Russian Federation

Russian National Junior Water Prize

A comprehensive assessment of drinking water quality in Kondopoga, Kareliya

Author: Eleonora Taranina

Contents

Resume

This project involved an analysis of physical, chemical and bacteriologic properties of spring water. Biological tests were conducted with *Ceriodaphnia affinis* test species. The results showed that visibly transparent water might contain a lot of bacteria and unwanted chemicals in concentrations which exceed maximum permissible levels (MPL). The water from local springs is unsafe for drinking because it is neither tested nor treated. Boiling of this water may transform chemicals into more dangerous compounds, and bacterial spores cannot be removed by boiling. Therefore, boiling of spring water can only be considered as alternative method of treatment, and tap water remains the safest source of drinking water. Tap water currently meets most of sanitary standards.

1. Introduction

Everyone consumes water. A survey of Kondopoga residents showed that they preferred to drink spring water and bottled water, because it looked more transparent and odorless than tap water. The latter has yellowish color and smells chlorine. However, one cannot measure water quality given its organoleptic properties. Drinking water should meet all sanitary standards, because unacceptable levels of waterborne chemicals and bacteria may negatively affect one's health. That is why I decided to conduct a comprehensive assessment of quality of ground and drinking water in Kondopoga. Is water quality favorable for one's health? I studied the samples of water from the springs which local residents most frequently use for drinking (Annex 1, 2).

The aim of study was to investigate the ground water from the five springs of Kondopoga and

Prionezhsky districts for their drinking suitability? According to this aim was tried to answer some questions. The first was: Could the spring water substitute tap water and bottled water? And the second one: Could the test-object *Ceriodaphnia affinis* be used for bioassay tests of drinking water quality?

This goal implied the following **tasks:**

1. Conduct instrument organoleptic tests (color and turbidity), as well as physical and chemical analysis of water samples.
2. Compare the results of physical and chemical analysis with the sanitary norms (MPLs) established for drinking water.
3. Determine total microbial count (TMC), *E. Coli* titer and index in the water samples and compare these with the sanitary norms.
4. Evaluate and compare the results of biological, physical and chemical tests.
5. Analyze the changes in physical and chemical indicators associated with activity of *Ceriodaphnia affinis*.
6. Determine applicability of *Ceriodaphnia affinis* for biological tests in various chemical conditions.

Study objects: Ground water from the five selected springs, tap and bottled water ("Karelskaya Zhemchuzhina"), *Ceriodaphnia affinis* bioassay.

Hypotheses: (i) if the spring water has acceptable organoleptic properties, then it is suitable for drinking; (ii) *Ceriodaphnia affinis* bioassay can be used as biological test to indicate the differences in physical and chemical properties of drinking water.

2. Methods and materials

2.1. Geography of water sources

Spring 1. This spring is located to the east of Lake Nigozero, 2,5 km from Zelenaya Street. Area = 4 m^2, depth= 80 cm (Annex 3).

Spring 2. Podgornaya village, 2,5 km from Kondopozhskaya Street. Area = 4 m^2, depth= 50 cm (Annex 4).

Spring 3. Zelenaya Street, in the suburbs, 2 m from the bank of Lake Nigozero, 5 m from the highway (Annex 5).

Spring 4. Onego-2 dacha cooperative, 2,5 km from Kondopozhskaya Street, near the waterlogged forest sections (Annex 6).

Spring 5. Crevice of the left bank of River Neglinnaya, Volnaya Street, north-west end of Petrozavodsk city, surrounded by highways, residential houses, cultural institutions (Annex 7).

Tap water. Cold running water was drawn at the following street address: 65

Oktyabrskoye Highway.

Bottled water. Karelskaya Zhemchuzhina brand, drawn at the depth of 120 m, in the water conservation area 12 km from Petrozavodsk [2] .

2.2. Chemical analysis was performed in Common Data Center of Federal Research Center "Karelia Scientific Center of Russian Academy of Sciences". Physical and chemical measurements conformed to the following State Standards: GOST 18309-2014 (phosphates), GOST 31868-2012 (color), PND F 14.1:2:4.213-05 (turbidity), GOST 31870-2012 (K, Na, Ca, Mg, Fe, Mn), GOST R 52708-2007 (dichromate oxidability), PND F 14.1:2:3:4.121-97 (pH), RD 52.24.361-2008 (chlorides), RD 52.24.367-2010 (nitrates), RD 52.24.381-2006 (nitrites), RD 52.24.394-2012 (ammonia nitrogen). MPLs in drinking water were taken from [6].

2.3. Bacteriologic analysis was conducted in Microbiology Lab of Medical Institute of Petrozavodsk State University, according to Aquatic Microbiology Protocol [3]. Three 1 ml samples were grown in Endo agar in Petri dish. Bacteria counts were obtained with ImageJ software. TMC was estimated as arithmetic sum of all colonies of *E. coli* – the colonies with metallic shine. Coli index and titer were calculated as $Coli\ Ind = \frac{\mathbf{n \times 1000ml}}{\mathbf{U}}$, $Coli\ T = \frac{\mathbf{U \times 1}}{\mathbf{n}}$, where n is *E. coli* bacterial count, U is sample volume. Russian hygienic standard for drinking water (SanPin) prescribes that TMC should not exceed 50 CFU/ml, *Coli Ind* should not exceed 3, and *Coli T* should be greater than 300 [6].

2.4. Biological tests conformed to aquatic toxicity measurement protocol [7]. Environmental status of water was determined by counting species in the third parthenogenetic generation of *Ceriodaphnia affinis* [5]. Ten parallel series were taken from each water sample to validate the results of biological tests. The newborn species were counted during 10-day period.

3. Results

3.1. Weather conditions. The following meteorology parameters were measured and recorded on each sampling date: air and water temperature, humidity, air pressure (Annex Table 1).

3.2. Chemical analysis of water samples and seasonality of chemicals

The measured levels of NO_2^-, Cl^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, Mn^{2+} and pH in all water sources did not exceed the hygienic standards for drinking water (Annex Tables 2-7).

The turbidity exceeded MPL at least once for each water source, with the exception of Spring 3. The violations of turbidity standard were recorded on 3.11.2017 in Springs 2, 4, 5, tap water; in December in Springs 4 and tap water; in July in Spring 4; on 31.08.2018 in Spring 2; in September in Springs 1,2,5, tap water.

Concentration of carbon, measured by dichromate oxidization, exceeded MPL in Springs 4,5, tap water because of low temperatures, which facilitated accumulation of organic substances.

High levels of carbon in bottled water were explained by accumulation of carbon at the well's depth. Rapid transformations of carbon caused its low levels during summer months. Nevertheless, MPL was exceeded by 2 mg/l in Spring 2 on 14.06.2018, and by 14 mg/l in Spring 3 on 31.08.2018. Hardly oxidizable organic substances increase color levels; and this indicator frequently exceeded MPL. Water color exceeded MPL in all water samples on 3.11.2017, except Spring 3; on 28.12.2017 in Springs 1,3,4,5; on 5.08.2017 in Spring 1 and bottler water; on 25.07.2018 in Spring 4 (by 20 degrees). The greatest violations of the standard for water color were recorded for tap water (exceeding MPL by a factor of 2 or 3) because of high levels of iron (between 0,318 and 0,367 mg/l).

Fairly high levels of NO_3^- in December of 2017 corresponded to low levels of NO_2^- because low temperatures slow down transformation of nitrate to nitrite. MPL for NO_3^- was violated in Spring 4 by 63 mg/l and in Spring 5 by 42 mg/l. This standard was violated on 25.07.2018 in Springs 3,4,5; and on 25.07.2018 in Spring 5 (50 mg/l). Nitrite ions are hazardous [4] and their levels never exceeded MPL.

MPL for NH_4^+ was exceeded on 25.07.2018 in Springs 1,2,3,5; on 3.11.2017 in Spring 1 and bottled water; on 11.09.2018 in bottled water by 4,5 mg/l. High anthropogenic load explains the violation of MPL for NH_4^+ in Spring 5. This standard is often violated in the samples taken from freely accessible springs.

Noticeably, MPL for potassium was exceeded by a factor of 3,5 in bottled water in June of 2017.

3.3. The influence of weather on chemical composition of water

The rain on 31.08.2017 did not produce uniform changes in concentrations of chemicals (Annex Table 9), because of the differences in source locations. The results were compared to those recorded on 5.08.2017. NO_3- and NH_4^+ levels generally increased (with the exception of Spring 5), probably because of a more intense hydrolysis of nitrogen compounds, which have both natural and anthropogenic origin. The levels of certain chemicals decreased due to dilution.

