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IMPACT OF BUCHAREST WASTEWATER ON DAMBOVITA RIVER WATER QUALITY (2010-2015)

Rodica-Mihaela FRÎNCU[1] & Olga IULIAN[2]

National Institute for Research & Development in Chemistry and Petrochemistry ICECHIM, 202 Splaiul Independenței, Sector 6, Bucharest, Romania, Călărași Branch, Corresponding author e-mail: icechim.calarasi@gmail.com
Politehnica University of Bucharest, Dept.of Applied Chemistry and Materials Science[2]

Abstract: Bucharest, the capital of Romania, is located on the banks of Dambovita River, tributary of Arges River, which, in its turn, flows into the Danube, the second longest river in Europe. Until 2011, Bucharest wastewater treatment plant (WWTP) had no advanced treatment, and since the end of 2011 the plant is able to treat half of the incoming flow. The second upgrading phase is under construction. This paper presents monitoring data of Dambovita River, upstream and downstream from Bucharest WWTP, during the period 2010-2015. Annual means of main nutrients concentrations show that water quality was mostly in the first class before the WWTP, according to Romanian norms, and in the worst class downstream from the WWTP, particularly for ammonium and total phosphorus, which are indicators of sewerage pollution. Pollution is attenuated by dilution after confluence with the Arges River. Principal Component Analysis and factor analysis of monitoring data show the differences between sampling locations and strong positive correlations between ammonium, orthophosphates and total phosphorus. Nutrient pollution downstream from Bucharest has decreased after 2010, but more efforts to improve wastewater treatment are needed in order to comply with national and international regulations.

Keywords: nutrients pollution, municipal wastewater, Bucharest, Dambovita, principal component analysis,

1. INTRODUCTION

Water plays an essential role in sustaining life, and it also has many uses in human activities, like power generation, transport, industrial processes, source of food etc. Industrial development and population growth had a negative impact on water quality in Europe during the 1970’ and 1980’ periods (Bodík 2006, Cociasu & Popa 2004). The main sources of water pollution are municipal sewerage, industrial wastewater, agricultural activities and atmospheric deposition (Diamantini et al., 2018). Pollution may originate from point sources and diffuse sources. The most important point source of water pollution in the European Union is untreated or insufficiently treated urban wastewater (European Commission 2019).

The release of nutrients from urban agglomerations to surface water bodies may lead to imbalances in the aquatic ecosystems, so appropriate wastewater treatment is required to avoid environmental damage. Pollution with sewerage wastewater poses several environmental and health risks, including eutrophication and loss of diversity in aquatic ecosystems, but also transmission of diseases, when drinking or bathing waters are contaminated (Kirschner et al., 2017, Hamchevici & Udrea 2015, Anghel et al., 2017, Spiridon et al., 2018, Lacatusu et al. 2019).

Council Directive 91/271/EEC (1991), also known as the Urban Wastewater Directive (UWWD), requires all member states to ensure collection and appropriate treatment of urban wastewater before discharging it to receiving water bodies, to preserve and improve water quality.

Romania has joined the European Union (EU) in 2007 and had to comply with the provisions of the UWWD until 31 December 2018. On 7 June 2018, the European Commission has sent a formal notice to Romania, because 189 large agglomerations still did not have collection systems and 198 did not have appropriate treatment capacities. Moreover, according to 2016 data, Bucharest was discharging 52% of its sewerage water without secondary treatment, and the rest of the flow did not meet removal requirements, mainly for nitrogen (N) and phosphorus (P). Another EU Capital City that failed to comply was Copenhagen (located at the Baltic Sea), while Bratislava (located on the Danube) has become fully compliant during the period analysed by a recent report released by the European Commission (Fribourg-Blanc et al., 2020). Among the reasons for Bucharest failing to comply, despite available financial support from the EU, were the lack of administrative capacity and issues with procurement rules (European Commission 2019).

Bucharest, the capital city of Romania, has a population of about 2 million inhabitants, and is located in the Lower Danube basin, on the banks of Dambovita River, an Arges tributary that flows into the Danube. Until 2011, municipal wastewater from Bucharest was discharged to Dambovita River right after mechanical treatment, and since the end of 2011 the wastewater treatment plant (WWTP) at Glina can ensure secondary treatment for about half of the incoming flow (~10 m^3/s). The other half is still being discharged after primary treatment, because the second phase of upgrading works was delayed, and only started in 2017, construction works being still in progress. The discharge of insufficiently treated municipal wastewater from Bucharest City has a negative impact on Dambovita and Arges rivers, the nutrients and organic pollutants being further carried to the Danube and the Black Sea.

During the 3rd Joint Danube Survey in 2013, a high level of faecal pollution was found downstream from Arges discharge. A follow-up study carried out in 2014 in three capital cities located on the Danube (Vienna, Budapest and Belgrade) found low to moderate sewerage pollution in Vienna, moderate pollution in Budapest and mostly critical pollution in Belgrade (Kirschner et al., 2017).

There are several studies investigating Lower Danube water quality, including the impact of wastewater discharges (Bodík 2006, Alygizakis et al., 2019, Gavrilescu et al., 2020), but to the best of the authors' knowledge no paper addressed the impact of Bucharest WWTP on Dambovita River nutrients pollution based on monitoring data during recent years.

A study by Dumitrache & Diacu (2010) ,has presented monitoring data for Ialomita River, another Danube tributary, based on monthly nutrients values during the period 2003-2008 and included only descriptive statistics (Dumitrache & Diacu 2010). The study identified pollution with municipal wastewater from Slobozia (around 45,000 inhabitants) and Tandarei (around 13,000 inhabitants) localities.

A project funded by the Ministry of Research of Romania has supported extensive studies regarding water quality in Bucharest area in the year 2018 (Ionescu et al., 2019a, Ionescu et al., 2019b, Radu et al., 2019, Dumitru et al., 2020). In the case of Dambovita River, the study was based on 4 samples collected in June 2018, 2 from Dambovita River, upstream and downstream from the Glina WWTP, and 2 from the Arges River, before and after confluence with Dambovita.

