DOI: 10.7251/QOL2503108B
UDC: 628.1.033:546.815(497.6Banja Luka)
Professional paper

Impact of the Technological Purification Process on the Drinking Water Quality in the Water Supply System of Banja Luka

Danijela Babić[1,2], Gojko Bunčić[2]
[1]*Public Health Institute of the Republic of Srpska, Banja Luka, Bosnia and Herzegovina; danijela.babic@phi.rs.ba*
[2]*Pan-European University "APEIRON", Banja Luka, Republic of Srpska, Bosnia and Herzegovina*

Abstract: This paper analyzes the impact of the technological purification process on the drinking water quality in the water supply system of the City of Banja Luka. Microbiological and physico-chemical parameters of raw water samples from the River Vrbas and purified water samples from reservoirs collected during three time periods: 1977, 2006 and 2025 were used. The research has showed a significant microbiological load of raw water, especially the presence of coliform bacteria and enterococci, which indicates fecal contamination of the source. Despite this, the analysis of the results has determined that the water conditioning process, which includes ozonation, filtration and chlorine disinfection, successfully eliminates contaminants and ensures the microbiological and physicochemical safety of drinking water. The results confirm that the purified water meets the requirements of the Regulation on the health safety of drinking water across analyzed years. Based on these findings, the need for continuous monitoring of raw water quality and technical improvement of treatment plants is emphasized in order to ensure the long-term safety of the water supply.

Key words: drinking water, conditioning, microbiological analysis, physicochemical parameters, water supply of Banja Luka and the River Vrbas.

INTRODUCTION

Water is the fundamental condition for life and existence of all living beings, representing a key medium for the development of biological processes. Due to its unique physico-chemical properties, water has enabled the development and maintenance of life, as well as a continuous circulation in the biosphere known as the hydrological cycle.

According to the World Health Organization, only 2.5% of the world's total supplies represent freshwater, while most of this portion is captured in glaciers, snowpack and difficult-to-reach groundwater, which further highlights the significance of managing available water resources.

In modern urban environments, supplying the population with safe drinking water is a public health priority. Due to the increasing pressures of anthropogenic activities and climate change that cause variability in the raw water quality, the water treatment and conditioning are becoming increasingly complex. In this context, monitoring and evaluating the efficiency of purification processes are key tools in ensuring the health and safety of end users (Figure 1).

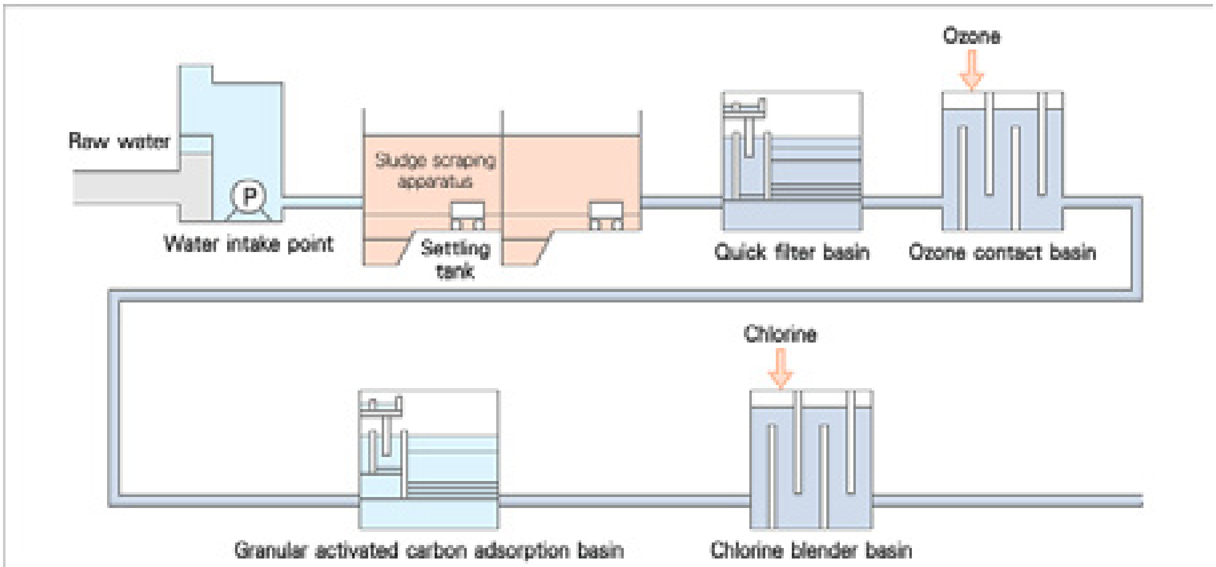

Figure 1. Flowchart of advanced water purification process (https://www.toshiba-clip.com/en/detail/p=147)

Climate changes alter the pH of water significantly and disrupt the carbonate system balance. Therefore, the corrosiveness of water is affected which can lead to increased concentrations of metals such as iron and manganese in underground sources. *(https://www.eea.europa.eu/en/newsroom/news/state-of-water)*.

Water, as a universal solvent, plays a key role in maintaining life and the stability of biological systems. According to the World Health Organization (WHO, 2016), the minimum daily water intake required to maintain basic physiological functions in an adult is between 2 and 3 liters, depending on individual and climatic factors. Water participates in the transport of nutrients, the elimination of metabolic waste, the thermoregulation and osmotic balance.

The health and safety of drinking water are directly related to the prevention of infectious diseases. According to WHO data, about 80% of diseases in developing countries are caused by poor water quality and inadequate sanitation. Populations consuming water contaminated with faeces are particularly at risk, as this enables the spread of enteric pathogens such as Escherichia coli, Salmonella spp., Shigella spp., and hepatitis A virus.