3.4. The influence of boiling on chemical composition of water

Boiling of water samples did not produce uniform changes in their chemical composition. NH_4^+ levels generally decreased, probably because of decomposition of organic substances. The color of water increased after boiling in some samples because of formation of insoluble salts. Boiling leads to alkalinization of water, probably because of accumulation of salts (Annex Table 10). Bacteriology analysis showed that single boiling suppressed only vegetative bacterial cells while the bacterial spores remained active. This is why water needs filtration after boiling [8].

3.5.Bacteriologic analysis of water sources

The results in this section are grouped by source.

Spring 1: One-time violation of TMC by 60 CFU/ml was observed on 31.08.2018. The counts of *Intestinal bacillus* group (*E. coli*) exceeded the standard for drinking water by a factor of 8-12, with the exception of samples taken in July.

Spring 2: Insignificant violation of TMC standard was observed on 14.06.2018 and 25.07.2018 because of seasonal factors. No microorganisms have been found on 3.11.2017 and 11.09.2018. *Coli Ind* exceeded the applicable standard on all other sampling dates, and varied between 4 and 11 CFU/ml.

Spring 3: TMC exceeded MPL on 5.08.2017 by 35 CFU/ml, and on 11.09.2018 by 950 CFU/ml. The level of intestinal bacillus group slightly exceeded MPL (by 1-6 CFU/ml).

Spring 4: TMC varied between 12 and 103 CFU/ml. The hygienic standard was violated in July, August and December. The standard for *Coli Ind* was exceeded in August and July. The counts of intestinal bacillus generally varied between 1 and 6 CFU/ml.

Spring 5: TMC standard was exceeded only once on 31.08.2018. However, TMC levels remained quite close to the sanitary norm on all other sampling dates. They varied between 36 and 49 CFU/ml. One colony from three sequences developed on 14.06.2018. *Coli Ind* and *Coli T* were far above the respective standards.

Tap water undergoes purification and has low levels of TMC (0-43 during the observation period), *Coli Ind* and *Coli T* (0-3), meeting the SanPin requirement.

Bottled water: The counts of intestinal bacillus group are high. TMC varied between 160 and 2100 CFU/ml, which greatly exceeded MPL. This indicator met the norm only in November (24 CFU/ml).

3.6.Seasonal changes in bacterial counts in the water samples

TMC gradually decreased during the study period in the water samples taken from Spring 2 (from 2100 CFU/ml to 1600 CFU/ml) and in the bottled water (from 87 CFU/ml to zero). The highest TMC values in Springs 1, 5 and in the tap water were observed in the end of August (123, 109 and 39 CFU/ml, respectively). The highest TCM values in Springs 3 and 4 were observed in the beginning of September, because, ground water receives greater amounts of nitrogen-containing organic substances during this time of the year.

Spore cultures were found in Springs 1, 4 and in the tap water on 31.08.2017; in Spring 1 on 31.12.2017 and in the tap water on 11.09.2018. The presence of bacterial spores of *Bacillus* family indirectly confirmed the contact of water with soil, or the presence of unfavorable environmental factors, which facilitate transformation of vegetative cells into spore cells.

Lower fungi were found in Spring 2 on 31.08.2017; in Springs 3 and 5 on 14.06.2018 and in the tap water on 11.09.2018 Lower fungi form large fluffy colonies with expressed vegetative mycelia in the agar media. Lower fungi are saprophytes and decomposers of organic substances.

Several bacterial cultures were planted in agar growth medium on 11.09.2018. Subsequent tests detected ammonification (saprogenic) bacteria in Springs 1, 4, 5 and the tap water, which confirmed presence of fresh organic pollution.

The results of *Coli Ind* and TMC tests showed similar trends. An increase in TMC was associated with more frequent detection of intestinal bacillus. *Coli T* inversely correlates with *Coli Ind* by definition. Annex Table 11 confirms this relation.

3.7 Analysis of daphnia activity

- **Seasonality in daphnia activity**

Weather conditions strongly influenced activity of daphnia (refer to Annex 8, results for November and December). An outbreak of daphnia fertility was observed in August, consequently, the concentrations of many chemicals in water simultaneously increased. High temperatures in July (26-28°C) explain the seasonal minimum of activity of daphnia.

Clean and chemically-free water could not support daphnia population, therefore, their vitality and productivity would decrease. Parallel tests in distilled water confirmed this statement because all daphnia died on the second day (presumably because of lack of nutrition).

- **Variations in daphnia activity in the studied sources**

Statistical analysis involved two-sample t-tests of differences in dispersion, performed in Microsoft Excel. The significance level was set at $p<0{,}05$.

In December and November, daphnia counts in Springs 4 and 5 significantly differed from those taken from all other water samples ($0{,}0001 < p < 0{,}01$). Daphnia counts in the tap water were significantly greater than those in the remaining samples ($p<0{,}05$). Daphnia counts in Spring 4 were significantly lower than those in the other sources ($0{,}0001 < p < 0{,}01$). On the same sampling dates, daphnia counts in bottled water was significantly lower than those in Spring ($p<0{,}05$). In July, daphnia counts in different water sources showed no significant differences. In August, daphnia counts in Springs 4, 5 were significantly lower than those in the remaining water sources ($0{,}0001 < p < 0{,}01$). In September, daphnia counts in Spring 4 were significantly lower than those in the remaining water samples ($0{,}0001 < p < 0{,}01$). Moreover, daphnia counts in Springs 3 and 6 were significantly lower than those in Springs 2 and 5 ($0{,}0001 < p < 0{,}05$). The data for Spring 3 significantly differed from those for Springs 1, 5 and for bottled water ($0{,}0001 < p < 0{,}05$).

3.7. Choice of the most informative indicators of water quality *Ceriodaphnia affinis* in different water sources

The changes in indicators were measured as the difference between the daphnia counts after

10-day breeding period and the daphnia counts in the original water sample. Most indicators did not show any stable trend; while some indicators gradually increased or decreased over time, following metabolic activity of ceriodaphnia. For example, increases in NO_2^- and PO_4^{3-} were caused by alcalinization of water. The studied water samples contained specific chemicals in different concentrations (Annex Tables 1-7). The changes in concentrations can be associated with seasonal changes in fertility of daphnia (Annex Table 10). Correlations in the studied indicators were identified in the warm (summer) season and the cold season (November and December). The most pronounced were the changes in pH, dichromate oxidizability, NO_2^-, PO_4^{3-} , Ca^{2+} and K^+.

Magnesium (Mg) content was the most informative indicator in the winter season, while turbidity was the most informative indicator during the summer period. During the warm and the cold periods, increases in daphnia fertility coincided with increases in NO_2^- and decreases in PO_4^{3-} (Annex Table 11).

4. Conclusions

1. The concentrations of Cl^-, NO_2^-, PO_4^{3-}, Na, Ca, Mg, Mn and pH in all sources were within the established MPL, thus meeting hygienic standards.

2. Occasional one-time violations were noticed for the following indicators: color; dichromate oxidizability (in Springs 2, 4, tap and bottled water; this finding may indicate the presence of hardly oxidizable carbon); nitrites (in Springs 4 and 5); ammonia (in Springs 1-4 and bottled water); turbidity (in Springs 1, 2, 4, 5 and tap water), iron (in tap water) and potassium (in bottled water).

3. Chemical reactions cause the changes in the measured concentrations. The intensity of chemical transformations is affected by weather, which also causes changes in the measured biological indicators.

4. In all studied water sources, excluding tap water, seasonal violations of sanitary standards for TMC, *Coli T* and *Coli Ind* confirmed the presence of organic pollutants. Ammonia-producing bacteria were observed in Springs 1, 4, 5 and the tap water; spore cultures were present in Spring 1 and tap water; lower fungi were found in Springs 2, 3, 5 and tap water. Physical and chemical properties of the studied water samples affected the activity of *Ceriodaphnia affinis* in various ways, depending upon assimilative and dissimilative processes.

5. It was concluded that *Ceriodaphnia affinis* could be used as a test object in water quality studies.

5. Summary

This study confirmed that even visibly clear water might contain a lot of bacteria and unwanted chemicals in concentrations above the prescribed MPLs. It is not recommended to drink unauthorized spring water because it is neither quality-checked nor treated.

Unfortunately, water boiling cannot remove bacterial spore cultures, and some chemicals are transformed in more hazardous forms. This is why boiling is considered as an alternative method of water treatment. Therefore, the first hypothesis could not be confirmed by our findings. The safest source of drinking water continues to be the tap water. Its quality meets most of the established sanitary norms.

