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ENVIRONMENTAL ENGINEERING SPECIALIZATION

Monitoring of surface water quality in the Mureș River Basin

THE SUMMARY OF DOCTORAL THESIS

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Content

Introduction

The doctoral thesis **"Monitoring the quality of surface water in the Mureș River Basin"** aims to analyze the quality indicators of the surface water, respectively of the Mureș hydrographic basin, for the period 2015-2020. Data used in the paper is related to biological, physico-chemical parameters, oxygenation and salinity conditions, water acidification status, nutrients, specific pollutants, but also it is based on other specific characteristics of this river.

The evaluation and monitoring of water is of particular importance both for the residents of Arad County and for those of the Mureș Valley from the source to the river mouth. Water is an essential and indispensable resource for life. This topic was chosen because we believe that the study of surface water deserves a more thorough approach, both from the point of view of water quality and the amount of water found in a country or region.

At the level of Arad County, water quality indicators are evaluated on the three sections related to the Mureș hydrographic basin. Based on them, an assessment of water quality can be made by transforming the monitored data for surface water and converting them into water quality classes. The data are provided by the Romanian National Water Administration (ANAR) (Department of Water Resources Management, Quality Management and Protection of Water Resources)

The paper is structured in four chapters. **The first chapter** refers to the fundamental notions regarding the characteristics of surface water on a general level. **The second chapter** refers to surface water monitoring indicators, respectively to water pollution, the types of pollutants and the main sources of pollution. Included here is also a comparative study of the pollution situation in the Mureș, Olt and Siret water basins. **The third chapter** refers to the research of the ecological state of the water of the Mureș hydrographic basin, the monitoring and evaluation of the quality parameters of the Mureș River in the sections of the Arad County and the investigation of the perception of the citizens of Pecica and related localities regarding the benefits of revitalizing the drinking water system and sewage. Finally, in **the fourth chapter**, the conclusions of the research, the ecological impact on the three water sections and recommendations and perspectives regarding the preservation of the water quality in the Mureș River Basin in the studied area are presented.

Objectives

The purpose of the research is the monitoring and evaluation of the physical, chemical and biological quality parameters of the surface water of the Mureș hydrographic basin, on the three bodies of water belonging to Arad County. The names of the sections and bodies of water that belong to Arad County are: Săvârșin, Arad and Nădlac.

The main objectives pursued are:

1. Monitoring the quality of surface water in the Mureș hydrographic basin, on the three bodies of water belonging to Arad County, respectively the processing and interpretation of monitoring data regarding biological, physical and chemical parameters.

2. The comparative study of the pollution situation in the Mureș, Olt and Siret water basins and the investigation of the perception of the inhabitants of the Pecica area regarding drinking and wastewater, the access and quality of water and their opinion regarding the distribution of water and the investments made in supplying the population with water .

3. Evaluation of the ecological impact of human activities on the three sections of the Mureș River, by calculating a pollution index according to the methodology advanced by Zaharia (2012), applying the formula: $EQ_i = C_i$ measured / MAC_i where EQ_i represents the pollution index, C_i is the measured value of the parameter taken into account, and MAC_i represents the maximum allowed limit for the measured parameter.

CHAPTER I

Introduction to water

1.1. Water – Earth's most precious resource

Water is found everywhere on our planet: on the ground, under the ground, in the air, in the body of living things. This ubiquity of water is ensured by fulfilling the circuit of water in nature – the hydrological cycle.

Water is used for the normal activity of the biosphere, i.e. directly by man, being indispensable to him. Until the 20th century, water efficiency and quality, water demand, was a secondary issue, and in the second half of the century drinking water became a critical raw material.

Thus, with the expansion of large-scale urbanization, the vital need for water is increasing. In recent years, concern has been expressed to address this problem not only at the national level, but also at the international level [1]. The most important event where the multiple aspects of humanity's water resources were debated was the United Nations Conference on Water Resources, which was held in Mar del Plata, Argentina, between March 14 and 25, 1977. Over time, a series of researches have shown the importance of water in nature, but also its implications in the development of sustaining life on Earth. And among these, one of the most important components is surface water; rivers, lakes, etc.

1.2. Water in nature – the general framework

In our solar system, evidence of underground ice, ancient water networks, and even an ancient ocean appear only on the planet Mars. Evidence of ice and perhaps even liquid water appears beneath the icy surfaces of three of Jupiter's moons, although none currently have free surface water.

However, among the planets orbiting the Sun, Earth is clearly the "water planet." It is well known that the Earth is also called the Blue Planet, because, seen from space, it has a blue color due to the water that covers it by two thirds.

Water appears on its surface as liquid, ice and gas. Ocean water now cover nearly 71% of the Earth's surface, according to the 1977 UN conference in Argentina, while fresh water in lakes and rivers cover less than 1% [1]. Ice caps permanently cover the Earth's polar regions, and glaciers are widespread in the mountainous heights. Water in the form of clouds hides about half of the Earth's surface at any given time. Volcanic eruptions continuously extract water and gases from the rocks inside the Earth.

1.3. Substances dissolved in water

Water is never found in a pure state in natural conditions, it contains a certain amount of dissolved or suspended chemicals. The diversity of these substances led to their classification into several groups [7]: dissolved gases (oxygen, carbon dioxide and hydrogen sulphide) – the most common substances found in the composition of water in nature, mineral substances and organic and biogenic substances.

1.3.1. Dissolved oxygen

Dissolved oxygen refers to the level of free, uncompounded oxygen present in water or other liquids, being an important parameter in the assessment of water quality due to its influence on the organisms living inside a body of water. Mănescu and collaborators [7] point out that "the balance of oxygen in the water results from the game - the dynamic balance - of two groups of processes. One group is represented by the processes that enrich the amount of oxygen in the water, and the other by those that reduce the amount of oxygen."

1.3.2. Carbon dioxide

Carbon dioxide is a gas whose dissolution in water is part of the category of processes that contribute to the reduction of oxygen in water by using it for the transformation and biochemical degradation of substances and sometimes for the oxidation of some mineral elements [5]. Carbon dioxide can be found in water in combined (CO3H) and free (CO2) form.

1.3.3. Hydrogen sulphide

Hydrogen sulfide is rarely found in water, especially in groundwater. Sulfates are a combination of sulfur and oxygen and are part of the minerals that occur naturally in some soil and rock formations that contain groundwater. Over time, the mineral dissolves and is released into the groundwater. Bacteria that use sulfur as an energy source are the primary producers of hydrogen sulfide chemically changing natural sulfates in water to hydrogen sulfide. These bacteria live in oxygen-deficient environments, such as deep wells and wells, plumbing systems, water softening systems, and water heating boilers. These bacteria usually proliferate on the heating side of water distribution systems.

1.3.4. Hydrogen ions

Hydrogen ions also appear in chemically pure water, as a result of the partial dissociation process. Although the dissociation constant of water is very low (1/555 million molecules), the concentration of hydrogen ions is a very important natural characteristic of water [7]. Hydrogen ion concentration is more conveniently expressed as pH, which is the reciprocal of the hydrogen ion concentration in moles grams per liter.

The most acidic water on Earth are in the Danakil Depression in Ethiopia, known as the "gateway to hell" (figure 1.1.). In a landscape of surreal colors, dominated by luminescent yellow and green pools, with hot water boiling like a cauldron and chlorine and sulfur gases poisoning the air, it is one of the most unfriendly places on Earth. However, a recent expedition to the region found it teeming with life [22].

Figure 1.1. ***Acidic lake in the depression of Ethiopia (credit foto: © Alamy, 2017)***

At the opposite pole of acidic water, with a low pH, are alkaline water with an extremely high pH. A notorious example of an alkaline lake is Lake Natron in Tanzania, with a pH of up to 10.5 due to high concentrations of the sodium salt of carbonic acid Na2CO3 (soda) and sodium bicarbonate NaHCO3, which enter the surrounding ground water [23]. While the lake supports a thriving ecosystem, including flamingos, alkaline cichlids and pH-resistant algae, the animal carcasses are preserved by sodium carbonate similar to the Egyptian mummification process, creating images of disturbing beauty (figure 1.2).

Figure 1.2. ***A petrified flamingo preserved by the mineral salts of Lake Natron (credit foto: © N. Brandt, 2010)***

1.3.5. Mineral substances

The mineral substances most frequently found in the composition of natural water are: calcium, potassium, sodium, magnesium, cobalt, nickel, lithium, barium and others. Natural water, depending on the degree of mineralization, are divided into [7]:

– weakly mineralized water (below 500 mg/dm3)

– mineralized water (between 500 and 1000 mg/dm3)

– highly mineralized water (over 1000 mg/dm3)

Surface water are less mineralized because mineral salts come from water in rocks and soil. Some studies show that their mineralization increases from mountain to lowland and according to flow, so mineralization increases during low flow and vice versa.

1.3.6. Organic and biogenic substances

Organic and biogenic substances are biological substances that come from organic substances under the enzymatic action of microorganisms: ammonia, nitrates, nitrates, phosphates, iron and silicon compounds. Dissolved organic matter is the largest reservoir of organic carbon in the aquatic environment. Their presence can be greatly influenced by land use, which can increase or decrease organic matter loads on waterways. Forested land, for example, may contribute more substances than agricultural land, but the nutrients bound in the material may be less bioavailable than those in agricultural fields [24].

Also added to dissolved organic matter are the remains of living and dead organisms that have decomposed in a body of water. Organic matter in waterways can be viewed as a mixture of living and dead things, including plant, microbial and animal products in various stages of decomposition [25]. Also in the mix are biologically and chemically synthesized compounds from the products of decaying organisms and general decomposition (fig. 1.10). These remains can be broken down into humic or non-humic substances.

Humic substances are the ones that make up most of the organic matter in both soils and water. They occur naturally, produced by living organisms, and are generally yellow-black in color. Humic substances have a high molecular weight and are formed largely as a result of microbial activity on plant materials. The resulting molecules are quite resistant to further microbial degradation and typically have low turnover rates in aquatic systems.

1.4. Drinking water

Drinking water is water that meets certain physical-chemical and hygienic-sanitary standards that allow it to be used for food without endangering health. It plays a very important role in the body, the World Health Organization considering a necessary intake of 5 liters of water per day for a person, of which 1.5 - 2 liters represent the water consumed as such, with variations depending on the context (climate, season, age, sex, effort). Added to these are much larger amounts of water used for other purposes (personal hygiene, food preparation, house cleaning and clothing) an optimum of approximately 100 liters per day, according to the WHO [3].

To be drinkable, the water must be clean, transparent, tasteless, odorless, microbiologically pure, maximum hardness 100mg/l, with a pH between 6.5 and 7.4 and turbidity ≤ 5. The temperature of the drinking water must be between 7-15oC, and the number of biological organisms should not exceed 20 in a liter of water, the amount of dissolved, colloidal or suspended chemical substances should be in relation to the legal norms [27].

Contaminants of drinking water are assessed worldwide by established regulations on the quality of water intended for human consumption and usually fall into distinct groups, including inorganic compounds, organic and synthetic compounds such as pesticides and microbial and other contaminants. Common contaminants and acceptable levels are regulated by the World Health Organization drinking water standards, the European Union Council Directive [28] and the US Environmental Protection Agency National Drinking Water Standards [29], based on the maximum contaminant level CMA – maximum concentration admitted.

Nowadays, clean drinking water is a matter of life and death. The scarcity of potable water is becoming the most technologically challenging problem of the 21st century, as human activities change the environment and render vast amounts of water unfit to support life. Whatever the origin of the water, it is now clear that drinking water can only be obtained through a process of filtration either at the source or at the consumer. There are currently no clean water sources in many of the world's major population centers.

CHAPTER II.

Surface water monitoring indicators. Water pollution – types of pollutants and sources of pollution

2.1. Water pollution - overview

Water pollution is the direct or indirect modification of the natural composition of water as a result of human action. Self-pollution is a natural phenomenon and comes from the massive deterioration of animals and algae in the water, also called the phenomenon of water bloom. After the occurrence of this phenomenon, the water becomes rich in decaying organic substances, high oxygen consumption and putrefaction occur.

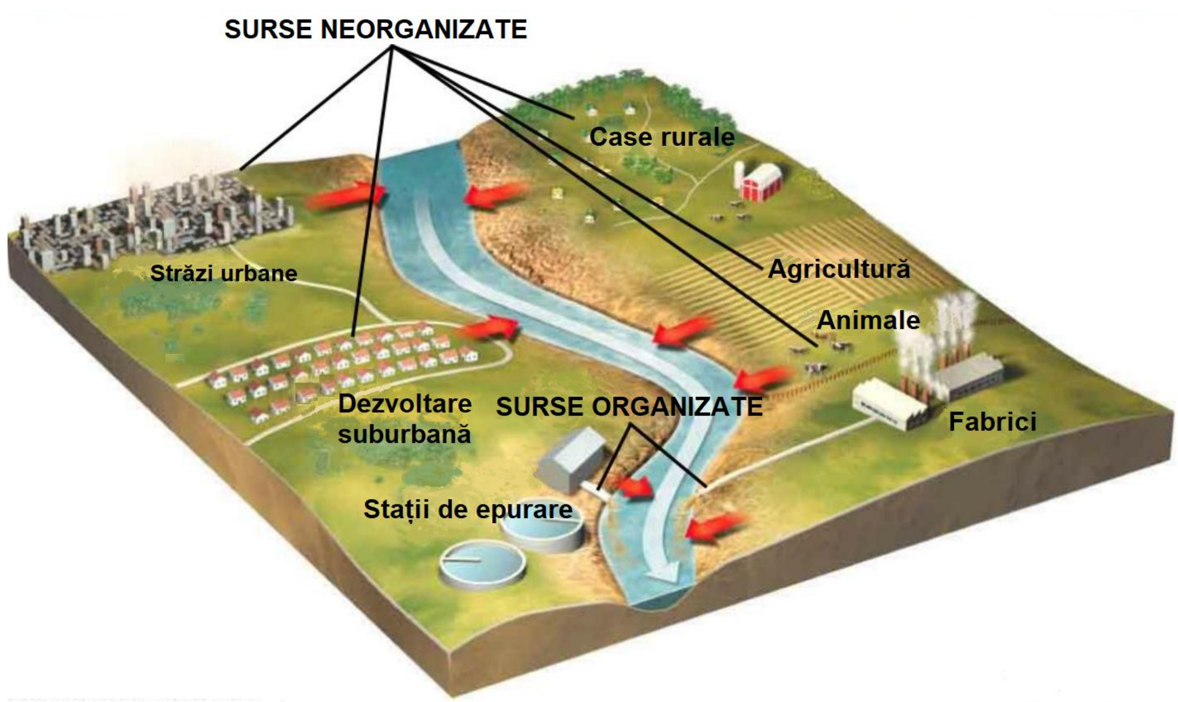

Figure 2.1. ***Sources of pollution (organized and unorganized) (adapted from Brooks/Cole – Thomson Learning, 2004)***

Pollution also occurs when we encounter changes in its composition. We cannot use it for different purposes, which produces inconvenience in the use of water or endangering the health of consumers. Impurity refers to changing the composition of water, and preventing the use of water leads to pollution. The factors that contribute to water pollution are [7]:

– demographic factors – pollution is proportional to population density,

– urban factors – the use of a large amount of water and the return of water in a used form,

– industrial factors – the industrial growth and development of a region goes hand in hand with pollution – detergents, solvents, cyanides, heavy metals, nitrogenous substances, fats, washing agents, ammonia, etc.

The main sources of pollution [5] are grouped into organized sources, where pollution can be done by means of sewage installations in cities and industrial discharges, and unorganized sources, where water pollution can be done by the uncontrolled infiltration of some substances in localities without sewage. After action over time there are permanent, non-permanent and accidental sources of pollution. By the mode of pollution generation there are natural and man-made sources of pollution, which include domestic and industrial wastewater and landfills.

2.2. Physical, chemical and biological pollution

Physical pollution – with radioactive substances, but also thermal or influenced by floating or sedimentable insoluble elements. Radioactive pollution - radiation - acid rain that can come from thermoelectric or atomic power plants.

Biological pollution – bacterial contamination of food water and eutrophication. Industrial wastewater has as a source of contamination the food industry. Food is indirectly polluted through contamination with human-influenced bacteriological, parasitological and virological substances. Eutrophication of water is a process of discharge of wastewater that is rich in organic substances and which has as consequences the impoverishment of water in oxygen, respectively the increase of water hardness and the concentration of salts.

Depending on the time and the polluting agent, the pollution can be permanent or systemic, periodic or accidental.

Chemical pollution – the infiltration of organic chemicals into the water, which can cause difficulties in water treatment. It is recommended to use modern installations to reduce the expenses of water treatment and the price of its distribution.

Household pollution depends on the number of inhabitants of a region, organic and mineral pollutants of liquid household waste. Chemical pollution includes toxins - pesticides or heavy metals, polluting gases - carbon monoxide, acid rain, lead and mercury particles, carcinogens.

2.2.1. Eutrofization

It is the process by which a body of water becomes enriched with chemicals (nitrates and phosphates). Algae and other aquatic plants then feed on these nutrients causing excess growth (blooms). This leads to a reduction in available dissolved oxygen and restricts the amount of sunlight entering the water. Limited photosynthesis causes the death and decay of aquatic plants and animals.

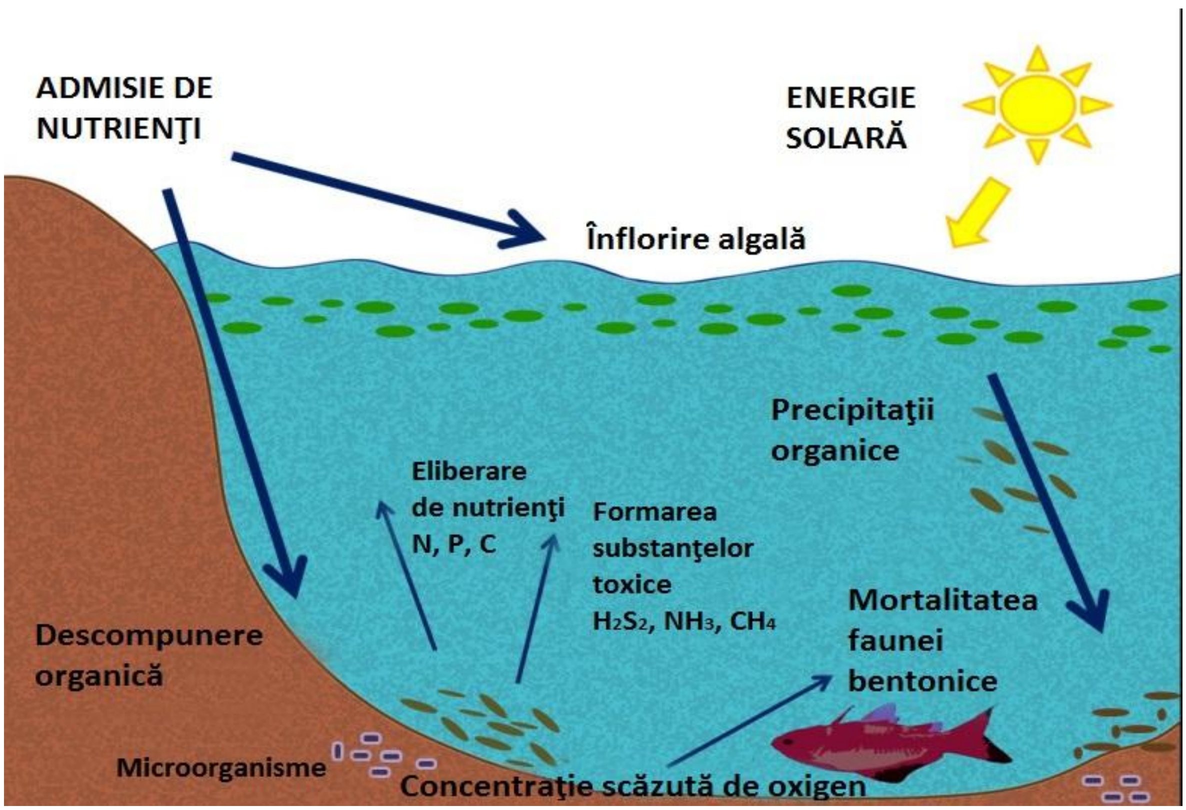

Figure 2.2. ***Representation of the eutrophication process (adapted from ARPA Umbria, 2009)***

Toxic cyanobacteria are a cause of ecological concern due to their ability to produce a wide range of hepatotoxins, neurotoxins and dermatotoxins. Microcystins (MC) are the most common toxins and are considered to be one of the most dangerous groups. Indeed, some of the largest aquatic ecosystems on earth are contaminated with these microcystins, which pose a potential risk to human health when they occur in freshwater for recreational or drinking purposes. To ensure the safety of drinking water supplies, a variety of physical, chemical, and biological processes such as coagulation, flocculation, sedimentation, filtration, disinfection, adsorption and biodegradation are applied to remove microcystins.

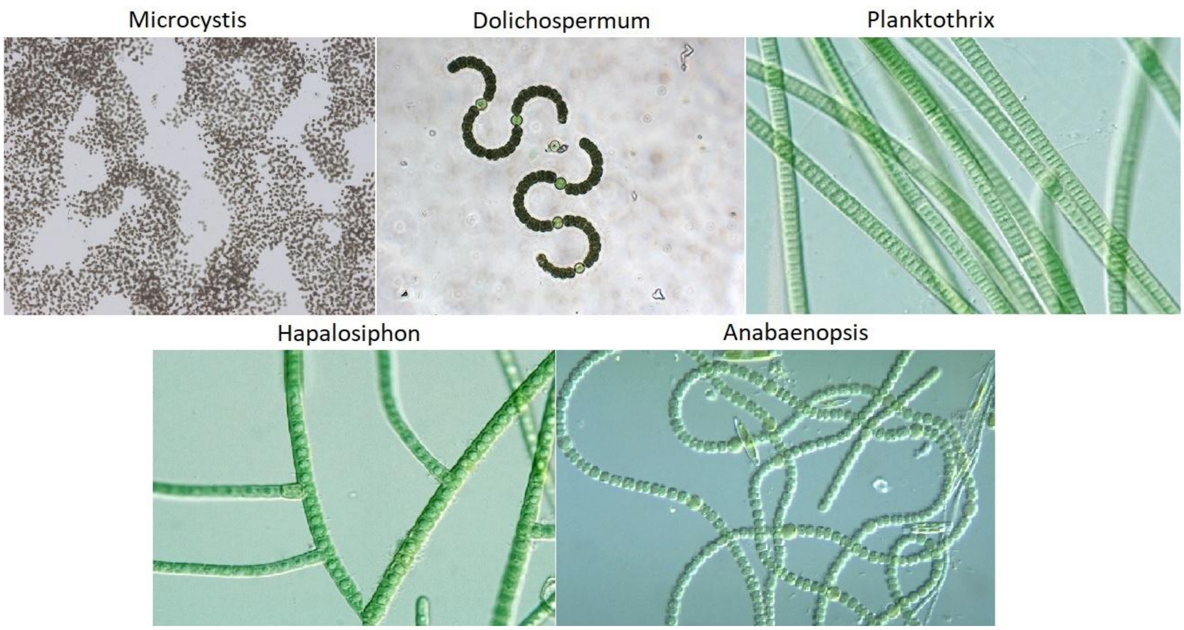

Figure 2.3. ***Cyanobacteria known to produce microcystins (source Dalcon Environmental, 2020)***

2.2.2. The process of bioaccumulation and biomagnification

Bioaccumulation is the accumulation of substances in living organisms or the result of food chains and includes heavy metals, pesticides or organic chemicals. Substances enter the body from water or compromised food. The body has mechanisms to eliminate toxic products from the body. The longer the lifetime of the substance, the greater the impact becomes. Bioaccumulative substances are normally fat-soluble and cannot be broken down into smaller molecules, so they tend to remain in the body.

