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An analysis of water from Prut river near Cahul City

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Abstract. Prut river has particular evolutions of its characteristics due to its geographical and political position (as border river between Romania and Moldova), specific climate and human activities (agriculture and industry). The dependences of analyzed characteristics mainly on seasons reflect that human activities is not yet dominant in modifying these parameters. The water sampling station is located near the city of Cahul, an emerging city as concerning economic, academic and social life in Republic of Moldova.
Based on the survey during the years 2018-2022, the following conclusions on water of Prut River could be drawn. Prut water characteristics has specific evolutions due to its geographical position, specific climate and human activities, also because this survey included the pandemic years. Except for pH, all other here-analyzed characteristics are more or less seasonally dependent.

Keywords: Prut River, water quality, five years, temperature, turbidity, transparency, chlorides, nitrates, nitrites, alkali, ammonia.

1. Introduction

The protection of fresh waters, as a whole, is essential for biodiversity and sustainable use of ecosystem functions. This complex activity starts with a reliable survey of longer time intervals. Santos et al. [1] proposed a new strategy for this objective, clearly assuming benefits on enhancing quality and comprehensiveness of the future ecological assessment framework for freshwaters. One tool of this strategy is effectively integrating distinct LoE (chemical, ecological and ecotoxicological issue), instead of using the conservative "one out, all out" principle, that could screen the reciprocating influence of two or more parameters.

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Prut River is at the Eastern border of Romania and European Community, but it could become an ”internal” river for the last organization, if Moldova adhered to the European Union. The political borders are not always on clear geografical characteristics and a survey of the Prut River could be of interest for a sustainable development of this region. Transboundary river water quality could be a core indicator for sustainable development in Europe [49] and this river could influence the Danube River, but for this one studies are quite numerous [28], [31], [38], [50]. Aslo, a Romanian river, the Siret River, flowing almost parallel to the Prut River, also being a tributary water to the Danube, has been in the specialists’ attention and there are resemblence [66] to the Prut River.
Surveying and analyzing river water characteristics is crucial for several reasons: water quality monitoring [21], [22], [49], ecosystem health and security, management of resources, including water resources conservation [11], [22], [73], flood and drought management, climate change impact [2], [10], [58] and community engagement. In the Special Report Implementing the Drinking Water Directive [74], formulated in 2017, ”water quality and access to it improved in Bulgaria, Hungary and Romania, but investment needs remain substantial”.
The Prut River has particular evolutions of its characteristics due to its geographical position, specific continental climate and economic activities. The dependences of analyzed characteristics mainly on seasons reflect that human activities is not yet dominant in modifying these parameters. This study will present the evolution of several characteristics, during five years (2018-2022).

2. The selected methodology and the time interval of the survey

The water sampling station is located near the city of Cahul, an emerging city as concerning economic, academic and social life in Republic of Moldova. Figure 1 presents the location of the water caption for this analysis.

Fig. 1. The water analysis center and the water sampling point.

The aim is to present the evolution of a set of characteristics from the River Prut water, for a five-year period, beginning early 2018 and over by the end of 2021, including the pandemic time. This report could be useful for evaluating trends. The samples have been collected from the river near Cahul city. It is worthy to mention that this time interval includes the pandemic years, 2020-2021, meaning a decrease of industrial and social activity all over the world, that could have affected some parameters.
There are few reports on the Prut River water [70], one including three sampling points in the middle of the watercourse, according to the cross-border monitoring protocols: North of Iasi–Victoria, Middle of Iasi-Tutora and South of Iasi Răducăneni, for 5-year period (2015–2019) [8]. Cahul is downstream these points and, as far as we know, this analysis is quite unique.

3. Discussion on recorded parameters

The discussion on the temperature of river water in Europe is based on the following references [2], [3]-[13].
During 2015-2022, the temperature of river water in Europe has been closely monitored due to its implications for ecosystems, human health and industrial water use (e.g., cooling in power plants). The trends during this period show both natural variability, the impact of climate change and the human activties (especially idustrial ones) [5], [12], [19], [26].
Key factors affecting river water temperature are climate change [6], [7], [11], [13, [18], [23], [24], [42], heat waves [4], [16], [17], rainfall patterns. Warming temperatures have been evident across Europe, leading to an increase in river water temperatures, particularly during summer months. Europe experienced several severe heatwaves between 2015 and 2022 (e.g., in 2018, 2019 and 2022), which led to elevated river water temperatures. Changes in precipitation and droughts [4] can also affect river temperatures. Low water levels and reduced flow rates can cause rivers to warm up more quickly.
The observed trends during 2015-2022 are the warming of river waters, the impact of the heat waves and the seasonal and regional variability [14]. Studies and monitoring programs have shown a clear trend of rising river water temperatures across much of Europe, during this period. The increase was particularly notable in Central and Southern Europe. In many rivers, summer temperatures rose above 25°C, which can stress aquatic ecosystems [20], [35], [36]. Some rivers, particularly in Southern Europe, recorded temperatures exceeding 28°C, during heatwaves [39]. While Northern Europe experienced more moderate increases, the overall trend was still upward. The heatwaves of 2018, 2019 and 2022 had significant impacts. The year 2018 was one of the hottest years on record in Europe. Rivers like the Rhine and the Danube experienced elevated temperatures, sometimes surpassing 27°C, causing issues for aquatic life and industries. The year 2022, with a record-breaking heatwave year, caused even greater spikes in river temperatures. In some cases, river water reached 30°C during prolonged heat

periods, particularly in Southern and Central Europe. While summers have been presenting the most extreme rises in river temperature, some regions experienced fluctuations depending on local climate and geography. In Western and Central Europe, rivers like the Loire, the Rhine and the Danube showed more consistent warming patterns, particularly during drought years. In Eastern Europe, rivers like the Vistula and the Dniester were affected by both heat and lower precipitation, which exacerbated warming trends.

There are ecological and economic impacts, including on fish and aquatic life, algal blooming and industrial challenges. Many species are sensitive to rising water temperatures. Salmon, trout and other cold-water fish struggle to survive in rivers where temperatures exceeded 23-25°C. Higher temperatures led to more frequent algal blooms, particularly in slower-moving waters. These blooms can deplete oxygen levels and, further, harm aquatic ecosystems. Many European power plants that rely on river water for cooling had to reduce output or shut down temporarily during peak heat events, particularly in 2018 and 2022.

For the Rhine River (Germany, Netherlands), temperatures regularly exceeded 25°C during summer months, causing ecological stress and industrial difficulties [56], [57]. For the Danube River (Central and Eastern Europe), the temperatures rose significantly, in some areas reporting 27-28°C during heatwaves [50], [60], [61], [62]. Also, the Loire River (France) was one of the warmest rivers during heat events, frequently reaching over 28°C, which caused significant stress on aquatic life.

Between 2015 and 2022, Europe's river water temperatures rose significantly, driven by both climate change and extreme weather events like heatwaves. This trend is expected to continue, posing risks to ecosystems, water quality, and industries reliant on rivers for cooling and fabrication processes [27].