The drinking water quality is defined by physicochemical (pH, turbidity, electrical conductivity, presence of ammonia, nitrates, chlorides, etc.) and microbiological parameters (total coliform bacteria, E. coli, enterococci). The control of these parameters is regulated by national legislation, such as the Regulation on the water safety for human consumption (Official Gazette of the Republic of Srpska, No. 88/17, 97/18, 93/23 and 96/24), as well as international standards (e.g. European Union (EU) Directive 2020/2184 and WHO guidelines).

Water quality monitoring encompasses all phases of the water supply system: from the source through processing to distribution. In that sense, it is important to separate operational monitoring conducted by water supply company from independent health control conducted by accredited laboratories. An efficient monitoring system must include properly determined sampling points, standardized analysis methods and continuity in testing.

Technological water treatment processes include a series of physicochemical and biological treatments. The main treatments include:

- coagulation and flocculation - removal of suspended matter,
- sedimentation and filtration - mechanical purification,
- disinfection - most often using chlorine, ozone or UV radiation.

Within the water supply system of the City of Banja Luka, the main water source is the River Vrbas, which is, due to urbanization and insufficient sewage infrastructure, subject to variations in quality. A modern water processing plant applies ozonation as an oxidation pre-reaction, then filtration through multilayer filters, and final disinfection with chlorine. This system enables efficient removal of microbiological contaminants and reduction of organic matter, thus improving the water supply safety.

The significance of regular monitoring and optimization of the purification process is reflected in the fact that climate change and anthropogenic impacts are increasingly leading to sudden changes in the quality of surface water sources. Therefore, it is necessary to harmonize local systems with international standards and recommendations (npr. Sustainable Development Goal 6 – SDG6: Clean water and sanitation for all).

THE ROLE OF WATER IN THE BODY

The role of water in the human body is vital and diverse. It is part of all tissues and biological fluids in the human body. On average, it constitutes 2/3 of an adult's body weight, and all life processes in the body are linked to its presence (Antonić, 2017). Water transports nutrients, maintains the normal structure of all tissues, and eliminates the final metabolic products – the matter and energy turnover in the human system. Due to the unusual physicochemical properties of water, substances with different physicochemical properties can coexist in biological fluids (Antonić, 2017). Due to the certain chemical inertness of water, substances dissolved in biological fluids can preserve their individual properties while passing through the organism, which is the course of biochemical processes in the organism (Antonić, 2015).

HYGIENIC-EPIDEMIOLOGICAL SIGNIFICANCE OF WATER

The hygienic significance of water is reflected, first of all, in the necessity of water for maintaining both personal and general hygiene, for cooking and dish washing, sports, recreation, as well as for satisfying a number of modern man's life needs.

Drinking water can also be contaminated with toxic metals and non-metals, radionuclides, poisons, as well as microorganisms. Contamination can be either accidental or intentional. The deficit of certain substances (iodine, fluorine, etc.) plays a significant epidemiological role in the development of caries, goiter, etc. For the reasons aforementioned, drinking water must meet standards and be subject to ongoing health controls (Kristoforović-Ilić, 2002).

If sufficient quantities of hygienically correct water are available to meet the hygienic and other needs of the population, then it is easier to maintain personal and general hygiene, which directly and indirectly affects the health status of the population. Water can fulfill its basic hygienic role only if it is available in sufficient quantities and if its physical, chemical and microbiological properties do not adversely affect health, and if it does not have such organoleptic properties that limit its use.

The world population growth along with the development of human civilization leads to a constant increase in the use of water resources. Water is taken from rivers, lakes, springs and aquifers for irrigation, domestic use, urban and industrial purposes. The amount of natural water consumed has increased by multiple orders of magnitude in the past 100 years. This is due to the increased growth rate of water demand, recently estimated to be about 2.5 times greater than the population growth rate (Stanojević, 2022).

According to WHO estimates in 2021, over 2 billion people lived in countries facing water shortages, and this problem is expected to worsen in some regions as a result of climate change and population growth. In 2022, globally, at least 1.7 billion people used drinking water contaminated with faeces. Microbial contamination of drinking water resulting from fecal contamination poses the greatest risk to the drinking water safety. Microbiologically contaminated drinking water can transmit diseases such as diarrhea, cholera, dysentery, typhoid and polio, and is estimated to cause approximately 505.000 deaths from diarrhea each year. In 2022, 73% of the world's population (6 billion people) used safely managed drinking water supply services – that is, the one that is located in a facility, available when needed and free from contamination (WHO, 2023).

Supplying the population with hygienically safe water arises as one of the basic prerequisites for good health. WHO has included drinking water quality in 12 basic indicators of the health status of the population, which confirms its role in health protection and promotion. For these reasons, WHO experts are constantly engaged in developing methods for improving and harmonizing drinking water quality standards and continuous evaluation in terms of the impact of water on human health.

The United Nations General Assembly, with its resolution number 64/292 from 2010, recognized the right to clean and accessible drinking water as one of the basic human rights (Antonić, 2017).

Given the growing trend of pollution and variability in the quality of surface waters, this work is designed to determine the efficiency of drinking water conditioning devices by comparing microbiological and physicochemical results from raw water of the River Vrbas and purified water across different periods.

DRINKING WATER MONITORING

Production, processing, transport and quality control of drinking water is a multi-phase system (Dalmacija, 2015). Water quality monitoring includes the control of four segments:

- source
- water processing and disinfection
- reservoirs and
- distribution network.

In each of the above segments, water contamination is possible, which represents a potential danger to end users. That is why an adequate system for controlling the water safety is the main goal of water safety monitoring. Control of all segments of the System is essential for safeguarding consumer health and monitoring the operation of purification and disinfection plants, as well as the basic raw material. Timely detection of contamination occurring in the first stages of the system prevents contamination of the entire system and endangering the population health. The goal is to present a method of systematic drinking water quality control based on regulations and experiences, WHO recommendations, as well as EU (European Union) regulations (Dalmacija, 2015).

