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Looking Back to go Straight Forward: A Proposal to Assess Trends, Seasonality and Ecological Status in Long-Term Data Sets in the Duero River.

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Abstract

DRAINAGE is a multidisciplinary project for the integral management of flood risk, mainly in urban and peri-urban areas. Risk mitigation strategies designed under this framework need to be based on the use of green infrastructures that are also compatible with Good status of water bodies. Prior to this design and implementation, analysis of long-term time series to determine the ecological status is essential for the identification of pressures and threats that could being affecting fluvial ecosystems and also for planning adequate measures. With this purpose, the research presented here proposes a methodological approach for the systematic treatment of a high volume of data, applied in this case to three water bodies in the Duero River between the cities of Toro and Zamora (Spain). Within the frame of this methodology, trends of temporal evolution and seasonality of different chemical and physicochemical water quality variables have been analysed. Also, the physico-chemical status has been evaluated according to Spanish regulations. Results obtained through this approach have allowed us to identify the main sources of disturbance in the study section, being them those coming from the agricultural sector and urban wastewater discharges, whereas industry sources have had a minimum impact. With this approach, therefore, water and natural resources managers can set the goals to achieve in water bodies' status in a realistic way and then choose measures accordingly.

Keywords: Duero River; Ecological Status; Temporal Trends; Flood Risk; Green Infrastructure.

1. INTRODUCTION

The assessment of the ecological and chemical status of water bodies is an essential aspect of the European water policy. The Water Framework Directive (WFD) 2000/60/EC requires Member States to guarantee the quality and comparability of the methods used to monitor and evaluate the ecological status of water bodies. In this sense, the statistical analysis of long-term time series of chemical and physicochemical parameters is presented as a fundamental tool for environmental monitoring of water quality, for the identification of pressures and threats that affect fluvial ecosystems, for the planning of adequate measures to mitigate or eliminate existing pollution and to evaluate the effectiveness of these programmes of measures based on the available scientific evidence (Bradley et al., 2015, Jung et al., 2020).

The DRAINAGE project for the integral management of flood risk (http://drainage.cedex.es/) is a multidisciplinary project whose main goal is to improve the resilience of urban and peri-urban areas to flooding. To achieve that, the fundamental idea beneath the project is that the design of risk mitigation strategies needs to be based on green infrastructure that is capable of both mitigating the risk of flooding and in turn is compatible with the Good status of the water bodies. That is, only through the recovery of the hydraulic connectivity between the river and its alluvial plain will it be possible to maintain the river functionality and manage flood risks, thus meeting the objectives set out in the WFD and the Flood Directive 2007/60/EC. Likewise, it is intended to involve the affected population, favouring a change in attitudes towards optimal flood risk management and environmentally sustainable practices. In this context, the prior step is knowing the current ecological status and having the ability to predict the behaviour of the variables in different alternative simulation scenarios. With this knowledge available, managers could choose the alternative that offers the best solution both in terms of flood risk control and in terms of water bodies' status.

2. METHODS

2.1 Study site

The main study site of the DRAINAGE project is located within the Duero River basin, in northwest Spain. In particular, a segment of the Duero River between the cities of Toro and Zamora (TDTZ hereinafter) about

49.3 km long has been selected to carry out the demonstrative initiatives proposed under the DRAINAGE approach (Fig. 1). Its flow regime is perennial and rain-dominated Mediterranean type. In this section, the river has a predominant flow direction from E to W and is embedded in a geological matrix of sandstones and quaternary terraced deposits, alluvial fans and dejection cones, leaving evidence of different riverbed locations in the floodplain (Sánchez del Corral Jiménez, 2007). In addition, it has a clearly meandering planform, which gives its floodplain a high capacity to laminate floods.

The selected segment comprises three defined water bodies (395-"*Río Duero desde confluencia con el río Hornija hasta confluencia con arroyo Reguera*", **396**-"*Rio Duero desde confluencia con arroyo Reguera hasta confluencia con arroyo de Algodre*" and **397**-"*Rio Duero desde confluencia con el arroyo de Algodre hasta confluencia con arroyo de Valderrey en Zamora*") and it belongs to a protected natural area (Special Conservation Area, SCA) that is part of the Natura 2000 Network under the name "*Riberas del río Duero y afluentes*" (code ES4170083, EEA 2019). Although it is a protected area, within the section there are small hydraulic infrastructures (weirs, ripraps, levees) and extensive land uses (gravel pits, forest plantations, crops) altering vertical and lateral connectivity.