Biomagnification is the increase in concentrations of substances in a food chain. For the biomagnification process to occur, pollutants must be long-lived. Also, to easily enter biological systems through food or water means, biomagnification should be mobile. If it is not mobile, it can remain inside an organism and will not be able to pass into another trophic level. Therefore, for biomagnification to occur, pollutants must be biologically active. Heavy metals, such as mercury, lead, zinc, etc. are toxic and can be biomagnified.

Bioaccumulation and biomagnification [33] are two different processes that often occur in tandem with each other. Through the process of bioaccumulation, toxins enter the food web by accumulating in individual organisms, while through biomagnification toxins are passed from one trophic level to the next (and therefore increase in concentration) in a food web.

2.2.3. Endocrine disruptors

In some organisms, hormones link the nervous system with body functions, immunity, metabolism, etc. Chemicals also called "endocrine disruptors" can affect the hormonal system and can produce harmful effects for both humans and wildlife [34]. Epidemiological studies on human health have suggested that it could be influenced by endocrine disruptors. With regard to fauna, it has been observed that adverse effects may be associated with endocrine disruptors in molluscs, crustaceans, fish, causing reproductive disorders and diminished reproduction.

Endocrine disruptors (REACH) are considered mutagenic substances, and the aim is to reduce their use or replace them with safer alternatives. In the Biocidal Products Regulation, active substances that may cause endocrine disruption will not be approved unless it is demonstrated that the risk of exposure to this active substance is low. This may endanger human health, animal health or the environment.

2.2.4. Oil and hydrocarbon pollution

Petroleum is an organic substance made up of living matter, plants and animals, and is composed of hydrocarbons, molecules made up of the two chemical elements hydrogen and carbon, and other substances [38]. It can be found in various forms, such as liquid crude oil, natural gas or a viscous substance called asphalt or bitumen.

Since most types of hydrocarbons are less dense than water, when spilled into bodies of water, they float on the surface of the water forming so-called oil or petroleum slicks. They stretch and are moved across the water by winds and currents. How spilled oil affects creatures near the surface depends on when and where the oil is spilled—those creatures may or may not even be in the area at the time and place of a spill [39]. According to the nature of the basic pollution, waste water from oil processing enterprises can be divided into [38]:

– wastewater containing oil and oil derivatives,

– wastewater containing sulfuric acid and sulfates,

– wastewater containing alkaline sulphides (sodium sulphides),

– wastewater containing hydrogen sulphide.

2.3. Effects of environmental pollution on human health

The insufficient amount of water can lead to a state of lack of sanitation and to spread of some diseases to the population. Lack of cleanliness and bodily hygiene and lack of sanitization of institutions or public premises can all spread digestive diseases: gastro-enteritis, hepatitis, skin diseases, etc.

These persistent pollutants are regulated worldwide by the Stockholm Convention and the Aarhus Protocol [41], and through the POPs Regulation, the European Union enforces the legislation. Among the specific control measures we mention [40]: prohibitation and stric restristion of the production, placing on the market and use of these substances; safe management of substance stocks; environmentally sound disposal of waste containing or contaminated with persistent organic substances.

2.4. Sources of surface water pollution

According to the National Synthesis of Important Water Management Issues [42], organic matter, nutrients and hazardous substance pollution in surface water is most often caused by discharges and emissions from human settlements, industrial and agricultural activities. The implementation of measures to reduce pollutant emissions aims to reduce pollution. This aspect has weight in the updating of the Management Plan intended to achieve and maintain good water status.

2.5. Water quality standards

The legislation in act regarding water quality assurance was developed in 1338 in England and in 1404 in France. A 6-volume collection of water quality legislation has also appeared in

Germany. In our country, STAS 4708/88 is in force for surface water. The categories and the technical conditions of water quality, which are provided in this standard, are [44]:

1. Category I – drinking water used in centralized supply, in zootechnical units, irrigation, fish farming, swimming pools, food industry.
2. Category II – use of water in the industrial field, fish farming, leisure.
3. Category III – cooling aggregates, hydropower plants, irrigation.

The Romanian National Water Administration (ANAR) has implemented the Integrated Management System in accordance with ISO 9001: 2015, ISO 14001: 2015, ISO 45001: 2018 standards through which they aim to promote a policy of permanent customer satisfaction and security risk reduction and health at work, as it emerges from the Policy in the field of environmental health and occupational safety [45].

2.6. Pollution sources of the Mureș River in Arad County

Regarding accidental pollution on this section, no such pollution was recorded for the period 2017-2020 in Arad County, except for the one on 31.08.2020. Thus, in the period 2017-2020 in Arad County there was only one accidental pollution, in the Micalaca area. From the data provided by the Mureș Water Basin Administration, it emerges that among the most frequent causes of accidental pollution on the Mureș River the following stand out [50]:

– non-compliance with technological discipline in production processes
– unsatisfactory condition of equipment, insufficient maintenance and spare parts,
– inadequate technical solutions, insufficient storage capacities
– insufficient self-monitoring of water users
– extreme hydrometeorological situations
– road accidents.

Regarding the sources of pollution at the Mureș hydrographic basin for the period 2017-2020, according to their origin, there are the following categories of wastewater:

– household wastewater
– public wastewater
– industrial wastewater
– wastewater from agro-zootechnical and fishery units

– wastewater resulting from satisfying the own technological water needs of the sewage system from washing and sprinkling streets and premises

– infected meteoric water.

The field of activity of the main sources of pollution of the Mureș River in the area of Arad County, monitored by ABA Mureș, is the collection and purification of household wastewater (these are the purification stations of the localities in the area). That is why water pollution can be disturbed in the following processes:

a) provision of drinking water for cities – it can be polluted with household and industrial residues and toxic substances

b) water supply to industrial areas – technological water can be contaminated with certain pollutants

c) water supply in households and farms for animal breeders – the existence of toxic substances that can affect animals, salt concentrations above 1.5% have proven fatal for animals

d) in the field of irrigation – the presence of heavy metals in water (boron, sodium, etc.)

e) in the fisheries sector – discharge of wastewater with toxic substances (sodium cyanide, copper zinc, phenol, ammonia, etc.)

f) hydroelectric power plants – the increase in the corrosiveness of the water of the rivers and streams related to the power plants, with a negative impact on the operation of the power plant equipment.

2.7. Comparative study of the pollution in the Mureș, Olt, and Siret water basins

The most important rivers in Romania, Mureș, Olt and Siretu, suffer from massive pollution. The causes are mainly the lack of ecological infrastructure, the indifference of people or, worse, the pollution is intentional and premeditated [42]. In most cases, pollution is the result of accidents that could have been prevented, but which, in the absence of a major interest of the authorities and investments in this field, lead to significant ecological deficits.

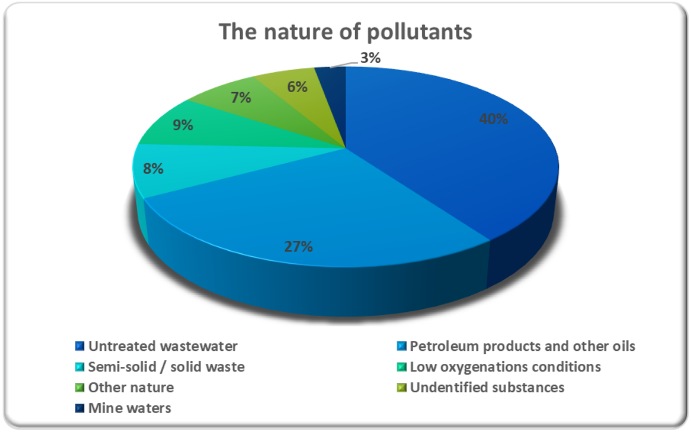

Figure 2.4. ***The nature of accidental pollution in the Mureș, Olt, Siret basins***

CHAPTER III.

Research in the Mureș River Basin.

Monitoring and evaluation of the quality parameters of the Mureș River on the sections in Arad County

3.1. Mureș hydrographic basin - general description

The Mureş hydrographic basin is located in the center and west of Romania and is bordered to the north by the Criș Rivers and Someș hydrographic basins, to the south by the Banat hydrographic basin (Jiu and Olt), to the west by Siret and to the east by the border with Hungary. It is bounded by the Eastern, Southern and Western Carpathians, and the lower part is located in the center of the Tisza plain (figure 3.1.).

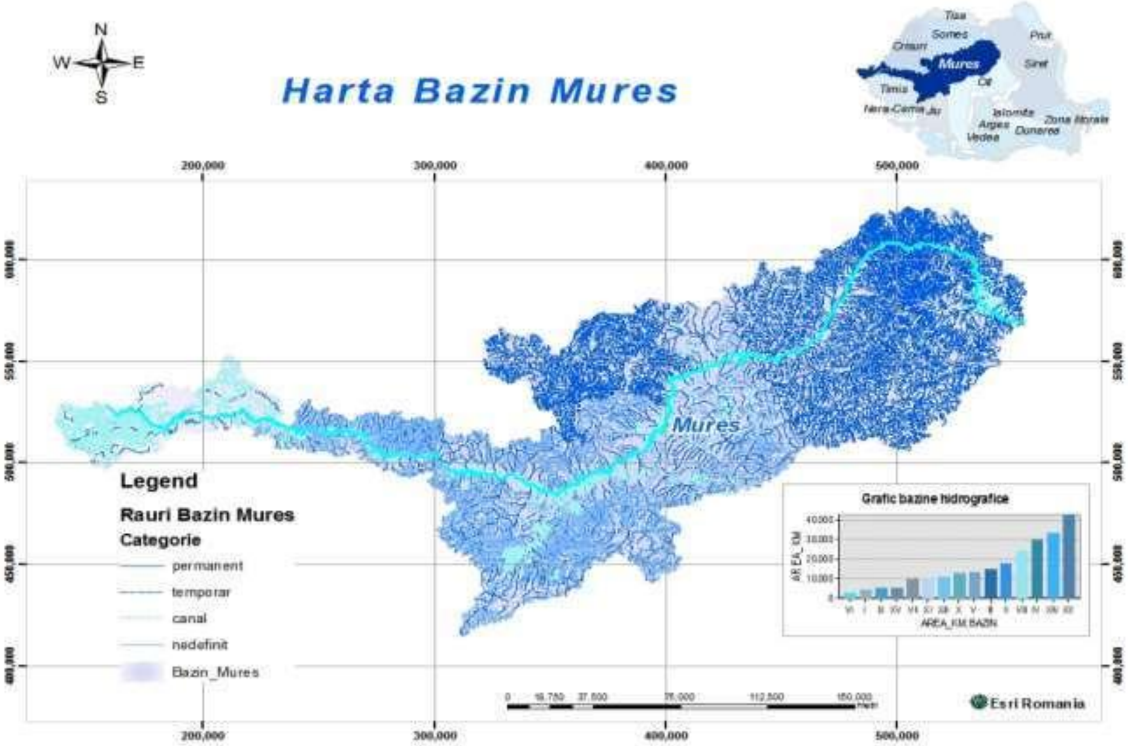

Figure 3.1. ***Map of the Mureș Basin (source ABA Mureș)***

The Mureș hydrographic basin has an area of 28,540 km2, including Canal Ier, the length of the main water course being 761 km, the total length of the coded hydrographic network (798 registered water courses of which 59 have areas smaller than 10 km2) is 10,861 km and has a density of 0.39 km/km2. The Mureș Basin (figure 3.1.) represents 11.97% of Romania's territory and has a variety of phenomena that are monitored in the information system [50].

The Mureș River rises from the south of the Giurgeului Depression, near the Izvorul Mureșului commune, at an altitude of 850 m.

The main tributaries of the Mureș River are:

– Gurghiu River (S=563 kmp; L=53 km):

– Aries River (S=3005 kmp: L=166 km):

– Niraj River (S=651 kmp: L=82 km):

– Târnava River (S=6253 kmp: L=246 km, at the source it is called the Târnava Mare River (S-3666 kmp: L=223 km: at the confluence with the Târnava Mică River S=2071 kmp: L=196 km)

– Ampoi River (S=576 kmp: L=57 km)

– Sebeș River (S=1304 kmp: L=96 km)

– Strei River (S=1983 kmp: L=93 km)

3.2. Surface water quality monitoring

In the basin of the Mureș River there are over 300 control sections of first order, of which 65 are in fast, daily information flow. Moreover, there are 250 in slow international flow of first order, monthly analyzes and other sections of the second order. All water data is included in the "National Water Management Data Pool". The National Company "Apele Române" monitors the activity of major polluters and also obliges them to carry out self-monitoring.

Surface water quality monitoring is carried out according to the surveillance, operational and investigative program. In the Mureș Basin, 88 sections are monitored with a surveillance program and biological, physico-chemical parameters and priority substances are taken into account. Between 2017 and 2019, 32 monitoring sections were translated on 25 bodies of surface water. Regarding the quantitative management of the surface water resource, there are several principles: cost recovery, users' pay, equal access to water resources and rational use of water resources.

Operational monitoring is applied to 35 surface water bodies and is carried out on 37 monitoring sections. Investigative monitoring takes into account the quality standards and the identification of the causes of exceeding the water management limits, the certification of the causes for a body of water to have an environmental objective, the impact of accidental pollution, etc.

3.2.1. Assessment of ecological status/potential 2015/2020 – Mureș River Basin

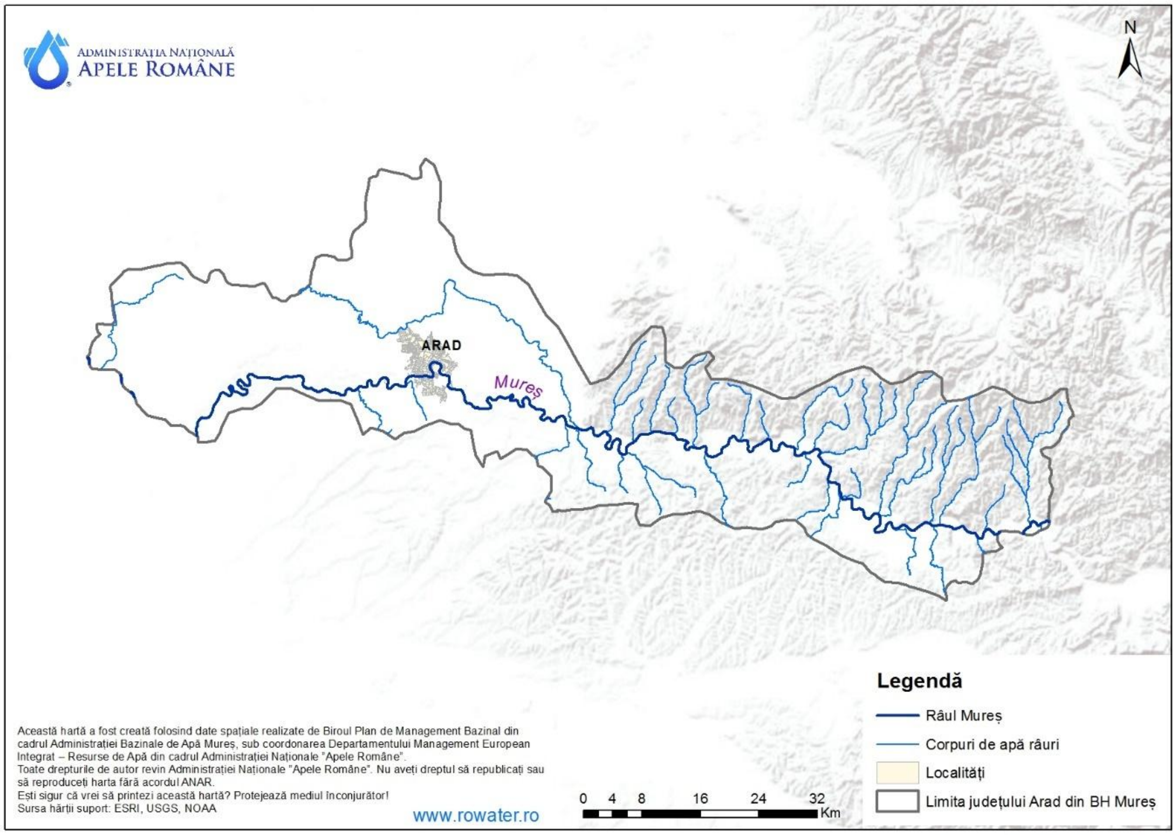

Figure 3.7. ***Map of water bodies related to Arad County of the Mureș hydrographic basin***

The Mureș Water Basin Administration (ABA) monitors the water quality of the Mureș River related to Arad County and presents the names of the sections and water bodies that belong to Arad County in three sections (figure 3.2.).

Courtesy of the Romanian National Water Administration (ANAR), the Department of Water Resources Management, Quality Management and Protection of Water Resources, the quality monitoring data of the Mureș hydrographic basin for the period 2015-2020 have been provided. So the monitoring indicators of surface water quality will be analyzed, such as biological, physico-chemical, oxygenation and salinity conditions, water acidification status, nutrients, specific pollutants and other specific elements. In this part of the work, the ecological status/potential for the period 2015-2020 will be assessed.

3.2.2. Pollution sources (2019) in the Mureș River Basin

Table 3.2. ***Discharges of organic substances, nutrients and specific pollutants in water resources from point sources (2019) in the Mureș River Basin***

Categories of pollution sources / pollutants bleed t/y	Substanţe organice (CCO-Cr) t/yr	Substanţe organice (CBO5) t/yr	Azot total (Nt) t/yr	Fosfor total (P) kg/yr	Cupru și compuși (Cu) kg/yr	Zinc și compuși (Zn) kg/yr	Cianuri kg/yr
Human agglomerations	3388,54	822,68	570,04	75,36	60,13	658,45	0
Industrial activities	385,94	89,91	39,94	2,82	0	96,95	0
Other point sources (including agricultural activities non-IED/IED)	56,40	10,34	0	0,18	35092,79	50296,55	4,74
Total	**3830,88**	**922,83**	**609,98**	**78,36**	**35152,92**	**51051,95**	**4,74**

In table 3.2. the main sources of pollution and related to the year 2019 in the Mureș hydrographic basin and the discharges of organic substances and specific pollutants in surface water resources are presented. Thus, in the category of pollution sources monitored in the field of human activity, 3388.54 t/year of organic substances (CCO-Cr) were recorded, in the field of industrial activity there were 385.94 t/year, and in the category other sources 56.40 t/year, which represents a total of 3830.88 t/year. Regarding cyanides, for the categories of human agglomerations and industrial activities, they did not exist at all. Instead, in the category of other point sources including non-IED/IED agricultural activity, there were 4.74 kg/year for the year 2019. These data are mentioned in the national inventory as average annual values for the year 2019 [50].

3.3. Research study: ecological status in the Mureș River Basin (2015/2020)

At the global level there are the programs "Integrated Global Background Monitoring of Environmental Pollution" IGBM, which deals with background monitoring before pollution and "Global Environmental Monitoring System" GEMS, which monitors the impact of pollution.

3.3.1. Instruments and methods

The selection of water test parameters depends solely on the purpose of water use: pH value, color, turbidity, electrical conductivity, content of iron, manganese, sulfate, fluoride, alkalinity, total hardness and chlorides.

Tabel 3.6. ***The main measurement methods***

Nr.	Parameter	Unit of measure	Method
1.	pH	unit pH	Electrometric method
2.	Turbidity	NTU	Turbidity meter
3.	Color	Pt-Co Unit	Visual comparison method
4.	Electrical Conductivity	µS/cm	Electrical Conductivity method
5.	Iron	mg/l	FerroVer method
6.	Manganese	mg/l	PAN method
7.	Sulfate	mg/l	SufalVar Turbidimetric method
8.	Fluoride	mg/l	SPADNS method
9.	Alkalinity	mg/l	Titration method
10.	Total hardness	mg/l	EDTA titrimetric method
11.	Chloride	mg/l	Argentometric method

3.3.2. Assessment of the ecological state of 3 water sections (Arad County)

To carry out the research, water quality monitoring data for the period 2015-2020 were provided courtesy of the Romanian National Water Administration (ANAR), through the Department of Water Resources Management, Quality Management and Protection of Water Resources (Annex 1). Thus, we will analyze surface water quality monitoring indicators, such as biological, physico-chemical, oxygenation and salinity conditions, water acidification status, nutrients, specific pollutants and other specific elements.