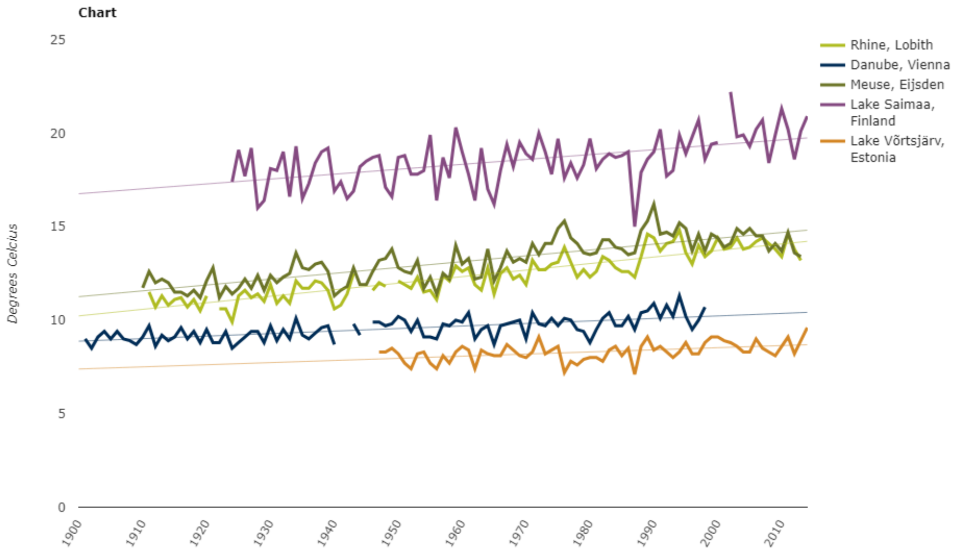

Fig. 2. Temperature evolution during a longer time period [19].

For the Prut River, during a year, there are two tendencies: cold water (November-March) and warm water (May-September), linked by a slope of 15 °C, lasting approximately 2 months. For the analyzed years, the water of the Prut River did not freeze. Figure 3 presents the evolution of river water temperature for the interval 2018-2022 and it varies with the seasons, local and continental geography and climate. It can impact the aquatic ecosystem, affecting the growth of aquatic plants and the behavior of aquatic organisms.

In Figure 3, the maximum, minimum and average measured values for water temperature during the surveyed period are represented. The average values are obtained for ecah month. The authors added the monthly evolution of the difference between the maximum and minimum values. Temperature evolution during this period is within a normal band, but with higher values for the summer of 2019. A seasonal variation is observed with maxima ranging from May to September. It is also observed the existence of cyclically varying differences with higher values in the months when the temperatures are higher (black line). Looking from right to left, the red line (the maximum values monthly recorded) has a light tendency to increase. Analysing Figure 3, the conclusion is that Prut River has a similar tendency with the central and Eastern Europe rivers.

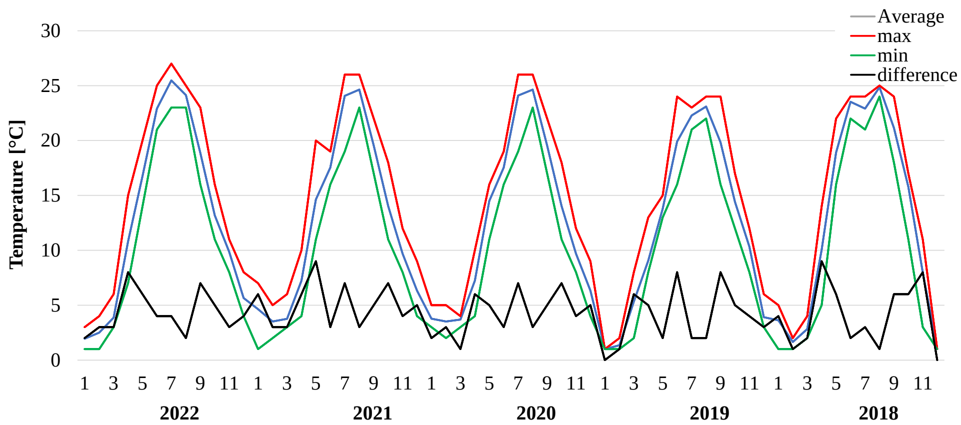

Fig. 3. Temperature graphs, in the time period 2018-2022.

The pH (acidity or alkalinity) of rivers in Europe during the period 2015-2022 has been influenced by a combination of natural factors and human activities, including climate change, industrial discharges, agricultural runoff and urbanization. Monitoring pH levels is important because pH can impact aquatic ecosystems, biodiversity, water quality and the suitability of water for human use [30], [33].

General trends during the period 2015-2022 include: stable but regionally variable pH levels, acidification and/or alkalinization, influences of climate changes, influences of pollution and human activities. Overall, the pH of most European rivers remained within a stable range, generally between 6.5 and 8.5, which is considered suitable for most aquatic life. However, there were regional differences due to factors such as local geology, land use, pollution and water management practices [34].

Some rivers, particularly in northern and western Europe, experienced slight acidification due to acid rain and runoff from acidic soils. This was particularly evident in Scandinavia, parts of the UK and Germany, where acid rain has historically affected river systems. In contrast, rivers in southern Europe and parts of central and eastern Europe showed tendencies toward alkalinization due to agricultural runoff (especially from fertilizers) and increased evaporation rates in drier climates, concentrating dicarbonate ions.

Climate change has indirectly affected pH levels by altering hydrological cycles (e.g., increased droughts and changes in river flow). Reduced river flow and higher evaporation rates in some areas have led to the concentration of dissolved substances, which can influence pH. For example, low water levels combined with increased nutrient loading in rivers can lead to eutrophication, which, in turn, can cause fluctuations in pH, especially in summer months.

Industrial discharge, agricultural runoff and sewage [37] can all impact pH levels. Rivers near urban or industrial areas, such as the Rhine, the Danube and the Loire, sometimes experienced localized fluctuations in pH due to these activities. In cases where mining activity (e.g., in parts of Eastern Europe) contributed to acid mine drainage, river pH levels temporarily dropped.

Many European rivers, particularly those flowing through regions with calcareous (limestone) geology, have a high buffering capacity, meaning they can neutralize acids and maintain stable pH levels even in the presence of acidic inputs. Rivers like the Danube, the Rhine and the Thames tend to have stable pH due to this natural buffering.

There are regional variations in river water pH in Europe. Rivers in Northern Europe (Norway, Sweden and parts of the UK) have experienced periods of slight acidification, especially in regions affected by acid rain. However, efforts to reduce sulfur and nitrogen emissions across Europe have largely improved conditions since the 1990s, leading to more stable pH levels during 2015-2022.

For Western and Central Europe, rivers like the Rhine and the Loire tend to have a neutral to slightly alkaline pH (around 7-8.5), influenced by agricultural runoff and urban pollution. However, these rivers are also well-buffered due to the geology of the regions they flow through. The Danube, being a large transboundary river, has been well-monitored and generally maintained stable pH levels, despite localized pollution [40], [60]. In Southern Europe, rivers such as the Ebro, the Po and the Tiber, have experienced slight alkalinization due to high evaporation rates and runoff from agricultural fields [39]. These rivers are also subject to seasonal fluctuations, with pH levels occasionally rising during summer months, when water levels are lower. In Eastern Europe, rivers such as the Vistula, the Dniester and the Dnieper have experienced localized fluctuations in pH, particularly in areas impacted by industrial pollution, mining and agricultural runoff. However, overall pH levels remained within the typical range of 6.5 to 8.5, with periodic monitoring showing no significant long-term trends toward acidification or alkalinization.

The values of pH for specific rivers are given bellow. The Rhine River has seen generally stable pH values, mostly ranging between 7.5 and 8.5, during the 2015-2022 period. Urban and industrial pollution have led to minor localized changes, but overall, the river benefits from its natural buffering capacity. The Danube, which flows through several countries, has had relatively stable pH levels ranging from 7 to 8. However, local pollution near industrial and agricultural areas caused occasional deviations. The Loire River (France) has experienced slight alkalinization, with pH values between 7.5 and 8.5 due to agricultural runoff. Seasonal fluctuations have been observed, especially during the summer when water levels drop. Poland's Vistula River revealed slight variations in pH, ranging from 6.8 to 8.2, influenced by both agricultural runoff and industrial effluents, with higher alkalinity in agricultural regions.
Based on references [30], [33], [61], it could be said that the pH levels in European rivers during 2015-2022 remained relatively stable, though subject to regional variations influenced by natural conditions, pollution, and climate change. Localized fluctuations due to acid rain, industrial discharge, and agricultural runoff were noted, but overall, most rivers stayed within the ecologically sustainable range of 6.5 to 8.5.

