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Optimisation of chlorine disinfection in drinking water supply network

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ABSTRACT

Chlorination is one of the most commonly used procedures for drinking water disinfection. The research aimed to soptimise the subsequent disinfection of drinking water with chlorine in the water supply network in the city Velenje, taking into account the applicable legislation. The gradual reduction of chlorine dosage was implemented with simultaneous monitoring of selected physico-chemical and microbiological parameters of drinking water. During the two-month period, 418 samples were taken at 22 previously defined different sampling spots. Free chlorine values were reduced from the initial 0,18 mg/L to the final 0,08 mg/L at the outlet, while values at some remote sampling sites reached only 0,01 mg/L of free chlorine. Microbiological analyses of samples showed that the drinking water met the limit values in the regulations, despite the low values of free chlorine. Based on the results, a modified chlorination of drinking water was introduced in the tested supply area, and the introduction of a similar regime in other supply areas is being actively considered. In this way, we reduce the consumption of disinfectants and ensure the supply of quality and healthy drinking water to consumers.

Key words: drinking water, chlorination optimisation, microbiological parameters, Slovenia – Velenje.

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INTRODUCTION

Drinking water distribution networks are one of vital infrastructures for our society. The deterioration of water quality is one of the major concerns for water utilities when transporting water through the distribution network [1]. Water quality deterioration can be due to several physical, biological and chemical phenomena such as re-growth and accumulation of microbial species, decay of disinfectant residuals, formation of disinfection by-products or leaching of metals from pipes due to corrosion [2, 3, 4]. Therefore, maintaining adequate water quality is important in water supply through distribution systems [5].
In Slovenia, drinking water comes from 858 supply areas standard control or monitoring is being supplied to more than 90 % of the population [6]. Monitoring of drinking water is determined by the statutory regulation Rules on Drinking Water [7] for ensuring control, taking measures, and supervising risks for human health at the stages from the collection, preparation, storage and distribution of drinking water. Where disinfection is part of the preparation or distribution of drinking water, the operator must verify the procedure's effectiveness and ensure that any contamination by disinfection by-products is as low as possible without compromising the disinfection effect [7]. As part of the monitoring, the microbiological parameters of drinking water are also controlled and must be under the regulations.
The cause of numerous water-borne diseases could also be the microbial contamination of drinking water inside the distribution system [8]. To prevent the spread of water-borne diseases, disinfection is usually necessary for the preparation of drinking water, where chlorination is one of the most commonly used procedures [9, 10]. Among disinfectants, chlorine is the most frequently used because it is comparatively cheap, easy to handle and, above all, ensures long-term free residual chlorine inside a water distribution network [11]. Chlorine is an oxidising agent that reacts with organic impurities, ammonia, metallic compounds, such as ferrous and manganese ions, biofilm, tubercles formed on pipe walls, and pipe wall material [12 – 22].

Although widely used, chlorination can lead to the formation of toxic disinfection-by-products (DBPs) due to the reaction of residual free chlorine with natural organic matter-based precursors and precursor compounds from the microbial population in biofilms on pipe surfaces [2, 23]. The World Health Organization (WHO) has established a guideline value of 5 mg/L for chlorine in drinking water, meaning that such concentrations are acceptable for lifelong human consumption [24]. The global drinking water standards also mandate the stringent control of residual disinfectant levels to prevent microbial contamination and, on the other hand, to limit the formation of disinfection by-products [24]. Numerous research indicated secondary disinfection with booster chlorination for providing uniform and adequate free residual chlorine concentration in the network [25]. This practice can also reduce the disinfectant dose, cost, and contact time of chlorine which, as well as minimise disinfection by-products, taste and odour complaints [13, 25 - 29]. Different studies aimed to define threshold concentration values of free residual chlorine for optimising dosage and the number and location of booster points [27 – 35]. However, various free residual chlorine thresholds are generally defined to ensure acceptable microbial, chemical, and aesthetic water quality.

In the case of water supply network in the city Velenje, the ultrafiltration process is used for pre-treatment of drinking water. After that, chlorine is added in a concentration of 0,18 mg/L [36] for safe drinking water distribution for all users, including those at remote abstractions.