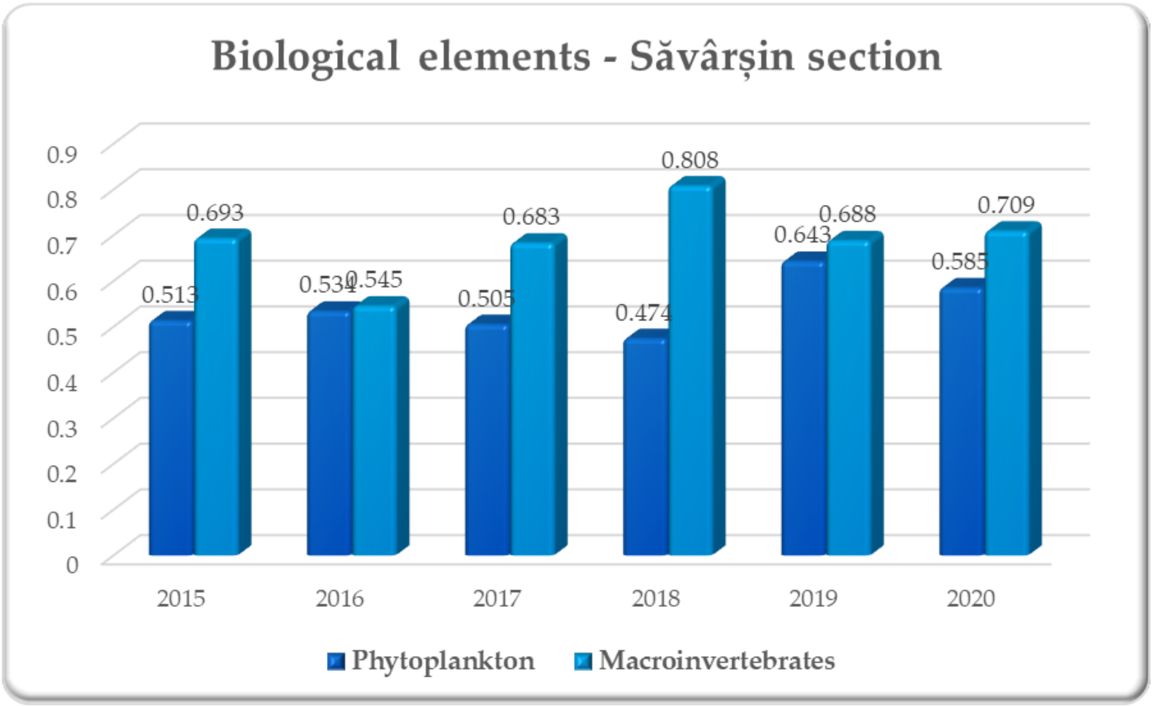

Figure 3.3. ***Distribution of biological elements - Săvârșin section***

Table 3.4. ***Biological elements***

Biological elements	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârșin section						
Phytoplancton (IM) (FP)	0,513	0,534	0,505	0,474	0,643	0,585
Macroinvertebrates (IM) (MZB)	0,693	0,545	0,683	0,808	0,688	0,709
Arad section						
Phytoplancton (IM) (FP)	0,751	0,717	0,786	0,788	0,928	0,879
Macroinvertebrates (IM) (MZB)	0,829	0,854	0,808	0,853	0,858	0,645
Nădlac section						
Phytoplancton (IM) (FP)			0,706	0,871	0,778	0,759
Macroinvertebrates (IM) (MZB)			0,713	0,762	0,602	0,769

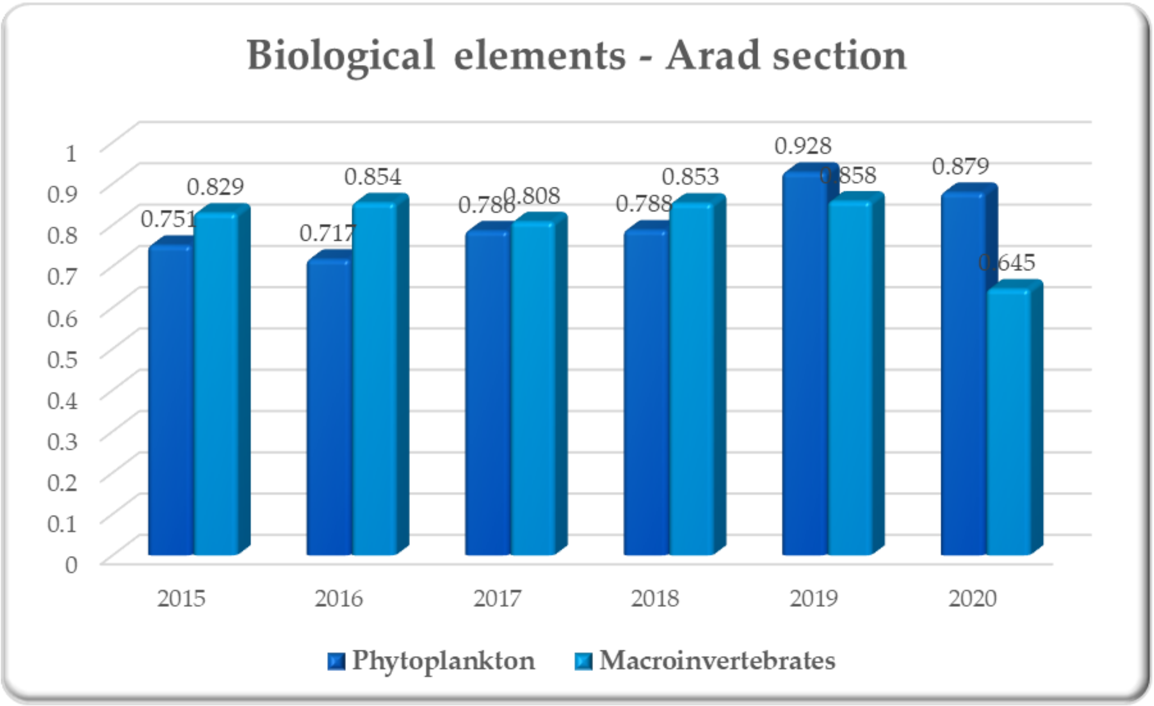

Figure 3.4. ***Distribution of biological elements – Arad section***

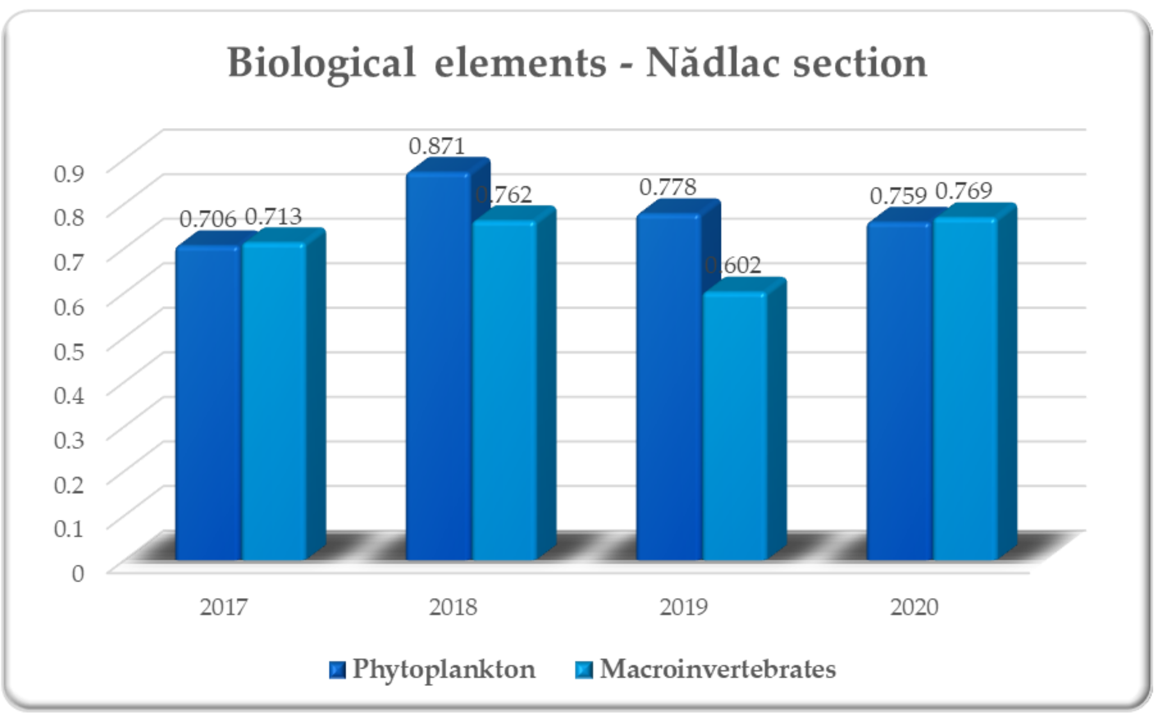

Figure 3.5. ***Distribution of biological elements – Nădlac section***

Biological analyzes provide us with information about water quality, i.e. a picture of the ecological state before sampling, because some biological communities react more slowly to environmental factors. These organisms adapt to the aquatic environment and are found on plants or stones, and their movement is done over short distances. They are abundant organisms, represented by insect larvae, molluscs and aquatic mites, influenced by habitat and water quality.

Macroinvertebrates have a different degree of tolerance to pollution and lower mobility. 35 taxa from the following systematic groups were identified in the Mureș River: Cyanobacteria, Bacillariophyta, Dinophyta, Euglenophyta, Chlorophyta. The dominant forms are diatoms with 19 taxa and green algae with 10 taxa. Several taxa from the genera Cyclotella, Cymbella, Synedra were identified [64]. The chemical parameters of the water, especially the oxygen regime and the nutrient regime, have a special influence on the aquatic macroinvertebrate communities.

In this context, aquatic bio-monitoring is justified in a holistic assessment of water quality and pollution levels. The samples taken for the three water bodies of the Mureș River, related to Arad County, collected both in the areas with anthropic influence and in those without anthropic impact, showed that the diversity of macroinvertebrates falls into the first quality class (values > 9 mg/l) or in the 2nd quality class (values in the 7-9 mg/l range).

During the time period taken into analysis, the distribution of phytoplankton and macroinvertebrate populations in the Mureș River was observed (table 3.4., figure 3.3. – 3.5.). Thus, on the Săvârșin section, phytoplankton recorded the highest values in 2019, and the lowest values in 2018. In the same year, macroinvertebrates reached the highest value, the proliferation of macroinvertebrate populations being evident with the decrease of phytoplankton - cause of water eutrophication.

In the Arad section, both phytoplankton and macroinvertebrates recorded good values, between 0.717 and 0.928 for phytoplankton, respectively, between 0.808 and 0.858, for macroinvertebrates. For the analyzed period, an upward trend is observed for macroinvertebrates in parallel with a decrease in phytoplankton, with the exception of 2020, a probable explanation being the increase in phytoplankton levels from 2019, with consequences on macroinvertebrate populations in 2020. Although the data for the section Nădlac are less, the situation is similar. For macroinvertebrates values of 0.871 were recorded in 2018, and lower values for 2019 and 2020, decreasing to 0.778 and 0.759, respectively. Phytoplankton distribution had values of 0.706 in 2017 and 0.871 in 2018, and in 2020 its value decreased to 0.759.

Table 3.5. ***Oxygenation conditions***

Condiții de oxigenare	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârșin section						
CBO5 (mgO_2/l)	4,25	5,199	5,932	4,633	4,464	4,402
CCO-Cr (mgO_2/l)	14,76	36,18	36,41	44,69	24,71	25,68
Dissolved oxygen (mgO_2/l)	8,335	8,267	7,901	7,567	8,411	7,81
Arad section						
CBO5 (mgO_2/l)	4,94	5,132	5,149	4,831	3,245	4,993
CCO-Cr (mgO_2/l)	16,8	40,42	36,95	21,85	15,4	19,74
Dissolved oxygen (mgO_2/l)	8,245	8,32	7,458	7,554	9,5875	7,295
Nădlac section						
CBO5 (mgO_2/l)			5,449	3,11	3,89	3,73
CCO-Cr (mgO_2/l)			31,38	12,7	21,3	24,1
Dissolved oxygen (mgO_2/l)			7,776	9,25	7,628	7,764

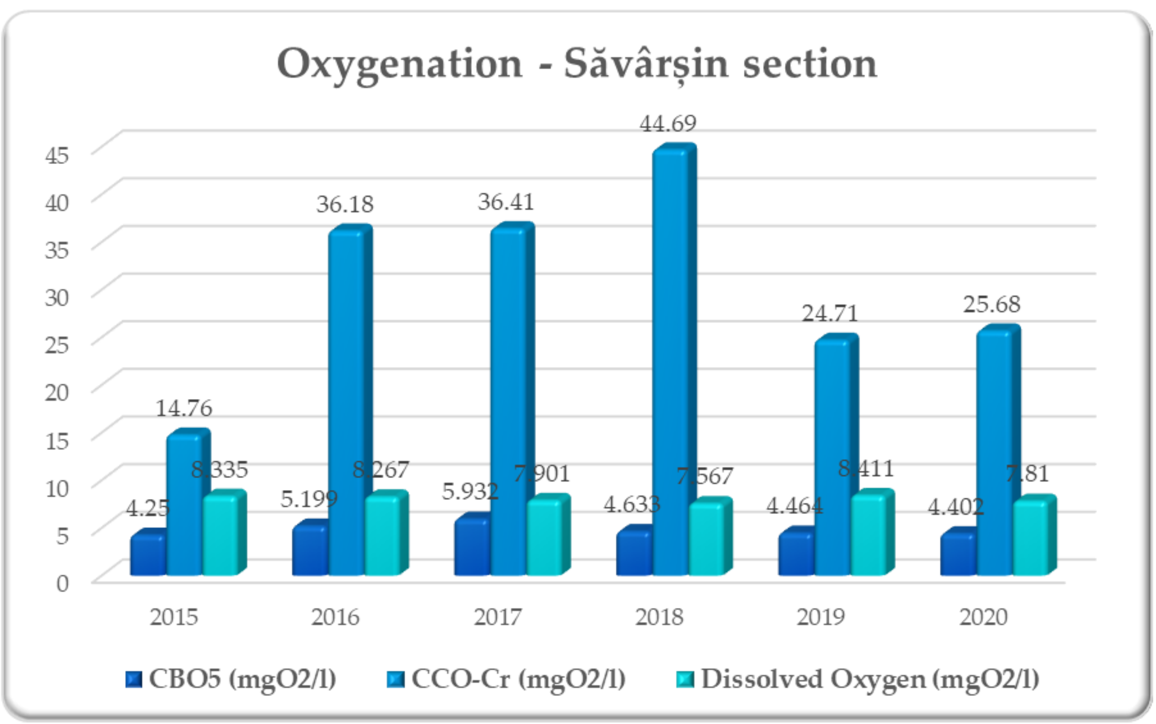

Figure 3.6. ***Distribution of gaseous substances – Săvârșin section***

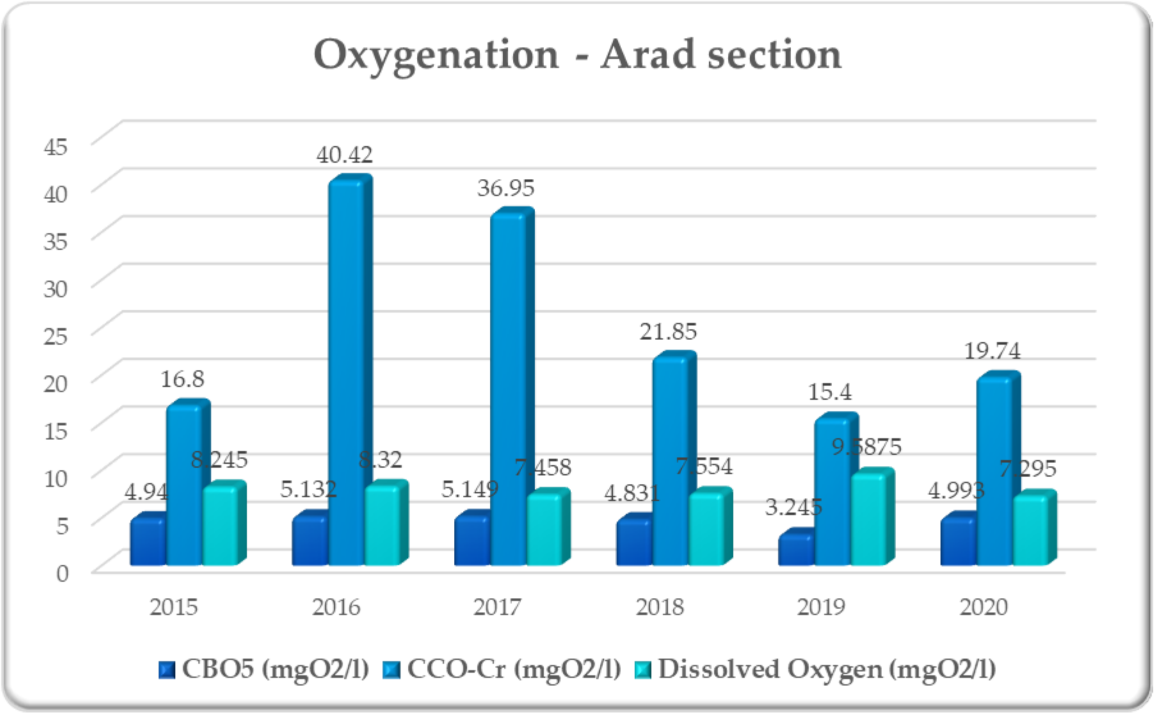

Figure 3.7. ***Distribution of gaseous substances – Arad section***

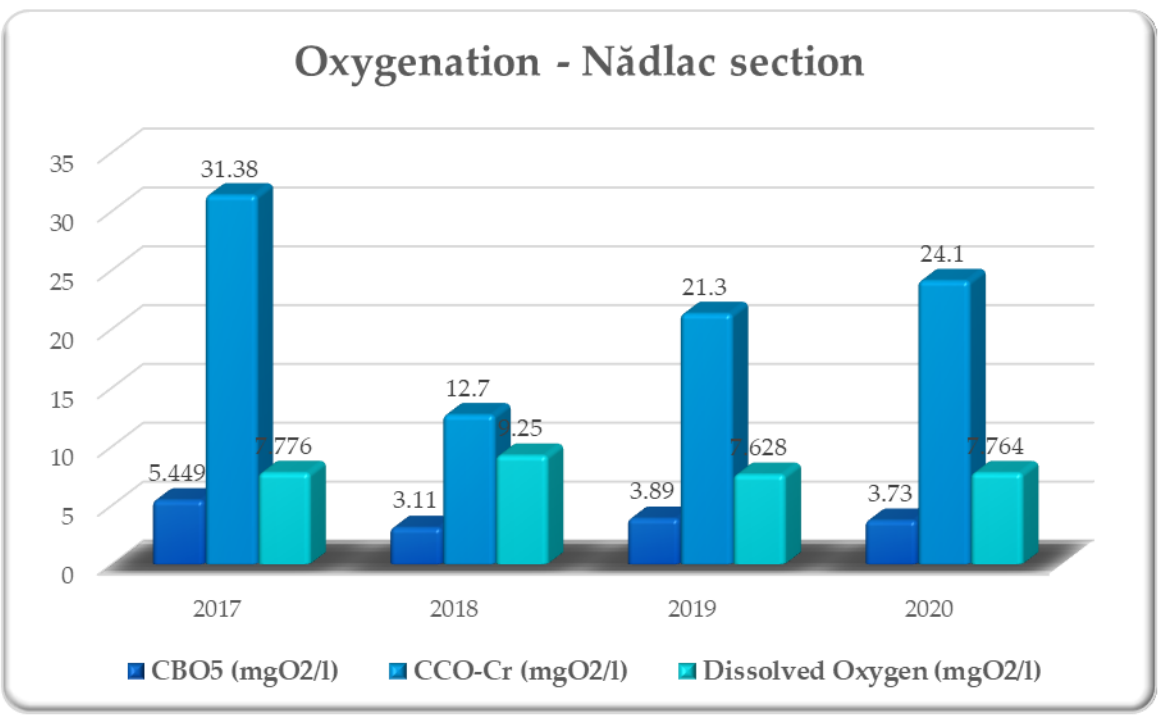

Figure 3.8. ***Distribution of gaseous substances – Nădlac section***

Oxygen has an important role for the aquatic fauna. The maximum permissible concentration of the parameters in the winter period must have values of 4.0 mg O2/l and in the summer period it must not be lower than 6.0 mg O2/l. If dissolved oxygen levels are reduced to 2 mg O2/l or less, aquatic fauna die.

In natural water, without anthropogenic influences, the oxygen concentration is high, which is favorable for the development of invertebrate communities sensitive to the oxygen concentration (ephemeroptera, plecoptera, trichoptera). The parameters used in determining the oxygen regime are: dissolved oxygen, chemical and biochemical oxygen consumption.

The situation of the Mureș River in the three analyzed sections is good, with few exceptions (table 3.5., figure 3.6. – 3.8.). In the Săvârsin section, from 2015 to 2017, the concentration of dissolved oxygen recorded a decrease in the level, then an increase in values was observed in 2019, with the highest concentration of oxygen (8.441 mg O_2/l) in 2019 and the lowest (7.81 mg O_2/l) in 2020. In the Arad section, dissolved oxygen falls between values between 8.32 mg O_2/l in 2016 and 9.587 mg O_2/l in 2019, with a decrease in 2020 to 7.295 mg O_2/l. In the Nădlac section, the concentration of dissolved oxygen increases from 7.776 mg O_2/l in 2017 to 9.25 mg O_2/l in 2018, and decreases to 7.764 mg O_2/l in 2020. From the analyzed data, we can see the interest in protecting aquatic life , the values indicating a good condition of the Mureș River in terms of the level of dissolved oxygen in the water. The average annual values recorded, between 7.81 mg/l and 9.25 mg/l, ensure the oxygen requirements of the aquatic fauna and indicate a low degree of pollution with organic substances. Analyzing all the data regarding the amount of oxygen from each sampling station, we can say that the values indicate a good condition of the water of the Mureș River from the point of view of this indicator, falling into class I (values > 9 mg/l) or class II quality (values in the range of 7-9 mg/l).

Knowing the value of chemical oxygen consumption CCO-Cr and CBO5 is extremely important in evaluating the degree of water pollution by expressing the amount of chemical organic substances contained in that water. Biochemical oxygen consumption per 5 days (CBO5) has the maximum allowable parameter concentration of 3.0 mg O_2/l. High values of the CBO5 parameter indicate the presence of biodegradable organic substances and the reduction of dissolved oxygen concentration in the water, with negative effects on aquatic fauna. In the Săvârsin section, the values increase significantly between 2015 and 2016, and in 2017 a very high annual average of 5.932 mg O_2/l is recorded, followed by a downward trend, up to 4.402 mg

O_2/l in 2020. In the Arad section, the lowest value is 3.245 mg O_2/l in 2019, with an upward trend until 2017 (5.149 mg O_2/l) and a decrease in recent years (4.993 mg O_2/l). In the Nădlac section, for the years 2017 and 2020, these values were between 3.11 mg O_2/l in 2018 and 5.449 mg O_2/l in 2017.