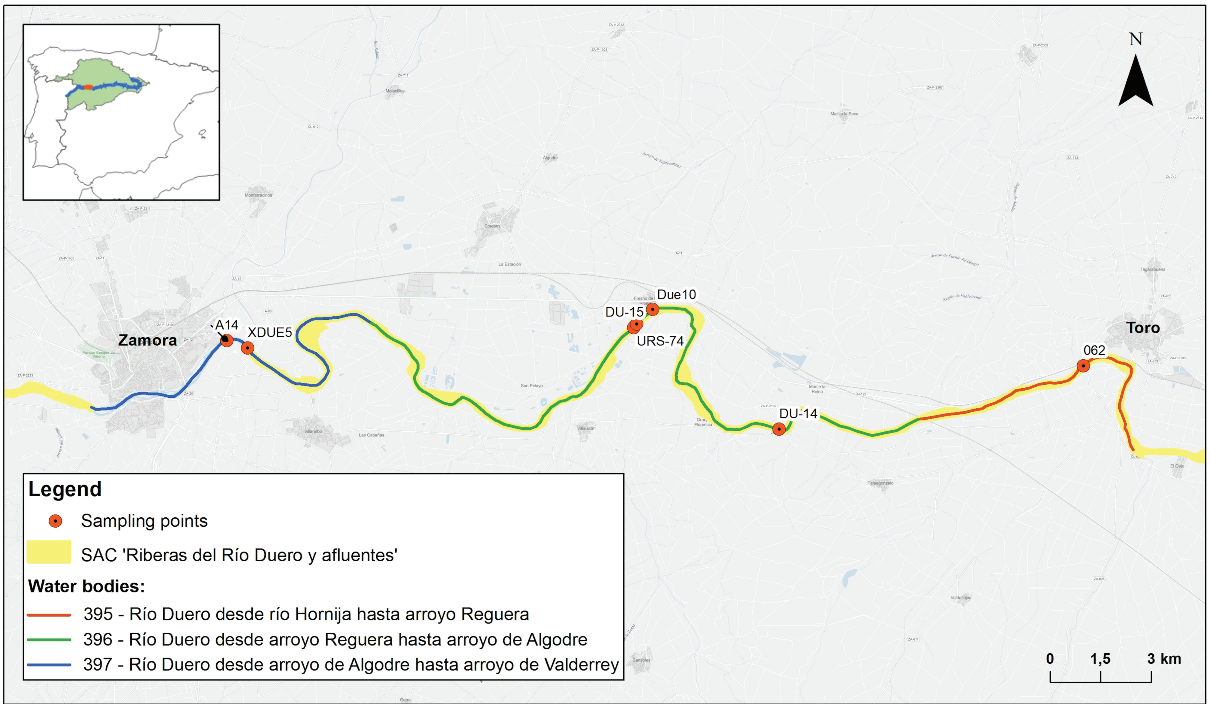

Figure 1. Location of the site of study within the Duero River Basin and available sampling points.

2.2 Physico-chemical data

The source of data used in this study is the Duero River Basin Authority (DRBA) either from the MIRAME-IDEDuero viewer (CHD, 2021), the Duero River Basin Management Plan (2015-2021) (CHD, 2015) or by direct request addressed to the DRBA after a review of the needs for the physico-chemical (PC) characterization. The information provided by the DRBA contains the location of the sampling points in each water body (WB) of the river section, the type of indicators (general PC indicators, specific pollutants, priority substances and other pollutants) that are available for each WB and the observed values of the parameters for the entire available period. In the study section, the available sampling points are shown in Table 1.

Table 1. Sampling points (SP) of each water body (WB) in the area of study.