This study confirmed that daphnia could be used as a bioassay or a biological test object, because daphnia population is a living system which is affected by various environmental chemicals. Activity of daphnia may serve as an indicator of chemical pollution. Utilization of daphnia is economically profitable, because it costs less (200-500 Rubles) than a complex analysis of water quality (3000-8000 Rubles).

A publication in a local newspaper "New Kondopoga", along with posting of public information boards near the springs, helped to build up awareness of local residents about water quality. This is a practical result of this study.

6. Literature

1. Google Earth [online], https://earth.google.com/web/@. Assessed on 27.01.2019.

2. Karelskaya Zhemchuzhina (Pearl of Karelia) [online] http://karelianpearl.ru. Assessed on 27.01.2019.

3. Melnikov V. D., Zhvachkina A. A. Aquatic microbiology. Practicum for students of biology department. Petrozavodsk, 1975, 100 pages.

4. Principal requirements to water quality [online] http://eco.bobrodobro.ru/9284. Assessed on 27.10.2018.

5. Ryabukhina E. V., Zarubin S. L. Biological methods of assessment of toxicity of water: Manual. Yaroslavl. Yaroslavl State University Publ., 2006, 64 pages.

6. SanPin 2.1.4.1074-01 Drinking water. Hygienic norms of water quality for centralized drinking water supply systems. Quality control. Hygienic standards of safety of hot water supply.

7. FR.1.39.2001.00282. Water toxicity assessment methods for soils, runoff sediments, and waste. Mortality and variations in fertility of ceriodaphnia. Moscow, Aquaross, 2001, 51 pages.

8. Chemical and physical methods of treatment of bacteria. Disinfection. Sterilization. [online] https://studfiles.net/preview/4666822/page:3/. Assessed on 27.10.2018.

7. List of tables and figures

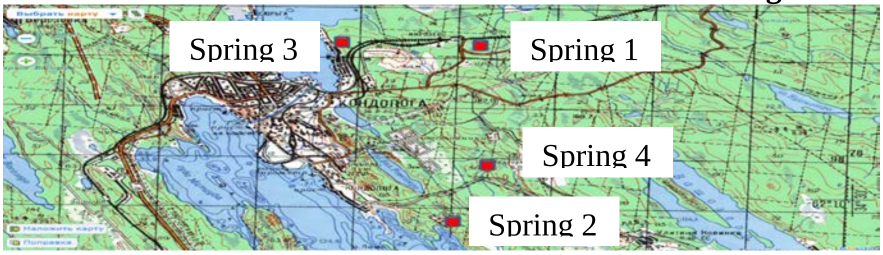


Fig.1. Water sampling points in Kondopoga district of Republic Karelia [1].

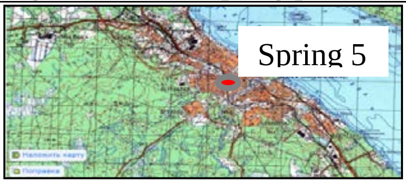


Fig.2. Water sampling point in Prionezhsky district [1].

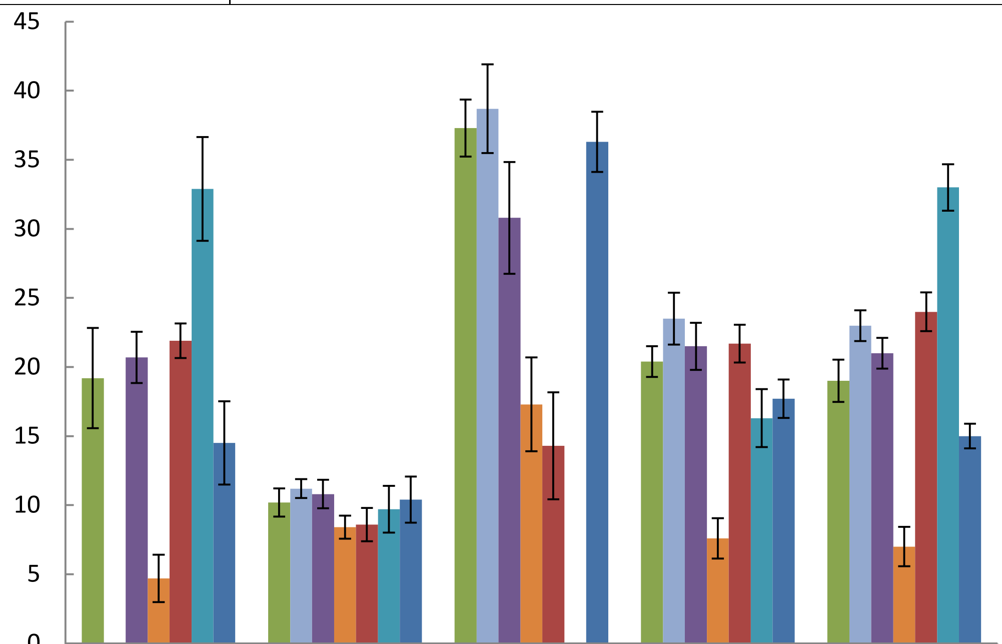
Fig.3. Spring 1

Fig.4. Spring 2

Fig.5. Spring 3

Fig.6. Spring 4

Fig.7. Spring 5



	December	June	August	September	November
Spring 1	19	10	37	20	19
Spring 2		11	39	24	23
Spring 3	21	11	31	22	21
Spring 4	5	8	17	8	7
Spring 5	22	9	14	22	24
Spring 6	33	10	0	16	33
Spring 7	15	10	36	18	15

Fig.8. Daphnia viability analysis in the studied sources

Table 1. Environmental conditions on sampling dates

Date / Indicator	05.08.2017	31.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018
Water t, ^{0}C	5-8							
Air t, ^{0}C	(+14)-(+17)	(+15)-(+17)	(-2)-(+2)	(-4)-(+1)	(+14)-(+16)	(+20)-(+24)	(+11)-(+12)	(+12)-(+15)
H, %	80-86	87-93	79-84	69-78	40-49	56-80	53-56	54-59
P, MmHg	747-751	752-759	745-751	747-753	753-757	757-760	758-765	761-762

Table 2. Physical and chemical analysis of water from Spring 1.

Date / Indicator	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
NO_2^-	0,0040 ± 0,0045	0,0090 ± 0,0052	0,0170 ± 0,0062	less than 0,1 mkg / l	0,0030 ± 0,0044	0,143 ± 0,023	0,0170 ± 0,0062	**3 mg/l**
C	16,1±4,8	19,1±5,7	21,7±6,5	12,6±3,8	less than 10 mg / l	24,3±7,3	less than 10 mg / l	**30 mg/l**
Turbidity	2,97±0,59	3,40±0,68	3,08±0,62	less than 0,1 mg / l	0,70±0,15	less than 0,1 mg / l	***7,3±1,5***	**3,5 mg/l**
pH	6,4±0,2	6,5±0,2	6,3±0,2	6,5±0,2	6,5±0,2	6,9±0,2	6,7±0,2	**(6-9) units pH**
Color	***42,3±8,5***	***57,2±5,7***	***62,3±6,2***	1,191±0,036	4,28±0,13	***30,1±6,0***	9,32±0,28	**30 degrees**
Ca	5,88±0,94	4,60±0,74	2,22±0,36	12,9±2,1	4,53±0,72	11,0±1,8	12,8±2,1	**140 mg/l**
Na	3,29±0,49	3,45±0,52	2,90±0,44	5,34±0,80	3,30±0,50	1,13±0,17	2,10±0,32	**200 mg/l**
Mg	6,14±0,95	5,90±0,89	6,34±0,95	6,7±1,0	7,8±1,2	8,9±1,3	9,5±1,4	**85 mg/l**
K	0,200±0,048	0,77±0,18	0,87±0,21	1,76±0,30	0,71±0,17	0,43±0,10	1,36±0,23	**12 mg/l**
NO_3^-	0,0030±0,0044	4,74±0,57	10,6±1,3	2,04±0,24	1,60±0,19	0,74±0,11	2,10±0,25	**45 mg/l**
Cl^-	3,75±0,57	2,67±0,49	4,34±0,61	0,51±0,34	3,60±0,56	9,7±1,0	2,60±0,49	**350 mg/l**
NH_4^+	0,137±0,056	***2,18±0,59***	0,169±0,064	1,00±0,28	***2,60±0,70***	0,025±0,027	0,020±0,025	**2 mg/l**
PO_4^{3-}	0,082±0,033	0,291±0,087	0,039±0,016	0,136±0,041	0,132±0,040	0,281±0,084	0,34±0,10	**3,5 mg/l**
Hardness	0,793	0,711	0,630	1,184	0,865	0,636	1,729	**7(10) Mg-equ/l**

Table 3. Physical and chemical analysis of water from Spring 2.