The biochemical oxygen consumption, CCO-Cr, has the maximum permissible concentration of 15.0 mgO_2/l. In the Săvârșin section, the recorded values increase from 14.76 mgO_2/l in 2015 to 44.69 mgO_2/l in 2018, with a significant decrease observed in 2020, to 25.68 mgO_2/l.

In the Arad section, the average value of CCO-Cr in 2015 was 16.8 mgO_2/l, increasing almost twice in 2016, to 40.42 mgO_2/l, and in 2020 reaching 19.74 mgO_2/l . For the Nădlac section, the data were not sent by ABA Târgu Mureș for the period 2015-2016, and for the years 2017 and 2020 the values were 31.38 mgO_2/l and 24.1 mgO_2/l.

In general, the values fall into the I and II quality classes (I class – values < 5 mgO_2/l, II class – values in the 5-10 mgO_2/l range). For the year 2018, the values fall into the IV quality class (values in the range of 20-50 mgO_2/l).

The salinity conditions of the river reflect the interaction of the water with the rock, in the case of the three sections, little oscillations of the average annual values were observed (table 3.9., figure 3.18. – 3.20.). For the Săvârșin and Arad section, the year 2016 records a lower concentration of mineral salts, and the year 2017 presents a higher concentration, a possible explanation being the level of precipitation in those years, with an impact on the salinity level. For the Nădlac section, the year 2018 records the lowest value (401.5 µS/cm).

Table 3.6. ***Salinity conditions***

Condiții de salinitate	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârșin section						
Conductivity (µS/cm)	551	459,8	614,2	508,3	562,4	476
Arad section						
Conductivity (µS/cm)	564	353,7	593,6	494,5	439	512,9
Nădlac section						
Conductivity (µS/cm)			520,9	401,5	550,1	458,6

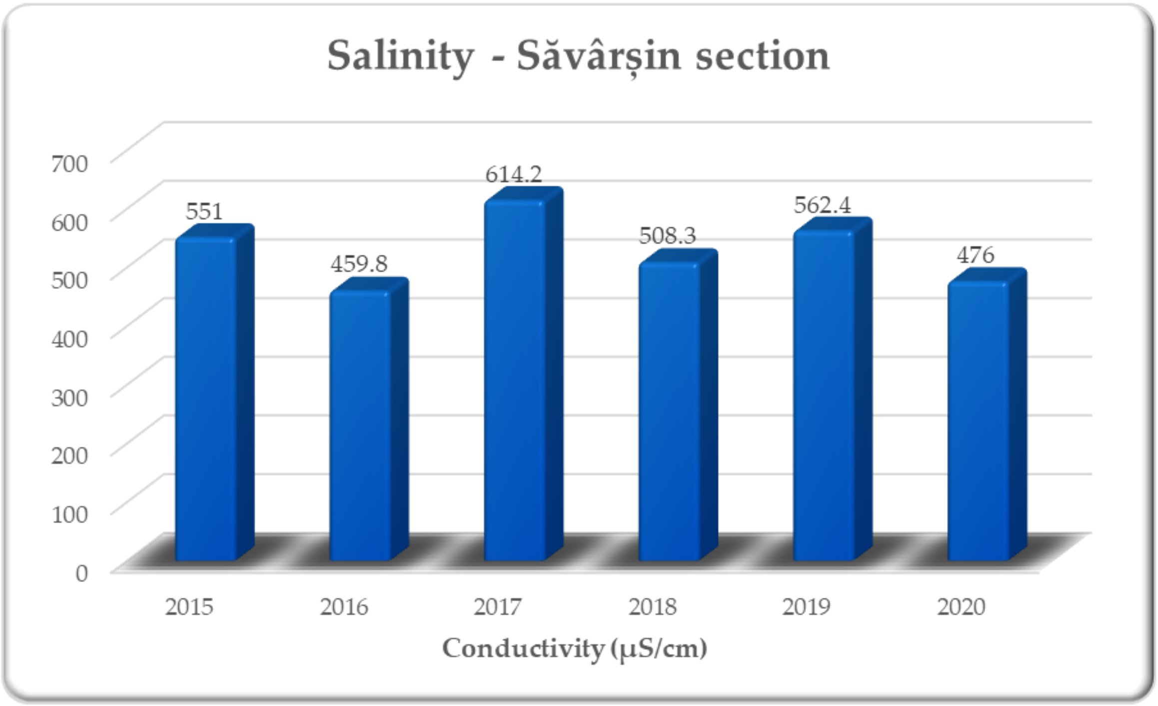

Figure 3.9. ***Distribution of mineral salts – Săvârșin section***

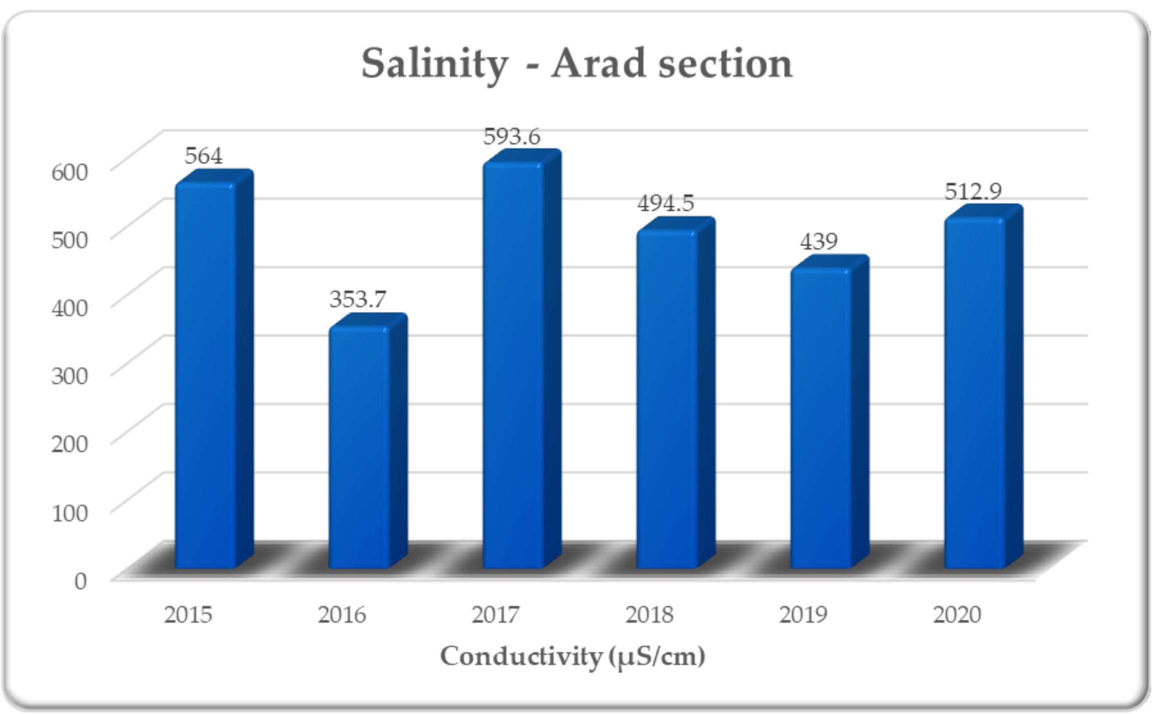

Figure 3.10. ***Distribution of mineral salts – Arad section***

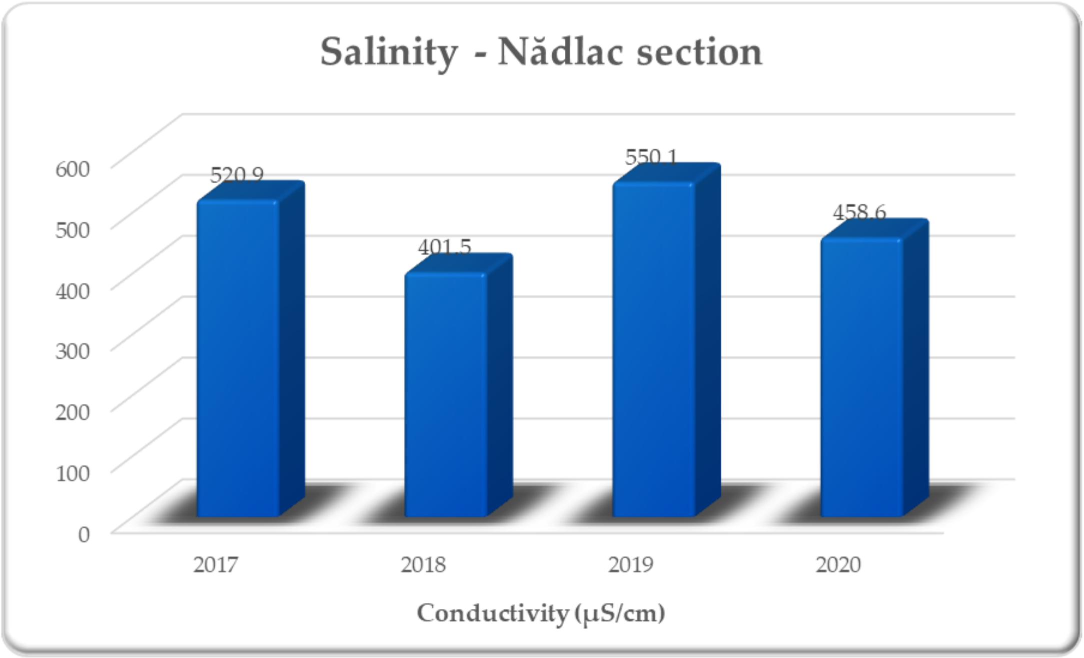

Figure 3.11. ***Distribution of mineral salts – Nădlac section***

The acidity or alkalinity of the water, or the pH value of the water, represents the active reaction of the concentration of hydrogen ions, which can influence the adsorption capacity of algae. On the three water sections of the Mureș River related to Arad County (table 3.7., figure 3.12. – 3.14.), the pH falls within normal values, between 7.8 pH units in 2016 and 8.39 pH units in year 2020. Thus, the most neutral values for the Săvârșin and Arad sections were recorded in 2016. In conclusion, the Mureș River has a good water pH in all three monitored sections, with a neutral character with slight alkaline tendencies upstream and a weakly basic character downstream.

Table 3.7. ***pH status***

pH status	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârșin section						
pH (unit pH)	8.16	7.8	8.16	8.28	8.19	7.99
Arad section						
pH (unit pH)	8.18	7.93	8.16	8.38	8.29	8.18
Nădlac section						
pH (unit pH)			8.1	8.19	8.2	8.39

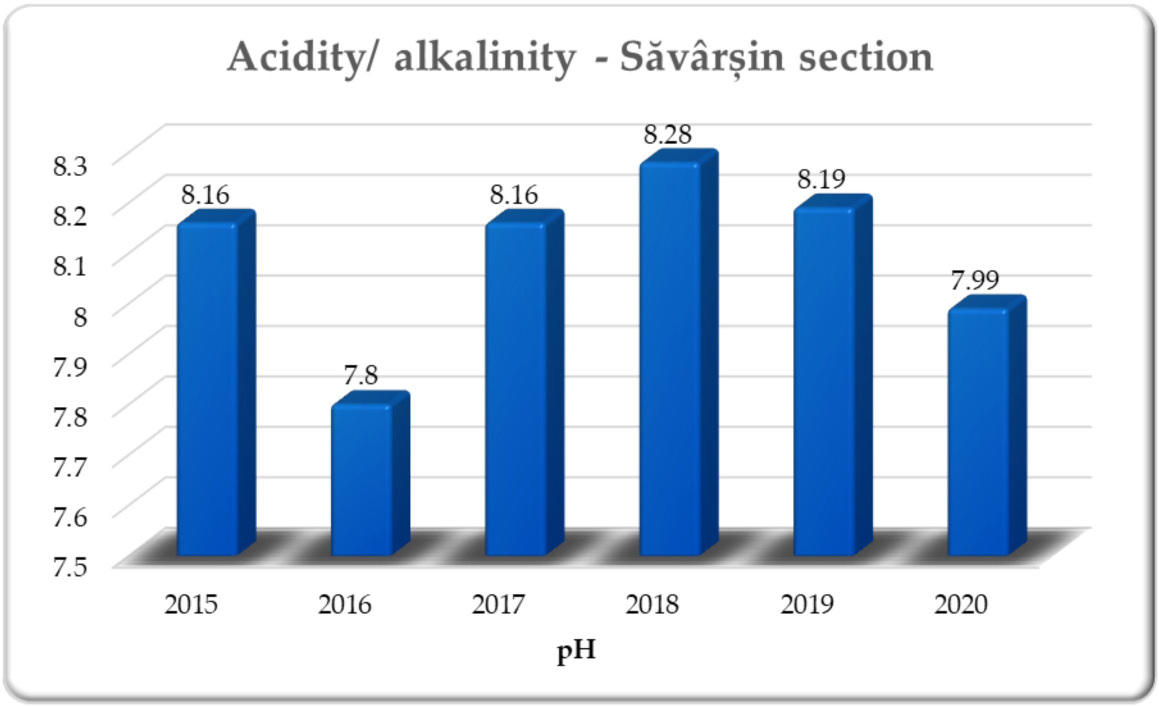

Figure 3.12. ***Distribution of pH values – Săvârșin section***

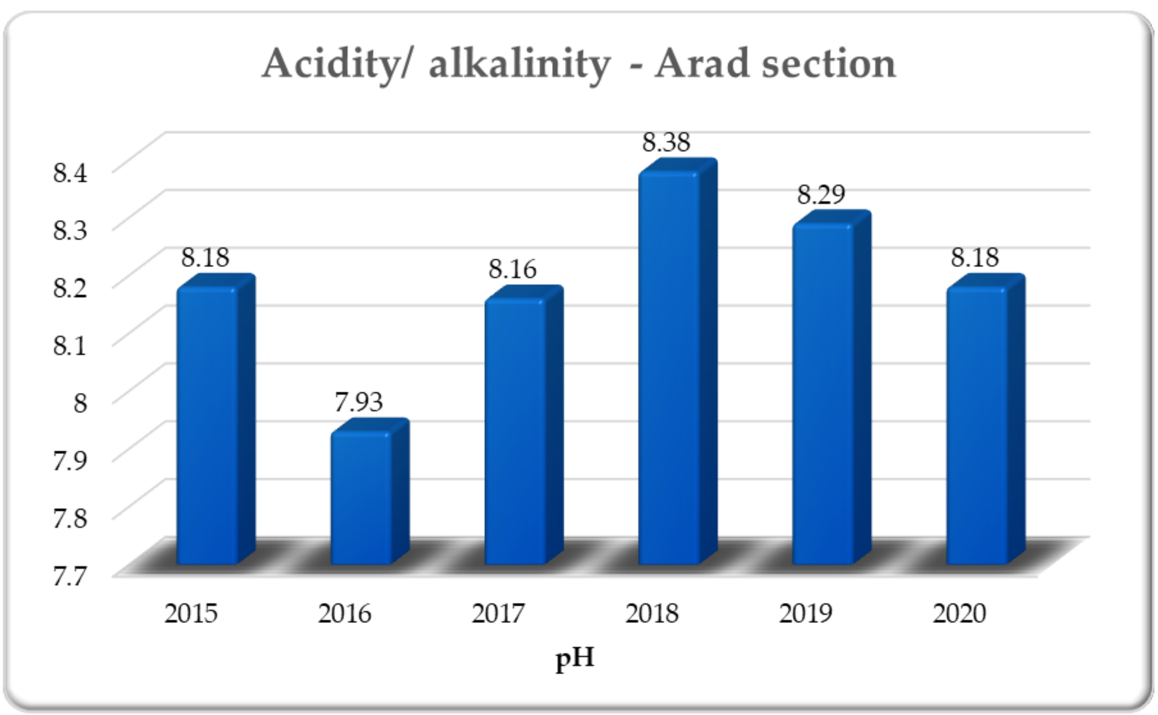

Figure 3.13. ***Distribution of pH values – Arad section***

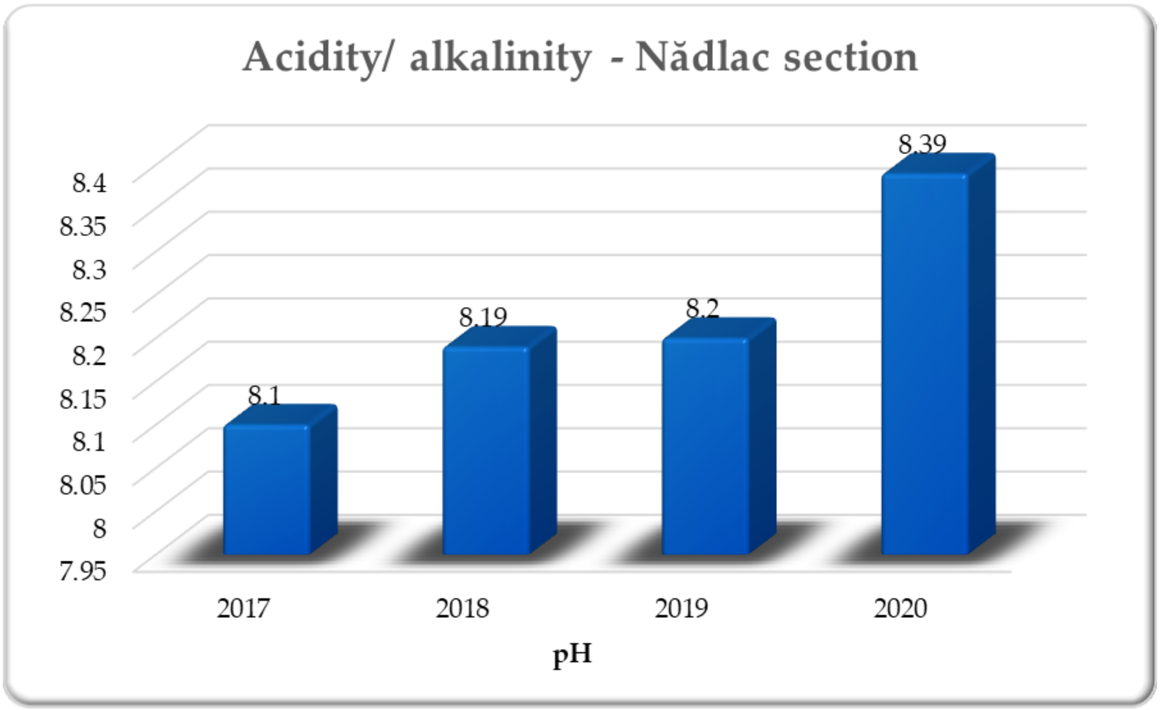

Figure 3.14. ***Distribution of pH values – Nădlac section***

Table 3.8. ***Nutrients***

Nutrients	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârșin section						
N total (mg/l N)	2.43	3.115	2.228	2.87	2.02	2.393
N-NH_4 (mg/l N)	0.197	0.126	0.083	0.069	0.099	0.22
N-NO_2 (mg/l N)	0.017	0.033	0.018	0.019	0.028	0.031
N-NO_3 (mg/l N)	1.703	0.935	1.154	1.047	0.958	1.002
P total (mg/l P)	0.173	0.169	0.111	0.271	0.242	0.319
P-PO4 (mg/l P)	0.072	0.063	0.044	0.069	0.072	0.069
Arad section						
N total (mg/l N)	2.455	3.127	2.416	2.758	2.34	2.185
N-NH_4 (mg/l N)	0.187	0.11	0.107	0.051	0.121	0.075

N-NO_2 (mg/l N)	0.017	0.028	0.02	0.016	0.028	0.029
N-NO_3 (mg/l N)	1.354	1.109	1.247	0.99	1.125	1.019
P total (mg/l P)	0.143	0.167	0.136	0.2	0.159	0.349
P-PO4 (mg/l P)	0.056	0.074	0.053	0.051	0.073	0.081
Nădlac section						
N total (mg/l N)			2.338	2.385	2.019	2.13
N-NH_4 (mg/l N)			0.114	0.085	0.145	0.108
N-NO_2 (mg/l N)			0.019	0.019	0.033	0.023
N-NO_3 (mg/l N)			1.114	1.037	1.163	1.315
P total (mg/l P)			0.121	0.146	0.239	0.268
P-PO4 (mg/l P)			0.042	0.059	0.077	0.079