Drinking water quality control is carried out at two levels:

1. Continuous water quality control carried out by the Public Utility Company for Water Processing and Distribution, the so-called "operational control", should ensure adequate processing and disinfection of raw water and distribution of drinking water to the end consumer,
2. Public health drinking water quality control which involves testing physical-chemical, chemical and microbiological, parasitological, biological and radiological integrity (Dalmacija, 2015).

Establishing drinking water quality monitoring implies a system of activities that ensure that sampling and laboratory testing are in accordance with defined quality standards and the required level of reliability, i.e. that the safety and quality control postulates are met (Dalmacija, 2015).

Given that the ultimate goal is to preserve the population health, the main task of establishing drinking water quality monitoring is to deliver hygienically safe water. In order to achieve such a task, it is necessary that data obtained are valid – accurate, precise, complete, representative, comparable and compatible (Dalmacija, 2015).

Quality assurance is ensured by:

- adequate selection of measurement points
- sampling frequency and proper sampling
- sample preparation and transport
- appropriate training of personnel.

Quality assessment consists of:

- report on the measurement results obtained and
- assessment of the measurement results obtained in relation to the maximum permitted concentrations.

Operational water quality control is carried out in accordance with predefined quality standards, with the Public Utility Companies defining the control programme themselves.

Monitoring pursuant to the Law on the Protection of Population Health from Communicable Diseases and the Rulebook on the Hygienic Safety of Drinking Water falls under the jurisdiction of health organizations authorized to control the drinking water quality, i.e. the Public Health Institute. Measurement points - places where samples are taken are

- sources,
- places conditioned by technological procedures for water processing,
- reservoirs and distribution network (Dalmacija, 2015).

DRINKING WATER PREPARATION PROCEDURES

Before assessing whether a certain water needs to be processed, in addition to getting acquainted with test results at a given moment, it is necessary to understand or predict the trend of water quality changes. Raw water can change quality during the day, season, year or over a longer period. Drinking water preparation can be more or less complex depending on the quality of the raw water, as well as the possibility of removing existing obstacles. Sometimes numerous procedures are to be combined to achieve the pollution elimination in the best way, while selecting the optimal processing method, both in terms of investment and exploitation costs. Figure 2 shows the basic water treatment technological lines. The selection of the technological lines depends on the quality of the raw water. The technological lines show procedures from the simplest (only disinfection) ones to the most complex ones. It should be emphasized that each stage of preparation can be improved by introducing a specific procedure with a performance (primarily) at only one parameter. Recently, a particularly significant increase has been observed in the total organic content in water, as well as the concentration of mobile bioresistant organic compounds (pesticides, organochlorine compounds, etc.), both in surface and groundwater.

Conventional water preparation procedures cannot remove such compounds and for these reasons, there has been a need for innovation in older plants, and for the development of new ones - the need to define new water purification procedures (Dalmacija, 2015).

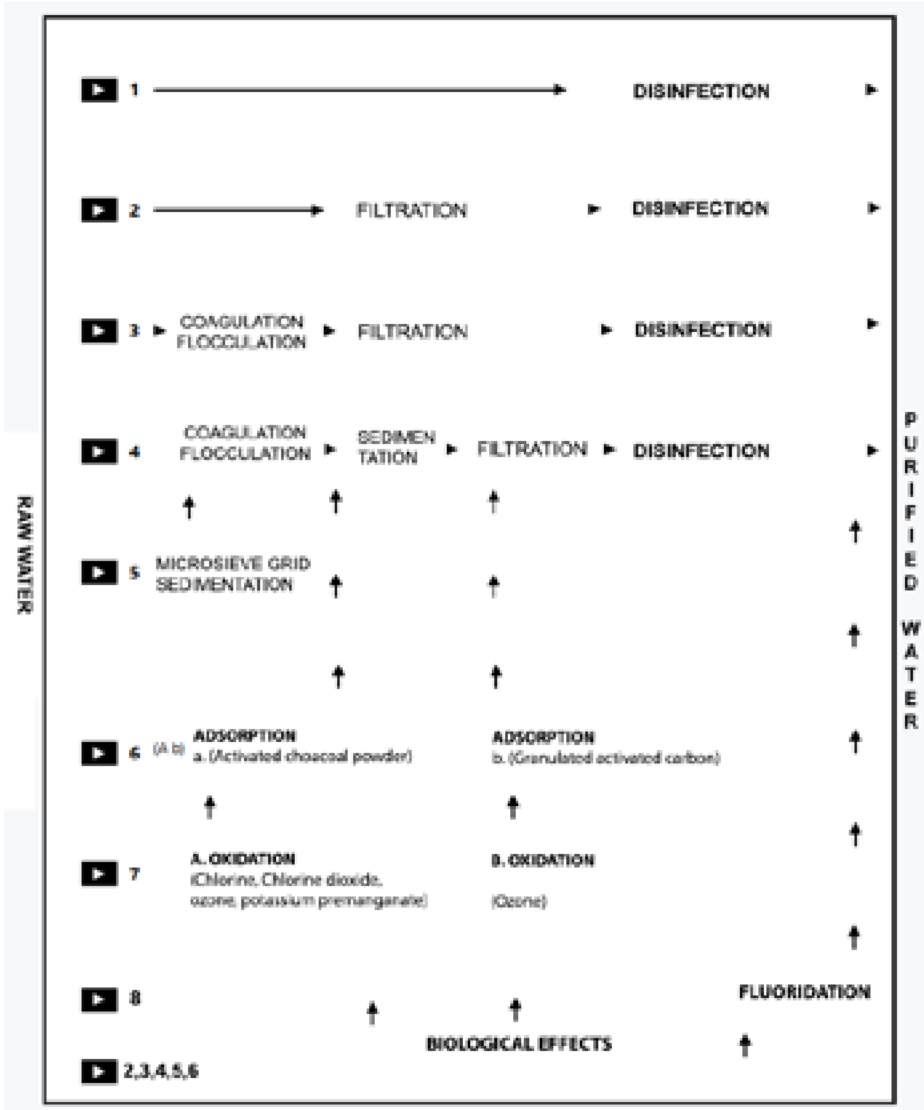

Figure 2. Water treatment lines depending on the raw water quality

1. It is applied when the raw water quality corresponds to the quality prescribed by the drinking water standard

2. It is applied for the processing of waters containing only suspended matter that can be removed by filtration (concentration of suspended particles below 10 mg/l).