Date / Indicator	05.08.2017	03.11.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL

NO_2^-	0,0030 ± 0,0044	0,0400 ± 0,0092	less than 0,1 mkg / l	0,0210 ± 0,0067	0,0187 ± 0,0064	0,0110 ± 0,0054	**3 mg/l**
C	17,7±5,3	23,9±7,2	***32,3±9,7***	less than 10 mg / l	27,1±8,1	27,0±8,1	**30 mg/l**
Turbidity	0,50±0,10	***4,25±0,85***	less than 0,1 mg / l	2,70±0,54	***4,49±0,90***	***4,50±0,90***	**3,5 mg/l**
pH	6,7±0,2	6,4±0,2	6,7±0,2	7,0±0,2	6,9±0,2	7,1±0,2	**(6-9) units pH**
Color	28,0±5,6	***63,6±6,4***	less than 0.05 degrees	6,21±0,19	***59,6±6,0***	0,61±0,12	**30 degrees**
Ca	48,6±7,8	7,5±1,2	22,6±3,6	14,3±2,3	16,0±2,6	24,2±3,9	**140 mg/l**
Na	2,84±0,43	2,23±0,33	5,39±0,81	2,06±0,31	less than 5 mkg / l	34,7±5,2	**200 mg/l**
Mg	5,93±0,89	6,50±0,98	6,12±0,92	7,4±1,1	7,0±1,1	10,1±1,6	**85 mg/l**
K	0,268±0,064	0,79±0,19	2,69±0,46	1,00±0,24	0,49±0,12	1,62±0,27	**12 mg/l**
NO_3^-	0,0020±0,0043	4,15±0,50	4,25±0,51	13,1±1,6	2,41±0,29	3,60±0,43	**45 mg/l**
Cl^-	4,33±0,61	3,08±0,52	0,40±0,33	4,00±0,59	8,27±0,90	2,10±0,45	**350 mg/l**
NH_4^+	0,129±0,054	1,64±0,45	0,84±0,24	***2,60±0,70***	0,002±0,021	0,004±0,021	**2 mg/l**
PO_4^{3-}	0,259±0,078	0,38±0,11	0,120±0,036	0,271±0,081	0,319±0,096	0,43±0,10	**3,5 mg/l**
Hardness	2,871	0,902	1,609	1,307	0,682	1,949	**7(10) Mg-equ/l**

Table 4. Physical and chemical analysis of water from Spring 3

Date / Indicator	**05.08.2017**	**03.11.2017**	**28.12.2017**	**14.06.2018**	**25.07.2018**	**31.08.2018**	**11.09.2018**	**MPL**
NO_2^-	0,0240 ± 0,0071	0,0060 ± 0,0048	0,0150 ± 0,0060	less than 0,1 mkg / l	0,0070 ± 0,0049	0,0320 ± 0,0082	0,0100 ± 0,0053	**3 mg/l**
C	15,4±4,6	18,1±5,4	25,5±7,7	16,6±5,0	less than 10 mg / l	***44±13***	15,6±4,7	**30 mg/l**
Turbidity	2,45±0,49	1,09±0,22	3,35±0,67	less than 0,1 mg/l	less than 0,1 mg/l	less than 0,1 mg / l	0,90±0,17	**3,5 mg/l**

pH	6,6±0,2	6,7±0,2	6,6±0,2	6,7±0,2	6,9±0,2	7,0±0,2	7,0±0,2	**(6-9) units pH**
Color	22,0±4,4	9,92±0,30	***30,7±6,1***	Less than 0.05 degrees	14,1±2,8	***52,5±5,3***	2,954±0,089	**30 degrees**
Ca	81±13	20,4±3,3	9,7±1,6	30,4±4,9	26,7±4,3	41,9±6,7	34,9±5,6	**140 mg/l**
Na	5,45±0,82	9,7±1,5	5,50±0,83	8,3±1,3	7,5±1,1	7,2±1,1	14,4±2,2	**200 mg/l**
Mg	6,32±0,95	6,9±1,0	6,52±0,98	5,55±0,83	7,1±1,1	9,0±1,4	5,49±0,82	**85 mg/l**
K	0,42±0,10	1,49±0,25	1,18±0,20	2,38±0,40	1,47±0,25	1,50±0,26	2,75±0,47	**12 mg/l**
NO_3^-	0,0140±0,0060	21,5±2,6	41,2±4,9	26,0±3,1	13,1±1,6	***125±15***	27,5±3,3	**45 mg/l**
Cl^-	5,14±0,67	4,32±0,61	4,66±0,64	0,77±0,36	5,00±0,66	12,9±1,2	3,50±0,55	**350 mg/l**
NH_4^+	0,143±0,057	1,43±0,39	0,160±0,060	1,17±0,33	***2,60±0,70***	0,003±0,021	0,040±0,030	**2 mg/l**
PO_4^{3-}	0,193±0,058	0,216±0,065	0,099±0,040	0,143±0,043	0,077±0,031	0,37±0,11	0,408±0,098	**3,5 mg/l**
Hardness	4,503	1,567	1,012	1,945	1,888	1,395	2,516	**7(10) Mg-equ/l**

Table 5. Physical and chemical analysis of water from Spring 4.

Date / Indicator	**05.08.2017**	**03.11.2017**	**28.12.2017**	**14.06.2018**	**25.07.2018**	**31.08.2018**	**11.09.2018**	**MPL**
NO_2^-	0,0030 ± 0,0044	0,0240 ± 0,0071	0,0010 ± 0,0041	less than 0,1 mkg / l	0,0060 ± 0,0048	0,0070 ± 0,0049	0,0160 ± 0,0061	**3 mg/l**
C	27,5±8,3	19,1±5,7	***34±10***	15,9±4,8	less than 10 mg / l	20,3±6,1	less than 10 mg / l	**30 mg/l**
Turbidity	2,43±0,49	***4,11±0,82***	***4,36±0,81***	less than 0,1 mg/l	***4,77±0,95***	less than 0,1 mg / l	2,78±0,56	**3,5 mg/l**
pH	6,6±0,2	6,8±0,2	6,6±0,2	6,6±0,2	6,7±0,2	6,8±0,2	7,1±0,2	**(6-9) units pH**
Color	17,1±3,4	***56,3±5,6***	***49,1±9,8***	less than 0.05 degrees	***50,4±5,0***	***39,2±7,8***	23,2±4,6	**30 degrees**
Ca	70±11	10,0±1,6	5,72±0,92	33,9±5,4	13,5±2,2	19,7±3,2	32,7±5,2	**140 mg/l**
Na	5,61±0,84	10,5±1,6	6,32±0,95	10,5±1,6	8,7±1,3	8,1±1,2	15,8±2,4	**200 mg/l**
Mg	21,2±3,2	16,7±2,5	18,1±2,5	18,1±2,7	18,4±2,8	22,8±3,4	30,2±4,5	**85 mg/l**
K	0,66±0,16	1,90±0,32	1,73±0,29	2,73±0,46	2,22±0,38	2,17±0,37	3,68±0,63	**12 mg/l**
NO_3^-	0,0020±0,0043	40,1±4,8	***87±10***	26,0±3,1	34,3±4,1	***192±23***	43,9±5,3	**45 mg/l**
Cl^-	8,06±0,88	6,15±0,74	7,07±0,81	0,77±0,36	7,20±0,82	18,1±1,6	6,20±0,75	**350 mg/l**
NH_4^+	0,143±0,057	1,08±0,30	0,169±0,064	1,00±0,28	0,300±0,098	0,001±0,020	0,015±0,024	**2 mg/l**

Indicator \ Date	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
PO_4^{3-}	0,34±0,10	0,46±0,11	0,084±0,034	0,101±0,030	0,152±0,046	0,188±0,056	0,66±0,16	**3,5 mg/l**
Hardness	5,185	1,864	1,765	3,151	2,168	1,423	4,243	**7(10) Mg-equ/l**

Table 6. Physical and chemical analysis of water from Spring 5.