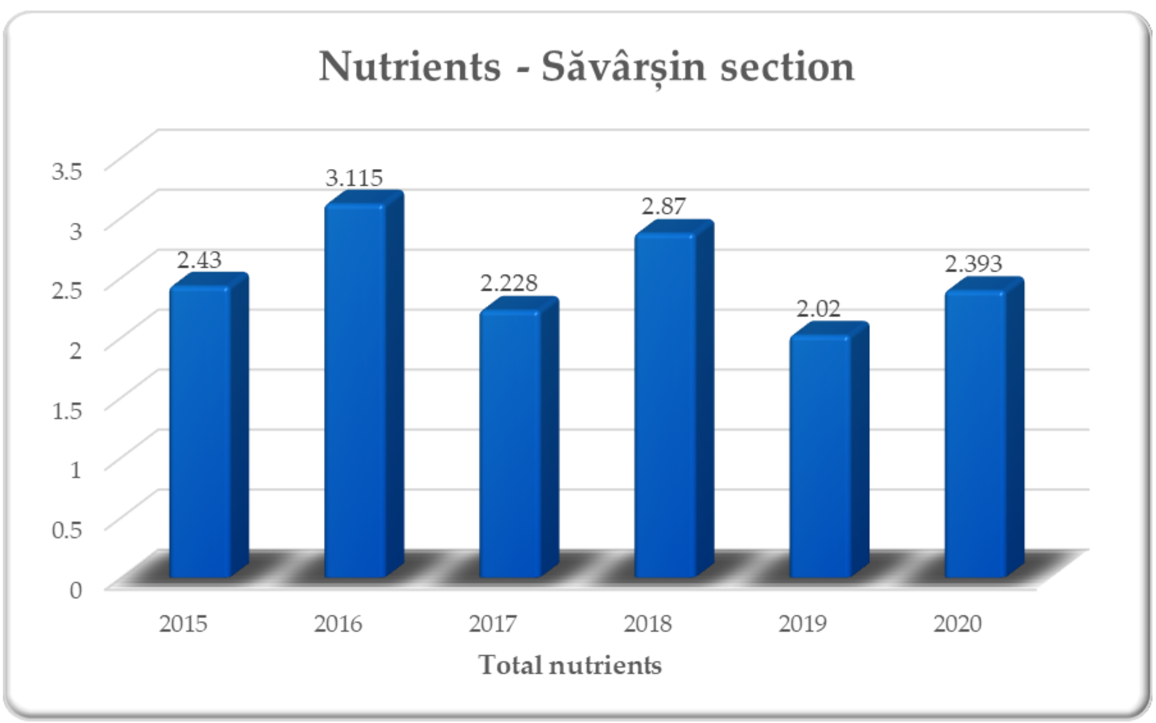

Figure 3.15. ***Nutrient distribution – Săvârșin section***

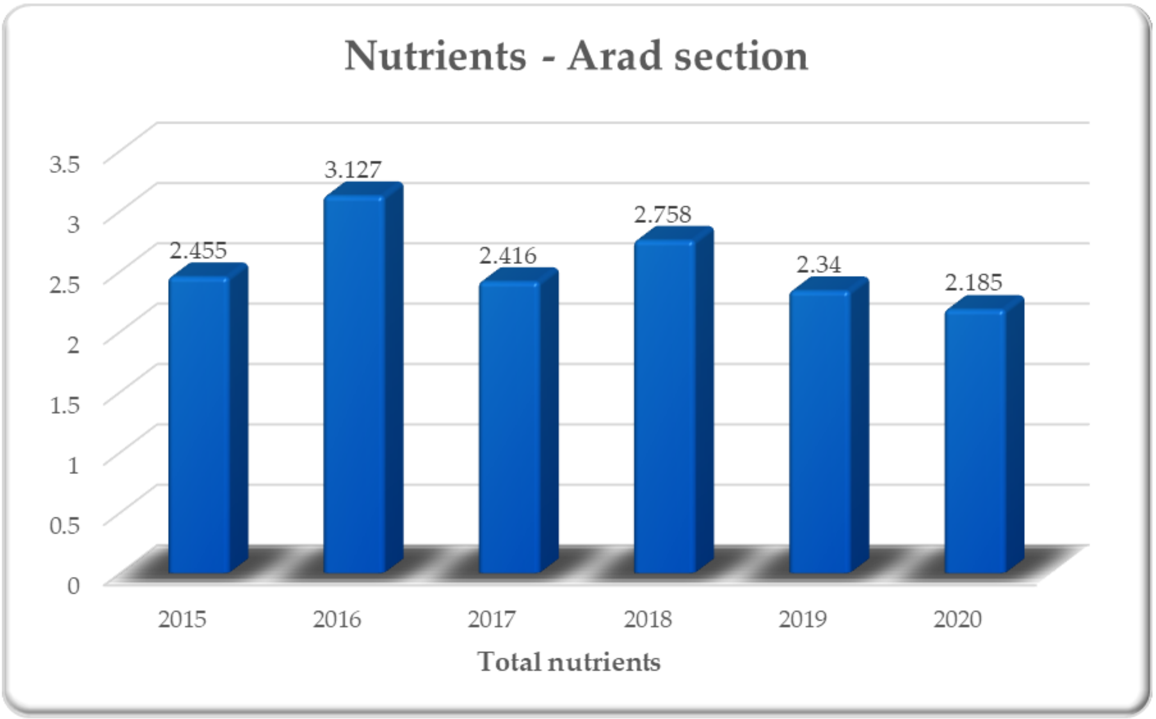

Figure 3.16. ***Nutrient distribution – Arad section***

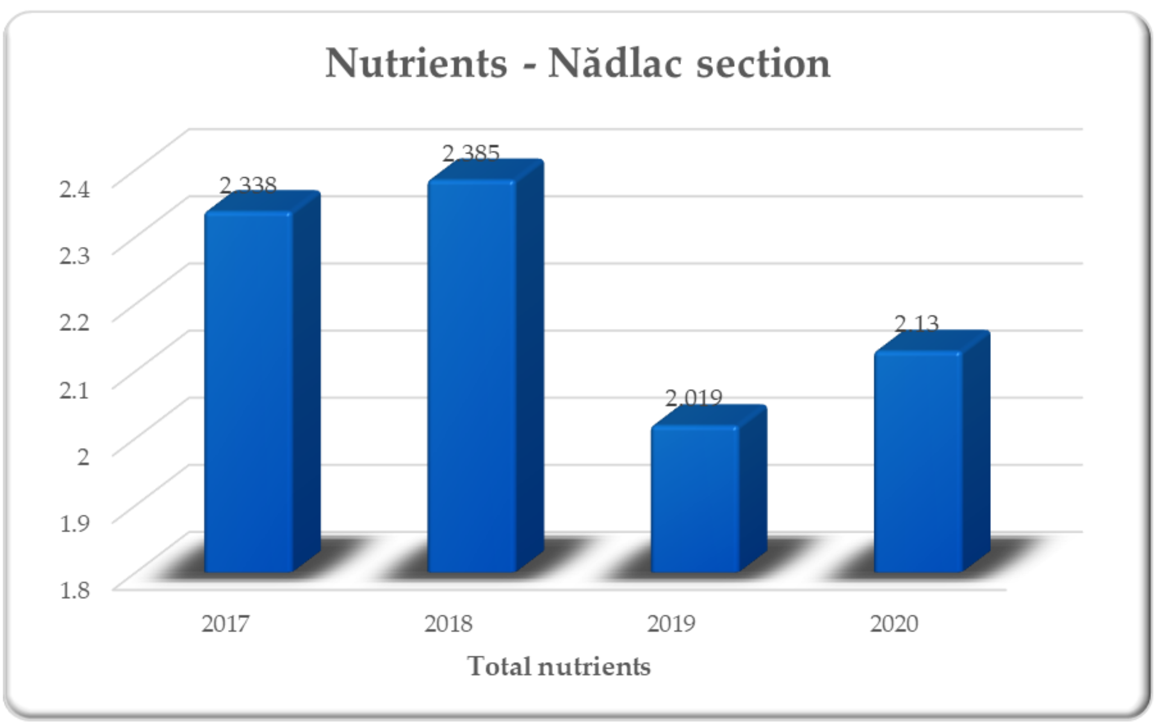

Figure 3.17. ***Nutrient distribution – Nădlac section***

The total values of the nutrients in the three water bodies of Mureș (table 3.8., figure 3.15. – 3.20.) are within normal limits, with lower values observed for the years 2017 and 2019 in the Săvârșin section, and for the years 2017, 2019 and 2020 in the Arad section. Also, in the Nădlac section, the lowest value of 2.13 mg/l was recorded in 2019.

Regarding ammonium nitrogen, N-NH4, the existence of ammonium ions in water is the consequence of a recent contamination with residues from the decomposition of plants and animals, of wastewater discharges from sewage treatment plants present in urban agglomerations, from livestock farms animal husbandry or agricultural farms that use nitrogen-based fertilizers by spreading them during the rainy season.

For the Săvârsin section, the highest value of ammonium nitrogen is 0.22 mg/l in 2020, followed by 2015, with a concentration value of 0.197 mg/l, and 2016, with a value of 0.126 mg/l. For the Arad section, the highest values were recorded in 2015 (0.187 mg/l), followed by a downward trend until 2018 (0.051 mg/l) and a slight increase in 2019 (0.121 mg/l). In the Nădlac section, there is also a peak in 2019, represented by the concentration value of 0.145 mg/l. For all three sections of water, the values of ammonium nitrogen concentrations are in quality class I, lower than 1mgN/l.

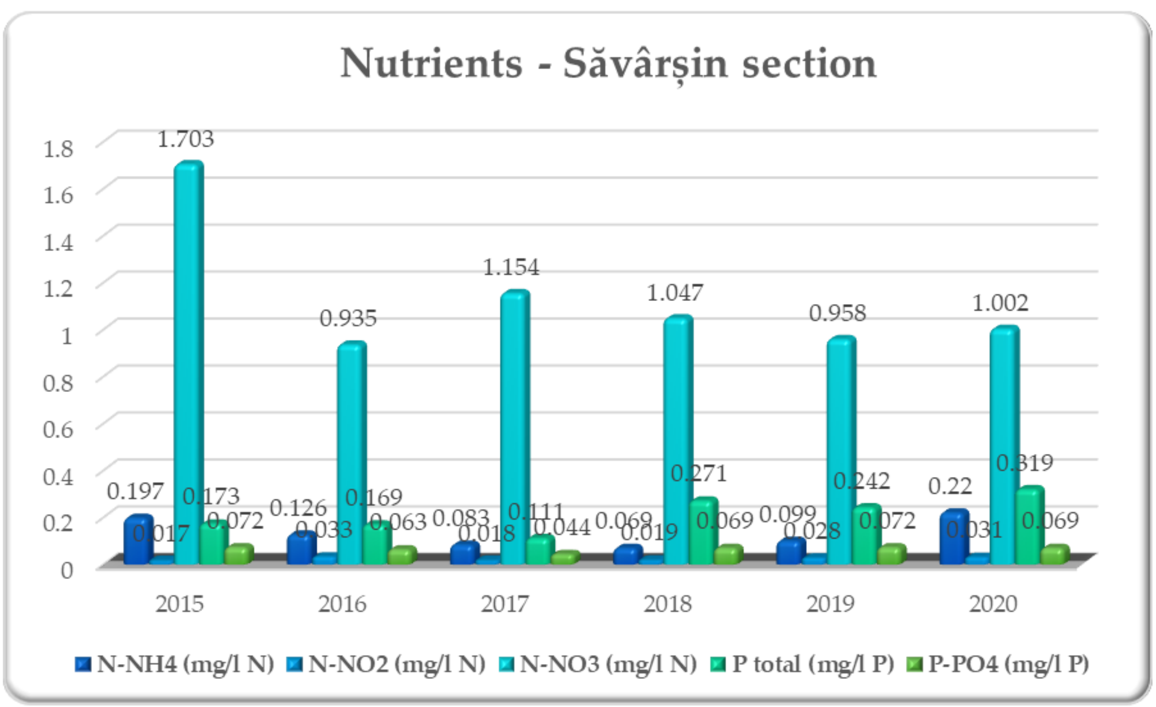

Figure 3.18. ***Distribution of nutrients by category – Săvârșin section***

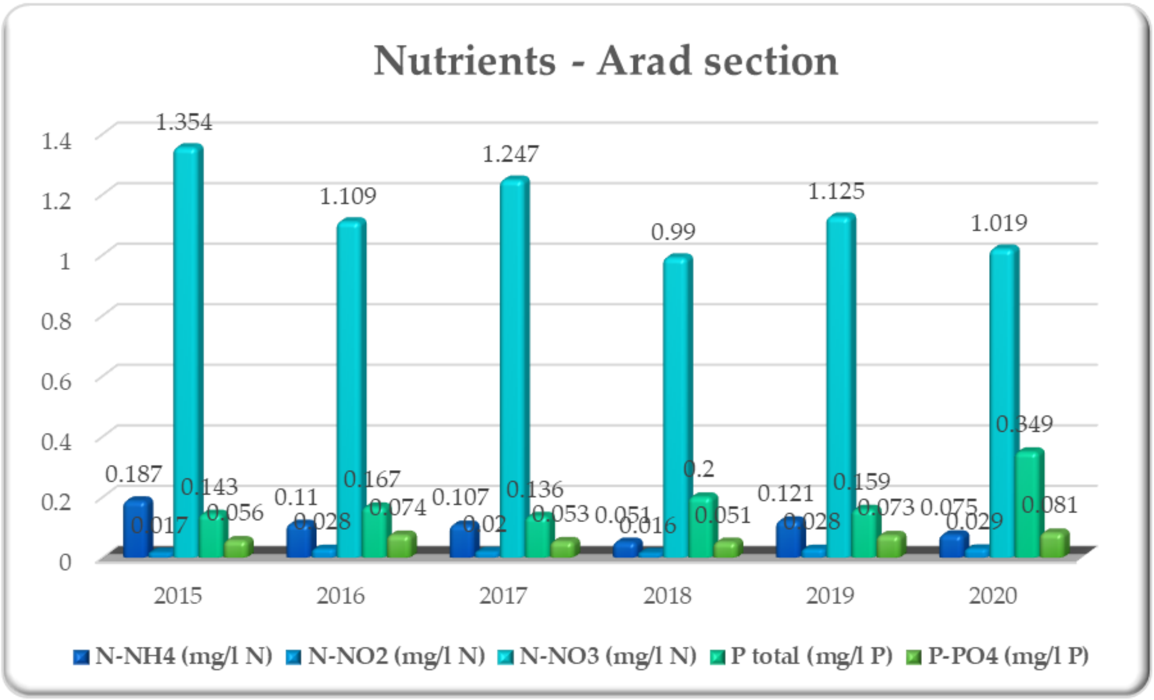

Figure 3.19. ***Distribution of nutrients by category – Arad section***

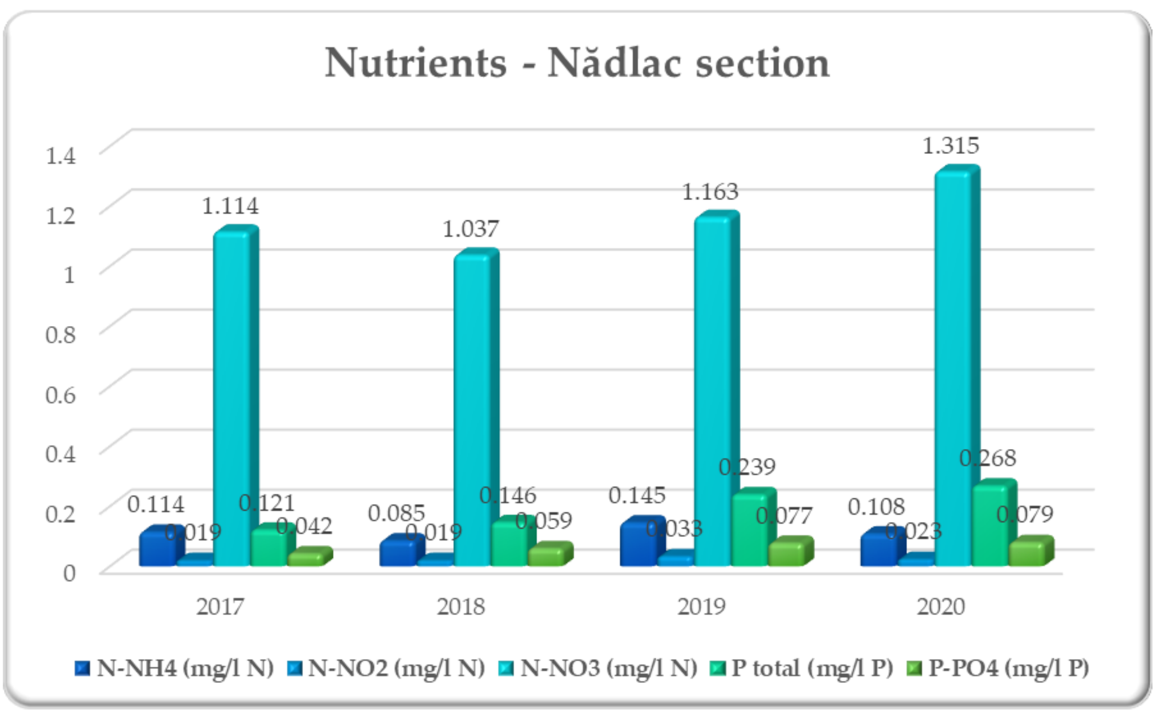

Figure 3.20. ***Distribution of nutrients by category – Nădlac section***

The nitrogen in nitrites, N-NO2, reflects the metabolism of nitrogen compounds being an intermediate phase in its degradation cycle. Also, its presence in water is an indicator of recent pollution with nitrogen-containing substances, dangerous substances for aquatic organisms.

For the Săvârsin section, the highest value of nitrogen from nitrites is 0.033 mg/l in 2016, followed by 2020, with a concentration value of 0.031 mg/l, and 2019, with a value of 0.028 mg/l . For the Arad section, the highest values were recorded in 2020 (0.029 mg/l) and in 2019 (0.028 mg/l), with values fluctuating from year to year, the lowest concentration being recorded in 2018 (0.016 mg/l). In the Nădlac section, the peak is represented by the year 2019, with a concentration value of 0.033 mg/l.

Nitrate nitrogen, N-NO3, represents an advanced stage of ammonium oxidation, which reflects older water pollution with fluctuations generally due to contamination during the rainy season (increase in concentration) and sedimentation (decrease in concentration).

For the Săvârsin section, the highest value of nitrogen in nitrates is 1.703 mg/l in 2015, a value that exceeds the quality class I level, high values are also recorded in 2017 and 2020, values that exceed the threshold of 1 mgN/l. For the Arad section, the highest values were also recorded in 2015 (1.354 mg/l), followed by 2017 and 2016, with values exceeding the first quality class. In the Nădlac section, the indicator values also show oscillations, with the highest value in 2020 (1.315 mg/l), values that belong to the II class of quality from the point of view of ecological classification.

With small fluctuations, the values of phosphorus concentrations and orthophosphate compounds fall into the I and II quality classes for all three water sections of the Mureș River related to Arad County.

Regarding the specific pollutants (table 3.9., figure 3.21. – 3.23.), it is noticeable that some compounds are missing in the monitoring data: arsenic, chromium, copper, zinc and dissolved toluene have been measured only since 2017, and cyanides, only from the year 2018.

Table 3.9. ***Specific pollutants***

Specific pollutants	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Săvârşin section						
Anion-active detergents (µg/l)	50	50	50	50	50	50
Total phenols (µg/l)	3.25	3.75	1.5	3.65	4.7	6.45
Dissolved arsenic (µg/l)			0.5	0.5	0.5	0.5
Dissolved chromium (µg/l)			11.07	9.91	7.38	7.08
Dissolved copper (µg/l)			5.73	7.05	3.3	12.99
Dissolved zinc (µg/l)			19	12.5	12.5	12.5
Arad section						
Anion-active detergents (µg/l)	50	50	50	50	50	50
Total phenols (µg/l)	3.25	5.45	1.5	3.75	1.5	1.5
Dissolved arsenic (µg/l)			0.5	0.5	0.5	0.5
Dissolved chromium (µg/l)			9.04	8.06	9.43	6.44
Dissolved copper (µg/l)			9.97	5.75	3.43	13.38
Dissolved zinc (µg/l)			5	12.5	12.5	12.5
Nădlac section						
Anion-active detergents (µg/l)			50	50	50	50
Total phenols (µg/l)			1.5	3.55	2.4	1.5
Dissolved arsenic (µg/l)			0.5	0.5	0.5	0.5
Dissolved chromium (µg/l)			3.96	8.61	8.29	6.52
Dissolved copper (µg/l)			4.49	4.13	4.48	12.65
Dissolved zinc (µg/l)			5	12.5	12.5	12.5
Toluene (µg/l)			1.5	1.5		
Cyanide (µg/l)				7.5	7.5	10

