfection of drinking water must be implemented across all water supply systems. In accordance with the Decision of the Council of Ministers No. 379, dated 25.05.2016, the required chlorine levels, as specified in the regulation, must be continuously maintained over a 24-hour period. Drinking water disinfection methods are generally categorized into two main types:

i) Physical methods, which include:

a) Boiling – Once water reaches the boiling point, it should be boiled for at least one minute. If the water is cloudy, it should first be filtered to remove sediments. This method is suitable for household use or during outbreaks of waterborne disease.

b) Ultraviolet (UV) radiation
c) Electromagnetic radiation
d) Ultrasonic waves
e) Activated carbon filtration

ii) Chemical methods, which involve the addition of substances such as ozone, chlorine, or chlorine compounds to disinfect drinking water.

Disinfection is primarily conducted before water enters the distribution network, with the aim of eliminating potentially harmful microorganisms. The most commonly used chemical disinfectants include chlorine, chlorine dioxide, and chloramine. These are applied both in water treatment facilities and throughout the distribution pipelines to maintain microbiological safety (DCM No. 379, dated 25.05.2016).

Ozone, while a powerful disinfectant, is not suitable for maintaining microbial control within distribution systems, similar to ultraviolet radiation, it is not an effective treatment for controlling biological contaminants. Common chemical disinfectants include calcium hypochlorite, sodium hypochlorite and chlorine gas, which are selected based on the specific water treatment technologies in use. The gravity-fed dosing apparatus, dosing apparatus with automatic adjustment of disinfectant quantity, Pressure dosing apparatus with automatic adjustment, three-tubes manual dosing systems, and the three-barrel system are the equipment used for disinfection purposes.

Residual Chlorine Measurement Tests include: i) Diethyl-Paraphenylene-Diamine (DPD) Test which uses DPD-1 or DPD-3 tablets. When added to chlorinated water, they produce color change, with the intensity of the color corresponding to chlorine level. The color is darker the higher the residual chlorine level. The DPD-1 tablets measure chlorine free, while the DPD-3 tablet, used after DPD-1, measure total chlorine. Following chlorination, the free chlorine concentration at the endpoints of the distribution system should be between 0.2 mg/l and 0.5 mg/l, ii) Ortho-tolidine test (OT) test uses ortho-tolidine solution, which turns yellow in the presence of chlorine. The deeper the yellow, the higher the residual chlorine concentration. This test measures the total chlorine in disinfected water (DCM No. 379, dated 25.5.2016).

Storage conditions for disinfectants

Disinfectants must be stored in dry, well-ventilated, and moisture-free rooms equipped with appropriate ventilation systems. Containers should be placed at least 25 cm above the floor surface to prevent contamination and moisture exposure.

Before using any disinfectant batch, users are required to conduct necessary inspections and analyses to determine the active chlorine concentration. For each batch tested, the water supply administrator must retain the analysis results along with official approval for use issued by the regional public health authority.The storage and preparation areas must be under con tinuous supervision to prevent any chemical leakage, which is strictly prohibited. Due to the corrosive, irritating, and potentially toxic nature of disinfectants, the use of personal protective equipment (PPE)—including rubber gloves, safety goggles, masks, and protective boots—is mandatory during handling and processing. Additionally, a fully stocked first aid kit must be maintained within these facilities (DCM No. 379, dated 25.05.2016).

3. RESULTS AND DISCUSSIONS

From January to December 2023, a total of 4,745 drinking water samples were analyzed for quality surveillance. Each sample was daily collected from each of the 13 monitoring points within the Barbulloja water supply system, which serves the population of Lezha.

Table 1 presents the number of samples analyzed, along with the values of free residual chlorine in drinking water, categorized into three groups: a) 0 mg/L (no residual chlorine), b) <0.5 mg/L, and c) =0.5 mg/L. According to the table, during the period from January to June 2023, several drinking water samples were found to contain no free residual chlorine (category a: 0 mg/L). However, from July to December 2023, there were no samples in category (a); all analyzed samples during this period showed the presence of residual chlorine, falling into either category (b: <0.5 mg/L) or (c: =0.5 mg/L).