WB code	SP code	Name	UTMX	UTMY	Available temporal series	Active
395	062	Toro (Duero)	298680	4598699	1962-2018	Yes
396	URS-74	Fresno de la Ribera (Duero)	285452	4599937	2003-2018	Yes

396	DU-14	Toro (Duero) - 2	289670	4596826	1980-1981; 1993-1994	No
396	DU-15	Fresno de la Ribera (Duero) - 2	285361	4599838	1993-1994; 1999-2000	No
396	Due10	Fresno de la Ribera (Duero) - 3	285921	4600375	01/10/2004	No
397	A14	Zamora (Duero)	273310	4599457	1978-2018	Yes
397	XDUE5	Villafranca del Duero (Duero)	273924	4599227	One-time sampling in 2012, 2013 & 2014	Yes

In view of all the available information, it has been considered convenient to study only one representative sampling point of each water body in order to address the objectives of this work. Based on the broadest temporal series available, the sampling points selected were: 062 for WB 395, URS-74 for WB 396 and A14 for WB 397.

2.3 Time-series analysis

Raw data received from DRBA contain a very wide diversity of parameters (up to 212), which in turn present a variety of scales and data classes (quantitative and qualitative), as well as sources of uncertainty and error dependent on sampling techniques and equipment. For that reason, it has been necessary to carry out a pre-treatment of these data for the homogenization and composition of the time-series. This pre-treatment has consisted of the detection and elimination of duplicate values, anomalies and errors after implementing basic descriptive statistics (count, arithmetic mean, median, first and third quartiles, maximum and minimum values, standard deviation and skewness), the identification of redundant parameters with linear regression, and the elaboration of an information chronogram for each sampling point (Figure 2).

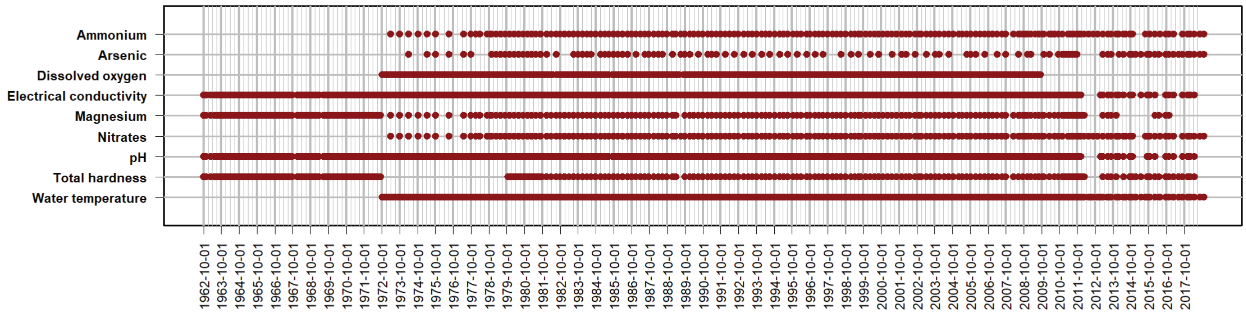

Figure 2. Example of the information chronogram obtained for sampling point 062.

After the pre-treatment, a detailed analysis was carried out for the variables at each sampling point. Three periods of time were selected depending on the analysis to be carried out:

- **Trends**. For this purpose, the complete available period of a variable at each sampling point was used. The period covers the beginning of the series, which varies according to the parameter, until, generally, September 30, 2018. The observed values were represented through temporal graphs, but only those parameters with more than 30 observations were represented.
- **Seasonality**. The period chosen to represent seasonality in the time-series analysis comprises from the hydrological year 2000/01, associated to the first implementation of measures derived from the WFD (EC, 2000), to the hydrological year 2017/18, which is the last year available with complete data. This period was used to display the seasonality of the data throughout the hydrological year. The data was represented by box plots. Only those parameters with more than 30 observations were represented, and those values below the detection threshold were removed.
- **Physico-chemical status assessment**. According to the Spanish legal regulation (MAGRAMA, 2015), the assessment of the ecological status of surface water bodies must be carried out from the data series available from a complete management cycle (six years). In the absence of data for the whole Second management cycle, the most recent available six-year period was selected, that is, from the hydrological year 2012/13 to 2017/18. This period was used to prepare a synthesis of the results of physico-chemical quality elements that are considered for the assessment of the ecological status.