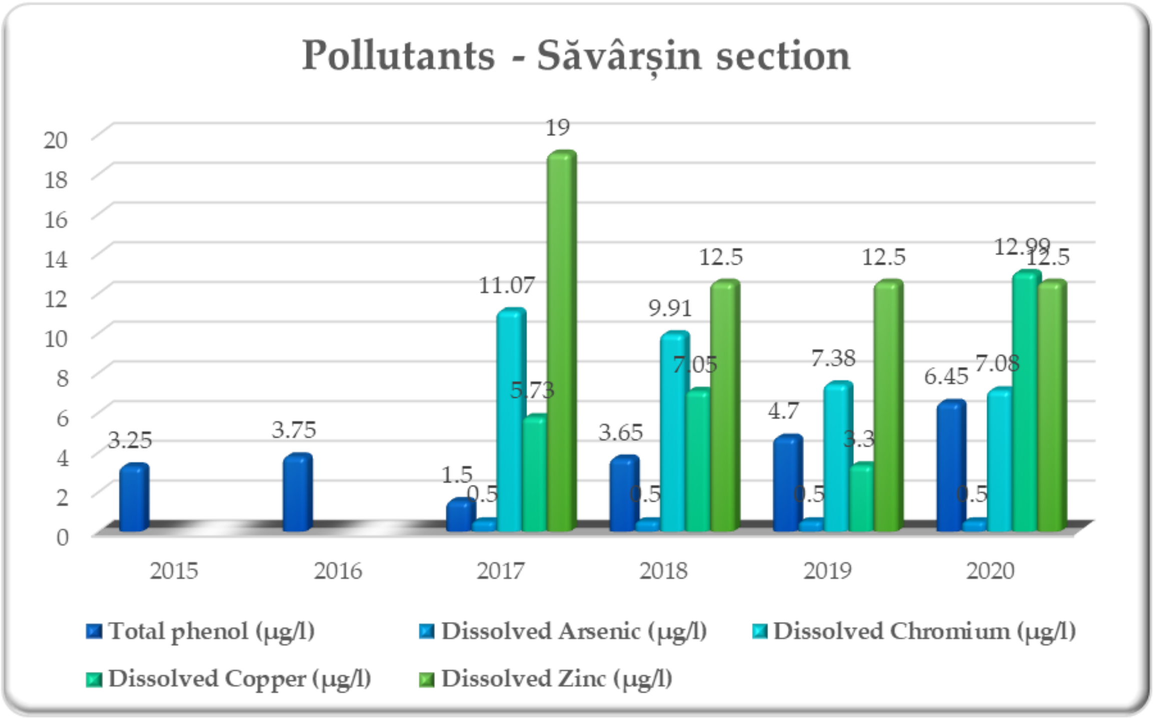

Figure 3.21. ***Distribution of specific pollutants – Săvârșin section***

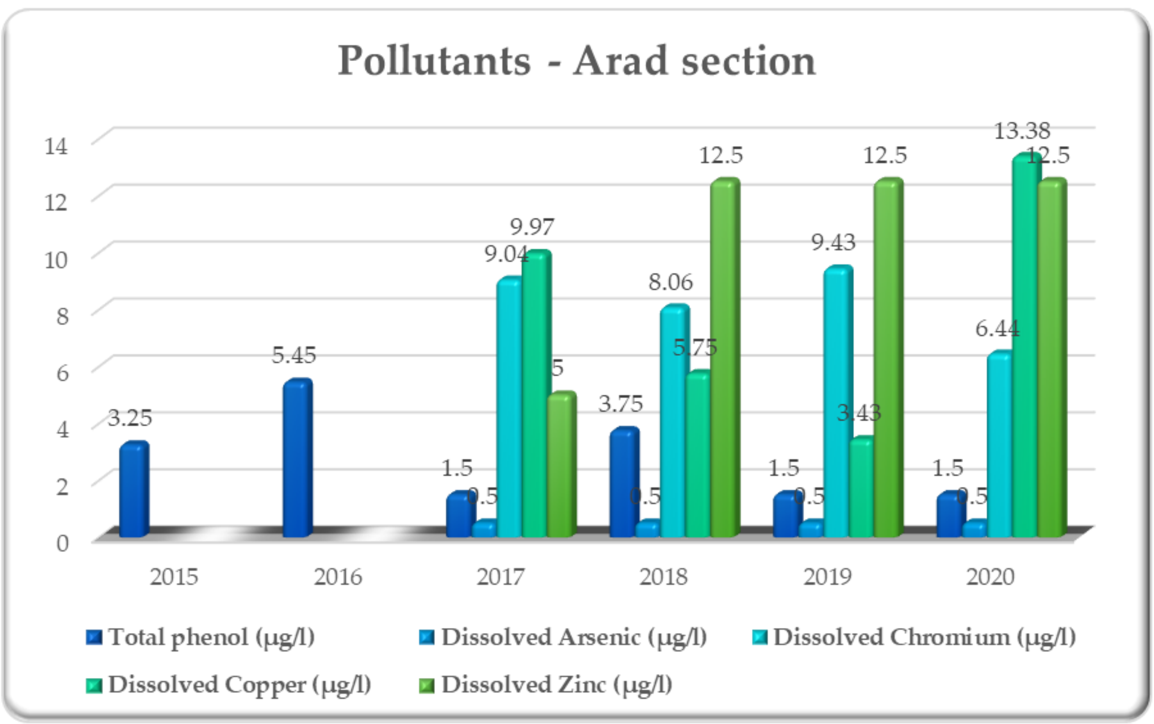

Figure 3.22. ***Distribution of specific pollutants – Arad section***

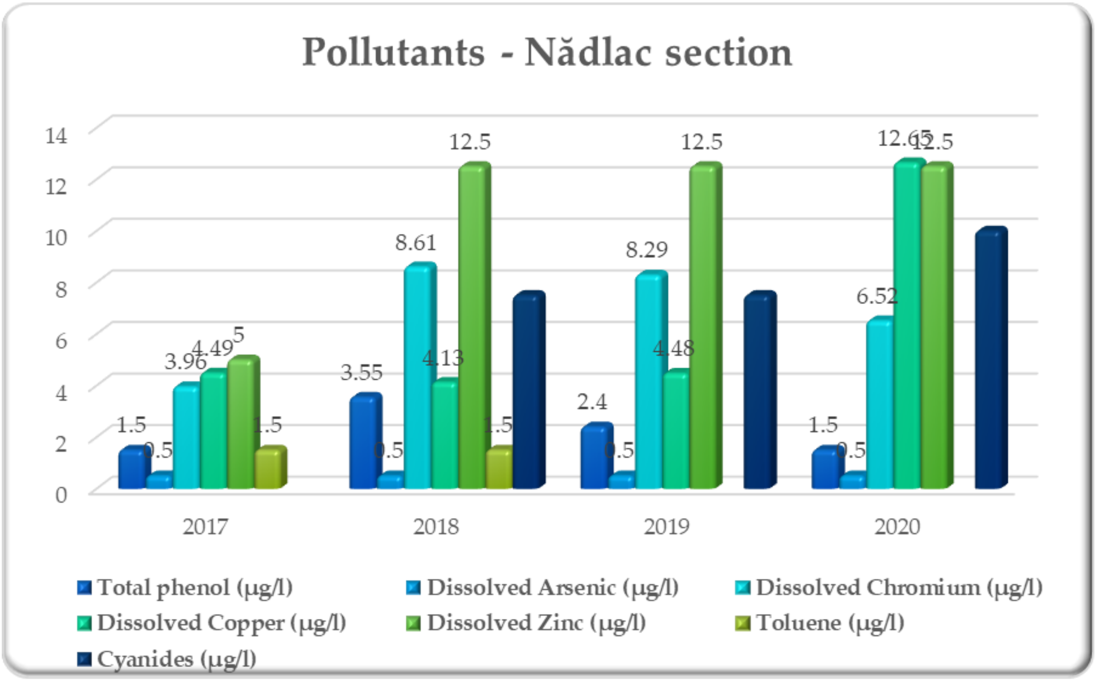

Figure 3.23. ***Distribution of specific pollutants – Nădlac section***

Anion-active detergents are considered basic pollutants of natural water. They are responsible for the production of foam accumulated on the surface of the water that hinders gas exchange between the water and the atmosphere. In this way, detergent pollution has a negative impact on the aerobic bacteria that break down organic waste, preventing the self-purification of water. The concentrations of anion-active detergents remain constant throughout the analyzed period and in all three water bodies of the Mureș River belonging to Arad County (50 µg/l).

Phenol, a substance previously used as a disinfectant in medicine, is a nerve toxin for the fish population imparting an unpleasant taste to fish flesh. Its presence in water is mainly due to the textile and pharmaceutical industry. On the Mureș River, the highest phenolic index was recorded in 2020, with a value of 6.45 µg/l, in the Săvârșin section, in 2016, with a value of 5.45 µg/l, in the Arad section, and in 2018, with the value of 3.55 µg/l, in the Nădlac section.

Heavy metals are among the most toxic water pollutants due to their long persistence in solutions and the difficulty of being transformed into insoluble compounds in surface water. Dissolved arsenic concentrations remain constant in all three water sections (0.5 µg/l), below the maximum allowed concentration. In 2017, the annual average values of dissolved chromium concentrations were the highest for the Săvârșin section, at 11.07 µg/l, followed by a downward trend until 2020. In the Arad section, the highest concentration of dissolved chromium was recorded in 2019, of 9.43 µg/l, and for the Nădlac section, the peak value was recorded in 2018, of 8.61 µg/l.

Regarding dissolved copper, an increase in concentration was observed between 2017 and 2020, with the exception of 2019, when a minimum value of 3.3 µg/l was recorded on the Săvârșin section. In the Arad section, a decrease in the concentration of dissolved copper was found in 2018 and 2019, with values of 5.75 µg/l and 3.43 µg/l, compared to 2017, with a value of 9.97 µg/l. In 2020, the highest value of dissolved copper was recorded, of 13.38 µg/l. In the Nădlac section, the concentration of dissolved copper had relatively constant values between 2017 and 2019, around 4 µg/l, and a sudden increase to 12.65 µg/l in 2020.

The concentration of dissolved zinc remained constant between 2018 and 2020 in all three sections related to Arad County. The peak concentration of dissolved zinc was recorded in 2017, in the Săvârșin section, of 19 µg/l. In the years 2017 and 2018, the presence of toluene in the water was observed in the samples taken from the Nădlac section, with constant values of 1.5 µg/l, and in the years 2018 - 2020, the presence of cyanides in the same section, with a strong upward trend.

3.3.3. Comparisons regarding the ecological status on 3 water sections (Arad County)

Based on the data received from the Târgu Mureș Basin Administration, we carried out a comparative analysis of the three sections for the years 2015 - 2020. In the following, the water quality situation of the Mureș River will be discussed, on the three analyzed sections, related to Arad County.

Table 3.10. ***Biological elements***

	2015	2016	2017	2018	2019	2020
Phytoplankton						
Săvârșin section	0.513	0.534	0.505	0.474	0.643	0.585
Arad section	0.751	0.717	0.786	0.788	0.928	0.879
Nădlac section			0.706	0.871	0.778	0.759
Macroinvertebrates						
Săvârșin section	0.693	0.545	0.683	0.808	0.688	0.709
Arad section	0.829	0.854	0.808	0.853	0.858	0.645

Nădlac section			0.713	0.762	0.602	0.769

From the analysis of phytoplankton variation on the three water bodies of the Mureș River, (table 3.10., figure 3.24.) it can be seen that the lowest average annual values were recorded in the Săvârșin section, therefore the Mureș River enters the more polluted Arad County by human activities in the Hunedoara area. Going downstream, the Arad section presents itself better than the Săvârșin section. In this area, there are mainly agricultural activities. Finally, the Nădlac section, which includes the Lunca Mureșului ecologically protected area, has good phytoplankton values, but not significantly higher than the previous section as a consequence of industrial activities in the municipality of Arad.

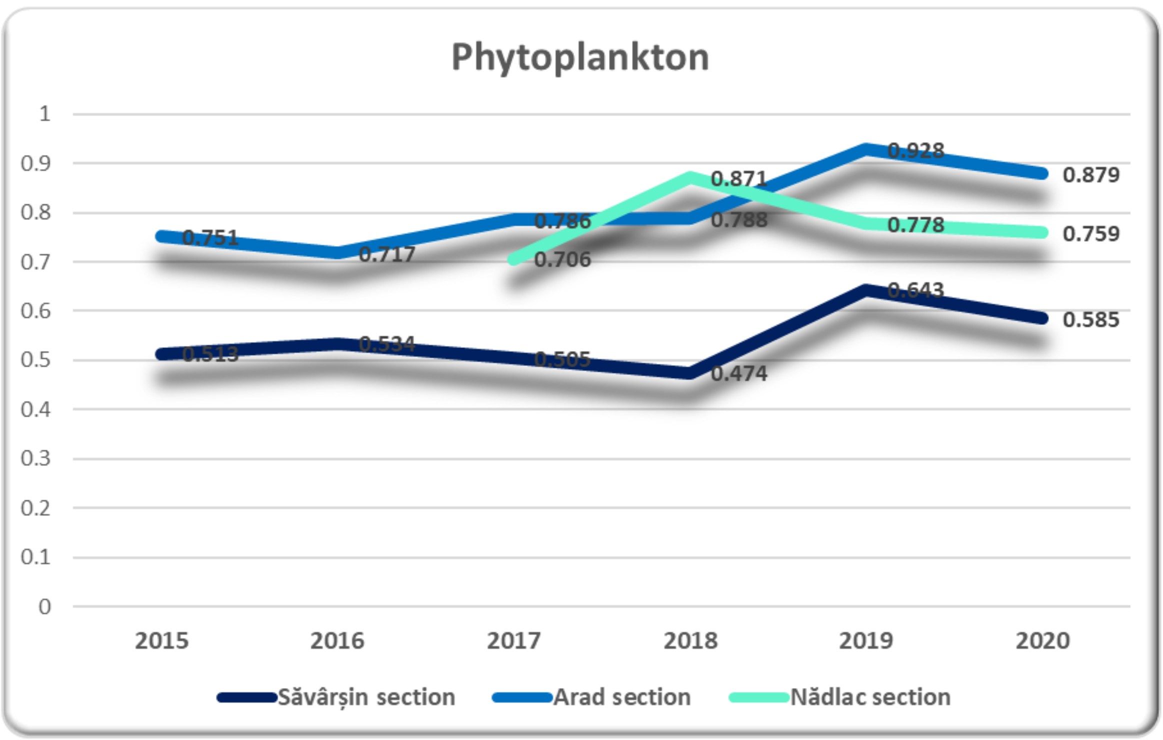

Figure 3.24. ***Phytoplankton comparisons on 3 sections***

The presence of macroinvertebrates (table 3.10., figure 3.25.) remains similar to phytoplankton in the period 2015–2020 with lower values, in general, in the first body of water, with a peak recorded in 2018. In the Arad section, the values are constant in the analyzed period, with decreasing trends starting from 2019. Inexplicably lower values are recorded in the Nădlac section, which, as we previously emphasized, includes a vast ecologically protected area. Therefore, it is expected that fauna and flora will be better represented than in the previous sections. However, recently there has been an improvement in the level of macroinvertebrates in this body of water, starting in 2019.

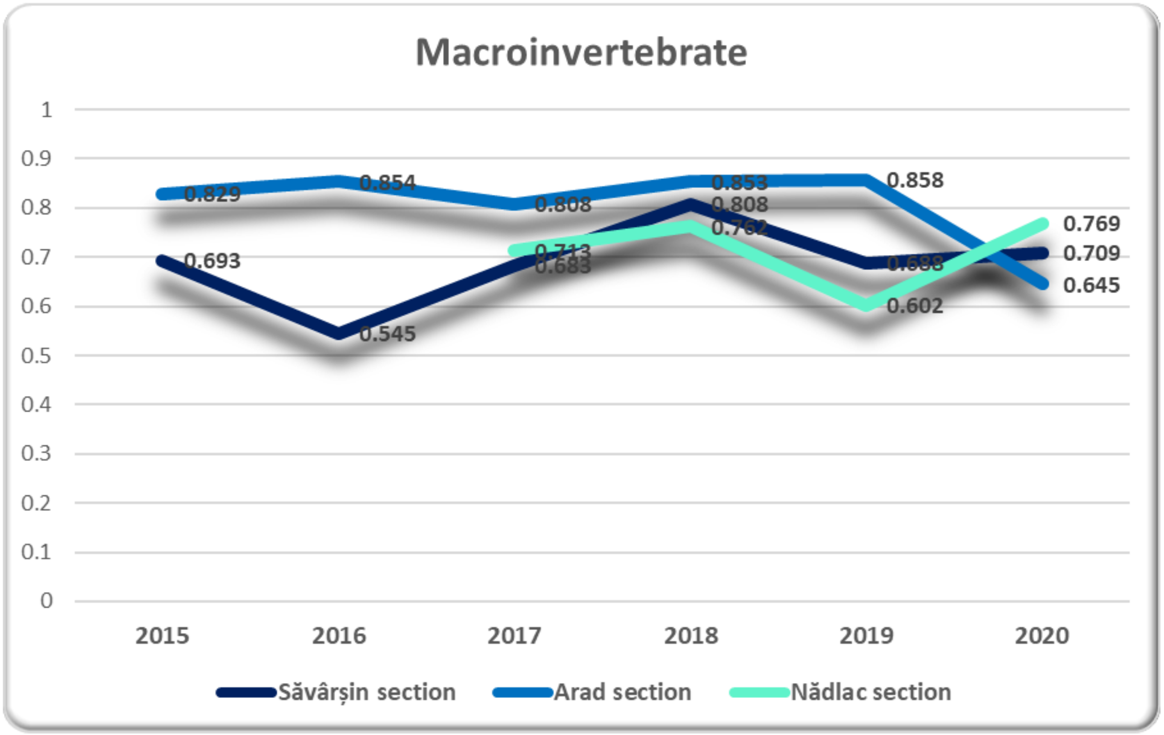

Figure 3.25. ***Macroinvertebrate comparisons across 3 sections***

Tabel 3.11. ***Oxygenation conditions***

	2015	2016	2017	2018	2019	2020
CBO5 (mgO_2/l)						
Săvârşin section	4.25	5.199	5.932	4.633	4.464	4.402
Arad section	4.94	5.132	5.149	4.831	3.245	4.993
Nădlac section			5.449	3.11	3.89	3.73
CCO-Cr (mgO_2/l)						
Săvârşin section	14.76	36.18	36.41	44.69	24.71	25.68
Arad section	16.8	40.42	36.95	21.85	15.4	19.74
Nădlac section			31.38	12.7	21.3	24.1
Oxigen dizolvat (mgO_2/l)						
Săvârşin section	8.335	8.267	7.901	7.567	8.411	7.81
Arad section	8.245	8.32	7.458	7.554	9.587	7.295

Nădlac section			7.776	9.25	7.628	7.764

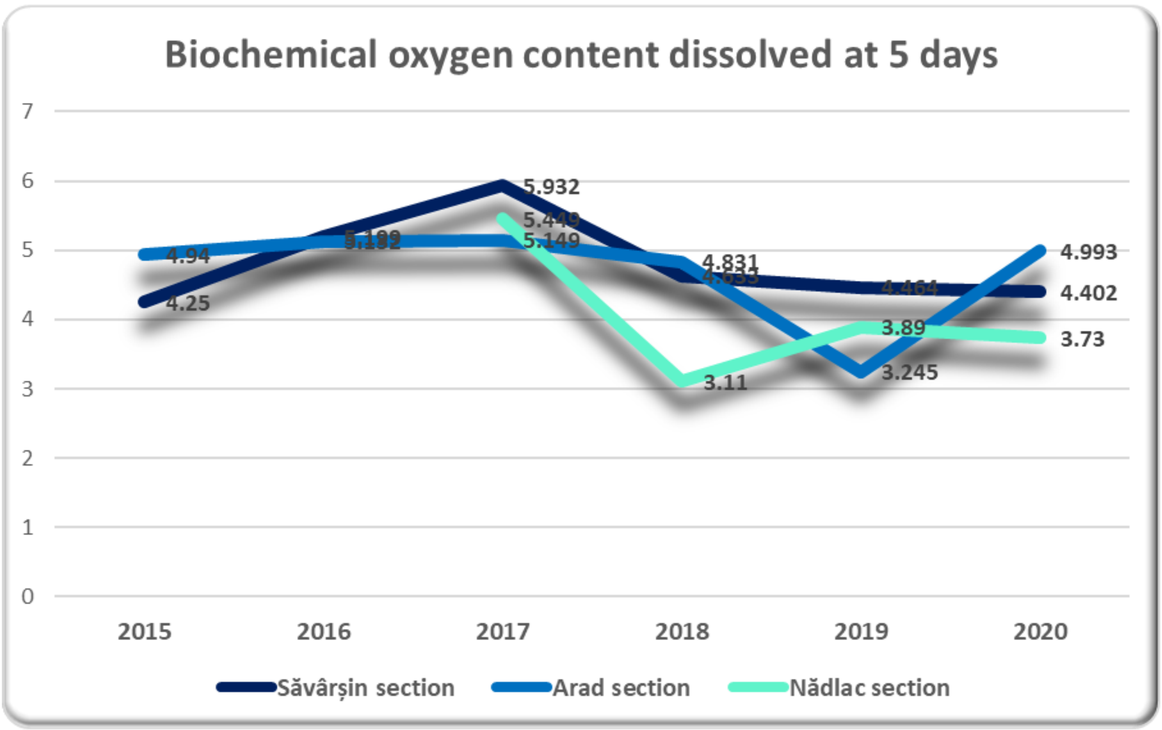

Figure 3.26. ***Biochemical oxygen content comparisons on 3 sections***

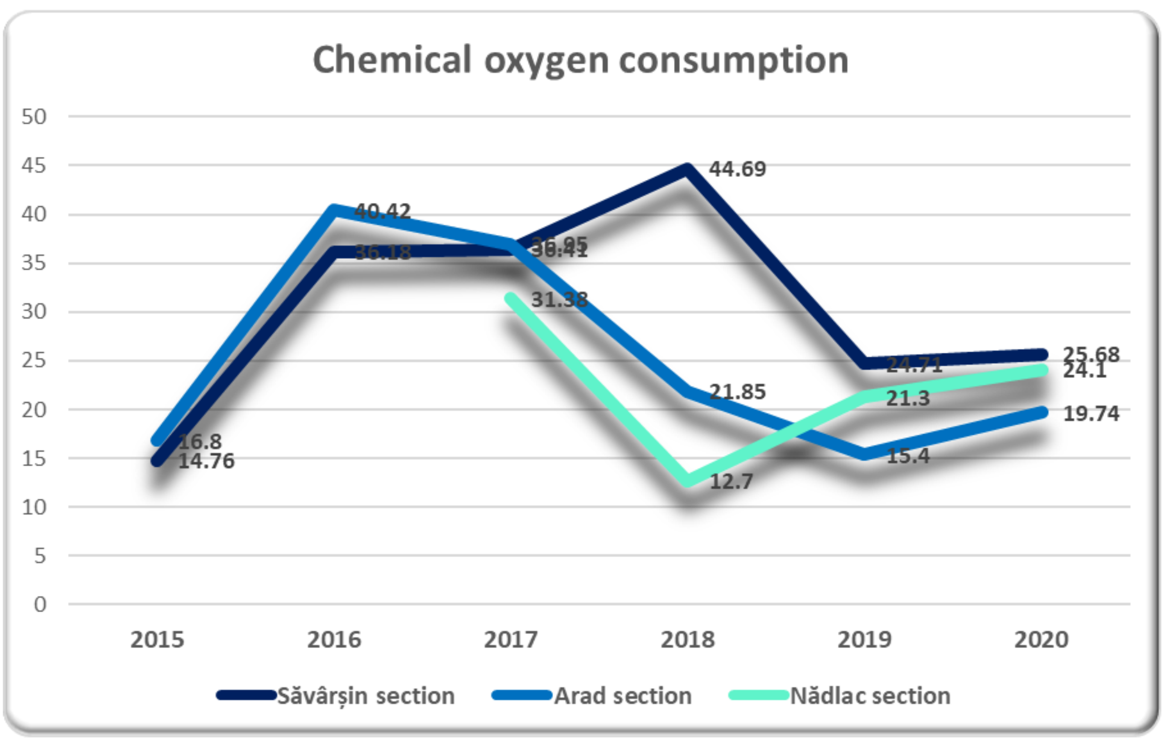

Figure 3.27. ***Comparisons of chemical oxygen consumption on 3 sections***

The biochemical content of dissolved oxygen (table 3.11., figure 3.26.), measured after 5 days (CBO_5) shows good levels of the indicators, with generally lower values of the Arad section than the other two sections, partly due to the bank development works from this area, which keeps the organic matter dissolved in the water under control. The Săvârșin and Nădlac sections cross areas is less affected by human activities – mountains and hills, as well as the ecologically protected area Lunca Mureșului. Therefore, the control of these materials is less noticeable.

Chemical oxygen consumption (CCO-Cr) (table 3.11., figure 3.27.) shows significant oscillations, both during the analyzed time period and on the three water sections. The Săvârșin and Arad sections remain similar between 2015 and 2017 but show a very high consumption on the Săvârșin section in 2018, while in the Arad and Nădlac sections, the biochemical oxygen consumption is significantly lower. A balancing of consumption is observed starting from 2019, with good values throughout the three sections.

Oxygen dissolved in water (table 3.11., figure 3.28.) shows good values within the limits of quality class I for the entire period analyzed in the three bodies of water.