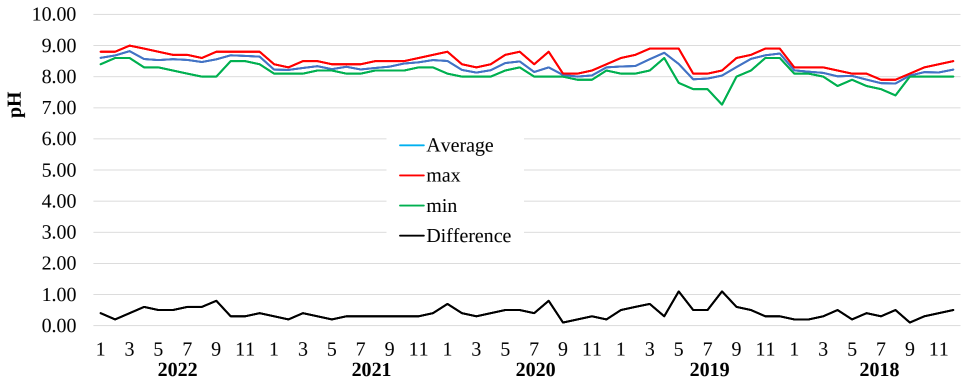

Fig. 4. pH graph of Prut River water, in the time period 2018-2022.

The pH level of river water shows acidity or alkalinity, on a scale of 0 to 14. The value 7.0 indicates the neutral level. The optimum pH for river water is considered around 7.4 and measuring this characteristic is very important for undergoing efficient drinkable water treatment and control processes. The maximum values for pH were recorded for late spring and winter in 2019, meaning a relationship to spring water (with high volumes and substances brought by affluents, seasonal rains, melting mountain snow). The pH values for the Prut River vary on a narrow scale, aprox. 7.7 to 8.9, for the monitored period. This graph shows that the waters of the Prut River are predominantly acidic, with peaks in the summer months. The observed variation is probably due to the low flow values, which produce an increase in the concentration of acid radicals in the river water.

The transparency (or water clarity) of European river waters is a critical parameter used to assess water quality and ecosystem health. It is typically influenced by factors like turbidity, sediment load, pollution and biological activity. Transparency is typically measured in centimeters. Factors affecting transparency in European rivers are sediment load [45], [46], algal blooms and eutrophication, pollution and urban runoff, dams and river regulation and seasonal and climate changes [67].

High sediment loads from upstream erosion, construction activities, deforestation, and agricultural runoff [25] can reduce transparency. Periods of heavy rainfall, particularly in Central and Eastern Europe, have led to high sediment levels in rivers like the Danube, the Rhine and the Po [47], [69]. Excessive nutrient loading (particularly from nitrogen and phosphorus) from agriculture and wastewater can lead to algal blooms, reducing water transparency. This issue has been notable in rivers like the Danube, the Loire and the Ebro. Pollution from industrial discharges, urban runoff, and untreated sewage [37] can introduce particulate matter and increase turbidity, reducing transparency in urbanized river sections like the Thames [55], [65], the Rhine and the Seine. Dams and river regulation can affect sediment transport and flow regimes, impacting water clarity both upstream and downstream. For instance, reservoirs in the Danube and the Rhine systems can trap sediments, improving clarity downstream, but leading to issues like sediment build-up upstream. Seasonal variations (especially in spring and autumn) and extreme weather events (e.g., floods and droughts) affect transparency across Europe. High rainfall can increase turbidity, while prolonged droughts, as experienced in Southern Europe (e.g., Ebro, Tiber), can concentrate pollutants and sediments, reducing clarity.

Here are some general observations from 2015-2022, on the European rivers.

In Northern European Rivers (e.g., Scandinavia, UK [55]), rivers like the Torne, the Thames and the Severn generally exhibit high transparency, with Secchi depths ranging between 50 cm and 200 cm. However, agricultural runoff and increased rainfall in some years have temporarily reduced clarity.

For Western and Central European rivers, representative data are given bellow. The Rhine River has shown a moderate increase in water clarity due to improved water quality management. Transparency typically ranges from 40-100 cm in more industrialized sections, but can reach up to 150 cm in cleaner, upstream parts. The Danube, which experiences considerable agricultural runoff, shows transparency varying between 30-100 cm, with reduced clarity during flooding events or algal blooms. The Loire in France has variable transparency (around 40-120 cm), with agricultural runoff and algal blooms impacting clarity, especially in warmer months [60]. Rivers in Southern Europe, such as the Ebro, the Po and the Tiber, often show lower transparency due to sediment from agricultural lands and higher evapo-transpiration. Transparency can range from 20-80 cm, particularly during summer months, when water levels are low and sediment concentration is higher. In Eastern Europe, rivers such as the Vistula and the Dniester tend to have moderate transparency, generally between 30-90 cm, depending on seasonal flows and sediment input from upstream agricultural areas. High rainfall during spring has led to lower transparency at times. The Dnieper has been affected by both sedimentation from upstream sources and pollution from industrial activities, leading to transparency levels between 30-70 cm in many regions.

Transparency in European rivers, during 2015-2022, could be reported as following:

- Northern Europe: higher transparency (50-200 cm) in rivers with less sediment load and pollution,
- Central and Western Europe: moderate transparency (40-150 cm), often affected by agricultural and urban runoff, but improved in well-managed areas like the Rhine basin,
- Southern Europe: lower transparency (20-80 cm) in rivers with high agricultural runoff and evaporation, such as the Ebro and the Po,
- Eastern Europe: moderate transparency (30-90 cm), but prone to reductions during high rainfall or pollution events.

For Prut River, the transparency is low, having the highest values during late autoumn and winter (16-23 cm), the lowest values being measured in late spring (May) till September, each year in this report. Only for the period 2020-2021, its transparency has high values during a longer period, this could be explained by the pandemic event.

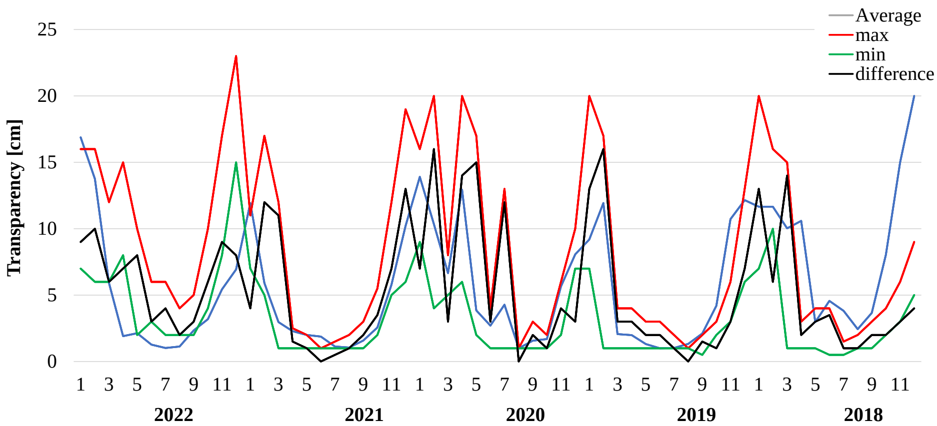

Fig. 5. Values of the water transparency, for the periode 2018-2022.

The transparency of European rivers during this period was generally stable, but subjected to regional variations based on factors like sedimentation, nutrient loading, and climate variability. But Prut River has lower values due to its geographical location, soil composition and seasonal rain regime (Fig. 5).

The monthly measured turbidity values are shown in Fig.6. Thus, some very important characteristics may be observed. The values of this parameter have an increasing trend from 2018 to 2021 and then an attenuating trend in the following period till 2022. The maximum values are, as expected, in the rainy months: March - May and the fall months, when the rains lead to a higher amount of silt. The maximum values during 2021 may possibly be explained by anthropogenic actions involving excavation activities or works upstream from the monitoring point.