Table 1. The monthly number of samples resulted with free residual chlorine

Year 2023	0 MG/L	<0.5MG/L	0.5MG/L	TOTAL
January	31	315	57	403
February	364	0	0	364
March	31	315	57	403
April	360	30	0	390
May	50	353	0	403
June	360	0	30	390
July	0	343	60	403
August	0	362	41	403
September	0	351	39	390
October	0	343	60	403
November	0	360	30	390
December	0	372	31	403
TOTAL				4,745

The Table 1 highlights a significant shift in residual chlorine levels in drinking water samples between the first and second halves of 2023. From January to June, all samples contained no free residual chlorine (0 mg/L), indicating a potential vulnerability to microbial contamination and suggesting inadequate disinfection during this period. However, beginning in July, 100% of the samples showed measurable levels of residual chlorine, with a substantial proportion reaching the World Health Organization (WHO)-recommended minimum concentration of 0.5 mg/L. This improvement strongly suggests that enhanced disinfection practices were implemented mid-year, resulting in increased compliance with international drinking water safety standards.

The World Health Organization (WHO, 2023) recommends a free residual chlorine concentration of ≥0.2 mg/L at the point of delivery and up to 0.5 mg/L in piped distribution systems to ensure effective disinfection. The drinking water samples categorized in Group b (<0.5 mg/L) and Group c (=0.5 mg/L) align with these guidelines, indicating that the samples collected from July to December were in greater compliance with international safety standards.

The absence of residual chlorine in the first half of the year indicates a heightened risk of microbial contamination, particularly in distribution systems with extended travel times or increased vulnerability to recontamination. In contrast, the consistent presence of residual chlorine in the second half of the year suggests a significant reduction in this risk, reflecting improved water safety and enhanced public health protection. This marked change between the two periods within the same year may be attributed to improvements such as the repair or optimization of chlorination systems, enhanced monitoring and quality control measures, or seasonal adjustments in water treatment practices.

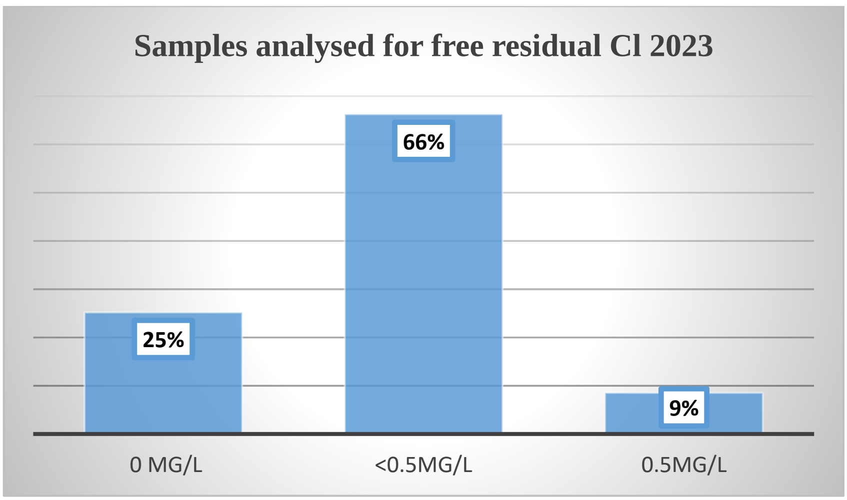

Fig. 1. Drinking water samples analyzed for Free residual chlorine for 2023.

Figure 1 illustrates the percentage distribution of drinking water samples collected in 2023 based on the presence of free residual chlorine. Of the total samples analyzed, 25% fell into Group a (0 mg/L, no residual chlorine), 66% were categorized in Group b (<0.5 mg/L), and only 9% were in Group c (=0.5 mg/L).

Distribution of free residual chlorine levels in drinking water samples during 2023

Of all samples analyzed, 25% had no detectable residual chlorine (Group a = 0 mg/L), 66% had chlorine levels below the recommended threshold (Group b < 0.5 mg/L), and only 9% met the WHO guideline level of 0.5 mg/L (Group c). These findings indicate a gradual improvement in disinfection practices over the year; however, the majority of samples still fell short of the effective residual chlorine concentration recommended by WHO for optimal water safety.