For this synthesis, the assessment unit is the hydrological year, so the evaluation was made both individually and then in an aggregate way for the six-year period. The value per assessment unit and variable was obtained using the medians of the annual observations, following the criteria established by the Spanish Ministry of Ecological Transition and Demographic Challenge (MITERD, 2021). For the aggregate evaluation (multi-year) the median of the medians was used. For the elaboration of the graphs, the annual medians obtained for each variable were classified into four categories ranging from 0 to 1 (0 – Poor or Bad status, 0.33 – Moderate, 0.66 – Good, and 1 – High), based on the status thresholds from the Spanish regulation (MAGRAMA, 2015). The score obtained was multiplied by ten to obtain easily readable graphics.

3. RESULTS

2.4 Trends

One of the most relevant changes observed in the temporal evolution was the progressive increase in water oxygenation conditions (Figure 3), a variable that is especially relevant for aquatic life. This is a good indicator of water status and confirms that, at least in terms of physico-chemical quality, the pressures on the water bodies have been reduced in the last decades. Both the concentration of dissolved oxygen (DO) and oxygen saturation (%) increased with the same pattern at the sampling points 062 and A14, which are located at both end points of the study area. In URS-74, which is located in the middle of the study section, monitoring of oxygen saturation began in 2007, presenting a similar pattern to the other two sampling points. The improvement in oxygenation conditions is a good starting point to achieve good ecological status, since the water availability of oxygen in sufficient quantities (> 5 mg/l) is an essential requirement for the establishment of complex and well-structured biological communities (Croijmans et al., 2021). This clear upward trend was not observed, however, in any of the other variables analysed.

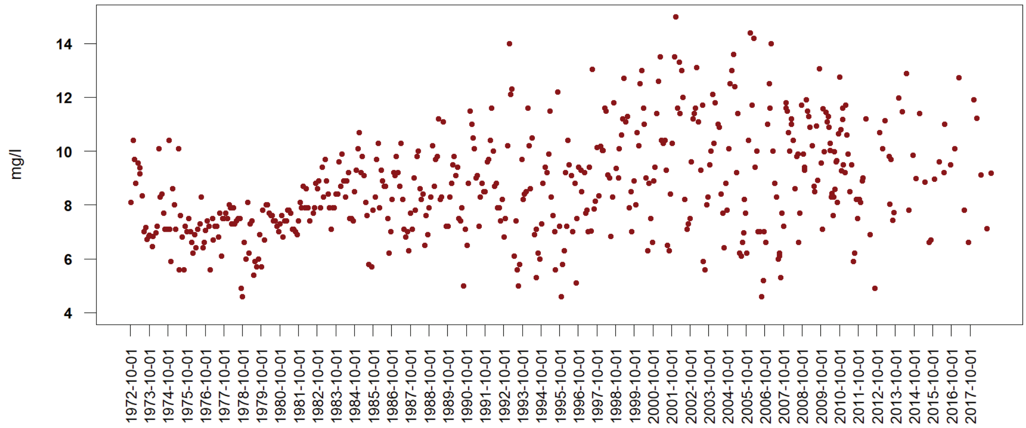

Figure 3. Dissolved oxygen (DO) at sampling point 062.

In the same direction, fluorides and nutrients experienced a very significant decrease (Figure 4), especially since the 1980s and 1990s decades, when they reached their maximum concentrations at the different sampling points, which in turn show a similar pattern. The initial decrease seems to coincide with the entry into force of the WFD, but it is really noticeable in all nutrient parameters (ammonium, phosphates, nitrates) from the beginning of the First management cycle (2009-2015). Controlling nutrient concentrations makes it possible to avoid eutrophication of waters and the proliferation of diatoms, chlorophyceae and cyanobacteria, the increase of which drastically reduces available oxygen. In the last years, nutrients have been kept at acceptable levels and that in turn has a positive impact on the oxygenation conditions.