The analysis of suspended mass is based on the references [21], [69]. Suspended mass, also referred to as suspended sediments or suspended particulate matter, is a critical factor in river water quality and ecosystem health. In Europe, suspended mass in river water originates from a variety of sources and influences rivers in several key ways.

Sources of suspended mass in European Rivers are: natural erosion, human activities (including agriculture, urbanization, industry and mining, dams and reservoirs), climate events. Soil erosion from riverbanks, mountain regions and floodplains during rainfall events or snowmelt adds suspended particles to rivers. In Europe, this is common in regions like the Alps, the Pyrenees and the Carpathians. Tillage and other farming practices lead to runoff that carries soil particles, fertilizers and pesticides into rivers. Construction, deforestation and improper land management increase soil erosion and lead to more particles entering in waterways. Industrial waste and mining activities can release fine sediments and chemicals into rivers, contributing to the suspended load. While dams trap a significant amount of sediment, they can also release fine particles when water is discharged downstream. Heavy rainfall, storms or flooding events increase runoff and erosion, causing a surge in suspended sediment in rivers. This effect can be more pronounced due to climate change.

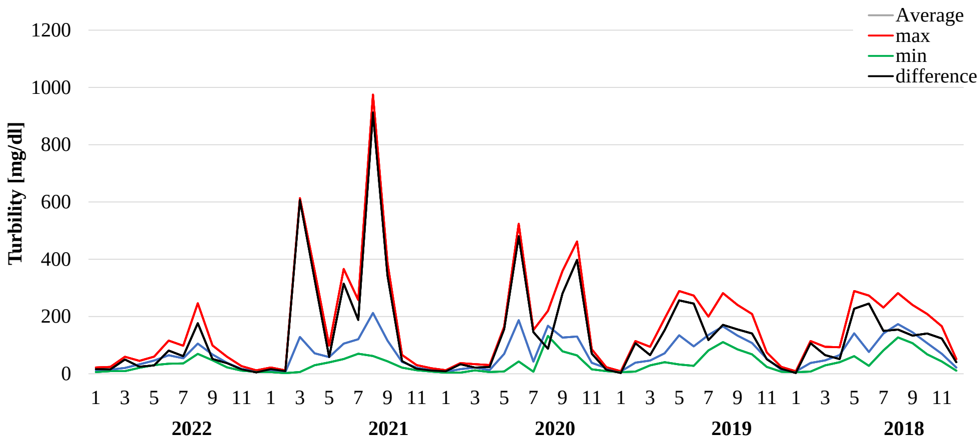

Fig. 6. Water turbidity in the time interval 2018-2022.

The impact of suspended mass in rivers affects water quality, ecosystem health, navigation and infrastructure [25].

High concentrations of suspended sediments reduce water clarity, which affects aquatic life, particularly photosynthesis for aquatic plants. Suspended particles can carry pollutants, such as heavy metals and organic contaminants, further degrading water quality [68], [75].

Sediment smothers fish eggs, affects benthic organisms (organisms living at the bottom of water bodies) and alters habitat structures. Fine sediments reduce the oxygen availability in the riverbed, which is crucial for many aquatic organisms.
High sediment loads can increase the need for dredging in rivers used for transportation (e.g., the Rhine or the Danube) and cause sediment deposition in reservoirs and dams, affecting their functionality.
Monitoring and regulation are key activity in maintaining a balance between river waters and human activities. The EU Water Framework Directive (WFD) [32], [41], [43], [44] plays a significant role in monitoring and managing suspended sediment levels in European rivers. It sets ecological and chemical water quality standards to ensure the health of aquatic ecosystems. Many European countries, through agencies like the European Environment Agency (EEA), have extensive monitoring networks in place to track suspended mass in rivers. Remote sensing technologies are also increasingly used for large-scale monitoring.
The trends in Europe could be particularly described by several geographical regions. In Scandinavia and parts of the UK, suspended sediment levels are generally lower due to less agricultural activity and better soil management practices, though flash floods can cause spikes. Regions in Central and Eastern Europe have intensive agriculture and industrial activities, like the Danube and the Vistula River basins, face higher levels of suspended mass. Sediment accumulation is a significant issue in these areas. Rivers in Mediterranean regions, such as Spain and Italy, can experience high suspended sediment loads due to more extreme rainfall patterns, steep terrain and ongoing land degradation.
Mitigation of issues related to suspended mass in rivers include: sustainable agricultural practices, riparian buffer zones and water treatment facilities. Reducing soil erosion through no-till farming, buffer zones and cover crops can limit the amount of soil entering in rivers. Planting vegetation along riverbanks can act as a filter, reducing the flow of sediments into the water. Improved treatment plants in urban and industrial areas can help reduce the entry of fine particles into rivers.
Suspended mass in European rivers is a complex issue influenced by both natural and anthropogenic factors, and its management is essential for protecting the region's water resources and aquatic ecosystems.
The period from 2015 to 2022 benefit of increased attention to suspended mass (or sediments) in European rivers [52]. During this time, significant developments were made in monitoring and managing suspended sediment loads. The following outlines trends and key data points related to suspended mass in European rivers during this period. During this period, the key factors influencing suspended mass were: climate change and extreme weather, land use changes and agricultural practices, human activity and urbanization, dam management and river regulation.
Increased frequency of heavy rainfall and flooding events in Europe between 2015 and 2022 led to more frequent surges in suspended sediment loads. Extreme weather events, such as those in Central and Eastern Europe, caused intense soil erosion and elevated sediment runoff into rivers. Droughts in Southern Europe (especially for the Mediterranean region) caused changes in sediment transport

dynamics [39]. When the rain returned after prolonged dry periods, there was a significant increase in sediment-laden runoff.

Intensified agriculture and deforestation in parts of Europe contributed to increased erosion rates, leading to higher levels of suspended mass in rivers. Some areas, like the Danube River Basin and parts of Central and Eastern Europe, experienced these effects more prominently. The European Union's Common Agricultural Policy (CAP) reforms introduced measures to reduce soil erosion and improve land management. These measures were progressively implemented, but impacts were variable across regions.

Urbanization during this period contributed to an increase in impervious surfaces, which exacerbated surface runoff and accelerated sediment transport into rivers, particularly in densely populated regions. Construction and infrastructure projects in urban areas (e.g., transportation networks, housing developments) significantly impacted local sediment dynamics. These effects were especially seen in major European cities, along rivers like the Thames, the Seine [54] and the Rhine.

Hydropower dams and other water management infrastructure have had complex impacts on sediment transport. Dams tend to trap large volumes of sediments in reservoirs, but periodic releases or sediment management activities can cause localized increases in suspended mass. There was an ongoing trend toward restoring river continuity and reducing the impact of dams on sediment transport. Notable projects, such as dam removals or improved sediment passage mechanisms, in countries like France and Spain, aimed to address sediment deficits downstream.

There is a very brief analysis of suspended mass for the period 2015-2022.

Rivers like the Rhine and the Thames (in Northern and Western Europe) showed generally lower levels of suspended sediments, except during flood events or following intensive storms. However, heavy industrial and agricultural activities contributed sporadically to localized increases in suspended loads. Restoration projects aimed at improving water quality and reducing sediment loads were particularly active. Initiatives to restore wetlands and riparian zones helped reduce the sediment entering rivers.

In Central and Eastern Europe, the Danube basin, one of Europe’s largest and most significant rivers, has exhibited varied trends in suspended mass. Some areas experienced reductions in sediment loads due to improved soil conservation practices, while others faced increased loads from upstream sources. Sediment transport in the Elbe and the Vistula rivers was also influenced by seasonal flooding and changes in land use. Flood control measures and river engineering projects affected suspended sediment dynamics.

In Southern Europe, Mediterranean rivers, such as those in Spain, Italy and Greece, experienced fluctuations in suspended sediment levels due to the dual impacts of drought and sudden heavy rainfall events. Intense storms caused flash floods, dramatically increasing suspended sediment loads. In regions like the Po River basin in Italy, agricultural runoff and sediment deposition became an increasing concern.