The research aimed to soptimise the subsequent disinfection of drinking water with chlorine in the water supply network of Velenje. The aim was also to determine the minimum concentration of chlorine that ensures the disinfectant effect of drinking water during transport to the last user. Based on the optimization performed in the representative supply area named R1 Velenje, the soptimisation in other supply areas will be considered.

We set up two working hypotheses:
H1: The prepared drinking water with a chlorine concentration of 0,05 mg/L will ensure healthy drinking water in accordance with the legislation.
H2: In the most remote parts of the water supply area, prepared drinking water with a chlorine concentration of 0,05 mg/L, will no longer provide healthy drinking water in accordance with the legislation.

METHODS

Study design (sampling area and sampling protocol):
The research was conducted at the supply area (R1 Velenje) in the network Čujež on the water supply system of Šaleška dolina (Figures 1, 2) which supplies 19,109 users.

Figure 1: Location of research at the water supply system of Šaleška dolina (R1Velenje – water supply area; VG1 and RZ Preska - validation control points of temporary chlorine measurements on the network)

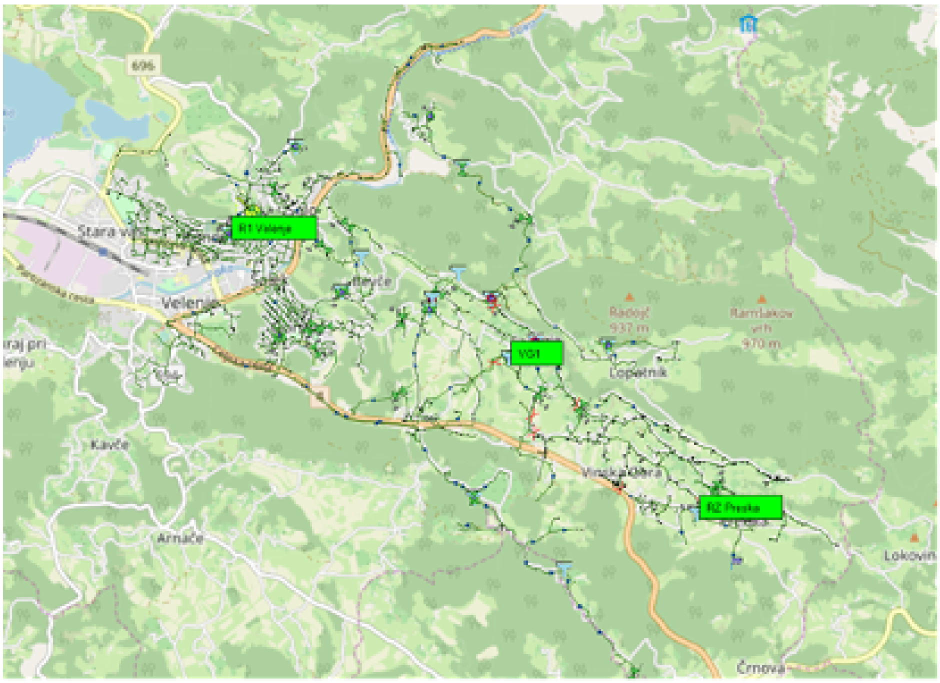
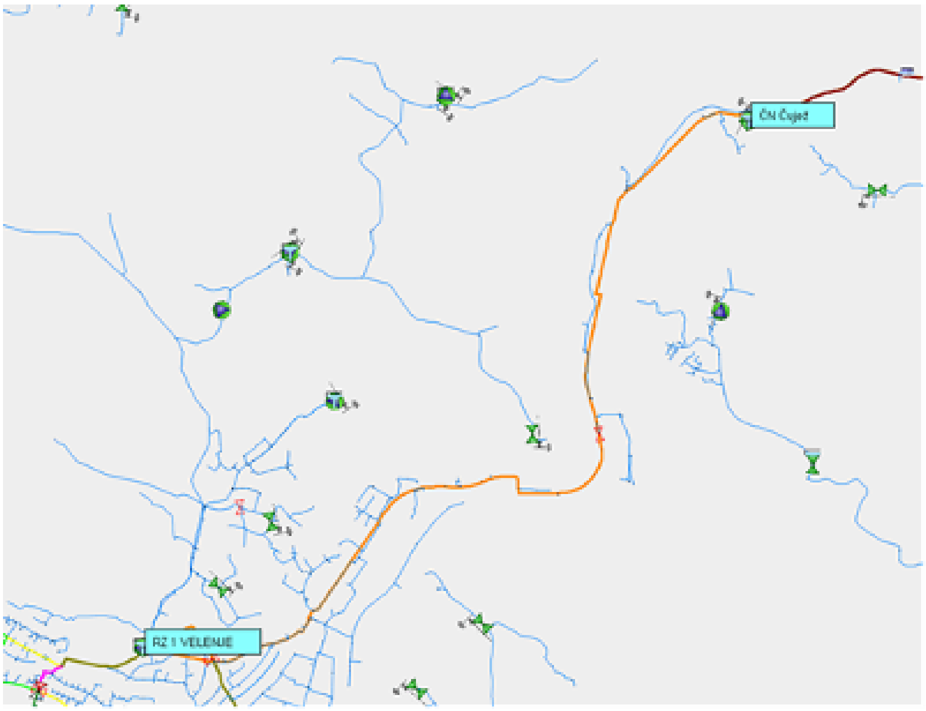
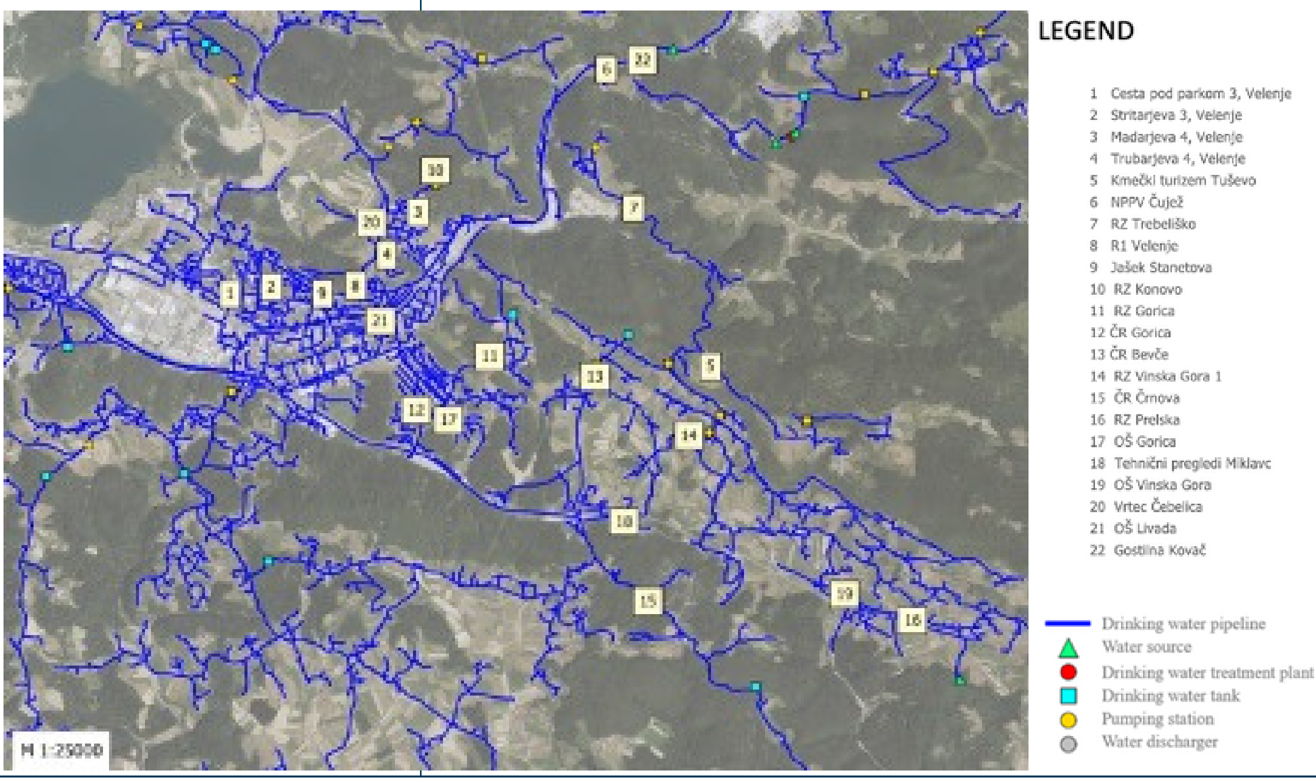