3. It is applied if, in addition to suspended matter, the water also contains colloidal matter (usually less than 20-40 mg/l)

4. It is applied in waters with a larger amount of suspended and colloidal matter compared to the previous case

5. It contains additional processes to the previous lines in case of using surface water from which it is necessary to remove a wide range of suspended matter, plankton, algae, etc.

6. and 7. These lines include additional water treatment phases that can be included in any of the previous technological lines, and are used in case of increased content of toxic organic substances or increased concentration of dissolved organic and inorganic substances.

8. It is applied if there is a lack of fluorine in the water (Dalmacija, 2015).

Water Supply System in Banja Luka

The development of the water supply system of every larger and urban settlement is always a complex technical-technological, economic and social **undertaking**. In the development of the water supply system in Banja Luka, it is possible to indicate certain characteristic stages, recognizable for providing drinking water. Namely, there are four periods:

- Gravity-flow water system “Subotica”
- exploitation of the underground aquifer in Novoselija,
- artificially enriched underground aquifer in Novoselija through infiltration,
- preparing drinking water from the River Vrbas using water conditioning device.

Today, the water supply system of Banja Luka is of a regional character because, in addition to Banja Luka, it provides drinking water supplies to the Municipality of Čelinac and part of the Municipality of Laktaši. The main water source is the Vrbas watercourse, upstream at the Novoselija site, on the right bank of the River Vrbas. The natural flow regime of the River Vrbas is characterized by significant oscillations in water levels and flow rates. A turndown ratio of minimum and maximum flow rates obtained by measuring profiles is greater than 1:1000 (Antonić, 2017). Not enough work has been done to regulate the water regime of the River Vrbas. The hydropower facilities built in the middle reaches of the Jajce I and Jajce II hydroelectric power plants have not had an impact on improving the water regime, while the situation is somewhat more favorable with the construction of the Bočac reservoir. Of the settlements, only Banja Luka, Jajce and Bugojno have a more complete sewage system. All of these sewage systems were introduced into the watercourses without any treatment. This shows that the Vrbas basin flow, as well as the Vrbas itself, are wastewater recipients and drinking water sources at the same time (Antonić, 2017).

In the region of Banja Luka, there is only one small wastewater treatment plant in the settlement of Zeleni vir, which is in operation and has a capacity of 500 equivalent inhabitants (EC), *(https://vodovod-bl.com)*.

The conditioning device has a capacity of 600 L/s in the first phase, and 1200 L/s in the second phase. In preparing documentation, connecting new 2x600 L/s has been taken into account so that the water conditioning device will have a final phase capacity of 2400 L/s. Today, Banja Luka is supplied from three sources:

1. source of ’’Subotica“ – gravity water supply,
2. well-based water intake structure ’’Stari pogon“,
3. open water intake structure and water conditioning ’’Novi pogon“, (Antonić, 2017).

The total reservoir space of the water supply system Banja Luka is 26,350 cubic meters, and it consists of 11 pumping stations that provide drinking water supply to the entire city. Pumping stations are located at key points in the water supply network and, in addition to enabling a uniform water supply, they are also key to maintaining pressure in the network, as well as avoiding leaks. There are over 40,000 connections in the region of Banja Luka, out of which 30,000 connections are for individual consumers, over 30,000 for residential buildings and 5,000 for bussinesses, skilled trades and institutions (*https://vodovod-bl.com*).

Conditioning process in the water supply system in Banja Luka

At the water intake, raw water of the River Vrbas is pumped and transported through a 1000 mm steel pipeline to a separation tower at 179 m above sea level to ensure further gravity flow. From the separation tower, the water goes to sedimentation tanks where clarification occurs. In the further preparation phase in the new factory facility, ozone is included as a new form of disinfection. Then the water goes to a filter station for filtering and then to a clean water tank where final disinfection with chlorine is performed. The water is then transported through pipelines towards the city using a pumping station. (*https://vodovod-bl.com*).

METHODS

Sampling methods

The sampling methods for water analysis are designed and defined by the standards ISO 5667-5:2007 Guidelines for sampling of drinking water from treatment works and piped distribution systems and ISO 5667-1:2004 Guidelines on the design of sampling programmes and sampling techniques.

Water samples for microbiological analysis were taken in clean 250 mL glass bottles, previously sterilized in a dry sterilizer at temperatures of 160-180 °C for 1 hour, previously closed with cork stoppers covered with aluminum foil. In the same bottles intended for taking chlorinated water, 0.15 mL of 5% sodium thiosulfate solution was poured to reduce chlorine. Before collecting water from the water supply, the tap was ignited with a flame and the water ran for 3 to 5 minutes. When the bottle was filled with water to ¾ of its volume, it was carefully closed with a stopper, the protective cap was replaced and tied with a rope.

Samples for physicochemical analysis were collected in chemically clean 1-liter bottles. When collecting water samples at the sampling point, the water temperature was measured and the organoleptic properties were determined.

The samples were delivered to the laboratory on the same day and, as a rule, immediately processed for microbiological and physicochemical testing.

Methods, instruments and techniques used in the research

Laboratory tests of the quality of both raw water and drinking water were carried out in accredited laboratories of sanitary chemistry and sanitary microbiology of the Public Health Institute of the Republic of Srpska Banja Luka. When determining the microbiological and physicochemical characteristics of raw water and drinking water samples, basic analyses were performed and BAS EN ISO methods were used for testing the hygienic safety of untreated and treated water.