The purpose of this paper is to analyse the impact that municipal wastewater discharged from Bucharest WWTP has on nutrients concentrations in Dâmbovița and Argeș rivers, as well as the way in which pollution levels have evolved during the analysed period (2010-2015).

This study is part of a series of studies dedicated to water quality in the Lower Danube, which have shown that some Danube tributaries, particularly the Arges River, receiving the Dambovita River, which flows through Bucharest, have a high pollution load, originating mainly from human agglomeration sewerage systems, but also from agricultural sources.

In this respect, nutrients were analysed in more detail, because they are the main components in municipal wastewater.

After the use of descriptive statistics, the study focused on applying complex statistical analysis methods, in order to assess their ability to reflect actual pollution patterns, and thus serve as useful instruments that can be used in designing protection plans and provide authorities with data for prioritising investments and evaluating their efficiency. The descriptive statistics, Principal Component Analysis and factor analysis methods were applied.

2. MATERIALS AND METHODS

Water samples were collected from 8 monitoring stations on the Dambovita River during the period 2010-2015 and were analysed by standard methods. In addition, one more point located on the Arges River after the confluence with Dambovita was included for comparison. The geographic coordinates of the sampling points are presented in table 1, and the locations are marked on the map in Figure 1.

Sampling points 01-06 are located upstream from the Bucharest WWTP (Glina), and 07-09 are located downstream from the WWTP.

Annual mean values of the following nutrients parameters were analysed: ammonium (N-NH4), nitrites (N-NO2), nitrates (N-NO3), total nitrogen (TN), orthophosphates (P-PO4) and total phosphorus

(TP). Monitoring data were provided by the National Administration “Romanian Waters” (ANAR). For Arges River, data were retrieved from the TransNational Monitoring Network (TNMN) water quality database, hosted by the International Commission for the Protection of the Danube River (ICPDR). The sampling frequency for each location, according to the Water Framework Directive (Directive 2000/60/EC) monitoring programme, is presented in Table 1. The stations with low pollution levels are included in surveillance monitoring and samples are taken at regular intervals 4 times/year. Stations with higher pollution levels are included in the operational monitoring programme, and samples are taken 8 times/ year. Arcuda is a drinking water abstraction point for Bucharest supply, so samples are taken 12 times/year. In addition, the operator of the water supply and sewerage system carries out its own analysis on a daily basis, but for water inside its facilities, not in the river.

Flow data are not available for the study period, however, it is known that the average flow of Dambovita River is around 9.59 m^3/s upstream from Bucharest and 19.1 m^3/s downstream from Bucharest, after receiving Colentina and Pasarea rivers and Glina WWTP effluents (Cocoş 2006). Arges mean annual flow at discharge is around 73 m^3/s (Mailat 2010). Land use is represented mostly by cropland and grassland in the centre and South, and by forests in the North (Fig. 1).

For each parameter, data were represented in scatterplots and their compliance with Romanian water quality classes was analysed.

Principal Component Analysis (Rencher 2002) is used to identify the parameters with the highest influence on the variance of the dataset and to highlight eventual correlations between parameters.

Table 1. Geographic locations and sampling frequency at the analysed monitoring stations on Dambovita and Arges rivers

Location	Latitudine	Longitudine	Type of monitoring, according to WFD	Frequency of sampling
01 Podu Dambovitei	45.4069	25.2021	Surveillance monitoring	4 / year
02 Malu cu Flori	45.1604	25.2071	Surveillance monitoring	4 / year
03 Brezoaiele	44.5738	25.7123	Surveillance monitoring	4 / year
04 Arcuda	44.4977	25.8583	Investigative monitoring	12/ year
05 Dragomiresti	44.4630	25.9447	Operational monitoring	8/ year
06 Popesti	44.3947	26.1997	Surveillance monitoring	4 / year
07 Balaceanca	44.3986	26.2814	Operational monitoring	8/ year
08 Budesti	44.2321	26.4540	Operational monitoring	8/ year
09 Arges	44.1450	26.5990	Operational monitoring	8/ year

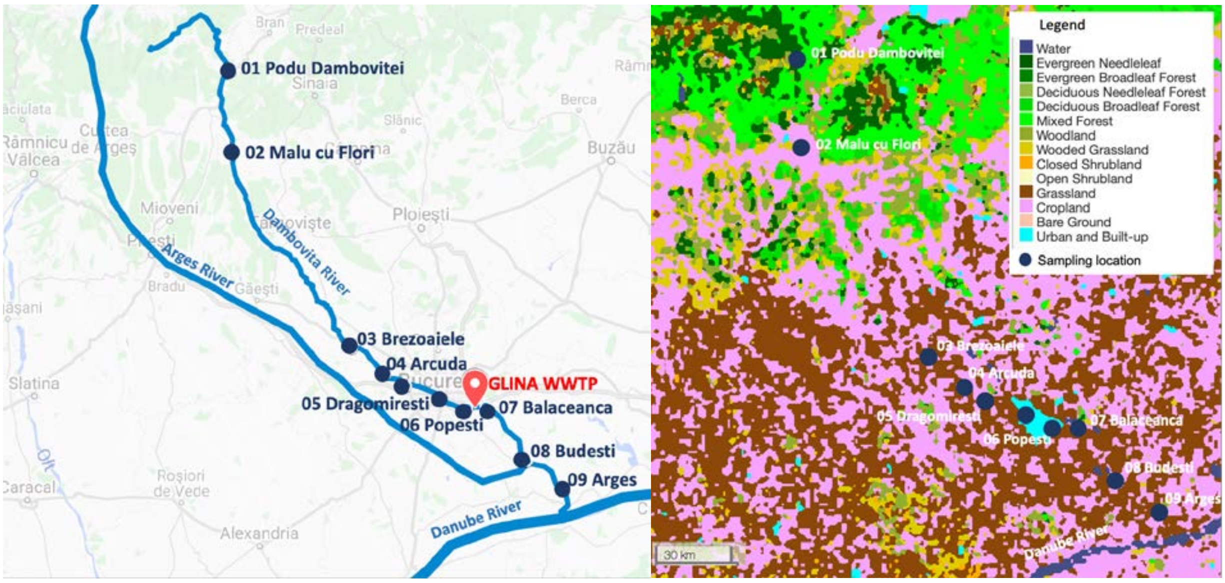

Figure 1. Left: location of monitoring stations on physical map: Dâmbovița (01-08), Argeș (09). Locations: 01 Podu Dambovitei, 02 Malu cu Flori, 03 Brezoaiele, 04 Arcuda, 05 Dragomiresti, 06 Popesti, 07 Balaceanca, 08 Budesti, 09 Arges. Right: land cover map of the study area (National Geographic http://mapmaker.nationalgeographic.org/fNy7apIq2pqNcyhyMOhCkl/)

Also, in the case of a large number of variables, the dataset may be reduced to a smaller number of principal components, without losing essential information. Principal components are linear combinations of the original variables. Multiple factor analysis (Konishi 2014) additionally highlights the differences between sampling locations regarding pollutants loads.