Figure 2: Location of research in the network Čujež



The selected supply area represents 45 % of all users, 25 % of the total volume of the water supply network and 35 % of the average daily distributed quantity of drinking water in the entire water supply system of city of Velenje. The systematic sampling of water was conducted at 22 pre-defined measuring points (Figure 3), which were distributed throughout the supply area at intermediate water supply facilities and at the outlets of end users.

Figure 3: Selected sampling points at R1 Velenje for measurement of chlorine concentration and microbiological parameters.



Water sampling was performed by Komunalno podjetje Velenje before and after water treatment, at water reservoirs, on the network and at the taps of fifteen users (residential buildings, schools, kindergartens, companies). The measurements for free chlorine and measurement of microbiological parameters were conducted twice a week in two months (May-June 2019).

Gradual reduction of chlorine dosage:

Different operating regimes have been defined to monitor the actual network responses by recording measurements of free chlorine:

- The first operating mode represents the unchanged state of operation. The regulated value of chlorine on R1 Velenje is 0,18 mg / l.
- The second operating regime is unreduced chlorination at the NPPV Čujež and the washed water supply network, carried out by rinsing with water from hydrants.
- The third operating mode represents the state when a lower chlorine concentration is dosed into the network than otherwise under normal operating conditions. The reference chlorination limit on NPPV Čujež is reduced to 0,13 mg / l.
- The fourth operating mode represents the state when chlorination at NPPV Čujež is further reduced from 0.13 mg / l to 0.08 mg / l.

Microbiological monitoring:

The BactiQuant (Mycometer, Denmark) method was used to analyse bacterial activity in the water sample. This method allows the measurement of microbial enzyme activity.

In samples where the value of free chlorine was lower than 0,01 mg/L additional parameters were measured:

- E. coli and total coliform bacteria using the Colilert, IDEXX (U.S. EPA approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (SM 9223)
- Enterococci using the Enterolert, IDEXX (U.S. EPA-approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (9230 D).
- total number of microorganisms at 22 ºC and 37 ºC using The SimPlate for HPC test, IDEXX (U.S. EPA approved and included in Standard Methods for Examination of Water and Wastewater) - IDEXX (SM 9215E).

Chlorine concentration monitoring:

Sampling was performed in accordance with the standard SIST ISO 5667-5: 2007 (Water quality - Sampling - Part 5: Guidance on sampling of drinking water from water supply systems). To measure free chlorine concentration a portable chlorine meter (HACH DR 300) was used.

Ethical issue:

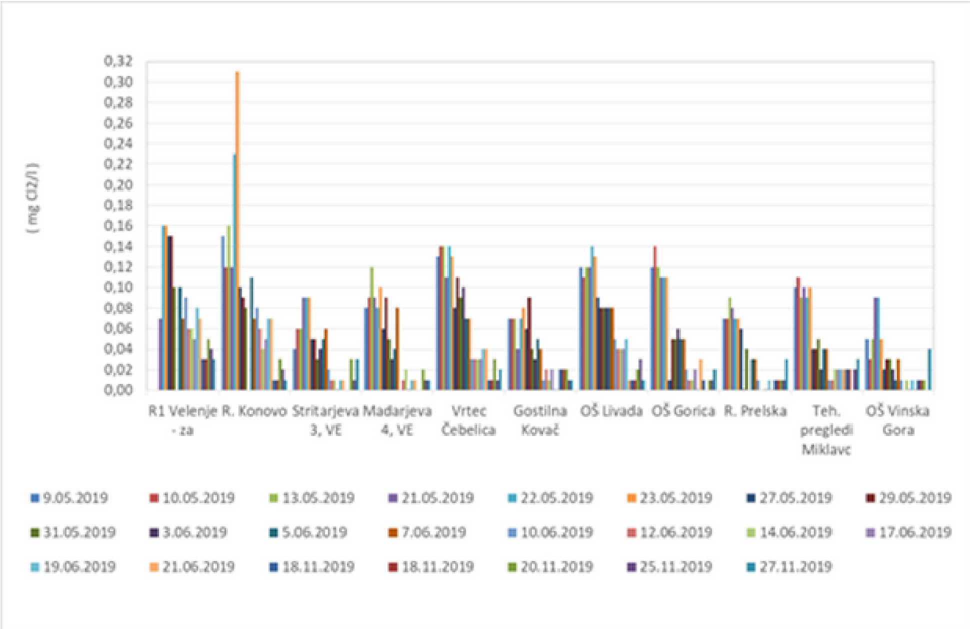
The research was conducted on a functioning water supply system, which is why the security of supply was ensured during the research by a more frequent sampling of drinking water daily. The measuring points were facilities managed by the utility company (tanks, pumping stations) and permanent measuring points in public facilities (schools, kindergartens) or inns and private facilities from which we obtained a sampling permit.