The measured monthly values for total suspended solids are shown in Fig. 7. Thus, some very important characteristics may be observed. The values of this parameter have a punctually more pronounced trend during 2018 and 2021 and, then, a local maximum trend during the spring-summer period in the following year. The maximum values are, as expected, in the spring-summer and fall months, respectively, when the rains entrain a higher amount of silt. Maximum values during 2021 may possibly be explained by anthropogenic actions involving excavation activities or upstream works and the fact that the pandemic period was ended and the industrial activities (including building and urbanization in Cahul, which have higher intensity).

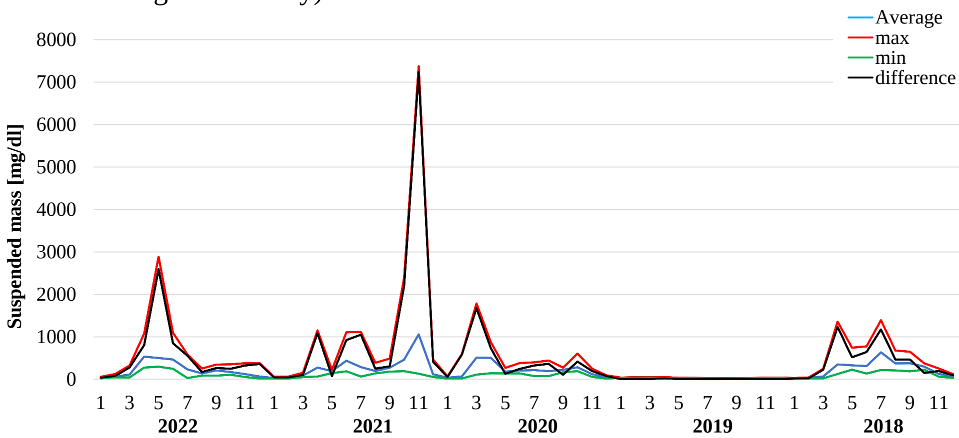

Fig. 7. Manthly values for total suspensions, in the time interval 2018-2022

Alkali levels in river water, which are influenced by the presence of alkaline substances, such as bicarbonates, carbonates and hydroxides of elements like calcium, magnesium, sodium and potassium, play an important role in the chemical composition of European rivers. Between 2015 and 2022, alkali concentrations in European river systems were influenced by a range of natural and anthropogenic factors, including land use, industrial discharges, urbanization, acid rains, agricultural runoff, hydrological variability, water treatment and climate change.

Fertilizer use, especially those containing potassium and sodium compounds, contributed to elevated alkali levels in some European river systems. Regions with intensive agricultural practices, particularly in Central and Eastern Europe, experienced this effect. The use of agricultural lime (calcium carbonate) to reduce soil acidity indirectly increased bicarbonate concentrations in water runoff, thereby elevating the alkalinity of rivers.

Alkali substances used in industries such as mining, chemical production and wastewater treatment contributed to the increase in alkalinity in certain river systems. This was especially relevant in areas with significant industrial activity, such as the Rhine and the Danube basins. Cement and construction activities along riverbanks, especially during urban expansion and infrastructure projects, added calcium and magnesium carbonates to water systems, influencing alkali levels.

In some areas, natural processes, like the dissolution of limestone and dolomite in catchment areas, played a role in neutralizing acid deposition (by acid rain), thus contributing to higher alkalinity in rivers. This was especially evident in parts of Southern and Eastern Europe, where geological formations are rich in carbonate rocks. The legacy of past sulfur dioxide emissions, despite reductions, had a continuing influence on soil and water chemistry, but the buffering capacity of alkaline substances in river systems mitigated some of the long-term effects of acidification.

Changes in precipitation patterns, temperature and evaporation rates due to climate change affected water flow and, consequently, the concentration of dissolved alkali substances in rivers. Drought conditions, particularly in Southern Europe, increased the concentration of dissolved ions (including alkalis) in river systems due to lower water volumes.

Wastewater treatment plants, particularly in urbanized areas, often discharge effluents with elevated levels of alkali substances, contributing to the overall alkalinity of river water. These impacts were most noticeable in heavily populated areas of Western Europe, such as the Thames and the Seine river systems. The use of chemicals like sodium hydroxide and calcium hydroxide in water treatment facilities to adjust pH levels also affected the downstream alkalinity of treated effluents.

Regional trends during 2015–2022 are summarized from [63].

Rivers in Western Europe, such as the Rhine and the Thames, exhibited moderate to high levels of alkalinity, largely due to industrial activity and wastewater treatment discharges. The Rhine River saw some fluctuations in alkali concentrations due to both industrial effluents and improved regulation under the Water Framework Directive (WFD).

In Central and Eastern Europe, in the Danube River Basin, agricultural runoff contributed significantly to increased alkali levels, particularly in areas where potassium-based fertilizers were widely used. The rivers in Poland (e.g., the Vistula River) experienced elevated alkalinity due to mining activities and agricultural practices that introduced alkaline substances into the waterways.

In Southern Europe, Mediterranean rivers, such as the Ebro and the Po, showed variations in alkali concentrations due to droughts, which concentrated dissolved substances in the water. Agricultural activities also played a role in raising the alkalinity in these regions.

The Tiber River in Italy had rising alkalinity, primarily due to both natural causes (carbonates from limestone) and anthropogenic activities such as agriculture and urban runoff.

In Northern Europe, rivers in Scandinavia (e.g., the Göta Älv in Sweden) exhibited relatively low levels of alkalinity as compared to other parts of Europe, though episodes of increased alkalinity were noticed, particularly during dry seasons or after industrial activities.

Key findings on alkalinity of European rivers, for the period 2015–2022, are:

- stable to slightly increasing alkalinity levels: across many European rivers, alkalinity levels were generally stable, though some rivers experienced slight increases, particularly those influenced by agriculture and industrial activities.
- regional variations: Southern European rivers, particularly those affected by droughts, showed more significant variations in alkalinity levels compared to rivers in Northern Europe.
- impact of human activities: human-induced changes, such as agriculture, industrial discharges and urbanization, continued to play a major role in influencing alkali levels in rivers.

The period from 2015 to 2022 highlighted both the resilience and vulnerability of European rivers to changes in alkali concentrations, with ongoing efforts to monitor and manage these changes as part of broader water quality improvement initiatives under the Water Framework Directive [59].

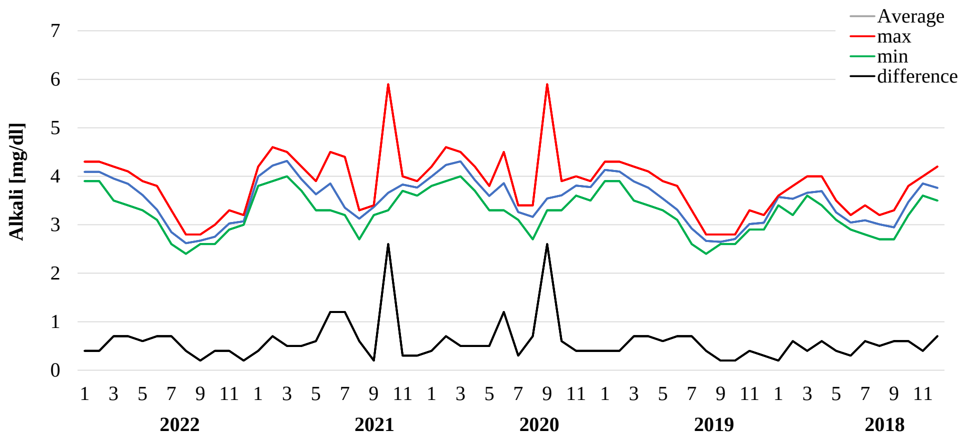

Fig. 8. Monthly values of alkali concentration, for the time interval 2018-2022

Figure 8 shows the monthly average measured values of alkali radical concentration for the Prut River, during the studied period. Maximum values are recorded in the fall months, with a unimodal maximum in the spring months. This interesting phenomenon has also been observed in the Danube studies [62]. The concentration of alkaline radicals and the concentration of ions with alkaline character is correlated with the erosion and transport phenomena.
Figure 9 shows the monthly measured values of chlorine radical concentration during the studied period. The maximum values are recorded in the months complementary to those previously observed (May-June), with a unimodal maximum in the spring-summer months. This phenomenon was also observed in the Danube studies. The concentration of chlorinated radicals is correlated with the biological pollution phenomenon and has a lag with the natural biological phenomena in the area.