All graphical representations and statistical analyses were carried out using the free RStudio software, version 1.1.463, based on the open source R statistical software, version 3.6.2.

3. RESULTS AND DISCUSSION

3.1. Ammonium (N-NH4+)

Ammonium nitrogen is an indication of recent pollution with insufficiently treated municipal wastewater. Figure 2, presents mean annual values for ammonium nitrogen (mg N/L) at the analysed stations, as well as limit values for water quality classes according to Romanian norms: I <0.4 (blue), II 0.4-0.8 (green), III 0.8-1.2 (orange), IV 1.2-3.2 (red), V >3.2 (2006).

From Figure 2, the difference between the locations upstream from Glina WWTP (01-06) and those located after Bucharest wastewater discharge point (07-09) can be clearly noticed. All annual means from the upstream stations are in quality class I, except for Dragomirești in the year 2012, which is in class II. All mean annual values downstream from Bucharest, from Bălăceanca and Budești, are in quality class V. Annual means for Argeș River are in quality class IV, except for year 2012, when the value is in class V. The high values from 2012 might be due to an extended period of drought, according to climatological data (Pavnutescu 2012). For the stations located downstream from Glina, points 07, 08 and 09, the values from the end of the analysed period are lower than those from 2010, but, given the relatively short period analysed, it is not possible to infer a clear trend.

3.2. Nitrites (N-NO_2^-)

Nitrites are unstable nitrogen compounds that occur during the nitrification process of ammonium. Annual means of nitrites concentrations from the period 2010-2015 are presented in figure 3, together with the limit values of water quality classes, according to Romanian norms: I <0.01 (blue), II 0.01-0.03 (green), III 0.03-0.06 (orange), IV 0.06-0.3 (red), V >0.3 (2006).

From Figure 3, it can be noticed that, at the first 4 stations, the mean annual values are in quality classes I and II. At Dragomiresti, the values are in classes II and III, except for the year 2013, when the annual mean was in class IV, and at Popesti annual means are in class II, except for the year 2014, when the mean was in class IV. At Bălăceanca and Budești, all annual means are in class IV, except for the year 2010, when they were in class I. In the Argeș River, annual means are also in class IV, except for the year 2010, when the mean was in class II.

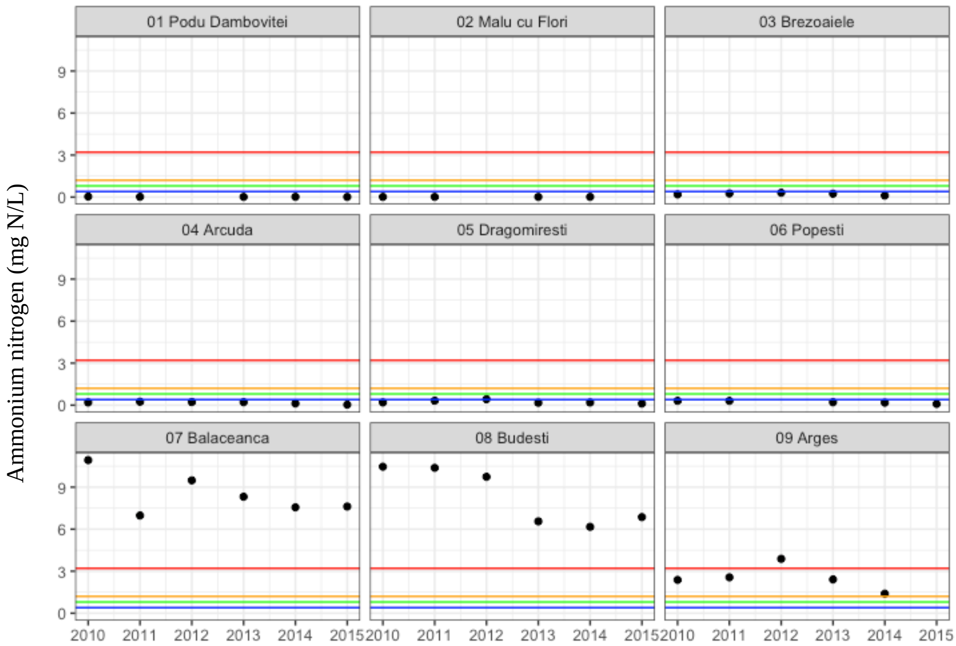

Figure 2. Mean annual values of ammonium nitrogen concentrations at the analysed stations during the period 2010-2015 (mg N/L) • mean annual value, — class I, — class II, — class III, — class IV