RESULTS AND DISCUSSION

The key goal of the project was soptimisation or reduction of chlorine concentration or even complete elimination of chlorine use in the water supply network. We focused on the R1 Velenje water supply area, where we gradually reduced the chlorine concentration from the initial 0,18 mg/L to 0,08 mg/L over two months. To eliminate the addition of chlorine to drinking water, a perfect hygienic condition must be ensured in the water supply system and in the tanks [37]. The main risks are the age of the water supply system, the oversized system and the fact that there is no online equipment for detecting microorganisms which could monitor the water supply system in real-time [38].

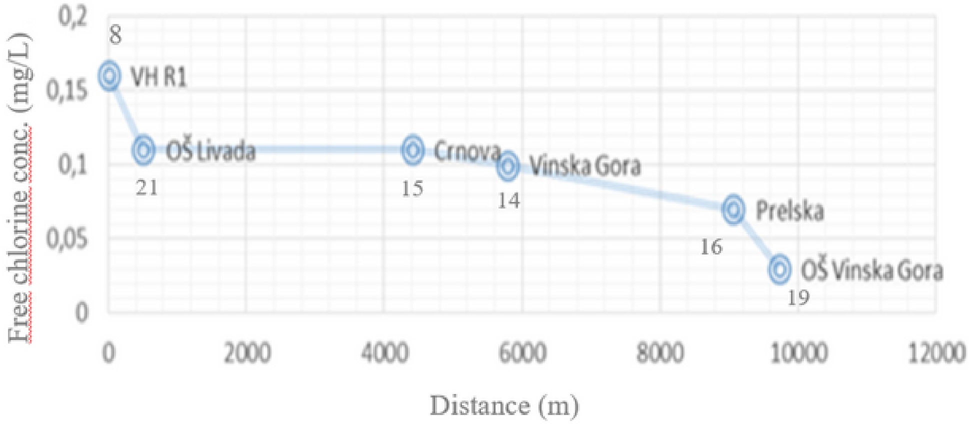
At the time of research, 418 samples were taken and analysed. The values of free chlorine at 11 sampling points were decreased due to lower initial concentrations (Figure 4). The average values decrease rom the initial 0,18 mg/L at sampling point R1 Velenje to the final lowest average concentration 0,08 mg/L - less than 0,01 mg/L (trace-free chlorine)at the farthest measuring point OŠ Vinska Gora (Primary school Vinska Gora).

Figure 4: Free chlorine concentrations at 11 measuring points from 9.5.2019 till 27.11.2019.