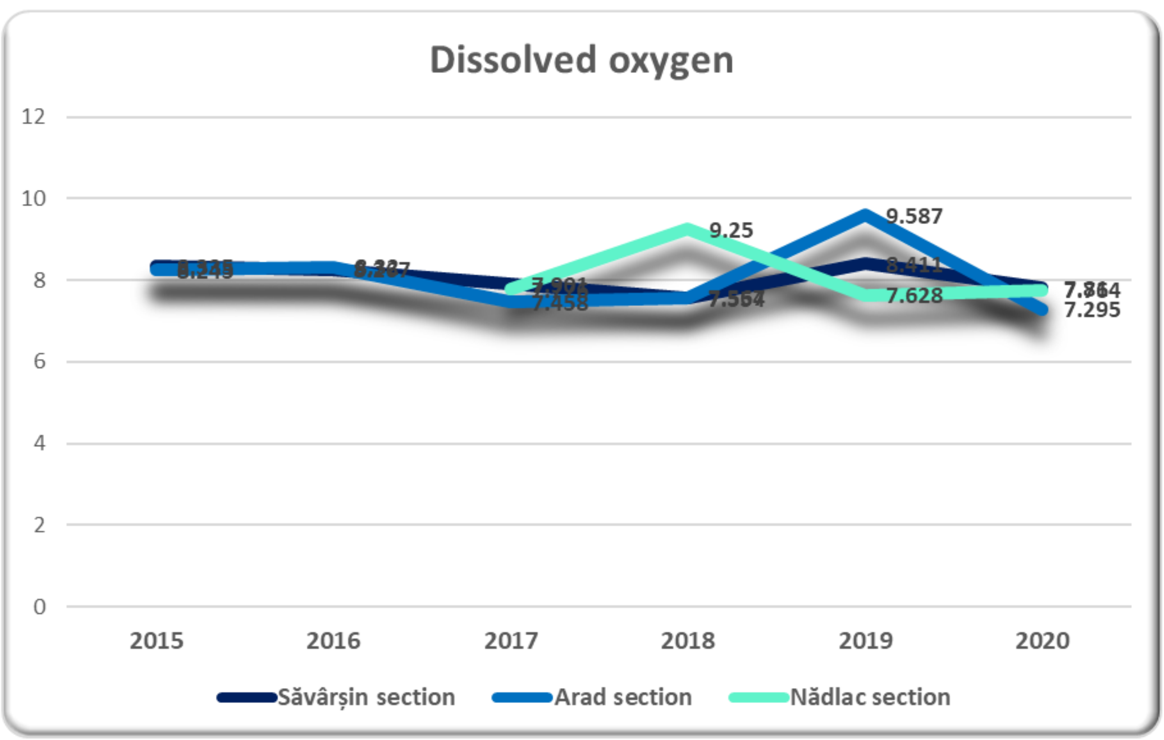

Figure 3.28. ***Dissolved oxygen comparisons on 3 sections***

Table 3.12. ***Physico-chemical elements***

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Salinitaty/Conductivity (μS/cm)						
Săvârșin section	551	459.8	614.2	508.3	562.4	476
Arad section	564	353.7	593.6	494.5	439	512.9
Nădlac section			520.9	401.5	550.1	458.6
Alkalinity/pH (unit pH)						
Săvârșin section	8.16	7.8	8.16	8.28	8.19	7.99
Arad section	8.18	7.93	8.16	8.38	8.29	8.18
Nădlac section			8.1	8.19	8.2	8.39
Nutrients						
Săvârșin section	2.43	3.115	2.228	2.87	2.02	2.393
Arad section	2.455	3.127	2.416	2.758	2.34	2.185
Nădlac section			2.338	2.385	2.019	2.13

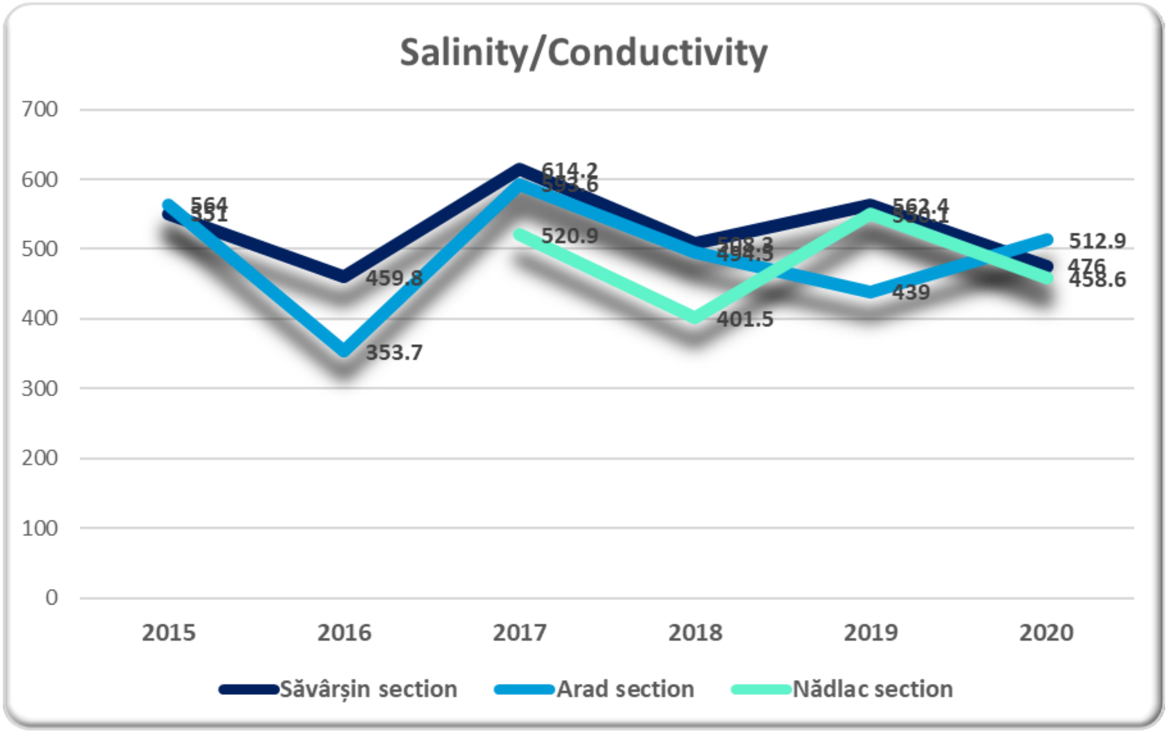

Figure 3.29. ***Salinity/conductivity comparisons across 3 sections***

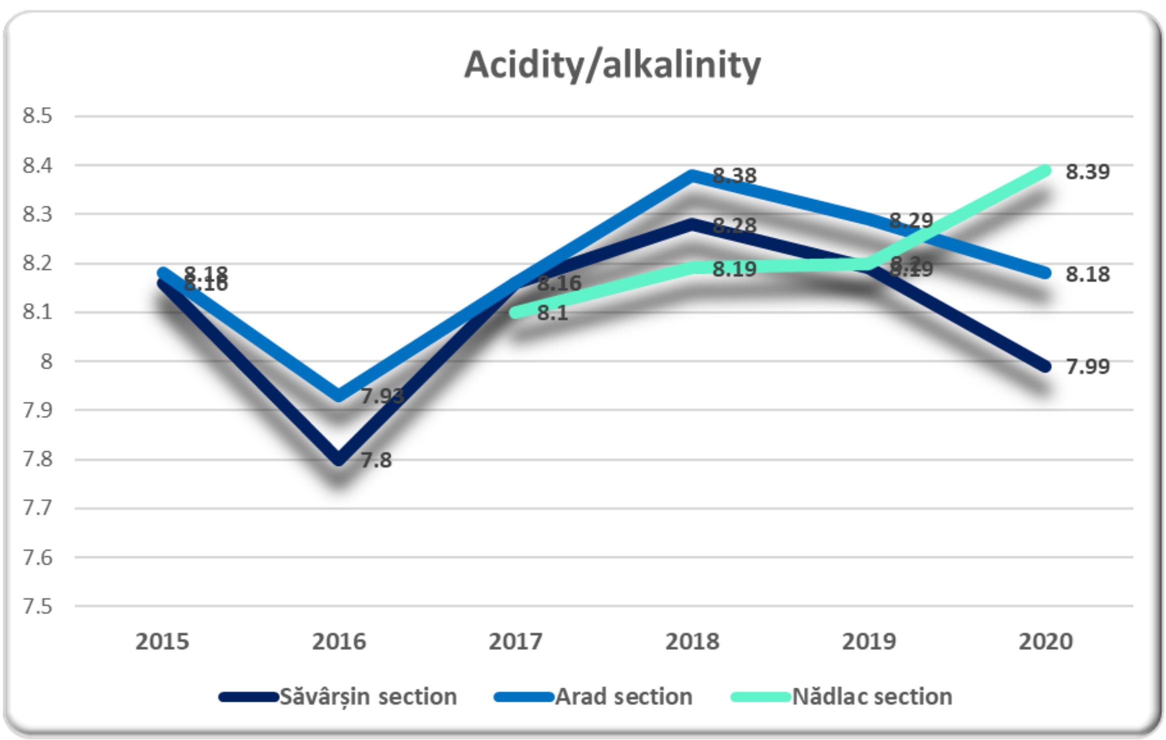

Figure 3.30. ***Acidity/alkalinity comparisons on 3 sections***

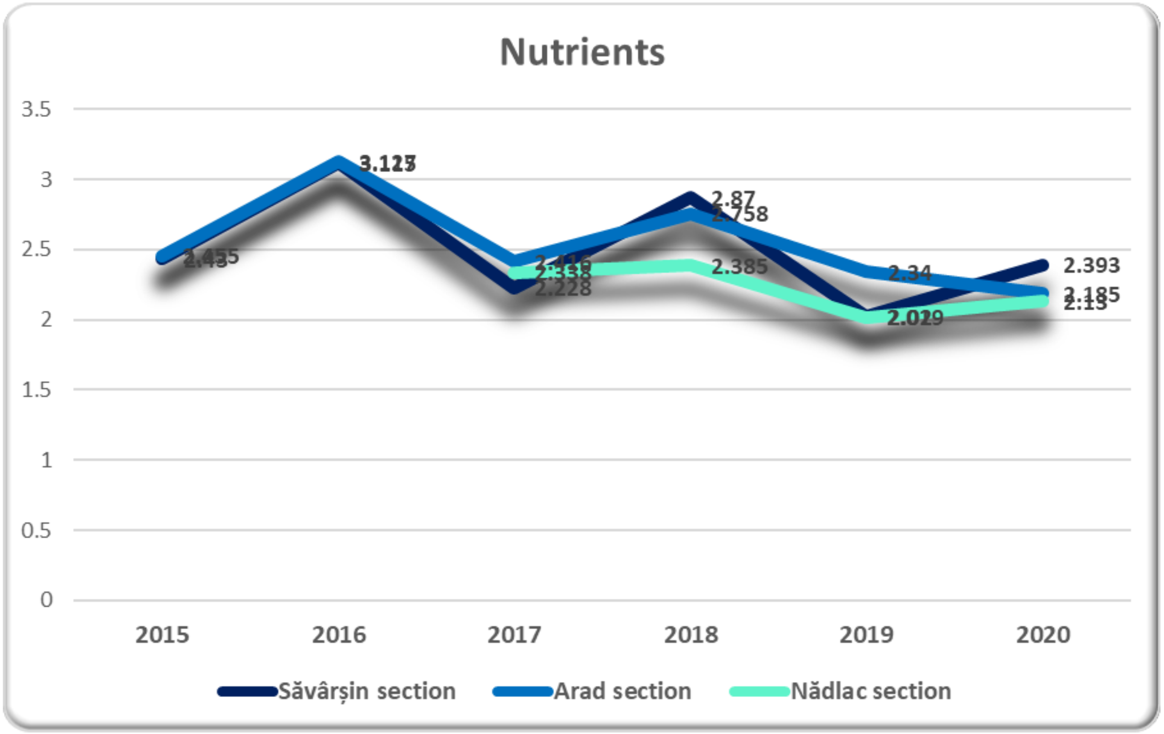

Figure 3.31. ***Total nutrient comparisons across 3 sections***

The salinity of the three water bodies (table 3.12., figure 3.29.) shows fluctuations in values, but it is maintained within the limits of the first two quality classes, with slightly higher values for the first section. This is explained by the nature of the mountainous area related to the water body and slightly lower values for the Arad and Nădlac sections.

The pH values (table 3.12., figure 3.30.) vary within narrow limits throughout the analyzed period and on the three bodies of water, recording values between 7.8 and 8.39, neutral values, favorable for aquatic life. The lowest value, close to the ideal value of 7.5, was recorded in the Săvârșin section, in 2016, followed by the Arad section, in the same year, of 7.9. Compared to this annual benchmark, slightly upward trends are observed for all three water bodies in the following periods.

Table 3.13. ***Specific pollutants***

	2015	2016	2017	2018	2019	2020
Total phenols (phenolic index) (μg/l)						
Săvârșin section	3.255	3.75	1.5	3.65	4.7	6.45
Arad section	3.255	5.45	1.5	3.75	1.5	1.5
Nădlac section			1.5	3.55	2.4	1.5

Dissolved arsenic (µg/l)						
Săvârşin section			0.5	0.5	0.5	0.5
Arad section			0.5	0.5	0.5	0.5
Nădlac section			0.5	0.5	0.5	0.5
Dissolved chromium (Cr3+ + Cr6+)						
Săvârşin section			11.075	9.915	7.385	7.08
Arad section			9.0475	8.065	9.435	6.44
Nădlac section			3.96	8.61	8.295	6.52
Dissolved copper (µg/l)						
Săvârşin section			5.735	7.055	3.3	12.99
Arad section			9.975	5.75	3.43	13.38
Nădlac section			4.495	4.13	4.48	12.65
Dissolved zinc (µg/l)						
Săvârşin section			19	12.5	12.5	12.5
Arad section			5	12.5	12.5	12.5
Nădlac section			5	12.5	12.5	12.5

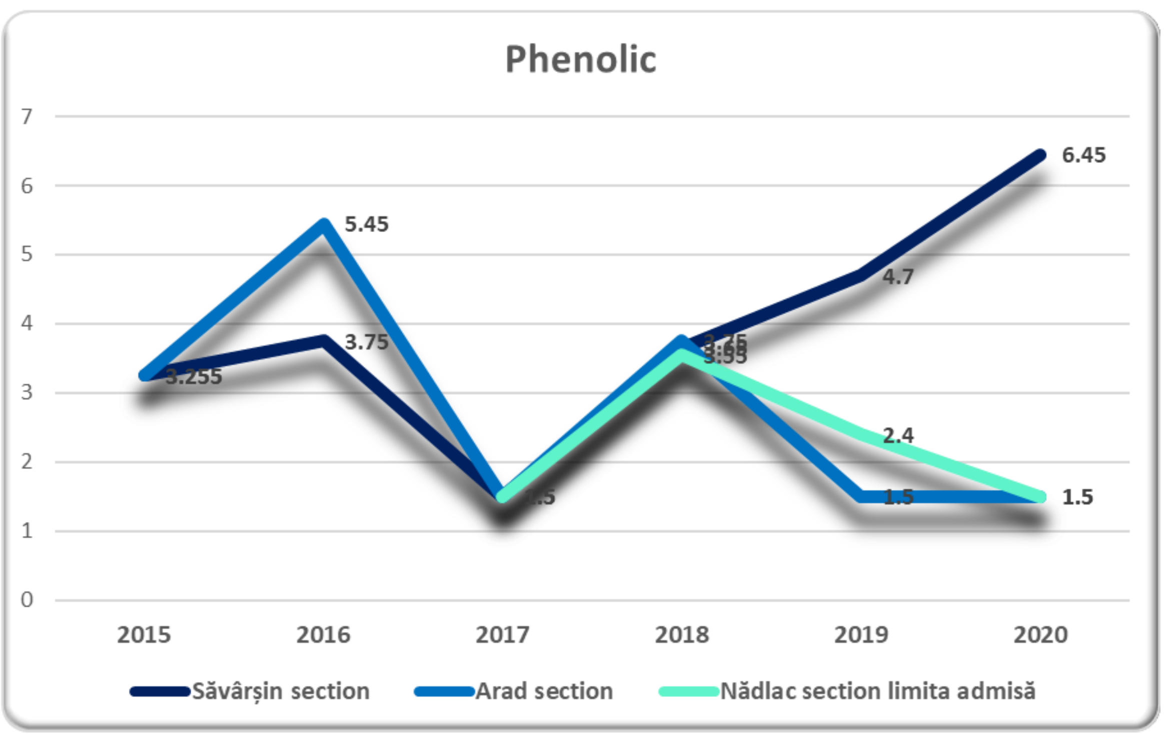

Figure 3.32. ***Phenolic comparisons across 3 sections***

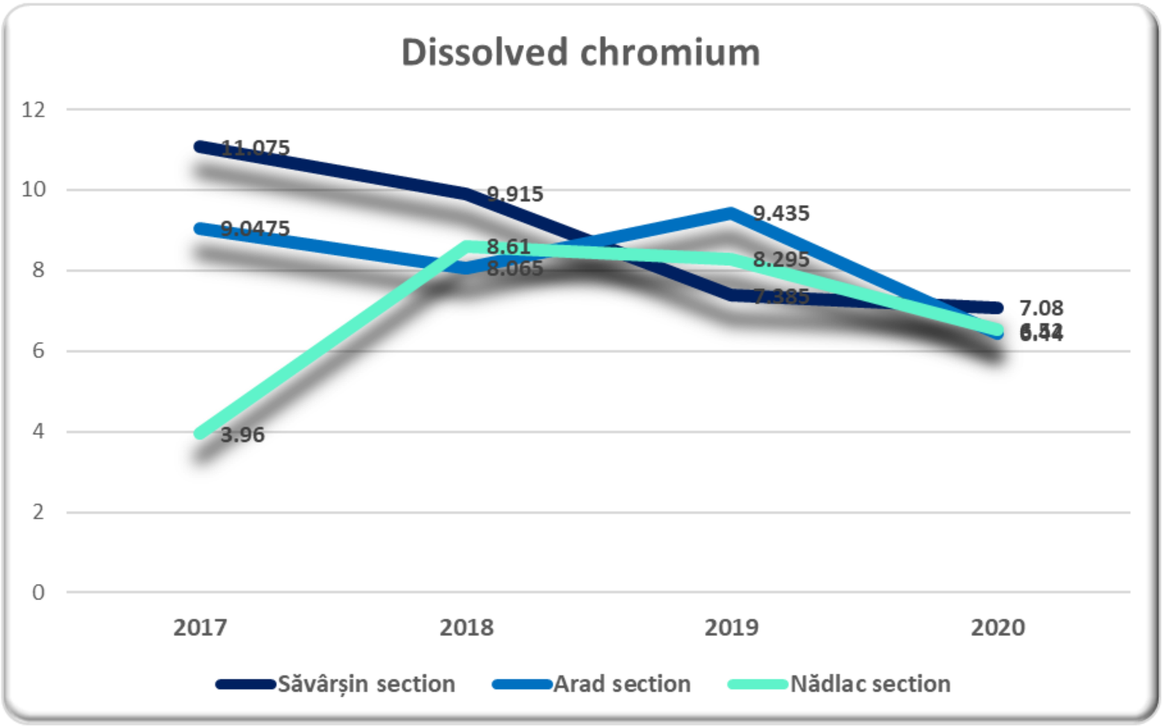

Figure 3.33. ***Comparisons of dissolved chromium on 3 sections***

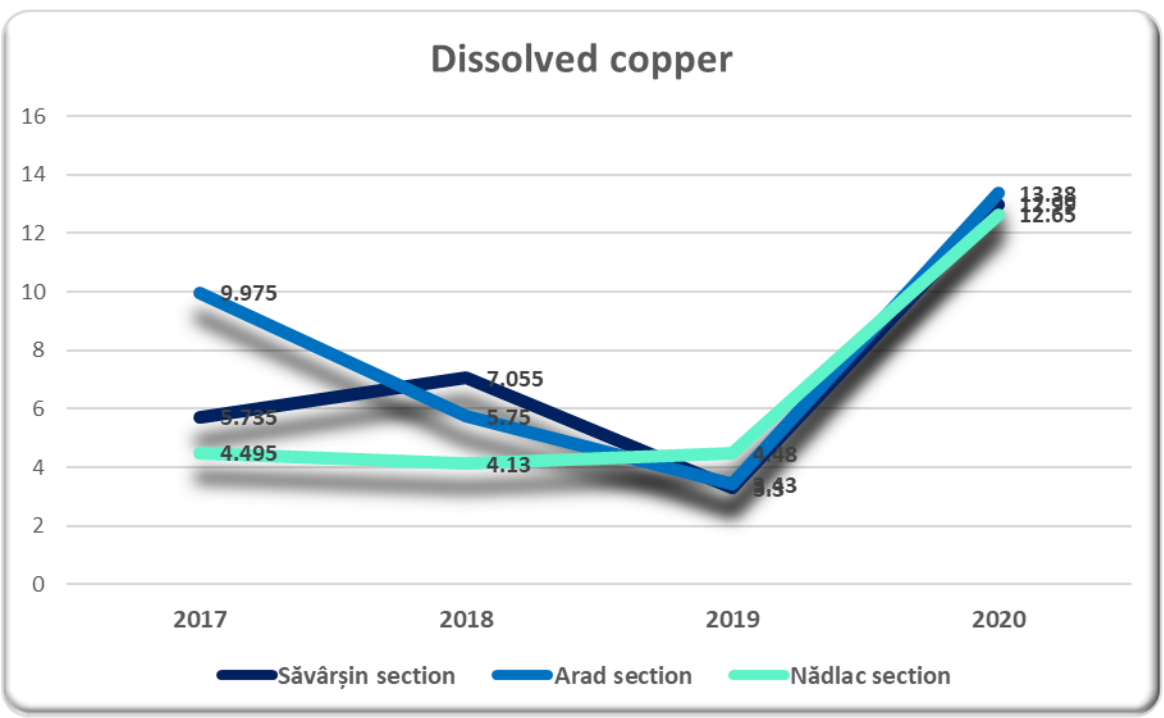

Figure 3.34. ***Comparisons of dissolved copper on 3 sections***

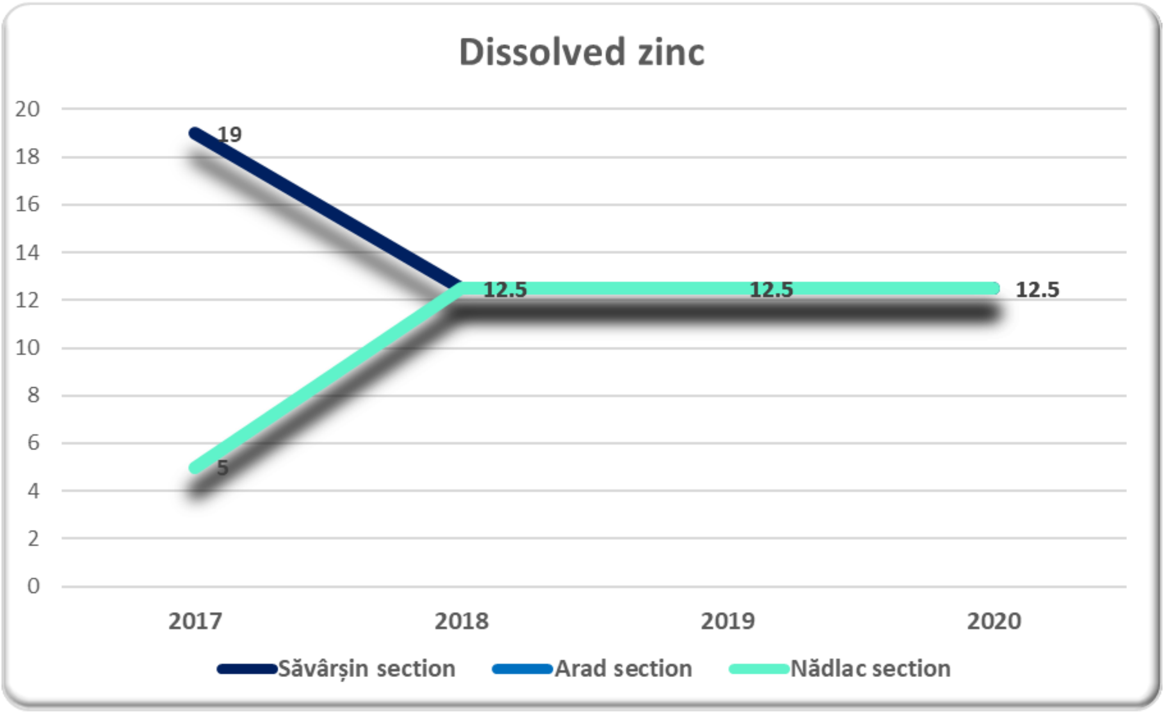

Figure 3.35. ***Comparisons of dissolved zinc on 3 sections***

Considering that pH measurement is logarithmic, not linear, it can be said that pH fluctuations are significant – a difference of one point, meaning a 10-fold increase in alkalinity or acidity.