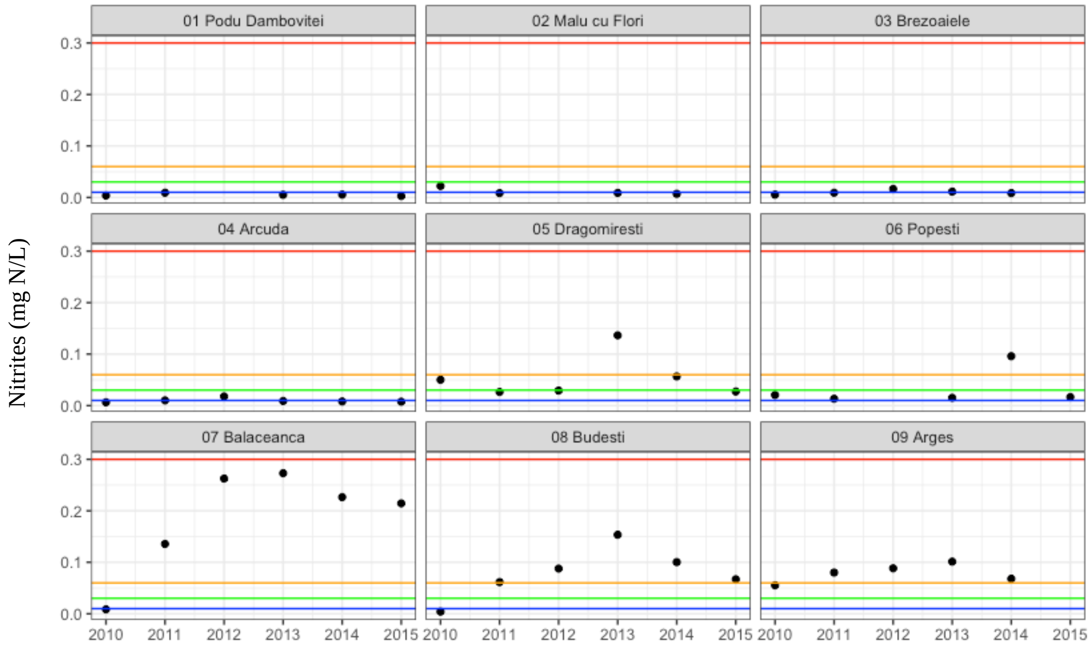

Figure 3. Mean annual values of nitrites concentrations at the analised stations during the period 2010-2015 (mg N/L); • annual mean value, — class I, — class II, — class III, — class IV

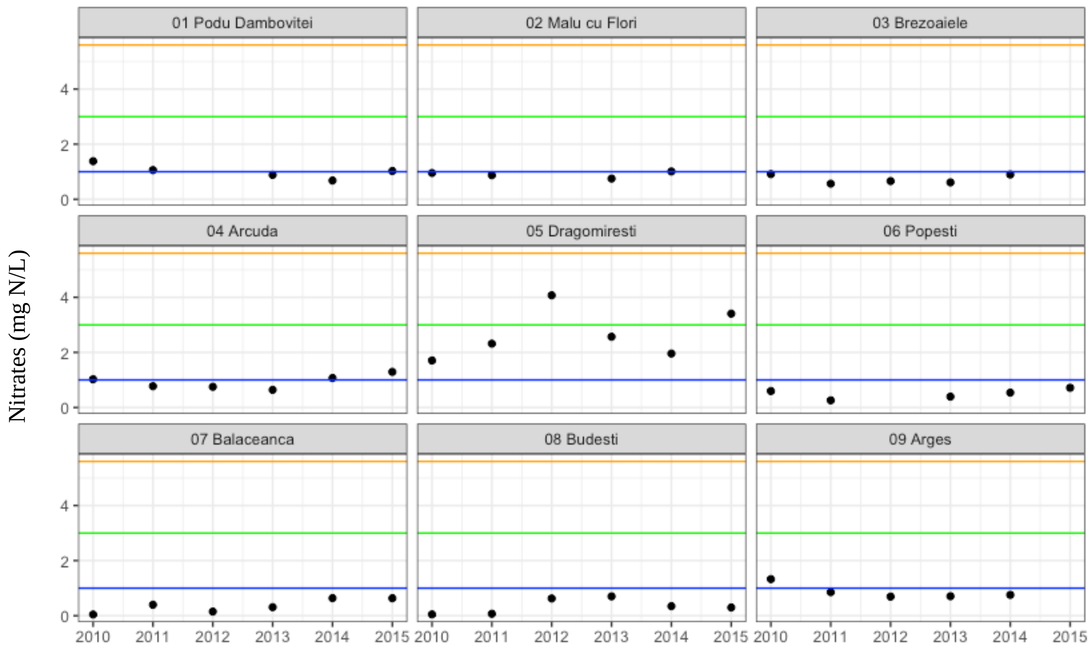

Figure 4. Annual mean values of nitrates concentrations during the period 2010-2015 (mg N/L); • annual mean value, — class I, — class II, — class III

3.3. Nitrates ($N\text{-}NO_3^-$)

Nitrates are more stable nitrogen forms that may originate from agricultural sources or from nitrification processes following decomposition of organic matter in aerobic conditions. Figure 4 presents the annual mean values for nitrates during the period 2010-2015, as well as the water quality class limits according to Romanian norms (mg N/L): I <1 (blue), II 1-3 (green), III 3-5.6 (orange) (2006). Classes IV and V were not represented, because there were no values in these classes.

In this case, all values are in quality class I, except for Dragomirești station. Also, in the Arges River, in the year 2010 the annual mean was in class II. At Dragomirești, the annual means are in quality classes II and III. The fact that annual means at Dragomiresti are much higher than those upstream, from Arcuda, indicates that between these two sampling points there is an important source of nitrates pollution. The source of pollution may be from agricultural sources, as the lower and middle parts of the river are dominated by cropland and grassland (Fig. 1).

3.4. Total Nitrogen (N)

Total nitrogen includes both organic and inorganic forms of nitrogen from water. Nitrogen is an essential nutrient and high concentrations in surface waters may lead to eutrophication (algal blooms followed by oxygen depletion of the aquatic environment).

Figure 5 presents the annual mean values for total nitrogen at the analysed locations during the period 2010-2015, as well as the water quality class limits, according to Romanian norms (mg N/L): I <1.5 (blue), II 1.5-7 (green), III 7-12 (orange). IV 12-16 (red) and V >16 (2006).

All annual mean values for total nitrogen are in quality classes I and II, except for those at Bălăceanca and Budești, downstream from Bucharest WWTP outlet into Dâmbovița River. In the year 2010, the annual means at these stations were in class V, and in the following years the values have decreased towards quality classes IV and III. During the period 2013-2015 mean values were in class III, however, because the analysed period is relatively short, it cannot be presumed that values will continue to decrease.