Indicator \ Date	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
NO_2^-	0,0010 ± 0,0041	0,0230 ± 0,0070	0,0270 ± 0,0075	0,0070 ± 0,0049	0,0010 ± 0,0041	0,0160 ± 0,0061	0,0070 ± 0,0049	**3 mg/l**
C	13,2±4,0	15,9±4,8	17,2±5,2	15,4±4,6	10,0±3,0	22,1±6,6	15,8±4,7	**30 mg/l**
Turbidity	2,10±0,42	***4,44±0,89***	0,030±0,010	0,100±0,020	0,100±0,020	2,94±0,59	***6,5±1,3***	**3,5 mg/l**
pH	6,6±0,2	6,8±0,2	6,6±0,2	6,7±0,2	6,7±0,2	6,8±0,2	6,7±0,2	**(6-9) units pH**
Color	5,03±0,15	***49,4±9,9***	***40,1±8,0***	4,66±0,14	3,82±0,11	***52,9±5,3***	27,5±5,5	**30 degrees**
Ca	18,3±2,9	1,60±0,26	9,3±1,5	33,7±5,4	18,6±3,0	36,3±5,8	34,6±5,5	**140 mg/l**
Na	23,1±3,5	54,1±8,1	31,4±4,7	25,6±3,8	33,9±5,1	19,9±3,0	30,9±4,6	**200 mg/l**
Mg	7,5±1,1	9,1±1,4	9,4±1,4	9,4±1,4	10,6±1,6	11,0±1,6	8,3±1,2	**85 mg/l**
K	2,69±0,46	3,74±0,64	4,86±0,83	5,67±0,96	5,08±0,86	5,9±1,0	7,6±1,3	**12 mg/l**
NO_3^-	21,0±2,5	36,4±4,4	***108±13***	24,1±2,9	***49,8±6,0***	***249±30***	42,3±5,1	**45 mg/l**
Cl^-	12,8±1,2	14,5±1,3	13,5±1,3	1,26±0,39	11,8±1,1	30,7±2,5	13,3±1,3	**350 mg/l**
NH_4^+	1,99±0,54	0,221±0,077	0,169±0,064	0,84±0,24	***8,3±2,2***	0,001±0,020	0,005±0,021	**2 mg/l**
PO_4^{3-}	0,51±0,12	0,42±0,10	0,129±0,039	0,054±0,022	0,285±0,086	0,46±0,11	0,46±0,11	**3,5 mg/l**
Hardness	1,048	0,827	1,226	2,431	1,785	1,339	2,611	**7(10) Mg-equ/l**

Table 7. Physical and chemical analysis of tap water.

Indicator \ Date	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
NO_2^-	0,0030± 0,0044	0,0290± 0,0078	0,0030± 0,0044	less than 0,1 mkg / l	0,0290± 0,0078	0,0260± 0,0074	0,0130± 0,0057	**3 mg/l**
C	18,3±5,5	17,9±5,4	***36±10***	15,7±4,7	less than 10 mg / l	19,9±6,0	23,7±7,1	**30 mg/l**
Turbidity	2,17±0,43	***4,19±0,84***	***6,8±1,4***	1,22±0,24	2,17±0,43	1,58±0,32	***6,1±1,2***	**3,5 mg/l**

Date / Indicator	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
pH	6,4±0,2	7,1±0,2	7,0±0,2	6,5±0,2	6,3±0,2	6,2±0,2	6,2±0,2	**(6-9) units pH**
Color	***62,9±6,3***	***93,6±9,4***	***89,2±8,9***	***32,9±6,6***	***47,7±9,5***	***106±11***	***36,2±7,2***	**30 degrees**
Ca	4,93±0,79	1,90±0,30	2,17±0,35	3,77±0,60	2,63±0,42	3,18±0,51	3,65±0,58	**140 mg/l**
Na	5,61±0,84	2,04±0,31	1,89±0,28	1,72±0,26	less than 5 mkg / l	less than 5 mkg / l	1,31±0,20	**200 mg/l**
Mg	0,81±0,12	0,99±0,15	1,00±0,15	1,30±0,19	1,08±0,16	1,02±0,15	3,16±0,47	**85 mg/l**
K	0,112±0,027	0,46±0,11	0,54±0,13	0,74±0,18	0,268±0,064	less than 5 mkg / l	0,80±0,19	**12 mg/l**
Fe	***0,318±0,080***	***0,370±0,093***	***0,330±0,083***	***0,367±0,092***	***0,326±0,082***	***0,344±0,086***	***0,327±0,082***	**0,3 mg/l**
NO_3^-	0,0020 ± 0,0043	7,55±0,91	15,8±1,9	6,77±0,81	1,80±0,22	7,34±0,88	1,50±0,18	**45 mg/l**
Cl^-	7,26±0,82	6,82±0,79	8,22±0,89	0,77±0,36	7,20±0,82	16,7±1,5	4,10±0,60	**350 mg/l**
NH_4^+	0,116±0,050	0,93±0,26	0,155±0,060	0,78±0,22	0,300±0,098	0,003±0,021	less than 0,1 mkg / l	**2 mg/l**
PO_4^{3-}	0,070±0,028	0,271±0,081	0,137±0,041	0,108±0,032	0,218±0,065	0,296±0,089	0,48±0,12	**3,5 mg/l**
Hardness	0,309	0,175	0,189	0,289	0,218	0,120	0,762	**7(10) Mg-equ/l**

Table 8. Physical and chemical analysis of bottled water.

Date / Indicator	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
NO_2^-	0,0030± 0,0044	0,0080± 0,0050	0,0290± 0,0078	less than 0,1 mkg / l	0,0110± 0,0054	0,0370± 0,0088	0,0120± 0,0056	**3 mg/l**
C	20,5±6,2	27,5±8,3	***60±12***	15,8±4,7	less than 10 mg / l	24,7±7,4	12,0±3,6	**30 mg/l**
Turbidity	2,53±0,51	1,44±0,29	0,60±0,12	less than 0,1 mg / l	0,250±0,050	3,32±0,66	2,10±0,42	**3,5 mg/l**
pH	7,9±0,2	7,9±0,2	8,0±0,2	8,1±0,2	8,2±0,2	8,1±0,2	8,4±0,2	**(6-9) units pH**
Color	***39,6±7,9***	***36,5±7,3***	18,2±3,6	6,45±0,19	5,25±0,16	***72,2±7,2***	6,00±0,18	**30 degrees**
Ca	17,5±2,8	12,9±2,1	5,48±0,88	36,1±5,8	11,7±1,9	28,1±4,5	23,5±3,8	**140 mg/l**
Na	30,3±4,5	48,9±7,3	5,54±0,83	26,0±3,9	32,3±4,8	17,7±2,7	24,8±3,7	**200 mg/l**
Mg	33,8±5,1	47,5±7,1	24,9±3,7	27,4±4,1	28,7±4,3	25,7±3,9	20,2±3,0	**85 mg/l**
K	1,06±0,18	3,18±0,54	4,14±0,70	***43,2±6,5***	4,23±0,72	4,74±0,80	6,2±1,1	**12 mg/l**
NO_3^-	0,063±0,013	20,2±2,4	16,3±2,0	5,53±0,66	1,90±0,23	6,10±0,73	3,60±0,43	**45 mg/l**

Date / Indicator	05.08.2017	03.11.2017	28.12.2017	14.06.2018	25.07.2018	31.08.2018	11.09.2018	MPL
Cl^-	6,41±0,76	4,77±0,64	5,65±0,71	0,91±0,37	5,20±0,67	16,2±1,5	3,20±0,53	**350 mg/l**
NH_4^+	0,165±0,063	***2,50±0,67***	0,169±0,064	1,17±0,33	0,80±0,23	0,003±0,021	***6,5±1,7***	**2 mg/l**
PO_4^{3-}	0,275±0,083	0,414±0,099	0,124±0,037	0,156±0,047	0,0210±0,0084	0,278±0,083	0,47±0,11	**3,5 mg/l**
Hardness	3,637	4,539	2,315	4,029	2,933	1,745	3,545	**7(10) Mg-equ/l**

Table 9. Influence of weather (precipitation) on chemical composition of water.