Determination of microbiological parameters

Raw water

- for the determination of all coliform bacteria by the MPN method, the following were used: one 50 mL tube (LAP) 5X10 mL LAP and 5 tubes of 5 mL LAP each (preliminary test), the media were incubated for 24-48 h at 36 ºC;
- all liquid media that showed a change (turbidity, acidity) after 48 hours at a temperature of 36 ºC were plated onto appropriate solid media for further identification (confirmatory test);
- for confirmed coliform bacteria and E. coli, the most probable number (MPN) is determined.

Table 1. MPN values per 100 mL of sample and 95 % confidence interval

Number of tubes with a positive reaction		**MPN (per 100 mL)**	**Limit values**	
1 50-mL test tube	***5 10-mL test tubes***		***lower limit***	***upper limit***
0	0	<1		
0	1	1	<1	4
0	2	2	<1	6
0	3	4	<1	11
0	4	5	1	13
0	5	7	2	17
1	0	2	<1	6

1	1	3	<1	9
1	2	6	1	15
1	3	9	2	21
1	4	16	4	40
1	5	>18		

Purified water

- To determine coliform bacteria, 100 mL of the sample water to be tested is filtered using a membrane filter; the minimum volume for filtration is 10 mL of sample; after filtration, the membrane filter is placed on homogeneous coliform agar (CCA) and the Petri dish is inverted to ensure that there is no air underneath; incubation follows at 36 ± 2 ºC for 21 ± 3 h; after which colonies suspected of being coliform bacteria other than E.coli are identified and confirmed using the oxidase test; if necessary (colonies too small for the oxidase test or located next to other colonies), subcultures are made and incubated on non-selective agar at 36 ± 2 ºC for 21 ± 3 h.
- To determine the number of colonies at 22 ºC, the pour plate method is applied by placing a certain amount of test sample ≤ 2 mL per Petri dish and adding 15-20 mL of dissolved medium, followed by mixing by gentle rotation, after which the media are left to solidify. The time between the addition of the test sample and the medium must not exceed 15 minutes, at least one incubation plate is incubated at each temperature; one set facing downwards is incubated at 36 ± 2 ºC, 44 ± 4 h, and the other at 22 ± 2 ºC, 68 ± 4 h. The plates are examined immediately after removal from the incubator and the colonies present in 1 mL of sample are counted for each incubation temperature.
- The determination of Enterococcus is performed by placing the filter membrane on Slanetz Bartley medium after filtration and incubating at 36 ± 2 ºC for 44 ± 4 h. If typical colonies are present, the membrane and colonies are transferred with sterile forceps to a bile-esculin-azide agar medium that has been preheated to 44 ºC and after incubation at 44 ± 0.5 ºC for 2 h, the results are read immediately.

Determination of physicochemical parameters

Table 2. Physico-chemical parameters

PHYSICOCHEMICAL PARAMETERS	TEST METHODS FOR THE PERIODS OF 1977 AND 2006	TEST METHODS FOR THE PERIOD OF 2025
Water temperature°C	*Thermometers with divisions of 0,1 ºC*	*Thermometers with divisions of 0,1 ° C*
Color-degree on the Co-Pt scale	*Colorimetric*	*Colorimetric*
Smell	*Organoleptic*	*Organoleptic*
MTurbidity	*Turbidimetric*	*Turbidimetric*
pH-value	*Potentiometric*	Potentiometric
$KMnO_4$ mg/L consumption	Titrimetric	Titrimetric
Electrical conductivity µScm^{-1} at 293,16 K (20 º C)	Conductometric	Conductometric
Ammonia	Colorimetric (Nesler method)	Electrochemical/spectrophotometric
Nitrates and nitrites	Colorimetric (Brucin method)	Spectrophotometric
Chlorides	Titrimetric by the Mohr method	Titrimetric by the Mohr method
Sulfates	Titrimetric BaC_2O_4	Not sought
Total alkalinity	Titrimetric with HCl	Not sought
Carbonate hardness	Titrimetric with HCl	Not sought
Total hardness	Complexometric	Not sought

Residue after evaporation	Gravimetric	Not sought
Loss on ignition	Gravimetric	Not sought
Residue on ignition	Gravimetric	Not sought
Residual chlorine	Colorimetric O-toluidine method	Photometric
Dissolved oxygen	Titrimetric according to Winkler	Not sought
Biological oxygen demand– BPK_5	Titrimetric according to Winkler	Not sought

A brief description of the determination of physical and chemical parameters

- Water temperature is determined during water sampling at the collection site; the measurement is performed by placing the thermometer in water directly and reading the temperature only after a period of time that ensures constant values.
- Odor is determined organoleptically at room temperature and at 40ºC; the water sample is poured into an Erlenmeyer flask, covered with a watch glass and placed on a water bath; when the desired temperature is reached, the flask is removed from the bath, uncovered and tested for odor immediately.
- As a standard method for color measurement, the platinum-cobalt method based on a visual comparison of the sample with specially colored discs of certain values according to the Pt-Co scale is applied.
- Turbidity is measured with an optical turbidimeter, i.e. by photoelectric measurement of the intensity of light transmitted through the suspension. The sample of water for testing is poured into a cuvette and the result is read on the display of the apparatus. Turbidity measured in this way is expressed using nephelometric units (NTU), results are usually in the range of 0-40 NTU. For the periods 1977 and 2006, a conductometric test method was also used, the values of which are comparative to those of 2025, but were expressed in different units (SiO_2/L).
- Determination of pH values of the samples is performed using a pH meter. Prior to performing measurements, the probe should be washed thoroughly with distilled water. The probe is immersed in water directly and the value is read on the display.
- Electrical conductivity measurement is performed using a probe that consists of two electrodes inside the unit, these establish electrical contact with the water and enable the measurement of electrical conductivity. The probe is immersed in water directly and the value is read on the display.
- Spectrophotometric determination of nitrates is carried out by direct transfer of water into quartz cuvettes of at least 1 cm, followed by measurements performed at 220 nm and 275 nm on spectrophotometer. A blank test is also performed using distilled water. Since dissolved organic matter can absorb at 220 nm, while NO_3^- does not absorb at 275 nm, the second measurement performed at 275 nm is used for nitrate correction.
- Spectrophotometric determination of nitrite is determined by the formation of a reddish-pink azo color at pH 2,0-2,5 in the reaction of diazotized sulfanilamide with N-(1-naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride). A 50 mL sample of the test water is poured into an Erlenmeyer flask, and 2 mL of colored reagent is added. The absorbance of the resulting solution is measured on a spectrophotometer at 543 nm using glass cuvettes.
- Determination of ammonia is carried out using the phenanthate method by pouring 25 mL of test water into an Erlenmeyer flask and gradually adding 1 mL of phenol solution followed by 1 mL of Na-nitroprusside solution (as a catalysts). This is followed by addition of hypochlorite solution (2,5 mL) for oxidation. The sample is covered with parafilm and left at room temperature