Before Dambovita enters Bucharest, between Arcuda and Dragomirești, there is a nitrogen pollution source (mainly nitrates), however, at the next station, Popești, the mean values decrease and comply with quality class I, most likely due to self-cleansing processes. At Bălăceanca and Budești, nitrogen values are similar. At Dragomirești nitrogen pollution is dominated by nitrates, which can be reduced to molecular nitrogen (denitrification), while at Bălăceanca ammonium is dominant (originating mainly from municipal wastewater), which needs to be oxidised to nitrate before being released to the atmosphere through denitrification. As order of magnitude, ammonium levels are around 12 mg N/L, nitrites 0.3 mg N/L, nitrates 4 mg N/L and total nitrogen 20 mg N/L. It results that, in the analysed case, municipal wastewater (characterised by high ammonium levels), is the main source of pollution.

3.5. Orthophosphates (P-PO_4^{3-})

Phosphorus can be present in surface waters in organic or inorganic form. Inorganic phosphorus is in the form of phosphates and polyphosphates, which are called orthophosphates. Orthophosphates (P - PO_4^{3-}) are the most abundant form of inorganic phosphorus and the most available to water bodies.

Monitoring data for orthophosphates at the analysed locations are presented in Figure 6. The figure presents orthophosphates annual mean values, as well as the limit values for water quality classes according to Romanian norms (mg P/L): I <0.1 (blue), II 0.1-0.2 (green), III 0.2-0.4 (orange). IV 0.4-0.9 (red) and V >0.9 (2006).

In Figure 6 it can be seen that annual mean values of orthophosphates concentrations are generally in water quality class I until Popești, upstream from Glina WWTP. At Bălăceanca and Budești, downstream from the WWTP, annual means are in class V for the year 2010 and in class IV during the

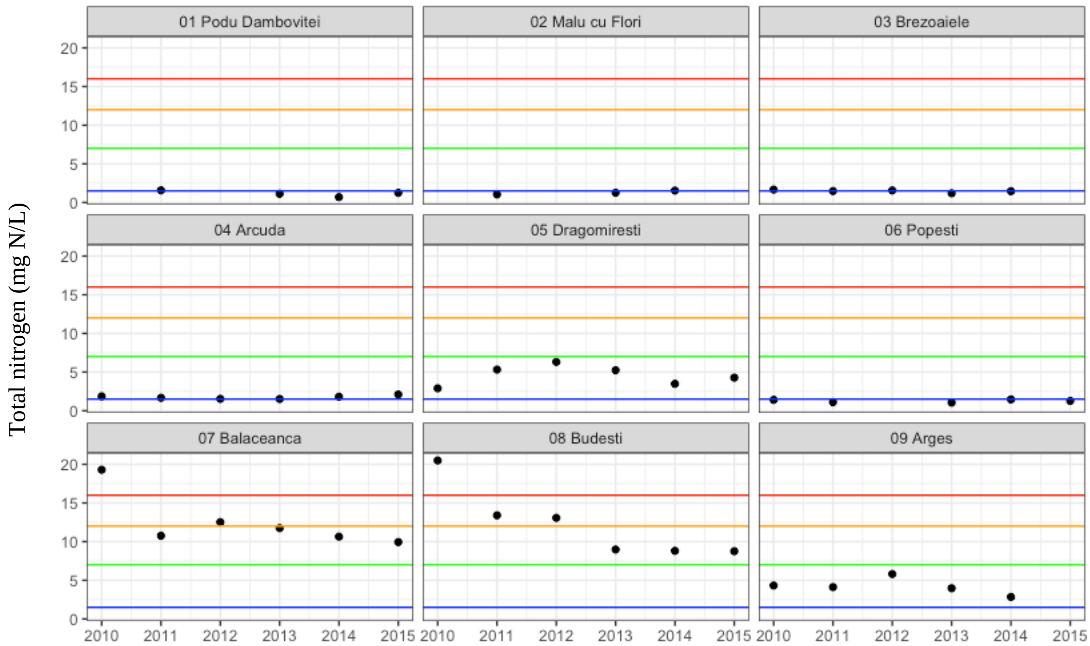

Figure 5. Annual mean values for total nitrogen at the analysed stations during the period 2010-2015 (mg N/L); • annual mean value, — class I, — class II, — class III, — class IV

period 2011-2015. In the Argeș River values are in class I in 2010, in class II in 2014, in class III in 2011 and 2013, and in class IV in 2012. There is no clear increasing or decreasing trend, and the highest values were not in the same year at all the stations, to allow an association with climatic factors, such as reduced flows due to prolonged drought.

3.6. Total Phosphorus (TP)

Together with nitrogen, phosphorus is an essential nutrient that can stimulate algal growth, when in abundance, and limit it when it its concentration is low. This is why the release of phosphorus to water bodies has to be controlled in order to prevent eutrophication.

Total phosphorus includes both organic and inorganic forms of phosphorus from surface waters. Figure 7 presents the mean annual values for total phosphorus at the analysed stations during the period 2010-2015, as well as the limit values of quality classes according to Romanian norms (mg P/L): I <0.15 (blue), II 0.15-0.4 (green), III 0.4-0.75 (orange), IV 0.75-1.2 (red) and V >1.2 (2006).