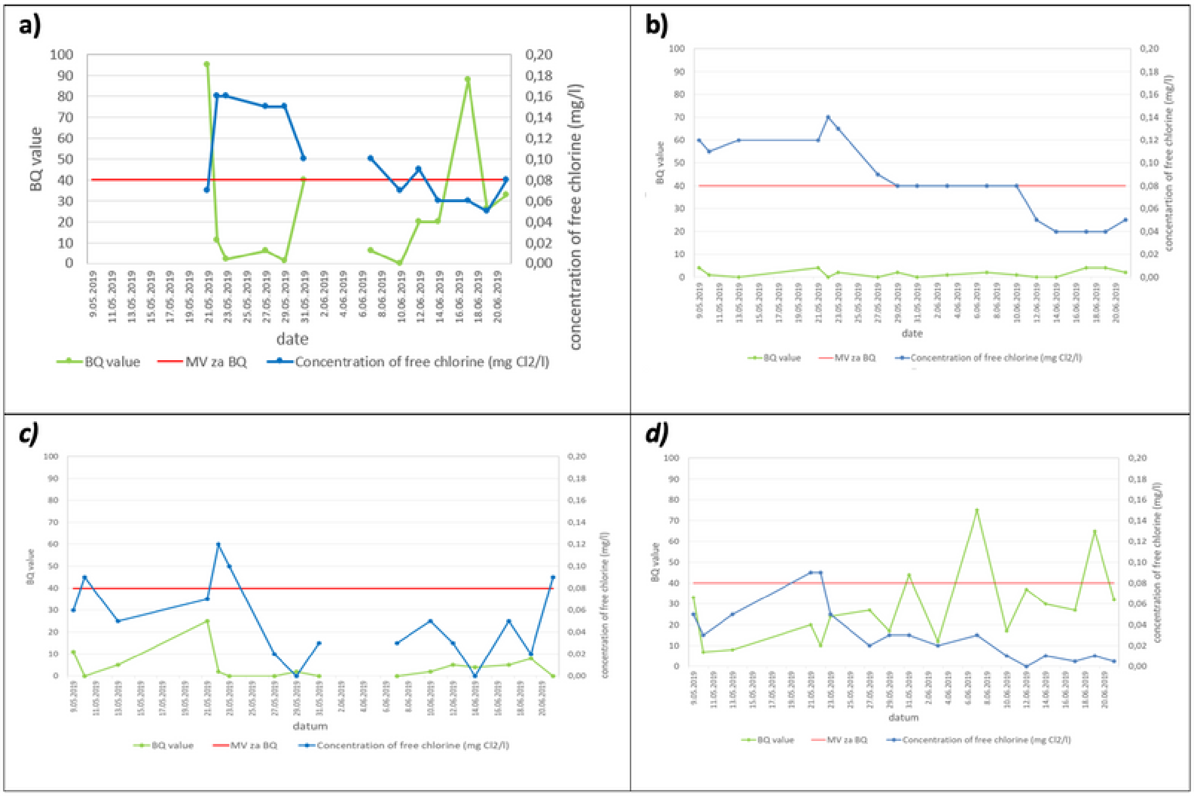
A gradient of free chlorine concentration reduction at the water supply system in the direction of water flow from the chlorination reference point to the farthest chlorine measurement location was constructed (Figure 5). The trail from R1 Velenje to OŠ Vinska Gora represents a distance of more than 9 km.

Figure 5: Reduction of free chlorine concentration concerning the distance from the dosing location to the final measuring point.



Since the chlorine concentration significantly affects the number of bacteria present in the water, microbiological parameters were also checked in the water samples (Figure 6). To determine microorganisms in water, we chose the Bactiquant method (BQ), as it allows us to quickly obtain results on the state of the system in terms of contamination, which means a proactive approach to monitoring. The Bactiquant®-water test for quantifying bacteria in water and other liquids and the Bactiquant® surface (now Mycometer® surface Bacteria) for quantifying bacteria on surfaces was presented to the market in 2007.

Figure 6: Concentration of free chlorine and BQ value at four sampling points (a) R1 Velenje, b) OŠ Livada, c) črpališče Črnova, d) OŠ Vinska Gora