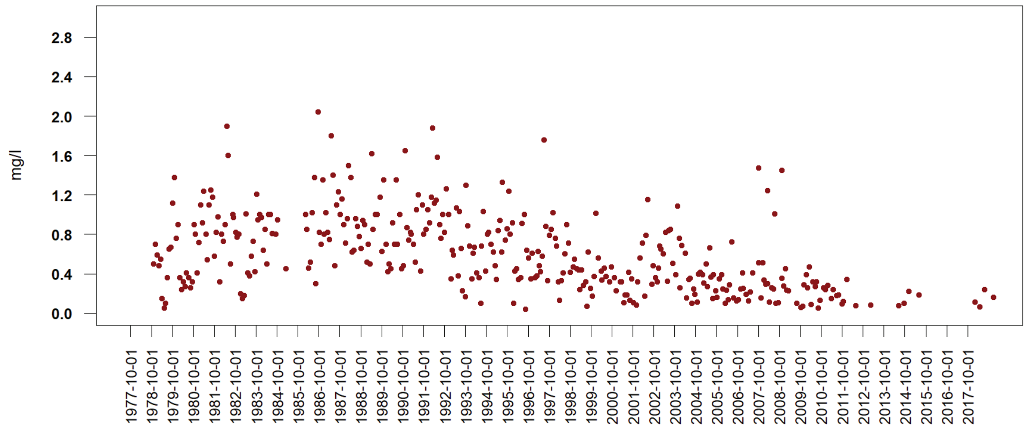

Figure 4. Phosphates at sampling point A14.

Another trend that deserves to be discussed is the one seen in the biodegradability index (Figure 5), which expresses the relationship between biological oxygen demand (BOD_5) and chemical oxygen demand (COD), and is used to roughly determine the organic compounds present in wastewater (Metcalf and Eddy, 2014). This index presented maximum values, up to 8 (sampling point 062) and 4 (A14), in the period 1994-96, which indicates that some type of highly degradable organic discharge occurred. In general, until the year 2000 there was a significant presence of organic compounds easily degradable by microorganisms, since the index was above 0.6 (Bedoya et al., 2014). These compounds probably came from urban wastewater, the agricultural sector or the food industry. On the other hand, from the year 2000, organic compounds were reduced and compounds that are less or non-biodegradable began to dominate.

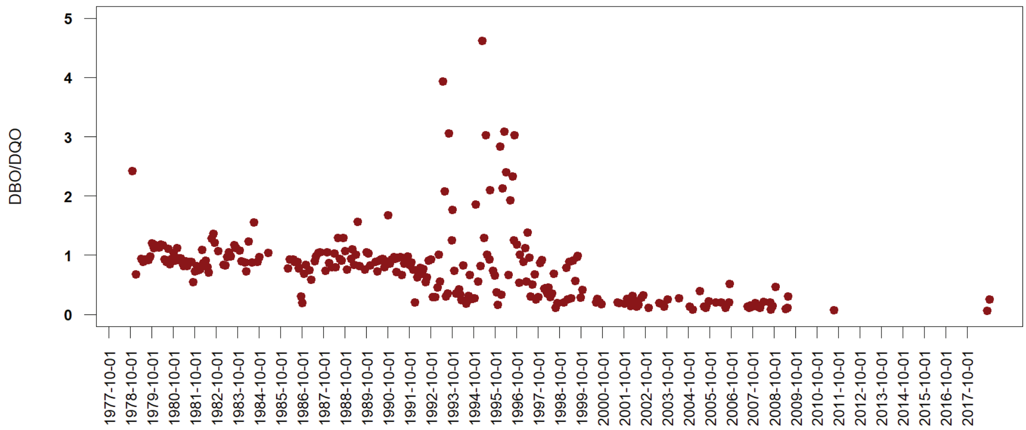

Figure 5. Biodegradability index at sampling point A14.

For some variables (pH, hardness and electrical conductivity), the absence of a clear, positive or negative trend, was observed. The main explanation is that these parameters present high intrinsic variability, being strongly linked to the characteristics of the basin, especially in large rivers such as the Duero River. Finally, the group of substances of priority concern in Spain presented a much narrower pattern of variability. In general, the observed values of the parameters with positive values (arsenic, chromium, chromium VI, zinc, metolachlor, terbutylazine) were below the established Environmental Quality Standard (EQS), or maximum permitted concentrations, and in any case with a tendency to decrease. For the rest of substances (ethylbenzene, toluene, 1,1,1-trichloroethane, xylene and dichlorobenzene -ortho, meta and para- isomers, selenium and chlorobenzene), concentrations above the detection limit were not detected. This could be either because they were absent in the study section, or they were found in very low concentrations that are difficult to quantify and in any case below the limit set in the EQS.