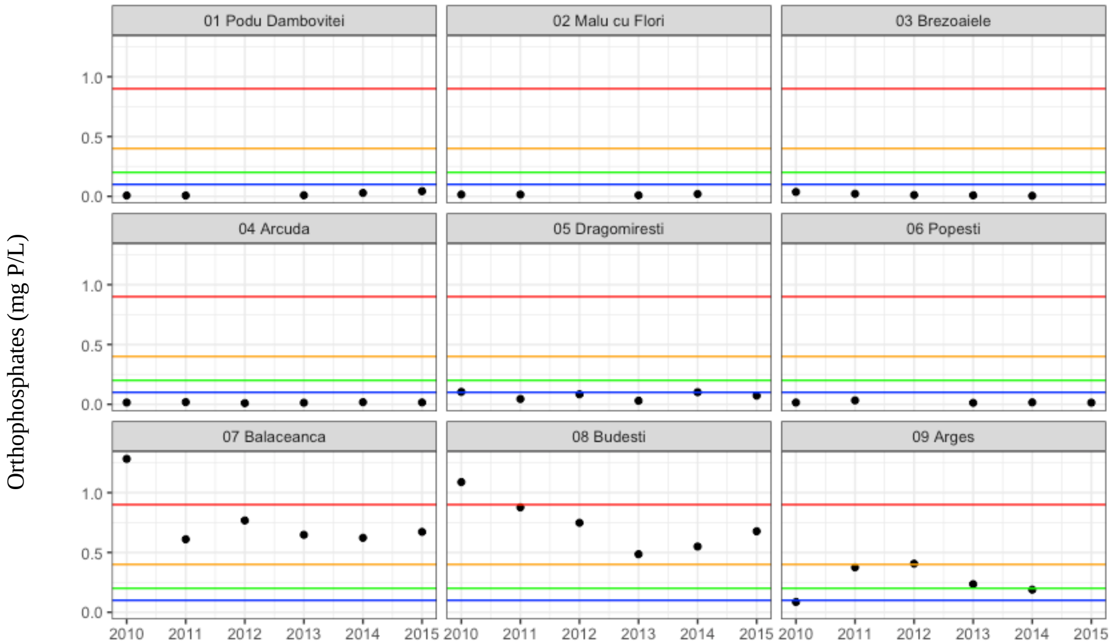

Figure 6. Annual mean values for orthophosphates at the analysed stations during the period 2010-2015 (mg P/L); • annual mean value, — class I, — class II, — class III, — class IV

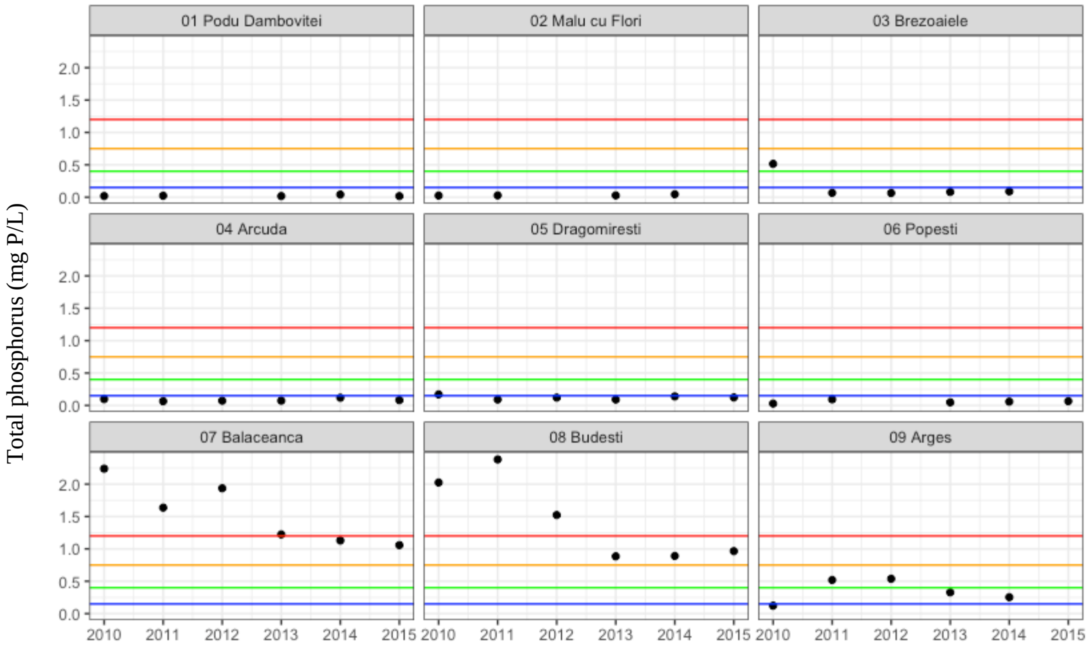

Figure 7. Annual mean values for total phosphorus at the analysed stations during the period 2010-2015 (mg P/L); • mean annual value, — class I, — class II, — class III, — class IV

Annual means are, generally, in quality class I upstream from Glina WWTP. Exceptions are Brezoaiele, which is class III, and Dragomirești, which is in class II in 2010. Downstream from the WWTP they move to class V at Bălăceanca (2010-2013) and Budești (2010-2012), and to class IV towards the end of the analysed period, Bălăceanca (2014-2015) and Budești (2013-2015). In the case of the Arges River, annual means vary between class I (2010), class III (2011, 2012) and class II (2013, 2014).

Given the fact that the analysed period is relatively short, it is not possible to draw conclusions regarding trends, and time correlations tests would not give relevant results.

Phosphorus variation is similar to that of orthophosphates; downstream from the WWTP, the pollution level is high, and levels decrease due to dilution in the Argeș River.

Annual mean values for total phosphorus are around 25 mg P/L, while for orthophosphates they are around 13 mg P/L, so the difference could be represented by organic phosphorus, originating from Bucharest municipal sewerage system.

3.7. Principal component analysis (PCA)

In order to assess the influence of all the analysed parameters on the variance of the dataset, the principal component analysis method was applied, highlighting at the same time the influence of the parameters, as well as the correlations between them. The coefficients of the principal components (PC) are presented in Table 2.

The first two components (PC1 and PC2) explain 88.09% of the variation of the dataset, and the first three components explain 98.66%, so the dataset could be reduced from 6 parameters to 3 principal components without losing essential information.

In PC1 the highest influence is given by ammonium (0.4734), followed by orthophosphates (0.4669), total phosphorus (0.4629) and total nitrogen (0.4519). It is very clear that this component reflects wastewater discharge from Bucharest, from Glina wastewater treatment plant, having a major impact on the dataset (73.39%).

The second component is dominated by nitrates (-0.8955), nitrites having also an influence, but smaller (-0.4049). PC2 reflects the pollution between Arcuda and Dragomirești, which is of a different nature than the one from domestic wastewater, the impact being much smaller than the one from Glina (14.71%).

The first two components (PC1 and PC2) are represented graphically in figure 8., in which arrow lengths are proportional with the coefficients of the respective parameters, and angles between arrows reflect correlations between parameters. Narrow angles reflect positive correlations, diametrically opposed arrows reflect negative correlations, and right angles indicate the absence of any correlation.