Sampling points / Indicator	Spring 1	Spring 2	Spring 3	Spring 4	Spring 5	Tap water	Bottled water	MPL
NO_2^-	less than 0,1 mkg / l	less than 0,1 mkg / l	less than 0,1 mkg / l	less than 0,1 mkg / l	less than 0,1 mkg / l	0,0010±0,0053	less than 0,1 mkg / l	**3 mg/l**
C	15,1±4,5	less than 10 mg / l	less than 10 mg / l	less than 10 mg / l	less than 10 mg / l	14,2±4,3	14,3±4,3	**30 mg/l**
Turbidity	less than 0,1 mg / l	less than 0,1 mg / l	less than 0,1 mg / l	less than 0,1 mg / l	less than 0,1 mg / l	less than 0,1 mg / l	less than 0,1 mg / l	**3,5 mg/l**
pH	6,5±0,2	6,7±0,2	6,7±0,2	6,6±0,2	6,6±0,2	6,2±0,2	8,2±0,2	**(6-9) pH**
Color	22,5±4,5	17,1±3,4	17,1±3,4	***39,7±7,9***	8,09±0,24	***57,1±5,7***	2,878±0,086	**30 degrees**
Ca	3,27±0,52	8,8±1,4	8,8±1,4	7,5±1,2	11,1±1,8	1,96±0,31	6,9±1,1	**140 mg/l**
Na	3,56±0,53	2,76±0,41	2,76±0,41	17,9±2,7	3,01±0,45	2,14±0,32	30,6±4,6	**200 mg/l**
Mg	3,15±0,47	3,55±0,53	3,55±0,53	13,4±2,0	4,66±0,70	0,95±0,14	23,6±3,5	**85 mg/l**
K	1,77±0,30	1,58±0,27	1,58±0,27	1,19±0,20	4,73±0,80	1,19±0,20	5,56±0,95	**12 mg/l**
NO_3^-	0,153±0,025	0,247±0,039	0,247±0,039	2,40±0,29	2,83±0,34	0,301±0,046	0,182±0,029	**45 mg/l**
Cl^-	2,40±0,47	2,40±0,47	2,40±0,47	7,11±0,81	10,5±1,1	6,04±0,74	5,73±0,71	**350 mg/l**
NH_4^+	***2,02±0,55***	***2,08±0,56***	***2,08±0,56***	1,54±0,42	***2,21±0,59***	1,90±0,51	***2,21±0,59***	**2 mg/l**
PO_4^{3-}	менее 0,1 мкг/л	0,139±0,042	0,139±0,042	less than 0,1 mkg / l	0,116±0,035	0,0090±0,0036	0,152±0,046	**3,5 mg/l**
Hardness	0,420	0,726	0,726	1,466	0,926	0,174	2,277	**7(10) Mg-equ/l**

Table 10. Influence of boiling on physical and chemical indicators of water quality, by source.

Sampling points / Indicator	Spring 1		Spring 2		Spring 3		Spring 4		Spring 5		Tap water		Bottled water		MPL
	before	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	

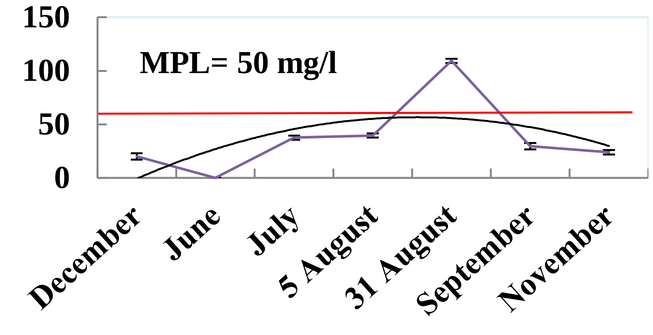
Sampling points / Indicator	Spring 1		Spring 2		Spring 3		Spring 4		Spring 5		Tap water		Bottled water		MPL
	before	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	
NO_2^-	0,0170 ± 0,0062	0,0350 ± 0,0086	0,0110 ± 0,0054	0,0170 ± 0,0062	0,0100 ± 0,0053	0,0110 ± 0,0054	0,0160 ± 0,0061	0,0040 ± 0,0045	0,0370 ± 0,0088	0,0330 ± 0,0083	0,0130 ± 0,0057	0,0110 ± 0,0054	0,0120 ± 0,0056	less than 0,1 mkg / l	**3 mg/l**
C	less than 10 mg / l	less than 10 mg / l	27,0 ± 8,1	11,9 ± 3,6	15,6 ± 4,7	less than 10 mg / l	less than 10 mg / l	17,9 ± 5,4	24,5 ± 7,4	25,6 ± 7,7	23,7 ± 7,1	***32,1 ± 9,6***	12,0 ± 3,6	less than 10 mg / l	**30 mg/l**
Turbidity	***7,3 ± 1,5***	0,200 ± 0,041	***4,50 ± 0,90***	***4,55 ± 0,91***	0,87 ± 0,17	1,23 ± 0,25	2,78 ± 0,56	2,43 ± 0,49	***6,1 ± 1,2***	2,69 ± 0,54	2,10 ± 0,42	0,470 ± 0,095	2,58 ± 0,52	0,79 ± 0,16	**3,5 mg/l**
pH	6,7 ± 0,2	8,4 ± 0,2	7,1 ± 0,2	8,7 ± 0,2	7,0 ± 0,2	8,9 ± 0,2	7,1 ± 0,2	8,5 ± 0,2	5,6 ± 0,2	5,6 ± 0,2	8,4 ± 0,2	9,3 ± 0,2	6,8 ± 0,2	7,8 ± 0,2	**(6-9) units pH**
Color	9,32 ± 0,28	8,05 ± 0,24	0,610 ± 0,020	12,9 ± 2,6	2,950 ± 0,090	3,82 ± 0,11	23,2 ± 4,6	17,5 ± 3,5	***36,2 ± 7,2***	***62,3 ± 6,2***	5,96 ± 0,18	12,4 ± 2,5	26,9 ± 5,4	***32,4 ± 6,5***	**30 degrees**
Ca	12,8 ± 2,0	16,6 ± 2,7	24,2 ± 3,9	22,3 ± 3,6	34,9 ± 5,6	34,9 ± 5,6	32,7 ± 5,2	40,6 ± 6,5	3,70 ± 0,60	14,2 ± 2,3	23,5 ± 3,8	23,6 ± 3,8	36,7 ± 5,9	39,6 ± 6,3	**140 mg/l**
Na	2,10 ± 0,32	3,93 ± 0,59	34,7 ± 5,2	4,93 ± 0,74	14,4 ± 2,2	11,2 ± 1,7	15,8 ± 2,4	23,0 ± 3,5	1,31 ± 0,20	2,10 ± 0,32	24,8 ± 3,7	28,4 ± 4,3	155 ± 16	168 ± 17	**200 mg/l**
K	1,36 ± 0,23	1,46 ± 0,25	1,62 ± 0,27	1,65 ± 0,28	2,75 ± 0,47	2,84 ± 0,48	3,68 ± 0,63	3,71 ± 0,63	0,80 ± 0,19	0,77 ± 0,18	6,2 ± 1,1	6,5 ± 1,1	6,0 ± 1,0	4,70 ± 0,80	**12 mg/l**
Fe	0,0150 ± 0,0038	0,0130 ± 0,0033	0,0320 ± 0,0080	0,041 ± 0,010	less than 5 mkg / l	less than 5 mkg / l	less than 5 mkg / l	less than 5 mkg / l	***0,327 ± 0,082***	***0,355*** ± ***0,089***	0,0200 ± 0,0050	0,041 ± 0,010	less than 5 mkg / l	less than 5 mkg / l	**0,3 mg/l**

Sampling points / Indicator	Spring 1		Spring 2		Spring 3		Spring 4		Spring 5		Tap water		Bottled water		MPL
	before	after	before	after	before	after	before	after	before	after	before	after	before	after	
NO_3^-	2,10 ± 0,25	3,40 ± 0,41	3,60 ± 0,43	7,60 ± 0,91	27,5 ± 3,3	44,8 ± 5,4	43,9 ± 5,3	48,2 ± 5,8	1,50 ± 0,18	1,30 ± 0,19	3,60 ± 0,43	13,1 ± 1,6	35,0 ± 4,2	55,7 ± 6,7	**45 mg/l**
Cl^-	2,60 ± 0,49	2,80 ± 0,50	2,10 ± 0,45	2,70 ± 0,49	3,50 ± 0,55	4,30 ± 0,61	6,20 ± 0,75	6,40 ± 0,76	4,10 ± 0,60	4,20 ± 0,60	3,20 ± 0,53	3,80 ± 0,57	20,1 ± 1,8	25,3 ± 2,1	**350 mg/l**
NH_4^+	0,020 ± 0,025	0,005 ± 0,021	0,004 ± 0,021	0,001 ± 0,020	0,040 ± 0,030	0,030 ± 0,028	0,015 ± 0,024	0,001 ± 0,020	less than 0,1 mkg / l	less than 0,1 mkg / l	***6,5±1,7***	0,004 ± 0,021	0,112 ± 0,049	0,184 ± 0,068	**2 mg/l**
PO_4^{3-}	0,34 ± 0,10	0,38 ± 0,11	0,43 ± 0,10	0,55 ± 0,13	0,408 ± 0,098	0,243 ± 0,073	0,66 ± 0,16	0,60 ± 0,14	0,48 ± 0,12	0,39 ± 0,12	0,47 ± 0,11	0,208 ± 0,062	0,158 ± 0,047	0,186 ± 0,056	**3,5 mg/l**