2.5 Seasonality

If we focus on the seasonality of the variables, four types of graphs (Figure 6) can be differentiated:

- **Type I.** Minimum values appear in winter and maximum values during summer months. The temperature of the water and the air are two variables that showed this typology more clearly. Other parameters that showed certain type I seasonality (especially at sampling point A14) were magnesium, sodium and potassium (Mg^{2+}, Na^{+} and K^{+}). These compounds, coming mainly from the lithological substrate, increased their concentration in the summer months, probably due to evaporation and the lower circulating flow during this time.
- **Type II.** Maximum values appear in winter and minimum during summer. The seasonality type seen in temperature variables, however, it is inversely related to two other parameters that also present very marked seasonality, such as dissolved oxygen and nitrates. When the temperature decreases, the values of these two parameters increase and vice versa. Although much less markedly, ammonium also showed a similar pattern of seasonality to DO and nitrates.
- **Type III.** Slightly higher values in winter and summer, with minimums during the spring months. This type of pattern was shown in parameters such as sulphates (SO_4^{2-}), hardness (permanent and total), electrical conductivity or dissolved solids. Thus, in all these parameters a decrease in values was observed in the spring months, and a small upturn in the summer months.
- **Type IV.** Without a clear seasonality pattern. On the other hand, there were parameters for which it was not been possible to identify a pattern of seasonality with the available data. Perhaps the most striking case was that of phosphates, which have a large record of observations. Other parameters that did not present a clear pattern would be BOD_5 and COD, although it is possible that this was due to the scarcity of samplings in the analysed period.

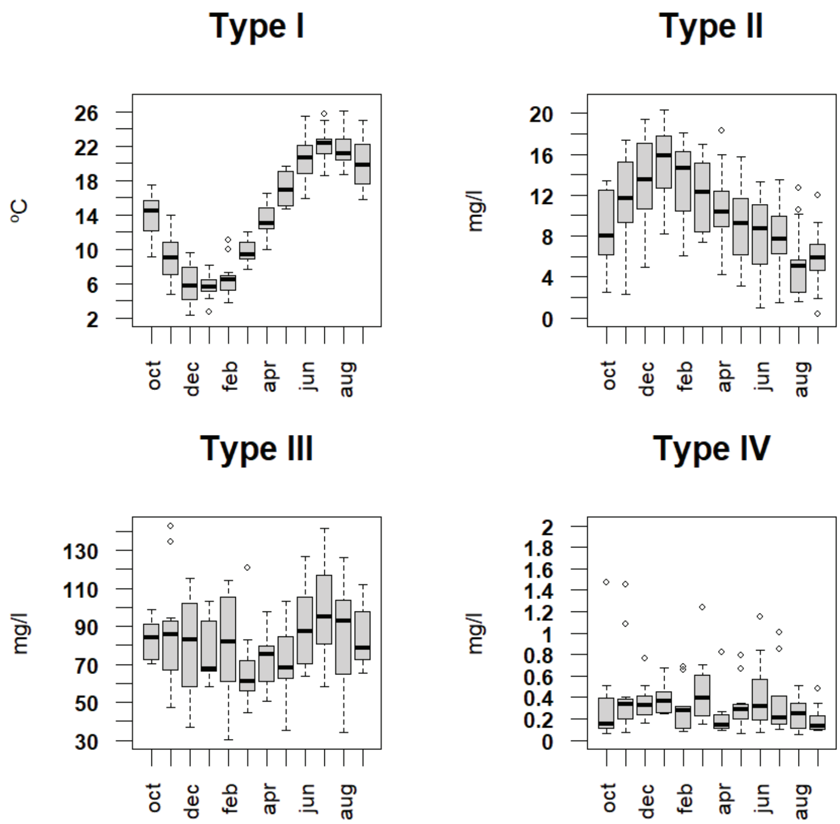

Figure 6. Types of graphs identified for seasonality of the analysed variables. Type I, water temperature (SP 062); Type II, nitrates (SP A14); Type III, sulphates (SP A14); Type IV, phosphates (SP A14).