In Figure 8, the major influence of the group ammonium, orthophosphates, total phosphorus can be noticed, which are in a close positive correlation, the arrows being almost overlapped. Total nitrogen is also positively correlated with ammonium, but the angle between the arrows is larger, because it is also influenced by nitrates.

Nitrates influence is quite high, but it is independent from the other parameters, and nitrites have the smallest influence on the variation of the dataset.

3.8. Factor analysis

In order to differentiate at the same time both the influence of the parameters and of the sampling point, the multiple factor analysis method was applied. The results of this analysis are represented graphically in Figure 9, where ellipses correspond to locations and points represent parameters.

In Figure 9, in the upper-left area, the group of stations 01-04 can be noticed, characterised by

Table 2. Principal component analysis for annual means during the period 2010-2015 at the analysed monitoring stations on Dâmbovița and Argeș rivers – coefficients of principal components (PC) and percentages of explained variances

Parameter	PC1	PC2	PC3	PC4	PC5	PC6
Ammonium	0.4734	-0.0139	0.0425	-0.0983	-0.3219	-0.8128
Nitrites	0.2982	-0.4049	-0.8551	0.0113	0.0565	0.1121
Nitrates	-0.2246	-0.8955	0.3302	0.0963	-0.1652	-0.0444
Total nitrogen	0.4519	-0.1828	0.2923	-0.3798	0.7288	0.0389
Orthophosphates	0.4669	-0.0033	0.1942	-0.3368	-0.5731	0.5499
Total phosphorus	0.4629	0.0223	0.1864	0.8505	0.0792	0.1447
Standard deviation	2.0984	0.9394	0.7962	0.2156	0.1393	0.1207
Percentage of variance (%)	73.39	14.71	10.56	0.78	0.32	0.24
Cumulative variance (%)	73.39	88.09	98.66	99.43	99.76	100

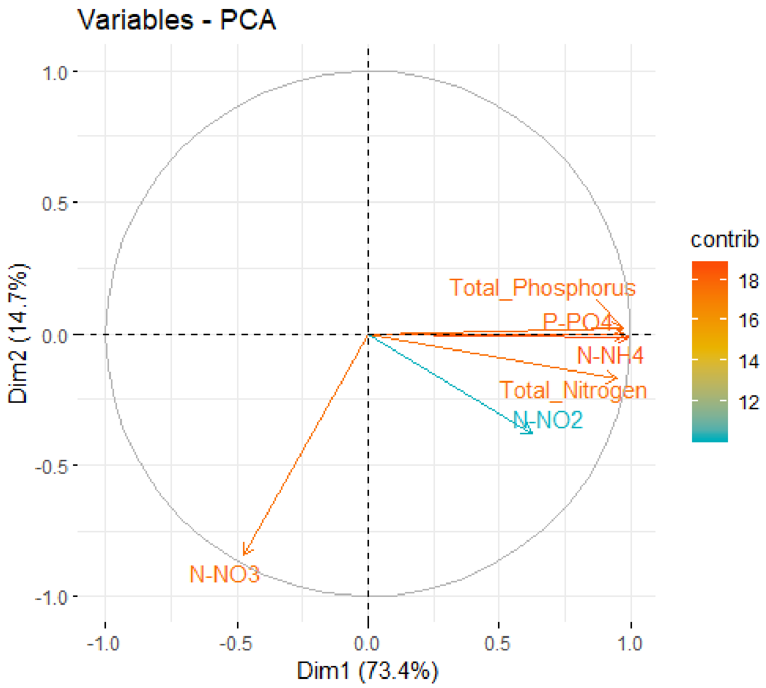

Figure 8. Graphical representation of PC1(Dim1) and PC2 (Dim2) for annual means at analysed stations during the period 2010-2015

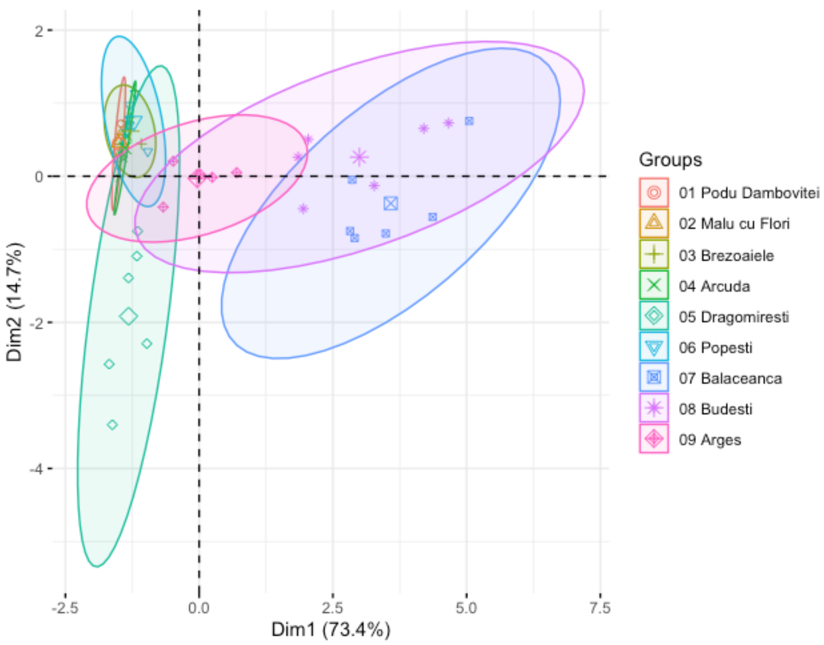

Figure 9. Multiple factor analysis of annual means at the analysed stations during the period 2010-2015

reduced pollution, where water quality is mostly in class I. Stations 07 and 08 (Bălăceanca and Budești) dominate the right side of the figure, being strongly affected by domestic wastewater discharge from Bucharest wastewater treatment plant. The figure also highlights the case of Dragomirești (05) station, located before Dâmbovița river enters Bucharest, which is affected by nitrates pollution.