(22-27 °C) for at least one hour for the color development. Measurement on a spectrophotometer at 640 nm with cuvettes of 1 cm or larger is performed. A test using distilled water as a blank is performed in parallel.

- Chlorides are determined by Mohr's method, by adding 1 mL of potassium chromate indicator into 100 mL of the sample, followed by titrating in a solution of $AgNO_3$ (0,02 mol/L) until the color of the sample changes to reddish-brown.
- Consumption of $KMnO_4$ - the permanganate index is determined by heating 25 mL of the test water sample and 5 mL of sulfuric acid in a boiling water bath (10 min). This is followed by addition of potassium permanganate (5 mL) and reheating for 10 minutes after which Na-oxalate solution (5 mL) is added and the mixture left until discoloration is observed. The discolored mixture is titrated with permanganate until a light pink color detected.
- Residual chlorine is determined during water sampling at the site using a chlorine photometer. The sample is poured into a cuvette and a few drops of the reagent are added. The sample is measured in a photometer, and the value is read off the display.

RESULTS

This chapter presents the testing results of microbiological and physicochemical parameters of raw and treated water in the periods April/May 1977, 2006 and 2025. The analyses were performed on samples taken at the water intake locations of the River Vrbas and from the reservoir following the conditioning process. The interpretation of the results was carried out according to the Regulation on the health safety of water for human consumption (Official Gazette of the Republic of Srpska, No 88/17, 97/18, 93/23 and 96/24)

Microbiological characteristics of raw water

Table 3. Microbiological Characteristics of Raw Water – The River Vrbas, April 1977, 2006 And 2025

MICROBIOLOGICAL PARAMETERS		TEST RESULTS April 1977	TEST RESULTS April 2006	TEST RESULTS April 2025
Coliform bacteria	/100mL	21000	more than 161	MPN>18
Among coliform bacteria, 2025 E.coli was identified	/100mL	E. coli	E. coli	MPN>18
Fecal coliform bacteria	/100mlL	not sought	found	not sought
Total aerobic mesophilic bacteria count/2025 colony count at 37 ºC	/1mL	1400	200	100
Colony count at 22 ºC	/1mL	not sought	not sought	220
Faecal streptococci/Enterococci	/100mL	0	found	>80
Proteus species	/100mL	0	0	not sought
Sulfite-reducing clostridia	/100mL	not sought	50	20
Pseudomonas aeruginosa	/100mL	not sought	0	not sought

Table 4. Microbiological Characteristics of Raw Water – The River Vrbas, May 1977, 2006 And 2025

MICROBIOLOGICAL PARAMETERS		TEST RESULTS May 1977	TEST RESULTS May 2006	TEST RESULTS May 2025
Coliform bacteria	/100mL	8800	more than 161	MPN>18
Among coliform bacteria, 2025 E.coli was identified	/100mL	E. coli	E. coli	MPN>18
Fecal coliform bacteria	/100mL	not sought	found	not sought
Total aerobic mesophilic bacteria count/2025 colony count at 37 ºC	/1mL	150	50	100

Colony count at 22 ºC	/1mL	not sought	not sought	220
Faecal streptococci /Enterococci	/100mL	0	found	>80
Proteus species	/100mL	0	0	not sought
Sulfite-reducing clostridia	/100mL	not sought	40	20
Pseudomonas aeruginosa	/100mL	not sought	0	not sought

The test results indicate the presence of a significant number of coliform bacteria, including fecal forms such as Escherichia coli, which confirms the sanitary-fecal contamination of the River Vrbas.

The number of aerobic mesophilic bacteria at 37 ºC was high in earlier analyses (in 1977, it was 1400 CFU/mL), while in 2025, it was 100 CFU/mL.

The number of colonies at 22 ºC in 2025 was 220 CFU/mL, while it had not been monitored before.

The presence of Enterococcus is also significant (>80/100 mL in 2025), while sulfite-reducing clostridia ranged from 0 to 50/100 mL.

The presence of other pathogens (Proteuss spp. and P. aeruginosa) was not detected in all the periods studied.