2.6 Physico-chemical status assessment

With regard to the status assessment of the chemical and physico-chemical elements, the most remarkable consideration is that, in the aggregate period (2012/13 - 2017/18), the three sampling points obtained a High status for the general PC indicators, and there was compliance with the EQS in general terms, although there were parameters that were not evaluated in any of the years of the period. At sampling point 062 (Figure 7a), the main deviations from the High status in the general indicators occurred in the years 2012/13 to 2014/15.

The variables that only reached the Good status were nitrates in 2012/13, oxygen saturation in 2013/14 and ammonium in 2014/15. However, the median of the annual medians for the analysed period reached the High status for all the indicators. Furthermore, these deviations were corrected in subsequent years, corresponding to the Second management cycle. At sampling point A14 (Figure 7b), the main deviations from the High status occurred in the years 2012/13, 2015/16 and 2017/18. Nitrates once again deviated from the High status, as it happened in the sampling point 062. That suggests that there was a pressure affecting the entire study section in that year, although there is no information at the URS-74 sampling point during this year. At A14, the dissolved oxygen saturation did not reach the High status in the years 2015/16 and 2017/18 either. Finally, at the URS-74 sampling point (Figure 7c), the most remarkable aspect was the lack of observations for dissolved oxygen levels in the analysed period. It is a very basic parameter in water quality assessments and it is difficult to explain the absence of observations when they do exist for DO saturation. Deviations from the High status mainly occurred precisely in DO saturation during the years 2012/13, 2015/16 (both Good status) and 2013/14 (Moderate status). In the year 2014/15 there was a slight pressure on nitrates and phosphates that prevented reaching the High status at this sampling point, probably from urban wastewater discharges.