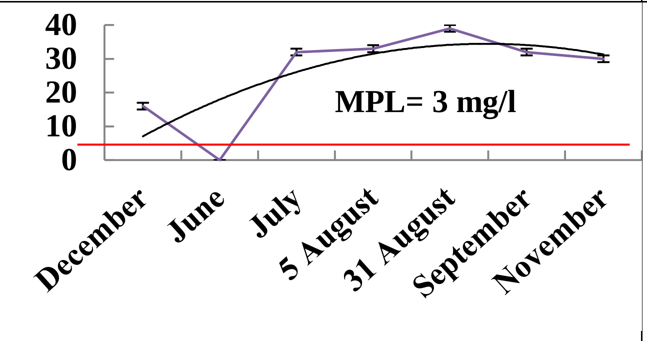
Table 11. Trends in *Coli T*, *Coli Ind* and TMC.

Spring 1

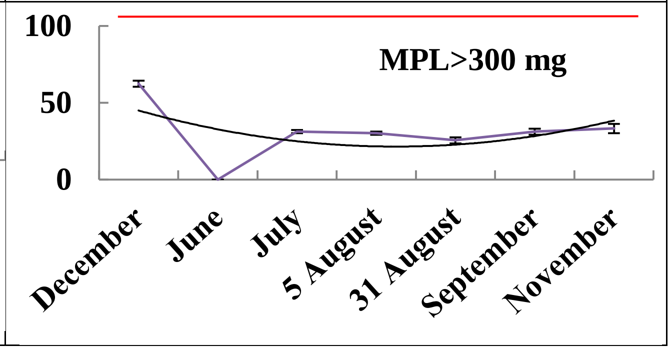
TMC

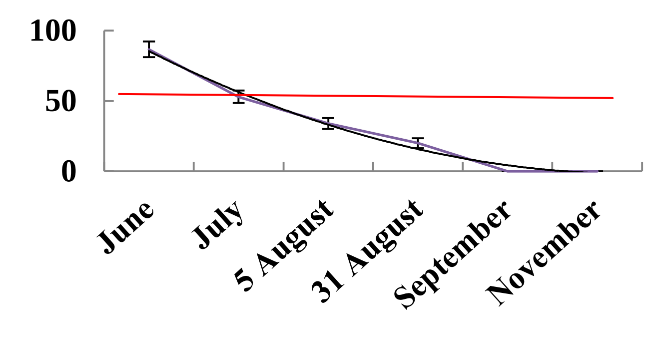
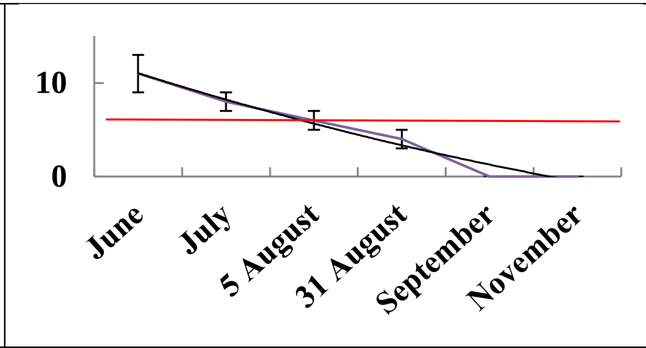
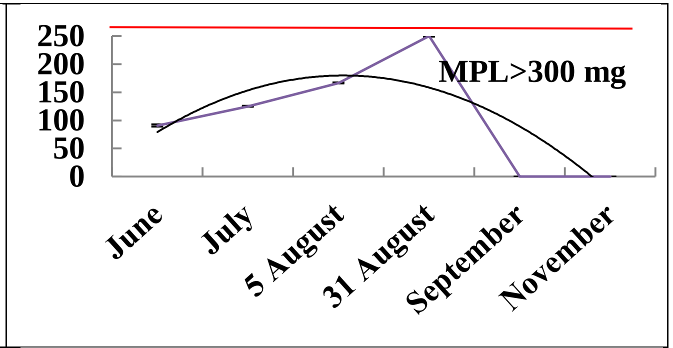
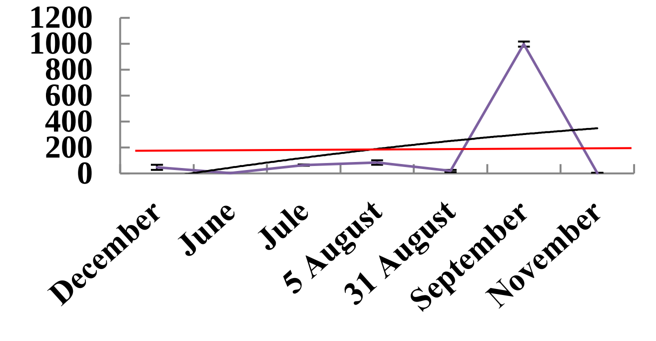
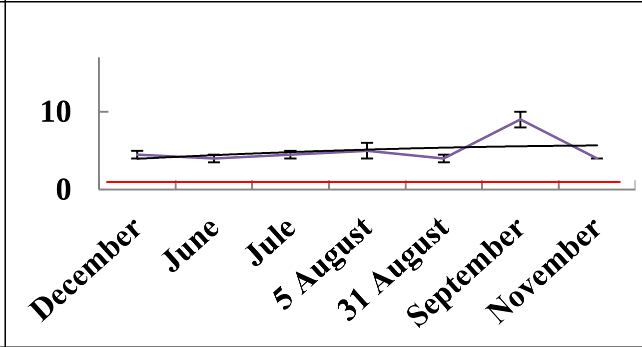
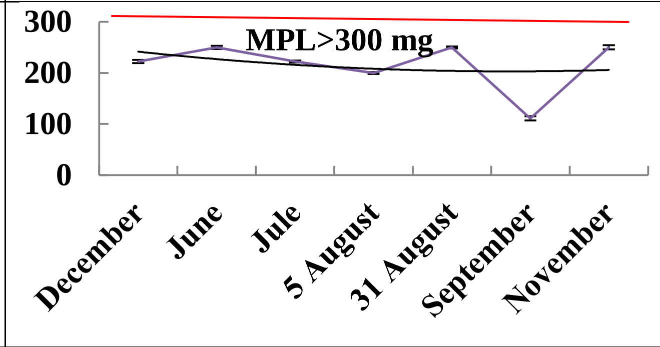
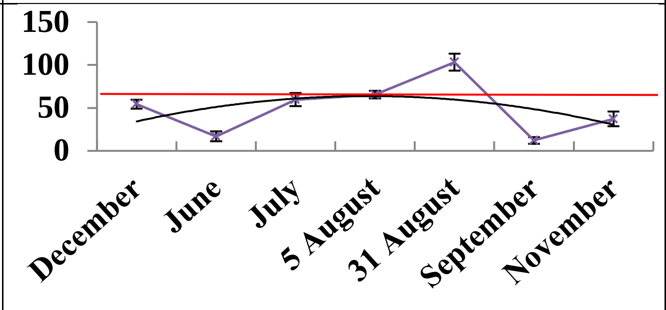
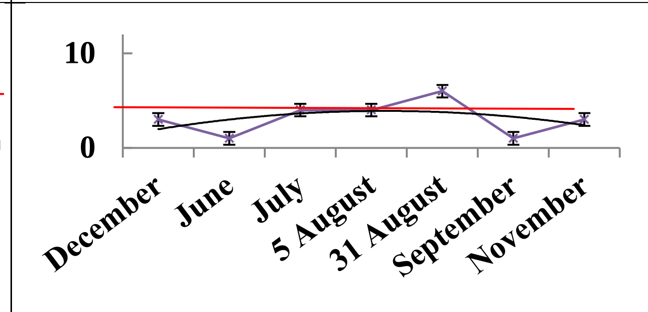
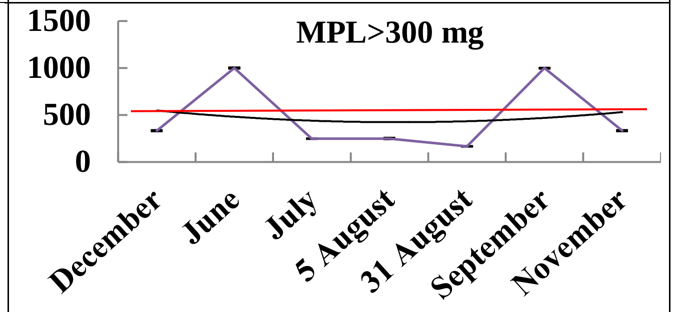
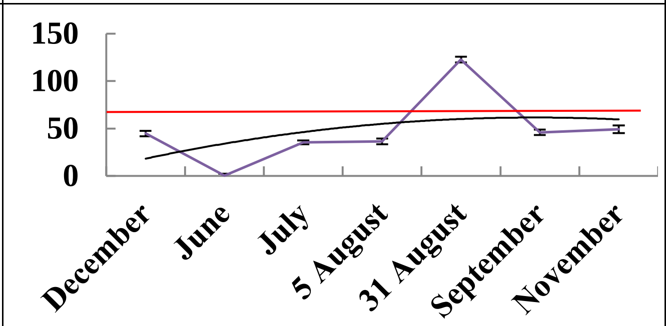
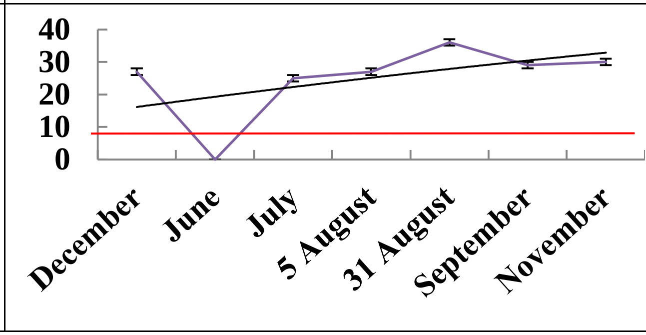
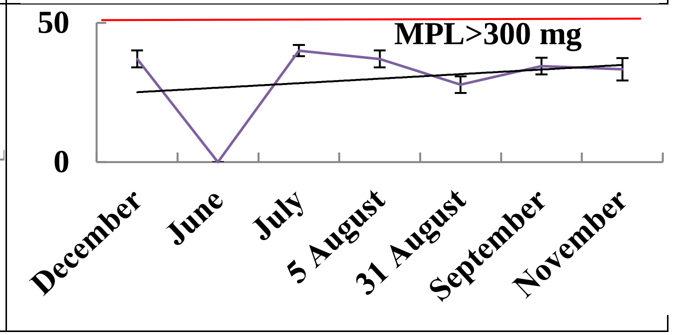