Physico-chemical characteristics of raw water

Table 5. Physico-Chemical Parameters of Raw Water – The River Vrbas, April 1977, 2006 and 2025

PHYSICOCHEMICAL PARAMETERS	TEST RESULTS April 1977	TEST RESULTS April 2006	TEST RESULTS April 2025
Water temperature at ºC	9,2	9,3	11,7
Color-degree on the Co-Pt scale	0	0	5
Smell	without	without	without
Turbidity	1000 mg SiO_2/L	5 mg SiO_2/L	2,56 (NTU scale)
pH-value	8,2	7,66	8,06
$KMnO_4$ mg/L consumption	21,5	7,3	< 0,5
Electrical conductivity µS/c^{m-}1	-	410	298
Ammonia	0,00	0,00	< 0,10
Nitrites as N mg/L	0,001	0,003	0,02
Nitrates as N mg/L	1,00	1,00	< 2,0
Chlorides mg/L	10	10	< 5,0
Sulfates mg/L	21,7	34,8	not sought
Total alkalinity $CaCO_3$/L	36	210,1	not sought
Carbonate hardness $CaCO_3$/L	10,8	210,1	not sought
Total hardness $CaCO_3$/L	12,46	228,1	not sought
Evaporation residue mg/L	448	250	not sought
Loss on ignition mg/L	152	61	not sought
Residue on ignition mg/L	296	189	not sought
Residual chlorine g/L	0	0,00	not sought
Dissolved oxygen	14,44	11,95	not sought
Biological oxygen demand-BPK_5	-	2,13	not sought

Table 6. Physico-Chemical Characteristics of Raw Water – The River Vrbas, May 1977, 2006 and 2025

PHYSICOCHEMICAL PARAMETERS	TEST RESULTS May 1977	TEST RESULTS May 2006	TEST RESULTS May 2025
Water temperature at ºC	12,4	10,3	13,4
Color-degree on the Co-Pt scale	0	0	5
Smell	without	without	without
Turbidity	20 mg SiO_2/L	5 mg SiO_2/L	3,01 (NTU scale)
pH-value	8,2	7,86	7,84
$KMnO_4$ mg/L consumption	11,89	6,8	< 0,5
Electrical conductivity µS/cm^{-1}	-	398	381
Ammonia mg/L	0,00	0,00	< 0,10
Nitrites as N mg/L	0,002	0,002	0,02
Nitrates as N mg/L	1,00	1,00	< 2,0
Chlorides mg/L	8	12	< 5,0
Sulfates mg/L	65,3	33,9	not sought
Total alkalinity $CaCO_3$/L	36	200,0	not sought
Carbonate hardness $CaCO_3$/L	9,59	200,0	not sought
Total hardness $CaCO_3$/L	10,08	231,3	not sought
Evaporation residue mg/L	270	249	not sought
Loss on ignition mg/L	112	63	not sought
Residue on ignition mg/L	158	186	not sought
Residual chlorine g/L	0	0,00	not sought
Dissolved oxygen	11,44	12,06	not sought
Biological oxygen demomd-BPK_5	-	1,92	not sought

The temperature of the raw water (the River Vrbas) varied from 9.20 ºC to 13.42 ºC depending on the sampling period. Smell and colour were not significant, while turbidity decreased significantly over the years, from 1000 SiO_2/L in 1977 to 2.56 NTU in 2025.

pH-value remained stable (7.66-8.20), and the $KMnO_4$ consumption decreased, indicating better oxidative capacity of the water in the recent period.

Electrical conductivity was within the prescribed values, and the concentrations of ammonia, nitrate and nitrite remained low.

In 2025, the chloride concentration was less than 5 mg/L, while sulfates and hardness were not analyzed.

The water was well saturated with oxygen (1977:14.44 mg/L), which indicates the capacity for natural self-purification in the river.

Microbiological characteristics of purified water

Table 7. Microbiological Characteristics of Drinking Water-Reservoir, April 1977, 2006 and 2025

MICROBIOLOGICAL PARAMETERS		TEST RESULTS April 1977	TEST RESULTS April 2006	TEST RESULTS April 2025
Coliform bacteria	/100mL	0	0	0
Among coliform bacteria, 2025 E.coli was identified	/100mL	0	0	0
Fecal coliform bacteria	/100mL	not sought	0	not sought
Total aerobic mesophilic bacteria count/2025 colony count at 37 ºC	/1mL	0	0	0
Colony count at 22 ºC	/1mL	not sought	not sought	0

Faecal streptococci/for 2025 Enterococci	/100mL	0	0	0
Proteus species	/100mL	0	0	not sought
Sulfite-reducing clostridia	/100mL	not sought	0	not sought
Pseudomonas aeruginosa	/100mL	not sought	0	not sought

Table 8. Microbiological Characteristics of Drinking Water – Reservoir, May 1977, 2006 and 2025

MICROBIOLOGICAL PARAMETERS		TEST RESULTS May 1977	TEST RESULTS May 2006	TEST RESULTS May 2025
Coliform bacteria	/100mL	0	0	0
Among coliform bacteria, 2025 E.coli was identified	/100mL	0	0	0
Fecal coliform bacteria	/100mL	not sought	0	not sought
Total aerobic mesophilic bacteria count/2025 colony count at 37 ºC	/1mL	0	0	0
Colony count at 22 ºC	/1mL	not sought	not sought	0
Faecal streptococci/for 2025 Enterococci	/100mL	0	0	0
Proteus species	/100mL	0	0	not sought
Sulfite-reducing clostridia	/100mL	not sought	0	not sought
Pseudomonas aeruginosa	/100mL	not sought	0	not sought

The test results showed that all samples of purified water from the reservoir were microbiologically correct. In all the years tested (1977, 2006 and 2025), coliform bacteria, including Escherichia coli, were not detected. There were no Enterococci, Pseudomonas aeruginosa, sulfite-reducing clostridia, or other microbiological indicators of contamination.