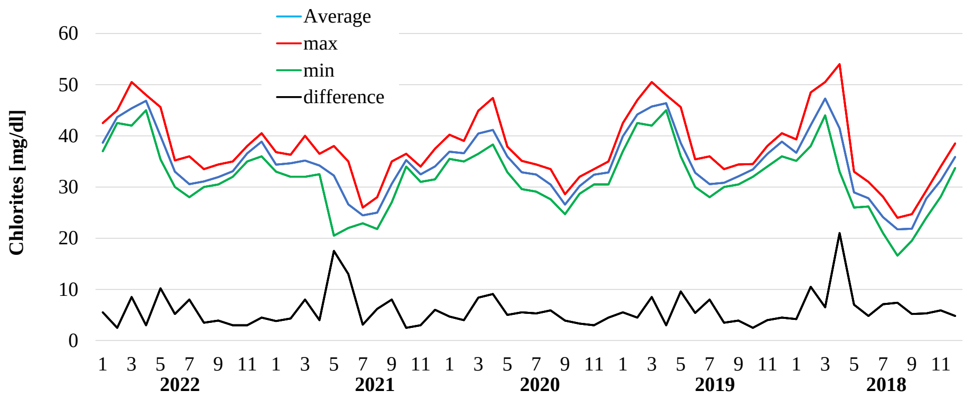

Fig. 9. Monthly values for clorites' concentration, for the time interval 2018-2022

The nitrogen coumpounds are analyzed based on references [25], [67]. Ammonia (NH_3), nitrites (NO_2^-) and nitrates (NO_3^-) are critical nitrogen compounds often monitored in river waters due to their impact on water quality and ecosystem health. These compounds can enter rivers through agricultural runoff, wastewater discharge and industrial activities, potentially leading to eutrophication, fish toxicity, and human health concerns when they are present in drinking water sources.

An overview of Nitrogen compounds in European rivers (2015–2022) are abstracted in the following lines, based on [25], [52].

Ammonia (NH_3/NH_4^+) primarily originates from agricultural activities (e.g., livestock waste and fertilizers) and wastewater treatment plant effluents. High ammonia concentrations are toxic to aquatic organisms and can lead to oxygen depletion in water bodies.

Nitrites (NO_2^-) are an intermediate compound in the Nitrogen cycle, produced by the oxidation of ammonia and reduced further into nitrates. Elevated nitrite levels can be toxic to fish and other aquatic organisms due to their role in disrupting oxygen transport in blood.

Nitrates (NO_3^-) form through the oxidation of nitrites and are often associated with agricultural runoff, particularly the leaching of fertilizers. Excess nitrates contribute to eutrophication, promoting excessive algal blooms and deteriorating water quality.

The European Union's Water Framework Directive (WFD, 2000/60/EC) [44], [50] and Nitrates Directive (91/676/EEC) [76] are the main frameworks governing nitrogen compounds in water bodies. The WFD aims to achieve good chemical and ecological status in European waters, while the Nitrates Directive specifically addresses agricultural sources of nitrate pollution, setting a limit of 50 mg/L for nitrates in freshwater.

The EU Drinking Water Directive (Council Directive 98/83/EC, updated in 2020) also sets standards for ammonia, nitrites, and nitrates in drinking water: Ammonia: 0.5 mg/L, Nitrite: 0.5 mg/L and Nitrate: 50 mg/L

The EEA's Water Quality Reports regularly assess nutrient levels (including ammonia, nitrites, and nitrates) in European surface waters. According to the 2022 Water Quality in Europe report [77], nitrogen pollution, especially from agriculture, remains a significant challenge in certain river basins such as the Danube, the Rhine, and the Po rivers. Nitrate concentrations frequently exceeded 25 mg/L in agricultural regions, with ammonia concentrations often high downstream of wastewater treatment plants.

In 2019, the Danube River Basin Management Plan, reportated that ammonia levels in the lower reaches of the river were found to be elevated due to untreated or partially treated wastewater discharges from urban and industrial areas. Concentrations of ammonia ranged from 0.1 mg/L to 0.6 mg/L, especially near industrial zones. Nitrate concentrations were reported to be higher in agricultural areas of the basin, with levels between 10 mg/L and 40 mg/L, particularly downstream of the Danube's tributaries in Hungary and Romania [38], [60].

The International Commission for the Protection of the Rhine (ICPR) published a report [71], highlighting that nitrate concentrations in the Rhine River remained stable, but high, especially in the middle and lower sections, from 20 mg/L to 40 mg/L. The source of the nitrates was largely agricultural runoff and fertilizers from the Netherlands and Germany. Ammonia concentrations were generally low, but were elevated near wastewater discharge points, peaking at 0.3 mg/L.

Italy’s Po River Basin Authority published a 2021 report showing an increasing trend in nitrate levels due to agricultural activities. Nitrate levels frequently ranged between 25 mg/L and 45 mg/L in the basin of agricultural plains. Ammonia levels were higher in urban and industrial areas of the Po River, with concentrations up to 0.5 mg/L detected near large cities such as Milan.

Specialists identified agriculture as the primary contributor to nitrate pollution [20]. The study focused on rivers in agricultural regions like the Loire (France) and Tagus (Spain and Portugal), with nitrate concentrations ranging from 15 mg/L to 50 mg/L during peak agricultural seasons. Nitrites were generally found at lower concentrations, ranging from 0.01 mg/L to 0.3 mg/L, but could spike near wastewater treatment plants or industrial effluents.

The Environment Agency of England reported in 2021 that nitrate pollution remained a critical issue in English rivers like the Thames and Trent [29]. The nitrate levels were generally above 30 mg/L in agricultural catchments, and occasional spikes of nitrite concentrations (up to 0.1 mg/L) were linked to wastewater treatment malfunctions. The UK also reported ammonia spikes in urban river stretches, particularly during combined sewer overflows, up to 0.4 mg/L.

During the time interval 2015–2022, there were noticed the following trends:

- for ammonia: ammonia levels have generally decreased in many European rivers, thanks to improved wastewater treatment processes; however, localized spikes still occur, especially near industrial zones and urban wastewater discharge points.
- for nitrites: nitrite levels have remained relatively stable and low across european rivers, largely due to effective nitrification processes in wastewater treatment plants. however, instances of nitrite pollution still occur near malfunctioning or overloaded plants.
- for nitrates: nitrate pollution remains a significant challenge, particularly in agricultural regions. Despite the efforts of the Nitrates Directive [76], many rivers in Western and Southern Europe continue to report high nitrate concentrations, particularly during rainy seasons when agricultural runoff is at its peak.

Monitoring and regulatory efforts continue to address these pollutants, but agricultural and urban wastewater sources remain critical challenges for achieving better water quality.

Naturally ammonia is monitored at the water source. Ammonia is harmless in low concentrations, but high concentration values cause environmental damage and bring health risks. For the river Prut, this characteristic evolves in the range 0.05-0.14 mg/dl, for the analyzed period. The spike during almost two weeks could be the results of industrial activity, but this seems to be an accidental event as it is not repeated for all the analyzed period. Lower values were recorded during 2020, giving researchers the baseline to presume that industry stops has impacted the content of ammonia in Prut water.