Table 2. Number and % of samples resulted with free residual chlorine (FRC) for 2023

Year 2023	0 mg/l	<0.5mg/l	0.5mg/l	Total
Samples	1196	3144	405	4745
%	25%	66%	9%	100%

As shown in the Table 2, analysis of drinking water samples for free residual chlorine (FRC) over the 12 months of 2023 revealed the following results: 1196 (25% of the total 4745) had an FRC value of 0 mg/l, 3144 samples (66%) had a FRC value of below 0.5 mg/l, and 4045 samples (9%) had a FRC of exactly 0.5 mg/l.

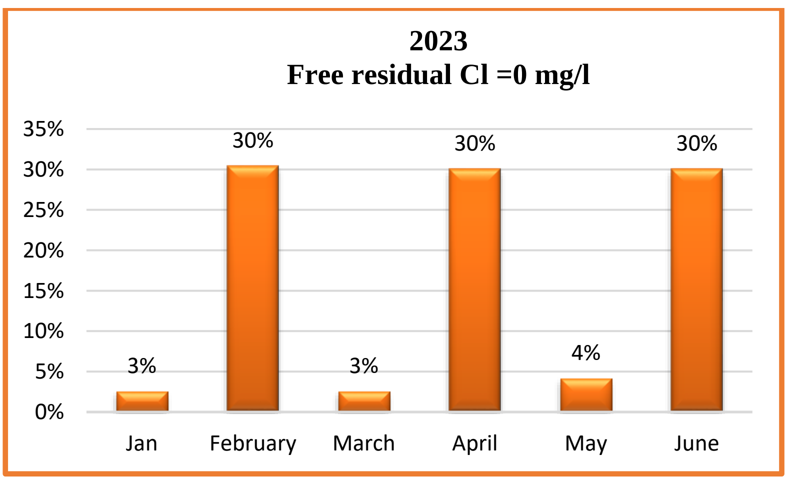

Fig. 2: Drinking water samples analyzed for Free residual chlorine for first 6 months of 2023 resulted with FRCl = 0 mg/l.

As shown in the Figure 2 above, analysis of drinking water samples for free residual chlorine (FRC) over the 12 months of 2023 revealed the following results: 1,196 samples (25% of the total 4,745) had an FRC value of 0 mg/L, 3,144 samples (66%) had an FRC value below 0.5 mg/L, and 405 samples (9%) had an FRC value of exactly 0.5 mg/L.

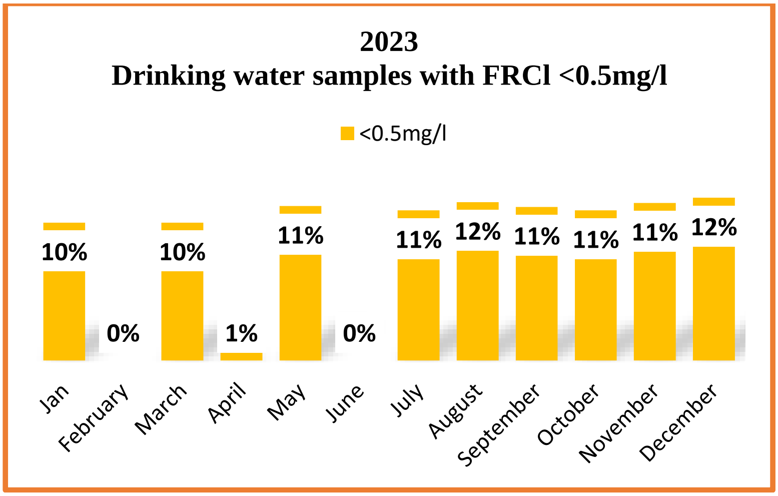

Fig. 3. Drinking water samples analyzed for Free residual chlorine for 2023 resulted with FRCl <0.5mg/l

As shown in the figure 3, a total of 3,144 drinking water samples with free residual chlorine (FRC) levels below 0.5 mg/L were analyzed throughout 2023. The monthly distribution of these samples is as follows: 10% were recorded in January and March; 11% were distributed across May, July, September, October, and November; 12% were found in August and December; while no samples (0%) with FRC < 0.5 mg/L were recorded in February and June.