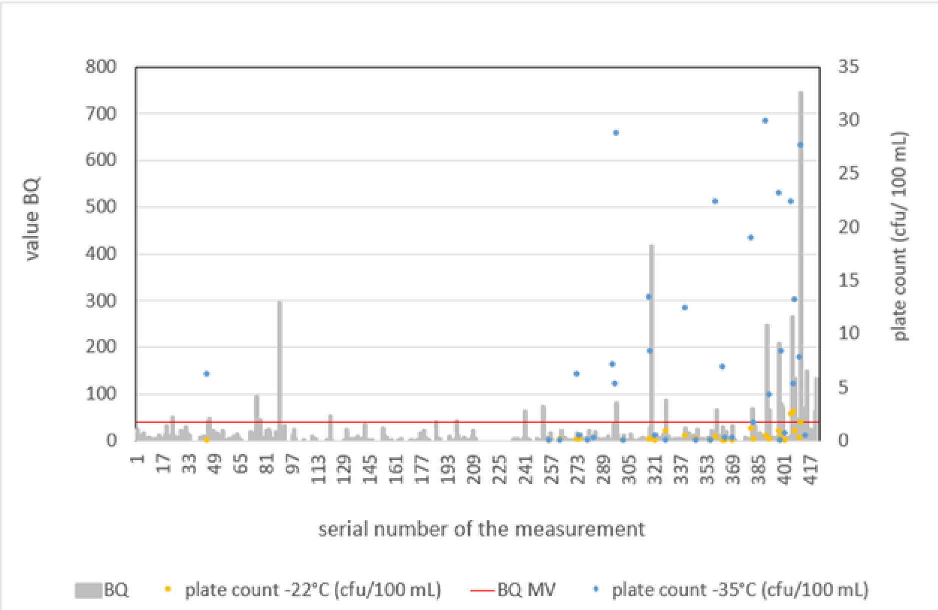


The introduction of the BQ method for the determination of microorganisms, which in contrast to classical methods allows the detection of microorganisms in 30 minutes instead of 24, 48 or 72 hours, allowed active monitoring of the microbiological state of drinking water in the system [39]. Reducing free chlorine in the drinking water system would be impossible without this, as the risk of possible uncontrolled growth of microorganisms would be too high. As a result, such a condition could lead to inadequate microbiological quality of drinking water and possible acute infections of users. We followed the example of other countries which introduced the BQ method for quality control of drinking water production or control of microbiological quality in the water supply system. The study on 976 samples of drinking water made in Copenhagen set the BQ value < 40 as less than 1% probability of exceeding 200 cfu on Plate count (DS/EN ISO 6222) at 22 and 36 °C [40]. According to this study, the BQ value of less than 40 was adopted as a safety value for our drinking water supply system.

In the samples with free chlorine concentration lower than 0,01 mg / l, additional parameters for E. coli, total coliform bacteria and - the total number of microorganisms at 22 ºC and 37 ºC were measured (Figure 6). The results show that despite the low concentration of free chlorine, the drinking water complied with the requirements of the Drinking Water Regulations, namely:

- total number of microorganisms at 22 ºC (parameter limit value 100 cfu/mL [10000 cfu/100 mL]),
- total number of microorganisms at 37 ºC (parameter limit value 20 cfu/mL [2000 cfu/100 mL]).

Figure 7: Motion of BQ, the total number of microorganisms at 22°C and the total number of microorganisms at 37°C



Hypothesis 1 can be confirmed, as despite the reduction of chlorine concentration to 0,08 mg/L, the health adequacy of drinking water was ensured in accordance with the legislation.

Hypothesis 2 can be rejected, as drinking water was compliant with the statutory regulation Rules on Drinking Water even at the most remote sampling points.

In many countries, chlorine is the primary disinfectant, but there are quite a few dilemmas about its use. One of the challenges in maintaining water quality is determining the right dosage of chlorine-based disinfectants and, at the same time, limiting disinfection by-products [41]. Although chlorination prevents the presence and development of pathogenic microorganisms in drinking water, the use of chlorine also has some adverse side effects, as it can lead to the development of various potentially toxic disinfectant by-products (trihalomethanes) [42, 43] which can be associated with many diseases. Therefore, we want the concentrations of free chlorine and, consequently, the concentrations of disinfectant by-products in drinking water to be as low as possible. The sustainable effect of the innovation of reducing chlorine dosing in the water supply system is mainly in reducing the consumption of disinfectant (i.e. chlorine gas), supplying quality drinking water to users and, consequently, a positive impact on user satisfaction.

CONCLUSIONS

The research results within the project contributed to improvements and better quality of drinking water, as well as tracking trends at the global level. With the introduction of a new way of drinking water chlorine disinfection, a sustainable effect has been achieved, primarily in reducing the consumption of disinfectants and supplying high-quality drinking water to users right up to the last user on the system.

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