Following the analysis of the total nutrient index (table 3.12., figure 3.31.) on the three sections of the Mureș River, fluctuations are found over the years within the limits of the allowed values for all three bodies of water. Comparatively, there is a pattern of nutrient level fluctuations, with increases in values in even years and decreases in odd years, a pattern observable especially for the Săvârșin and Arad sections where the data cover the entire analyzed period. This situation can also be generalized for the Nădlac section in the four years considered.

Regarding the specific dissolved pollutants (table 3.13.) in the water of the three sections of the Mureș River, the year 2017 stands out for the presence of phenol at limits below the measurement level, with an upward course for the Săvârșin section and a worrying value of the phenolic index in 2020 explained by the industrial and mining activity in the Hunedoara area. For the Arad and Nădlac section, the situation is more positive, with a decreasing character of the presence of phenol in these sections (figure 3.32.). Also, a constant presence of 0.5 µg/l of dissolved arsenic can be noted on all analyzed sections (table 3.13.).

The presence of heavy metals in the Mureș River, within Arad County, shows a decrease in chromium values (table 3.13., figure 3.33.), with a remarkable difference of 5 units in 2020, compared to previous years. In contrast, dissolved copper (table 3.13., figure 3.34.) shows upward trends (approximately 12-13 µg/l) in 2020, conferring quality levels of class II, but with good values in previous years, even very good in 2019, for all three sections. The presence of zinc (table 3.13., figure 3.35.) remains constant on the three sections, with a peak concentration on the Săvârșin section in 2017.

3.4. Pecica case study

THE PERCEPTION OF THE CITIZENS OF THE PECICA AREA ON BENEFITS BROUGHT BY THE REVITALIZATION OF THE SYSTEM OF DRINKING WATER AND SEWERAGE

The town of Pecica [65] is located in Arad County, in the Arad Plain, on the right bank of the Mureș. It was declared a city in 2004, and in the 2011 census it had a population of 12,762 inhabitants [66]. The administrative territory has an area of 23,717 ha and administers the villages of Bodrogu Vechi, Turnu and Sederhat. Pecica is located in the Crișana region and is crossed by the National Road (E68) and the A1 Timișoara – Arad – Nădlac Highway, which connects Romania to Hungary. The town of Pecica is 20 km from the municipality of Arad, 30 km from the border point Nădlac and 14 km from the border point Turnu. Pecica is documented from 1335 with the name of Petk, and the villages under the administrative subordination: Turnu, from 1333, with the name of Mok, Bodrogu Vechi, from 1422, with the name of Bodruch and Sederhat, from 1913 [65].

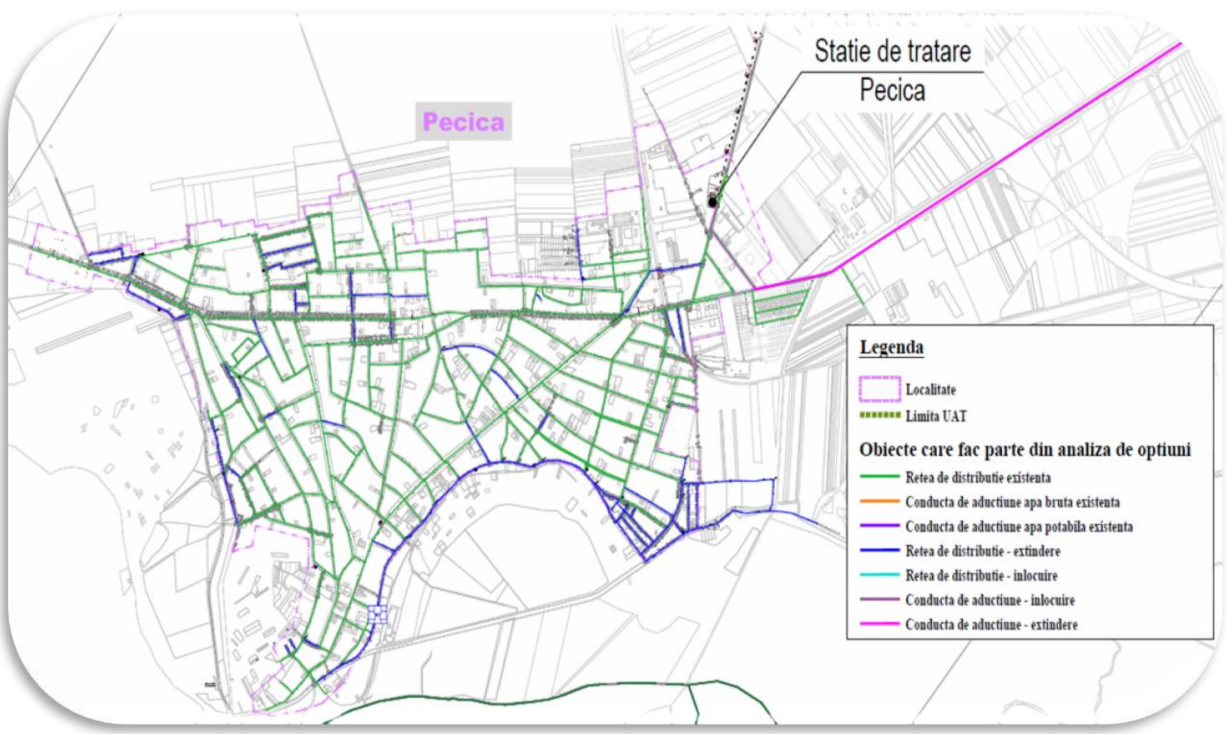

Figure 3.4.1. ***Presentation of the proposed works - drinking water***

3.4.3. The objectives investigated: the study aimed to investigate the perception of the citizens of the Pecica area on the quality of water, the supply and access to drinking water. Also, it analyses their opinion regarding the treatment and discharge of wastewater, as well as their perception on the benefits that the expansion and revitalization of the drinking and used water distribution system brought them to the level of the individual and to the level of the localities.

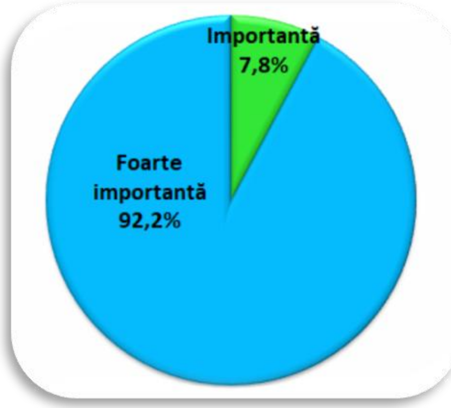

Figure 3.4.3. ***The importance of water***

3.4.4. Data collection and sampling methodology: The application of the questionnaire (Appendix 5) took place online through media applications and social networks. The participating sample consists of 192 participants from the studied area (Pecica – 117 people, representing 60.9% of the sample, Turnu – 72 people, representing 37.5% of the sample, and Sederhat – 3 people, i.e. 1.6% of the sample), 90 men (46.9%) and 102 women (53.1%), aged between 18 and 65 years, the average age being 37.27 years.

Figure 3.4.4. ***The importance of water - women***

The first direction of the study is aimed researching the perception of the citizens of the administrative area of Pecica on the importance of water in their lives, considering that we often forget the impact of simple things in life, about the use of water in the household and the amount of water consumed daily. It is well known the role that water has in the human body, from transporting nutrients and oxygen to cells, fluidizing blood

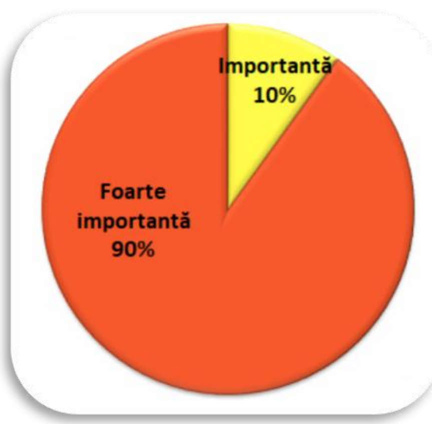

Figura 3.4.5. ***Importanța apei – bărbați***

circulation, to the digestive, detoxifying and preventive role of kidney diseases, etc. In this sense, when asked how important water is in their lives, for 15 people, i.e. 7.8%, water is important, and the overwhelming majority of 92.2%, representing 177 people, believe that water is very important in their life (figure 3.4.3).

The proportion about the importance of water is also maintained by gender, thus, 90% of the men questioned and 96% of the women consider that water is very important in their lives (figures 4. - 5.), and by localities: 92.3%, i.e. 108 of the residents of Pecica and 91.7%, i.e. 66 of the residents of Turnu realize the importance of water in their lives. The group of respondents from Sederhat being very small was not included in the analysis.

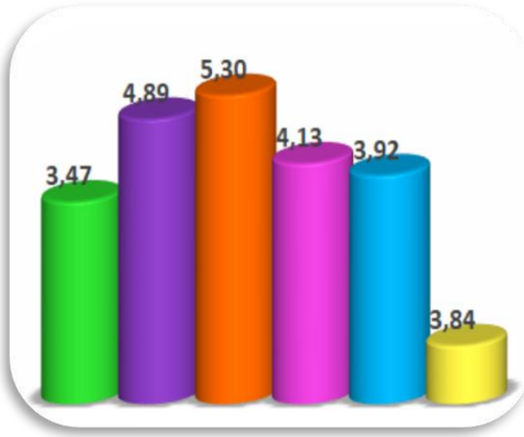

Figure 3.4.6. ***Water use***

Regarding water use in the household, water is used most for indoor washing – clothes, dishes (m = 5.30), cooking (m = 4.89), outdoor washing – car, yard (m = 4 ,13), watering gardens (m = 3.92), other uses (m = 3.84) and, finally, for drinking (m = 3.47) (figure 3.4.6). The differences between the frequency of uses were found to be statistically significant, with the Chi square coefficient having values from 13.87 to 212.53, at thresholds lower than 0.05, therefore it can be stated that the results are significant for the population within of the city of Pecica in general.

3.4.5. The conclusions of the opinion survey: the objective of the study has been to investigate the perception of the inhabitants of the Pecica area regarding drinking and wastewater, access and quality of water and their opinion regarding the distribution of water and the investments made in the supply of water to the population.

Without exception, residents consider water of crucial importance in their lives, are generally satisfied with drinking water supply services and the distribution network, however, they prefer to drink bottled water and use tap water for household activities and for cooking mainly. It is observed that the inhabitants are very well informed about the importance of water for health and the recommended amount of consumption, and less informed about the quality standards of drinking water and its measurement parameters, although there are dissatisfactions related to water quality and the quality/price ratio.

Most of the respondents have been connected to the distribution system for about 2 years and believe that currently the conditions of water supply and access have improved compared to previous years. The respondents who are not connected to the network want the connection of their localities (Turnu), but only a quarter of them are aware of plans to expand the water distribution network and a third know of the existence of plans to expand the sewerage network. The sources of information on the investments and the origin of the funds have an uneven distribution. Most of the citizens get their information from the mass media rather than from local autorities and believe that the money comes mainly from bills paid by customers and proportionally from the funds of the municipality and the European Union.

Most of the respondents know that the environment is protected in the case of wastewater treatment. However, they do not know if the quality standards are met and, moreover, they agree with the principle that the polluter should pay, highlighting in the general picture the awareness of the population towards environmental protection and the efforts made in this regard at the local administrative level. In the end, the inhabitants of the Pecica area positively appreciate the changes brought to their lives by the revitalization of the water distribution system and the treatment of wastewater for health, hygiene, time and, in general, for increasing the standard of living.

3.5. Ecological impact

The last stage of the research has consisted in evaluating the ecological impact of human activities on the three sections of the Mureș River. Thus, a pollution index was calculated according to the methodology advanced by Zaharia [70], applying the formula:

$$EQ_i = \frac{C_i, measured}{MAC_i}$$

where EQ_i represents the pollution index, C_i is the measured value of the parameter taken into account, and MAC_i represents the maximum limit allowed for the measured parameter. After calculating the indices for all the studied parameters, each parameter was assigned a pollution score in accordance with the correlative scale [70] presented in Appendix 6. The data for years and sections were summarized in table 3.17.

From the analysis of the obtained data, a synthesis of the ecological impact can be made for the three sections of water on the parameters taken in the research. Thus, the salinity level (pH) is constant during the period 2015-2020. Water bodies are affected by anthropogenic activities but are within the permissible limits with potential effects on water quality.

The same situation occurs with dissolved oxygen. The pollution indices (score 7) are between the permissible limits, with the exception of section 3 (Nădlac) in 2018, and section 2 (Arad) in 2019, both having an index of pollution of 6, which means that they are affected above the permissible limit and show a pronounced effect of pollution. A similar pronounced effect of pollution is revealed by the biochemical oxygen consumption per 5 days (CBO5) over the entire period 2015-2020. The total oxygen consumption shows oscillations over the entire period and for all sections being even at critical levels (index of pollution 4), with pronounced pollution effects, harmful - microorganisms with a health risk.

Table 3.14. ***Pollution scores***

		ES pH	**ES O2D**	**ES BOD5**	**ES COD**	**ES N-NH4**	**ES N-NO2**	**ES N-NO3**	**ES P total**	**ES Cu**	**ES Zn**	**ES Cr**	**ES fenol**	**ES arsen**
Săvârșin	2015	7.00	7.00	6.00	6.00	8.00	6.00	6.00	3.00				4.00	
Arad	2015	7.00	7.00	6.00	6.00	8.00	6.00	6.00	3.00				4.00	
Săv	2016	7.00	7.00	6.00	5.00	8.00	5.00	7.00	3.00				4.00	
Arad	2016	7.00	7.00	6.00	4.00	8.00	5.00	6.00	3.00				3.00	
Săv	2017	7.00	7.00	6.00	5.00	8.00	6.00	6.00	4.00	8.00	9.00	8.00	5.00	8.00
Arad	2017	7.00	7.00	6.00	5.00	8.00	5.00	6.00	3.00	8.00	9.00	8.00	5.00	8.00
Nădlac	2017	7.00	7.00	6.00	5.00	8.00	6.00	6.00	3.00	8.00	9.00	9.00	5.00	8.00
Săv	2018	7.00	7.00	6.00	4.00	9.00	6.00	6.00	2.00	8.00	9.00	8.00	4.00	8.00
Arad	2018	7.00	7.00	6.00	5.00	9.00	6.00	7.00	2.00	8.00	9.00	8.00	4.00	8.00
Nădlac	2018	7.00	6.00	6.00	6.00	8.00	6.00	6.00	3.00	8.00	9.00	8.00	4.00	8.00
Săv	2019	7.00	7.00	6.00	5.00	8.00	5.00	7.00	2.00	9.00	9.00	8.00	3.00	8.00
Arad	2019	7.00	6.00	6.00	5.00	8.00	5.00	6.00	3.00	9.00	9.00	8.00	5.00	8.00
Nădlac	2019	7.00	7.00	6.00	5.00	8.00	5.00	6.00	2.00	8.00	9.00	8.00	4.00	8.00
Săv	2020	7.00	7.00	6.00	5.00	8.00	5.00	6.00	1.00	7.00	9.00	8.00	2.00	8.00
Arad	2020	7.00	7.00	6.00	6.00	9.00	5.00	6.00	1.00	7.00	9.00	8.00	5.00	8.00
Nădlac	2020	7.00	7.00	6.00	5.00	8.00	5.00	6.00	2.00	7.00	9.00	8.00	5.00	8.00

The pollution situation is equally precarious with regard to ammonia. Although ammonia levels are acceptable throughout the studied period, this is because this substance breaks down quickly into nitrates and nitrites. The real situation can be assessed by analyzing the scores for N-NO_2 and N-NO_3, the pollution index for these having values between 5 and 7. Therefore, the water bodies are affected by pollution at critical levels, above the admissible limits.

CHAPTER IV.

General conclusions, perspectives and recommendations

The present work aimes to analyze the quality indicators of surface water from the Mureș hydrographic basin for the period 2015-2020. Data related to biological, physico-chemical parameters, oxygenation and salinity conditions, water acidification status, nutrients, specific pollutants, and other specific characteristics of this river were used.

In the first two chapters, the fundamental notions and general characteristics of water were presented, as well as pollution, surface water monitoring indicators, types of pollutants and the main sources of pollution. It was also included a comparative study of the pollution situation in the Mureș, Olt and Siret water basins, which demonstrate that the Siret is the second most polluted river in Romania. From 2012 to 2017, there were recorded here 40 ecological accidents, which makes the Siret River a real ecological disaster.

Based on the analysis carried out, the final conclusions of this work are as follows:

Ecological status and water quality of the Mureș River:

The water quality of the Mureș River varies depending on the sections. It is influenced by human activities, but most of the quality indicators fall into classes I and II. This indicates a moderate degree of pollution with a few critical points. Dissolved oxygen, essential for aquatic fauna, has generally good values, with few exceptions, ensuring the survival of aquatic ecosystems.

Sources and types of pollution:

The main sources of pollution include untreated sewage, industrial and agricultural discharges and contamination with heavy metals and phenols. Phenolic pollution remains a critical problem, and it is caused by historical spills and the lack of effective remedial measures.

The impact of human activities:

Organic pollution expressed by biochemical oxygen consumption (CBO5) and the presence of nitrogen in the form of ammonium, nitrites and nitrates highlights the recent and persistent contamination, especially in the Săvârșin and Arad sections.

Although heavy metal levels are mostly within acceptable limits, copper showed high values in 2020, indicating potential environmental risks.

Evolution of pollution indicators:

Quality indicators such as nutrients, pH and conductivity fluctuated between 2015 and 2020, suggesting a combined influence of natural (precipitation) and anthropogenic factors.

The global pollution index study shows that, despite some improvements, the Mureș River is significantly affected in some sections, with ecological impact and potential harm to human health.

Residents' perception:

Residents of the Pecica town believe that access to drinking water has improved, but they prefer bottled water consumption, a sign of concerns regarding the quality of the distributed water.

They show a high level of awareness of the importance of environmental protection and support the "polluter pays" principle, but they are less informed about drinking water quality standards.

Recommendations:

Expanding the number of monitoring points and more detailed analysis of emerging pollution are essential for a complete assessment of the river's condition. Implementation of a sustainable water management strategy based on strict standards and collaboration between authorities and local communities is essential. The development of a standardized global index for water quality monitoring would facilitate the prioritization of interventions and the tracking of long-term progress.

This research highlights the urgent need for integrated and sustainable measures to reduce pollution and protect the Mureș River, both for the health of the ecosystems and for the human communities that depend on this important water body.

Importance of public education and awareness:

It is essential that the population understands the serious impact of water pollution on health and daily life. Education and awareness campaigns can encourage more responsible behaviors regarding water use and waste management.

Creation and implementation of a water quality index:

A comprehensive index, based on chemical, physical and biological indicators, could be used to monitor the condition of the Mureș River and other aquatic resources. It would facilitate the prioritization of interventions and the assessment of progress over time.

Consolidation of legislation and its rigorous application:

Harmonization is needed between national and European regulations in the field of recycling, waste management and water protection. Fines for pollution and non-compliance must be deterrents.

Investments in protection infrastructure:

Construction and maintenance of dikes, retaining walls and dams is necessary. Upgrading water treatment plants and adding green spaces around them to filter additional pollutants is recommended.

Adapting agriculture to climate change:

Introducing efficient irrigation methods such as drip systems would be helpful. Cultivation of plants that are more resistant to drought could save water. Reducing the use of pesticides and fertilizers that can contaminate groundwater and rivers is imperative.

Clean energy through hydropower plants:

Exploring the potential of hydropower to generate clean energy, but without compromising biodiversity and the health of the river's ecosystem is recommended.

Partnerships and collaborations:

Authorities, local communities, non-governmental organizations and private companies must work together to implement sustainable solutions.

Sustainable water management:

A detailed plan that includes protecting existing resources, reusing water through modern technologies and adopting efficient consumption practices in industry, agriculture and households is necessary.

Digitization of monitoring:

Technologies such as IoT sensors and artificial intelligence can provide real-time monitoring of water quality and quickly identify sources of pollution.

Rehabilitation of ecosystems:

In addition to strict measures, the reforestation of areas near the river and the protection of its biodiversity must be promoted.

Global implications:

Effective practices applied locally can become models for other regions with similar water pollution problems, contributing to a better management of global resources.

These measures, correctly applied and supported by sound policies, can help reduce water pollution, preserve the Mureș River and protect the health of the population.

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