The station on the Argeș river (09), located after the confluence with Dâmbovița, has a median position in Figure 9, here the pollution level being lower than at stations 07-08, at the same time the water quality being worse than at stations 01-04. The figure suggests that, apart from the fact that the Argeș river has a higher flow than Dâmbovița (73 m^3/s respectively 19 m^3/s at discharge, multiannual mean flow), it is also less polluted, so that pollutants are diluted at confluence, reducing the impact of Bucharest wastewater upon the aquatic environment.

A factor analysis was carried out, to differentiate locations more clearly, the results being presented in Figure 10.

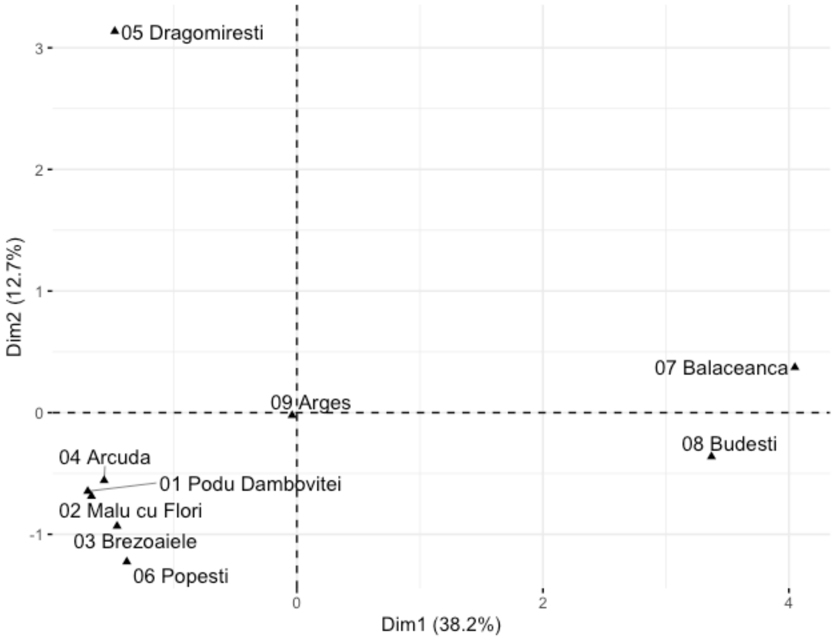

Figure 10. Factor analysis according to location, for annual means at Dâmbovița and Argeș stations during the period 2010-2015

The conclusions drawn from the analysis of Figure 10 are similar to those from Figure 9. In addition, it can be observed more clearly that the effects of nitrates pollution between Arcuda and Dragomirești are removed by self-purification, so that downstream, at Popești, before Glina, water quality is close to the one upstream, from stations 01-04.

The discharge of domestic wastewater from Bucharest Municipality has a major impact upon Dâmbovița water quality, highlighted by severe pollution with ammonium and phosphorus, as it results from the analyses carried out. Regression dependencies between flows and nutrient concentrations previously carried out on the Danube have shown that flow does not have an important impact on long-term trends (Jaruskova & Liska 2011, Hamchevici & Udrea 2015).

A study carried out in June 2018 in the area of confluence between Dâmbovița and Argeș also highlighted the fact the ammonium was in class V in Dâmbovița river before confluence, in class I in the Argeș river before confluence, and in class IV in Argeș after confluence (Ionescu et al. 2019a), which shows that the problem persisted in the years after the period analysed in this work.

4. CONCLUSIONS

Nutrients concentrations at 8 monitoring stations on Dambovita River were analysed for the period 2010-2015 as indicators of urban pollution, in order to assess the impact of Bucharest wastewater on Dambovita and Arges rivers.

Ammonium and total nitrogen were in classes I or II, according to Romanian norms, at stations 01-06, upstream from Bucharest WWTP, and in classes IV or V downstream from Glina.

For nitrites there are some values in classes III and IV starting from Dragomiresti, and most values are in class IV downstream from Glina.

For nitrates there are some values in classes III and IV at Dragomiresti (05), but the values go back to class I at the next station, Popesti (06), and they stay in class I also after Glina, which shows that municipal wastewater discharged from Glina does not contain high amounts of nitrates.

Orthophosphates and total phosphorus are, generally, in class I until Popesti (06), and go to classes IV or V downstream from Glina, at stations 07 and 08. In the Arges River the values are lower, in classes II, III or IV; Arges has a higher flow and better water quality, so pollutants from Dambovita River are diluted. Total phosphorus values are two times higher than orthophosphates, so the difference is represented by organic phosphorus from the sewerage system.

During the analysed period, Dambovita River water quality was, in general, in class I upstream from Glina WWTP, and in classes IV and V downstream, after receiving municipal wastewater.

PCA has shown that the first principal component has the most important influence on the dataset and is dominated by ammonium, orthophosphates, total phosphorus and total nitrogen, which reflect the insufficiently treated wastewater discharge from Bucharest sewerage system.

The second principal component has a lower influence on the dataset, and is dominated mostly by nitrates to a lower extent by nitrites. It reflects the pollution occurring between Arcuda and Dragomiresti, which is of a different nature than municipal wastewater. This pollution source is not known and requires further investigation so that the causes can be properly addressed by authorities.

The factor analysis of the dataset shows a clear difference between the analysed stations: 01-04 and 06, with very good water quality, 05 Dragomiresti with nitrates pollution, 07-08 strongly affected by wastewater discharge, 09 Arges with medium pollution. With a higher flow and better water quality than Dambovita, the Arges river reduces the impact of Bucharest wastewater on the Danube River ecosystem.

The analysis highlights the need to improve the treatment capacity of Glina WWTP in order to reduce pollution of Dâmbovița river and, consequently, of the Argeș and Danube rivers, with nitrogen and phosphorus compounds.

The study has shown that the applied statistical methods can be a very useful instrument to integrate monitoring data from locations with different profiles, providing authorities with information regarding compliance with norms, indicating also, at the same time, pollution hotspots where measures need to be taken and possible sources, shown by the correlations between parameters.

In this respect, the present study is the first of this type regarding Dambovita River and it shows clearly the differences in water quality upstream and downstream from the WWPT. It identifies the most relevant pollution issues and provides reference values for the main nutrients, which may serve as a benchmark for assessing the performance of municipal wastewater treatment and other measures for reducing nutrients pollution in the future.

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