Nitrates are found in different forms in land and aquatic ecosystem as ammonia (NH3), nitrates ($-NO_3$) and nitrites ($-NO_2$). In excess nitrates can cause significant water quality issues, like eutrophication, hypoxia, temperature and other water characteristics. It can become toxic to warm-blooded animals at higher concentrations than 10 mg/dl. Lower levels of nitrates were recorded starting with autumn 2019 and 2020, but the following year had had higher values. The higher values characterized the winter end and the spring of each year.

The monthly measured values for total nitrate concentration are shown in Figure 10, allowing for noticing important characteristics. Nitrate concentration is related to natural biological pollution phenomena. In this case, the configuration of the graph is unimodal, with a maximum during the vegetal growing season. The values of this parameter have a somewhat constant trend between 2018 and 2022, which may be explained by constant biological activity undisturbed during this period.

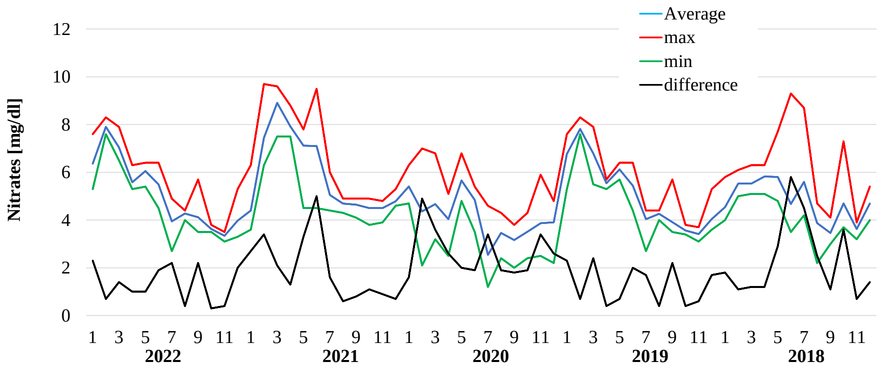

Fig. 10. Montly measured values for nitrate concentration in the time interval 2018-2022.

The monthly measured values for total nitrite concentration are shown in Figure 11. Nitrite concentration is related to natural biological pollution processes. In this case, the configuration of the graph is unimodal, with a maximum during the vegetation period. The values of this parameter have a somewhat constant trend between 2018 and 2022, which can possibly be explained by constant undisturbed biological activity during this period (pandemy started in the december 2019 and continued till 2021).

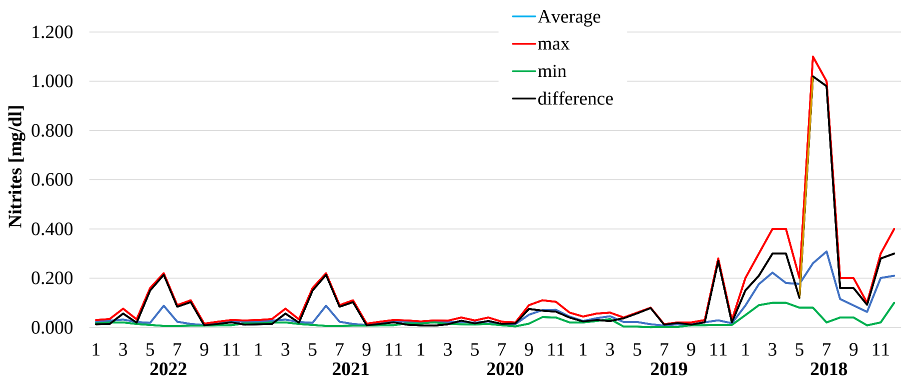

Fig. 11. Monthly measured values for concentration of nitrites, during the time interval 2018-2022.

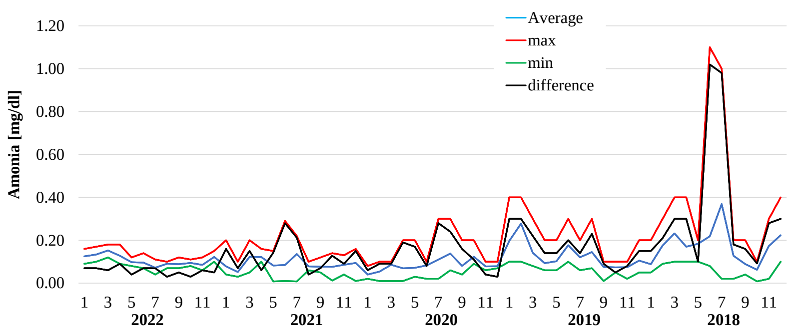

Fig. 12. Monthly measured values of amonia concentration, during the time interval 2018-2022.

The monthly measured values for total ammonia concentration are shown in Figure 12. The ammonia concentration, in correlation with the other nutrient concentrations, is related to natural biological pollution phenomena. This graph, too, is unimodal, with maximum during the vegetation period. The values of this parameter have a somewhat decreasing trend between 2018 and 2022, which can possibly be explained by anthropogenic actions that led to the elimination of this compound.

Oxidability is a measure of the capacity of river water to undergo oxidation, which generally reflects the presence of organic and inorganic compounds that can be oxidized. It is often linked to water quality indicators such as organic matter content, pollution levels, and biological activity. In European rivers, oxidability is an important parameter for assessing the chemical quality of water, as it can indicate the presence of contaminants such as industrial pollutants, agricultural runoff, and untreated wastewater [53].

Oxidability is typically measured using two primary indicators:

- chemical oxygen demand (COD) – a measure of the total amount of oxygen required to chemically oxidize organic and inorganic matter in the water,
- biochemical oxygen demand (BOD) – a measure of the oxygen consumed by microorganisms while decomposing organic matter in the water over a set period (typically five days).

These indicators give insight into the organic pollution load in river waters. High oxidability can result from pollution sources such as agricultural runoff (rich in organic matter and nutrients), industrial discharges, and urban wastewater.

The European Union's Water Framework Directive (WFD, 2000/60/EC) sets the framework for monitoring and achieving "good chemical status" for surface waters, including rivers. This includes monitoring parameters like BOD and COD to assess organic pollution levels and the general oxidability of water.

The EEA publishes regular assessments of water quality in European rivers. In the 2020 EEA Report on water quality, COD levels were noted as critical indicators of organic pollution, especially in heavily urbanized and industrial regions. The report highlights that although there has been an overall improvement in European water quality, some regions, especially Eastern and Southern Europe, still exhibit high oxidability due to untreated or partially treated wastewater. In 2021, the EEA noted that rivers like the Danube, Rhine, and Seine had relatively stable BOD levels, but certain hotspots showed increased oxidability due to diffuse pollution sources such as agriculture.

The Danube River Basin Management Plan [68] reported that the river's upper reaches had relatively low oxidability (measured by COD levels), reflecting better water quality. However, in the lower reaches (especially downstream of large urban areas like Budapest and Belgrade), COD values reached 40-60 mg/L, signaling significant organic pollution. BOD levels in the lower Danube also increased due to untreated urban wastewater and agricultural runoff, with values around 4-8 mg/L in more polluted stretches, compared to 1-3 mg/L in cleaner sections.

A 2020 report from the International Commission for the Protection of the Rhine (ICPR) [53] noted that the Rhine's overall water quality has improved, with a general reduction in BOD and COD levels. COD levels were reported at around 10-20 mg/L in the upper Rhine and 20-30 mg/L in the lower Rhine, showing a moderate organic load from industrial and urban sources. In particular, BOD levels ranged between 1-3 mg/L in the upper sections and increased slightly in the middle and lower sections (especially near urban centers like Rotterdam), with values up to 4-6 mg/L.