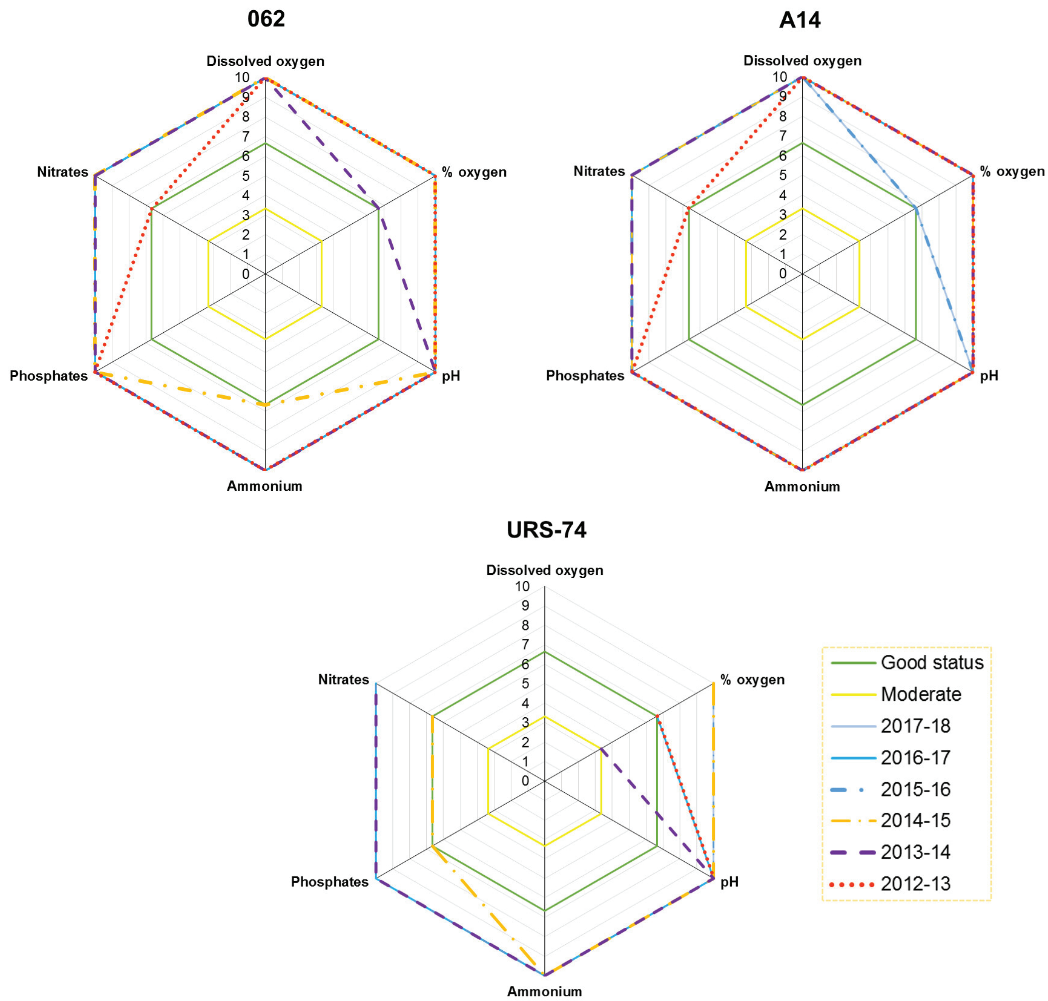

Figure 7. Physico-chemical status assessment graphs at sampling points a) 062, b) A14 and c) URS-74.

4. CONCLUSIONS

From the study on long-term time series of the chemical and physico-chemical quality elements available in three water bodies of Duero River, the following conclusions can be drawn.

- Raw data provided by River Authorities could contain a very wide diversity of parameters, scales, data classes, and sources of error dependent on sampling techniques. A pre-treatment of the data before carrying out subsequent analyses is, thus, needed.

- As the science in the field of water quality advances, the precision of techniques and equipment is greater and the regulations and management criteria become more demanding, so the comparability between observations in long-term data sets could be trickier. The approach presented here allows the comparability of results for long-time series after the pre-treatment has been done.
- It is important to bear in mind that some of those data are largely dependent on climatic factors, which vary according to seasonal and daily cycles, on the geological characteristics of the basins and on the way that water resources are managed. As a consequence, the descriptive analyses used in this study only serve as an orientation to slightly understand the behaviour of these parameters, the usual range in which they fluctuate, the periods in which sudden changes occur, the general trends of the series and whether a certain seasonality occurs. Even so, all these assumptions must be taken with some caution, since they are made based on a very high degree of uncertainty about the quality of the data.
- Results obtained through the descriptive methods used have made it possible to identify the main sources of alteration. The trends indicate that activities related to the agricultural sector have exerted the greatest pressure on the section of study throughout the period considered. However, the preparation and approval of the 1998 river basin management plan, together with the entry into force of the WFD and the following management cycles, represented a considerable improvement in pollution levels, which experienced a notable decrease. From then on, the pollutants originated by this sector were, in general, at values lower than the limits established by the regulations. On the other hand, the lower representation of the industrial sector in the TDTZ was also reflected in the results, showing that contamination by products derived from any type of industry had little influence in the period studied. As in the case of the agricultural sector, the WFD and river basin management plans implied a decrease in the levels registered, which generally oscillated in a range of values well below the established limits. Lastly, urban wastewater discharges supposed, together with those derived from the agricultural practices, another source of important alteration in the TDTZ. Nevertheless, the numerous actions related to sanitation, purification and control of discharges that were established in successive river basin management plans have decisively contributed to reducing this source of disturbance.
- Finally, the availability and the analysis of long-term time series –with observations in the study section that dated back to the year 1962– represent an excellent starting point in the search for green infrastructure measures that improve the environmental quality of water bodies in accordance with the criteria established in the WFD. With the knowledge provided by the approach presented here, managers can set the goals to achieve for physico-chemical variables, based on prior observations on – to some extent– less disturbed ecosystems. Once the goals have been set, they could choose between different green infrastructure alternatives that offer the best solution to mitigate flooding and to meet the pursed objectives for water bodies' status. Therefore, this proposal to assess trends, seasonality and physico-chemical status could be extrapolated to any River Basin District and could also be used to monitor the effects of global warming and socio-economic changes in River Basin Districts.

5. ACKNOWLEDGEMENTS

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