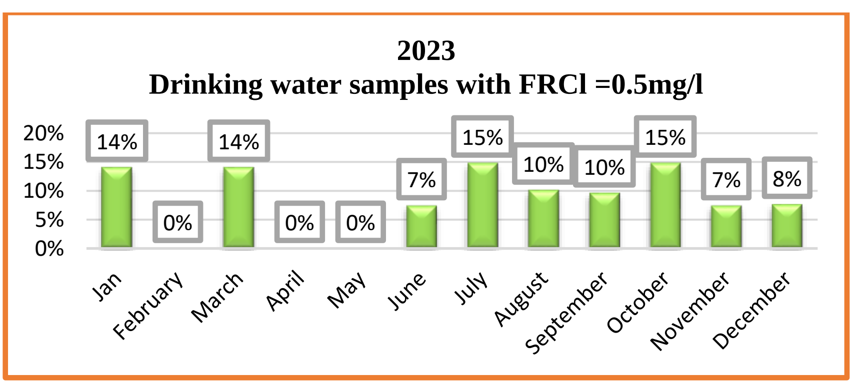

Fig. 4: Drinking water samples analyzed for Free residual chlorine for 2023 resulted with FR Cl = 0.5 mg/l.

As shown in the figure 4, drinking water samples analyzed for free residual chlorine (FRC) at a concentration of 0.5mg/l during the 12 months of 2023 were distributed as follows: 7% of the samples were recorded in June and November, 8% in December, 10% in August and September, 14% in January and March, 15% in July and October, while no sample (0 %) with FRC=0.5 mg/l were recorded in February, April and May.

Table 3. % of samples resulted within allowable limits for various physicochemical parameters for 2023.

Parameters	**PH**	**Ammonium (NH4)**	**Color**	**Aroma**	**Taste**	**Temperature**	**Turbidity**
Allowable limits	6.5-9.5- unit ph	0.1 mg/l	mg/l (pt/co)	dilution no.	dilution no.	15 °c	mg/l (sio2)
% within limit	100%	100%	100%	100%	100%	100%	100%

As shown in the table above, drinking water samples analyzed for free residual chlorine (FRC) throughout 2023 were also tested for other physicochemical parameters. The results indicated that all samples complied with the permissible limits set by Albanian standards and regulations (DCM 2016).
According to recent international literature, disinfected water can become re-contaminated during transportation from the treatment plant to the point of use. Therefore, maintaining disinfectant residues in the distribution system is essential to protect water from potential contamination. When chlorine is used as the disinfectant, it is added to ensure that a residual amount remains throughout the distribution network, sufficient to prevent unexpected microbial pollution. The term free residual chlorine (FRC) refers to chlorine compounds present in water, specifically hypochlorous acid (HClO), hypochlorite ion (OCl^-), and dissolved chlorine gas (Cl_2). However, due to potential health risks, it is advisable to reduce or remove FRC concentrations at the point of consumption. As noted by Sheikhi *et al.* (2014), long-term exposure to residual chlorine may have adverse health effects, underscoring the importance of balancing microbial safety with chemical exposure limits in drinking water.

Health concerns: Numerous studies have shown that chlorine in treated water can pose risks to human health, potentially causing allergic reactions ranging from skin rashes to gastrointestinal symptoms and even arthritis (Sheikhi *et al*., 2014). Additionally, chlorine may destroy protective lactic acid bacteria in the colon, which play a crucial role in strengthening the mucosal immune response against foreign pathogens in the intestine (Hattersley 2000; Sheikhi *et al*., 2014).

Formation of Harmful By-products: Most people consume tap water daily; however, free residual chlorine (FRC) can react with organic compounds present in food and beverages during preparation, leading to the formation of disinfection by-products such as trihalomethanes (THMs), which are potentially harmful (Huang 2005; Sheikhi *et al*., 2014). Therefore, it is advisable to remove chlorine from water before using it for cooking or drinking. While the presence of FRC during water distribution is necessary to maintain microbial safety, it serves no disinfection purpose once the water is consumed and essentially acts as an additive. For this reason, Sheikhi *et al*., (2014) recommend removing FRC from drinking water at the point of use.