The Seine River Basin Report (2021), published by Seine-Normandie Water Agency, indicated that COD levels in the river have been decreasing over the past decade, reflecting improved wastewater treatment infrastructure. However, despite these improvements, parts of the Seine downstream of Paris still exhibited COD levels of 30-50 mg/L, particularly in periods of high flow or following rain events that wash pollutants into the river. BOD levels in the Seine were also higher in urban sections, with values between 4-7 mg/L, indicating ongoing organic pollution from untreated or partially treated urban wastewater [64], [63].

The Po River, which runs through one of Italy's most industrialized and agriculturally intensive regions, experienced high oxidability levels, particularly in its lower stretches. COD values ranged from 20 mg/L in the upper sections to 40-60 mg/L downstream of major cities like Milan and Turin. BOD levels were also higher in the Po's lower reaches, with values ranging from 3-6 mg/L, linked to agricultural runoff and urban wastewater inputs [79].

According to a 2020 report from the UK Environment Agency [55], the Thames River experienced fluctuating oxidability levels, with COD values averaging 25-35 mg/L in urban stretches. Improved wastewater treatment has helped reducing BOD levels to around 2-4 mg/L in most sections. The Trent River, flowing through the Midlands, showed similar trends, with COD levels ranging between 20-30 mg/L and BOD values around 3-5 mg/L, particularly in areas with significant agricultural and urban discharges.

Trends for this parameter for the period 2015–2022 include a general improvement and localized hotspots.

Many European rivers have improved water quality and lower oxidability levels over the past few decades due to investments in wastewater treatment infrastructure and tighter regulatory frameworks like the Water Framework Directive [44], [50]. However, regional disparities remain, with Eastern and Southern Europe exhibiting higher oxidability levels, particularly in river basins with intensive agricultural or industrial activities.

Urban areas, industrial zones and regions with intensive agriculture continue to show elevated oxidability levels due to organic and inorganic pollutants entering the water systems. Heavy rainfall and flood events can lead to temporary spikes in oxidability, as pollutants from agricultural runoff and untreated wastewater are washed into rivers. Examples of measured oxidability (BOD and COD) in European Rivers (2015–2022) are given: the Danube River has COD with 40–60 mg/L (lower reaches) and BOD with 4–8 mg/L, the Rhine River recorded for COD10–30 mg/L and for BOD 1-6 mg/L. The Seine River had COD of 30-50 mg/L and BOD of 4-7 mg/L (near Paris), the Po River has COD of 20–60 mg/L and BOD of 3–6 mg/L (downstream Milan and Turin) and the Thames River recorded COD of 25–35 mg/L and BOD of 2–4 mg/L.
Figure 11 shows the monthly measured values of dissolved oxygen concentration (COD) during the studied period. The maximum values are recorded in the months complementary to those previously observed, with a unimodal maximum in the spring-summer months. This phenomenon has also been observed in the Danube studies [28], [30], [31], [67], [70], but values are higher than those for the Prut river. The dissolved oxygen concentration is correlated with the biological activities and has a lag with the natural biological phenomena in the area.

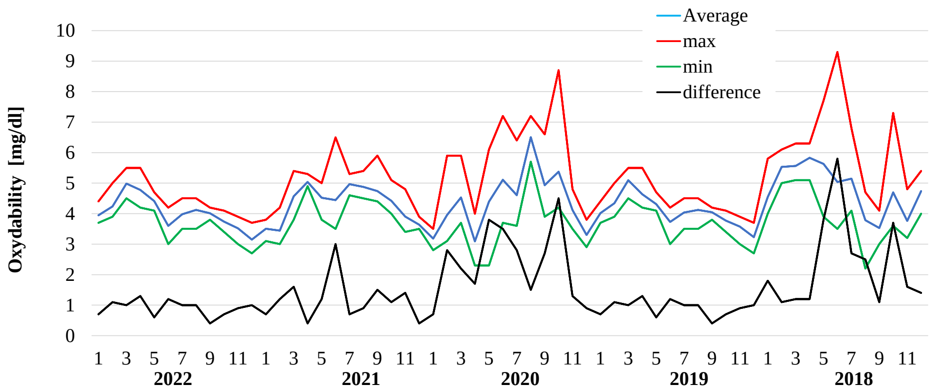

Fig. 13. Monthly measured values for disolved oxygen,
for the time interval 2018-2022.

4. Conclusions

The Prut River, a major tributary of the Danube, forms part of the border between Romania and Moldova and runs through Ukraine. It plays a critical role in regional water supply, agriculture and ecosystems. Monitoring water quality in the Prut during 2018–2022 provides insights into the river's condition relative to other European rivers.
Key characteristics of the Prut River water for the analyzed period (2018–2022) lead to the conclusion that the Prut River basin is moderately impacted by human activities, including agriculture, wastewater discharges and urban development,

being considered less polluted as compared to highly industrialized European rivers. Based on water monitoring reports from Romanian [72] and Moldovan authorities (such as the Romanian National Administration "Apele Române"), the Prut water quality is generally classified as moderate to good, particularly in its upper and middle sections, with some local areas experiencing higher pollution levels.

Similar to other European rivers, nutrient pollution in the Prut is primarily driven by agricultural runoff. Excess nutrients can lead to eutrophication (overgrowth of algae, which can reduce oxygen levels and harm aquatic life) [51]. Nitrogen compounds (nitrates and nitrites) have been reported at moderate levels as compared to heavily polluted rivers like the Rhine or the Danube. According to a study for the year 2021, published by the International Commission for the Protection of the Danube River (ICPDR), nitrate concentrations in the Prut were typically around 2-10 mg/L, which is lower than agricultural hotspots in the Danube, where nitrate levels often reach 15-40 mg/L in polluted sections [50].

Chemical Oxygen demand (COD) values were reported between 15-30 mg/L, generally comparable to European rivers with moderate pollution levels. The Danube, for instance, reports COD values between 20-40 mg/L in more polluted stretches, while the Rhine has COD values of 10-30 mg/L in its main sections [50].

The Prut River exhibits seasonal variations in temperature and flow, typical of rivers in Eastern (continental) Europe. The water temperatures during the summer months were reported between 20-24°C, similar to the Danube and the Dniester. During winter, temperatures drop below 10°C, and in some stretches, the river may freeze during colder winters. The Prut experienced moderate flow fluctuations between 2018 and 2022, with occasional floods, although these events were less frequent and much less severe as compared to larger European rivers, such as the Rhine or the Po.

The comparison with other European rivers (for the period 2018–2022) reveals that the Prut River has a moderate water quality, with relatively low industrial pollution as compared to Western European rivers that are more heavily impacted by urbanization and agriculture, particularly in its lower reaches. The Prut River is a tributary of the Danube, the contributing water being of generally better quality to the Danube. The Rhine River being significantly more industrialized, has higher levels of organic pollution (BOD, COD) and chemical contamination (heavy metals) [71]. The Po River is a heavily polluted river in Northern Italy, with high levels of nutrients, organic pollution and industrial chemicals [78].

The Prut River has moderate nutrient levels, with nitrates in the 2-10 mg/L range. The Loire River (France) reveals higher nitrate levels, often exceeding 15-20 mg/L in agricultural areas. The Po River has very high nutrient concentrations due to extensive agriculture, with nitrate levels often above 25 mg/L [52].

The Danube River has slightly higher organic pollution in its lower reaches, with BOD values between 4-8 mg/L and COD ranging from 20-40 mg/L. The Seine River has been recorded higher organic pollution in urban sections near Paris, with BOD levels often reaching 4-7 mg/L and COD up to 50 mg/L.

The Prut water quality relative to other European rivers, is indicating that the Prut water is moderately impacted by pollution, but fares better in terms of industrial contaminants as compared to heavily industrialized rivers in Western Europe.

Based on the survey during the years 2018-2022, the following conclusion on water of Prut River could be drawn. Prut water characteristics have specific evolutions due to its geographical position, specific climate and because the survey included the pandemic years.

There were identified two groups or parameters: parameters that are not depending on the year seasons (like pH) and those depending on the year seasons (most of the analyzed characteristics here presented).

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