Physico-chemical characteristics of purified water

Table 9. Physico-Chemical Characteristics of Drinking Water – Reservoir, April 1977, 2006 and 2025

PHYSICOCHEMICAL PARAMETERS	TEST RESULTS April 1977	TEST RESULTS April 2006	TEST RESULTS April 2025
Water temperature at ºC	8,6	9,5	11,7
Color-degree on the Co-Pt scale	0	0	< 2,5
Smell	without	without	without
Turbidity	0 mg SiO_2/L	0 mg SiO_2/L	< 0,02 (NTU scale)
pH-value	8,1	7,96	7,70
$KMnO_4$ mg/L consumption	4,4	4,1	< 0,5
Electrical conductivity µS/cm^{-1}	-	325,5	317
Ammonia mg/L	0,00	0,00	< 0,10
Nitrites as N mg/L	0,003	0,00	< 0,01
Nitrates as N mg/L	1,00	1,00	< 2,0
Chlorides mg/L	12	12	< 5,0
Sulfates mg/L	26,9	28,3	not sought
Total alkalinity $CaCO_3$/L	40	38	not sought
Carbonate hardness $CaCO_3$/L	11,2	11,9	not sought
Total hardness $CaCO_3$/L	11,76	12,26	not sought
Evaporation residue mg/L	268	211	not sought
Loss on ignition mg/L	158	70	not sought
Residue on ignition mg/L	110	141	not sought
Residual chlorine g/L	0,5	0,5	0,48

Table 10. Physico-Chemical Characteristics of Drinking Water – Reservoir, May 1977, 2006 and 2025

PHYSICOCHEMICAL PARAMETERS	TEST RESULTS May 1977	TEST RESULTS May 2006	TEST RESULTS May 2025
Water temperature ºC	8,6	9,5	13,4
Color-degree on the Co-Pt scale	0	0	< 2,5
Smell	without	without	without
Turbidity	0 mg SiO_2/L	0 mg SiO_2/L	< 0,02 (NTU scale)
pH-value	8,1	7,96	7,43
$KMnO_4$ mg/L consumption	4,4	4,1	< 0,5
Electrical conductivity $\mu S/cm^{-1}$	-	325,5	404
Ammonia mg/L	0,00	0,00	< 0,10
Nitrites as N mg/L	0,003	0,00	< 0,01
Nitrates as N mg/L	1,00	1,00	< 2,0
Chlorides mg/L	12	12	< 5,0
Sulfates mg/L	26,9	28,3	not sought
Total alkalinity $CaCO_3$/L	40	38	not sought
Carbonate hardness $CaCO_3$/L	11,2	11,9	not sought
Total hardness $CaCO_3$/L	11,76	12,26	not sought
Evaporation residue mg/L	268	211	not sought
Loss on ignition mg/L	158	70	not sought
Residue on ignition mg/L	110	141	not sought
Residual chlorine g/L	0,5	0,5	0,47

The temperature of the treated water ranged from 8.6 ºC to 13.4 ºC.

Smell and colour were absent, and turbidity was reduced to values below 0.02 NTU.

pH-values were stable (7.43-8.1). $KMnO_4$ consumption was significantly lower in 2025 (< 0.5 mg/L), indicating a high degree of oxidizability after treatment.

Residual chlorine was stable and in accordance with recommendations (0.47-0.50 mg/L). Ammonia, nitrite and nitrate concentrations were low, and chlorides showed a decrease in concentration (< 0.5 mg/L). Other parameters (hardness, alkalinity, sulfates) in compliance with applicable regulations were not analyzed.

Conclusions based on the results:

1. Raw water of the Vrbas shows signs of fecal contamination and significant variability in physicochemical parameters, but with a decrease in load in recent years.
2. The water conditioning process in the Banja Luka Water Supply System effectively removes microbiological and most physicochemical pollutants.
3. Purified water meets all applicable microbiological and physicochemical standards prescribed by the Regulation.

These results confirm the validity and functionality of the existing technological line for water purification, as well as the need for its constant improvement in accordance with changes in raw water quality.

CONCLUSION

According to analyses in three time periods (1977, 2006 and 2025), the raw water of the River Vrbas still represents a valuable, although challenging, source for the drinking water production. Progress has been noted in reducing the microbiological and chemical load of raw water, but continuous water quality monitoring and preventive measures aimed at preserving the quality of the source are still required.

On the other hand, the water conditioning in the Banja Luka Water Supply System has proven to be highly efficient and stable. Through the application of modern methods – including ozonation, filtration and chlorination – a high degree of contamination elimination has been achieved, thus ensuring safe drinking water supply for end users.

All tested purified water samples met the criteria of the Regulation on the health safety of drinking water, both in microbiological and physicochemical terms. This confirms that the existing water treatment system in Banja Luka is in compliance with modern standards and can meet the challenges of modern urban supply.

Given the increased hydrological oscillations and climate change that may affect the quality of surface waters, these activities are recommended:

1. continuous 24-hour monitoring of raw water quality,
2. improving measures to protect water sources from fecal and industrial contamination,
3. regular technological improvement in processing plants and
4. additional education of personnel and strengthening laboratory capacities.

Maintaining a high-quality drinking water is of crucial significance for protecting population health and preserving ecological stability in a broader social context.

Climate change gives rise to changes in chemical composition of water. In order to sustain a safe and stable water supply, it is crucial to develop strategies for chemical monitoring and prompt actions to the changes (*https://www.eea.europa.eu/en/newsroom/news/state-of-water*).

LITERATURE

Antonić, B. (2017). Voda za piće: kvalitet i bezbjednost. Sveučilićte/Univerzitet Vitez.

Dalmacija, B. (2015). Kontrola kvaliteta vode za piće od izvorišta do potrošača. Novi Sad: Univerzitet u Novom Sadu, Prirodno-matematički fakultet; Institut za hemiju.

Kristoforović-Ilić, M. (2002). Komunalna higijena. Novi Sad: Prometej.

Stanojević, M. (2022). Prečišćavanje vode za piće. Beograd: AGM knjiga

SZO (2016). Guidelines for Drinking Water Quality, Second Edition, Volume 2. World Health Organization.

Tehnička dokumentacija Vodovoda Banja Luka (1977).

Javno preduzeće „Vodovod" Banja Luka.

https://www.who.int/news-room/fact-sheets/detail/drinking-water [accessed13.06.2025.]

https://www.toshiba-clip.com/en/detail/p=147 [accessed 14.07.2025.]

https://www.eea.europa.eu/en/newsroom/news/state-of-water [accessed 13.07.2025.]

Recived: May 31, 2025

Accepted: July 23, 2025