Uneven Distribution in the Network: Free residual chlorine (FRC) concentrations tend to be higher near the start of the water distribution system and decrease toward the end. As a result, residents closer to treatment plants are exposed to higher chlorine levels (ISIRI 1053, 2009). To address this imbalance and potential health concerns, it is recommended to remove residual chlorine at the point of use. Increasing public awareness of the health risks linked to disinfection by-products has led many households to prefer non-chlorinated water and adopt in-home water treatment systems to reduce chlorine levels (Sheikhi *et al*., 2014).

Effects chlorine exposure on humans

According to the second edition of *Chlorine in Drinking-water: Background Document for Development of WHO Guidelines for Drinking-water Quality* (WHO/SDE/WSH/03), health criteria and supporting data are presented concerning the effects of exposure to chlorinated water in human populations across different durations.

In one study assessing the effects of progressively increasing chlorine doses (ranging from 0, 0.001 up to 0.26 or 0.34 mg/kg of body weight) in healthy male volunteers, no adverse or physiologically significant toxicological effects were observed in any of the study groups (WHO/SDE/WSH/03). However, exposure to chlorinated water has been reported to trigger asthma and has been associated with episodes of dermatitis (WHO/SDE/WSH/03).

Another study investigated the impact of chlorine levels in water, ranging from 0.2 to 1.0 mg/l, across 46 communities in central Wisconsin. The findings indicated that serum cholesterol and low-density lipoprotein (LDL) levels were elevated in communities consuming chlorinated water. Additionally, in these communities, high-density lipoprotein (HDL) levels and the cholesterol/HDL ratio showed a significant correlation with calcium levels in the drinking water (WHO/SDE/WSH/03).

Furthermore, population-based case-control study found an increased risk of bladder cancer among adults who had consumed chlorinated water for at least half of their lives, suggesting a potential long-term health risk associated with such exposure (WHO/SDE/WSH/03). Chlorine and its by-products—such as chloramines—can often be tasted in drinking water at concentrations below 5 mg/l, and some individuals may detect them at levels as low as 0.3 mg/l (WHO/SDE/WSH/03).

4. CONCLUSIONS

The results of this study indicated that the concentration of free residual chlorine (FRC) in drinking water across the Barbulloja water supply system ranged from 0.1 to 0.5 mg/L, falling within the limits established by Albanian drinking water standards (VKM 2016). Monitoring was conducted throughout 2023 at 13 sampling points in Lezha, northwestern Albania, with a total of 4,745 samples analyzed. The distribution of chlorine concentrations showed that 25% of the samples had no detectable residual chlorine (FRC = 0 mg/L), 66% had levels below 0.5 mg/L (FRC < 0.5 mg/L), and only 9% reached the target value (FRC = 0.5 mg/L). Monthly trends revealed that samples with optimal FRC were most frequent in July and October (15%), while no such samples were recorded in February, April, and May.

These results highlight the fluctuating performance of the disinfection process, which plays a critical role in preventing microbial contamination in drinking water systems (Mahmood *et al.*, 2018). While chlorine is essential for public health protection, prolonged exposure to residual chlorine has raised concerns. Research has linked it to allergic reactions, gastrointestinal issues, and potential disruption of beneficial gut microbiota (Sheikhi *et al.*, 2014; Hattersley 2000). Moreover, the formation of disinfection by-products such as trihalomethanes (THMs) during food preparation may pose additional risks, prompting recommendations to remove residual chlorine before consumption (Huang 2005; Sheikhi *et al*., 2014). Chlorine levels were also observed to be higher at the beginning of the distribution system, exposing residents near treatment plants to higher FRC concentrations (ISIRI 2009). In response to growing public concern, point-of-use treatment devices are increasingly adopted in households to mitigate residual chlorine exposure (Sheikhi *et al*., 2014). Despite these concerns, all physicochemical parameters in the sampled water remained within regulatory standards, affirming general compliance with Albanian national guidelines (VKM 2016).

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