Coli Ind



Coli T



Spring 2			
Spring 3			
Spring 4			
Spring 5			

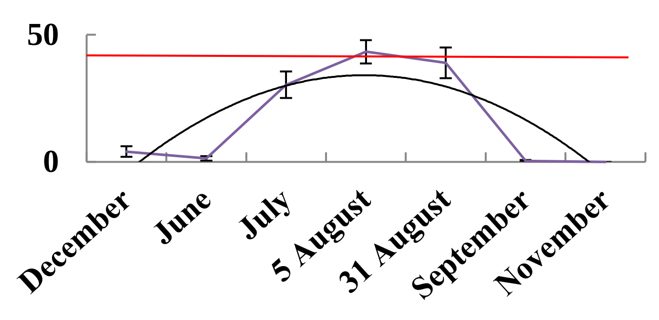
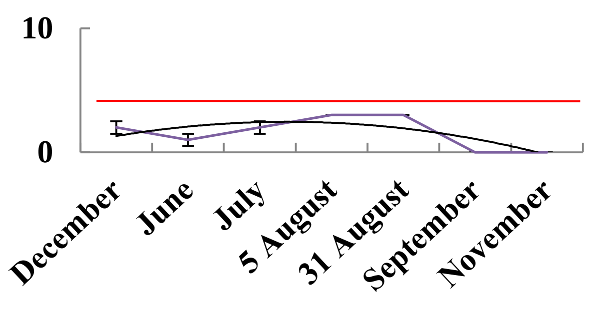
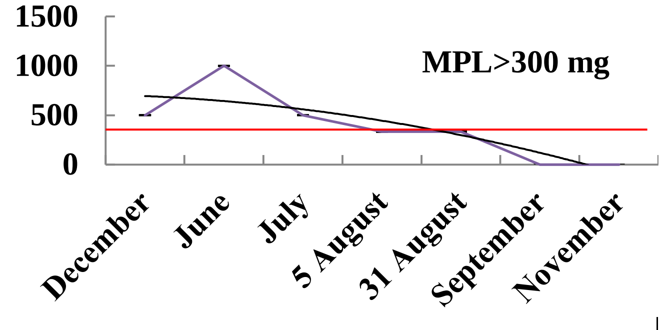
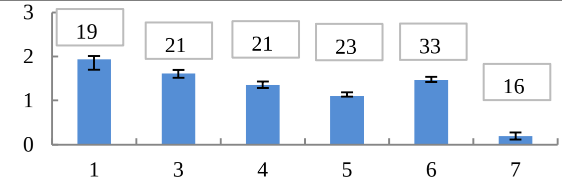
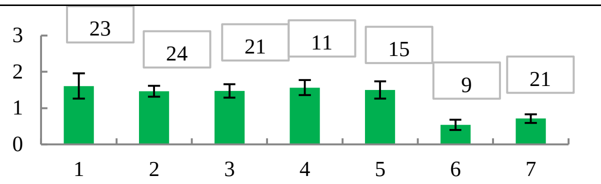
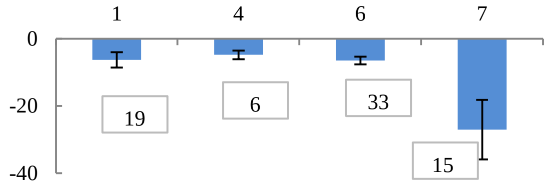
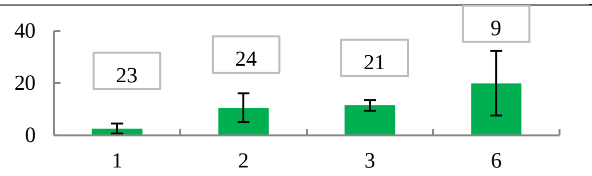
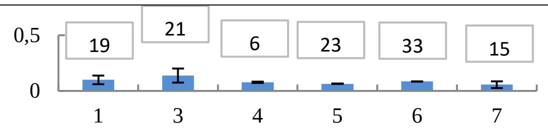
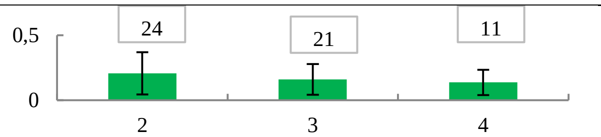
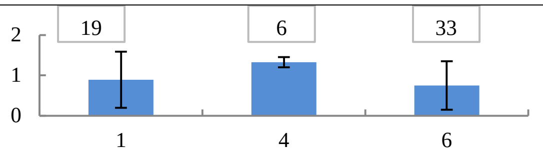
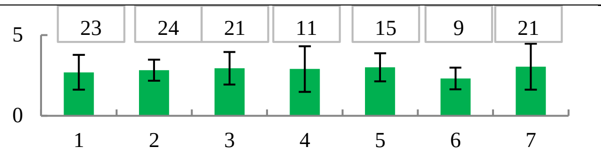
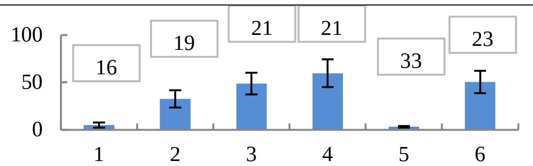
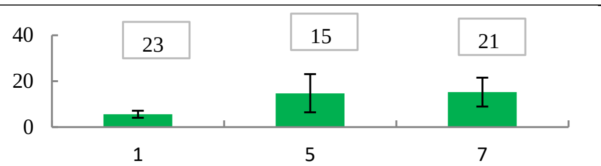
Tap water	50 0 December June July 5 August 31 August September November	10 0 December June July 5 August 31 August September November	1500 1000 500 0 MPL>300 mg December June July 5 August 31 August September November

Table 12. The most informative chemical indicators of water quality, identified during the study period.

pH		
C		
NO_2^-		
PO_4^{3-}		
Ca		
K