ASSESSMENT OF WATER QUALITY IN THE FERVENÇA RIVER USING THE WATER QUALITY INDEX (WQI)

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Abstract

Water quality is crucial for the survival of living organisms and their environment. To monitor and minimize pollution, the Water Quality Index (WQI) is commonly used. This study utilized The WQI was used to evaluate the water quality of the Fervença River in Bragança, Portugal from January to June 2022. Water samples were collected monthly from five locations along the river. The WQI, which is based on physical, chemical, and biological parameters, provides a comprehensive numerical assessment ranging from 0 to 100. In general, points 1 to 4 exhibited a good WQI and showed similar results. However, at point 5, reduced WQI values were consistently observed in all sampling campaigns, indicating a likely connection with discharge from the nearby wastewater treatment plant. The winter season, which is typically characterized by higher rainfall in the region, experienced severe drought during the study period. Consequently, the influence of rainfall on the WQI parameters could not be evaluated as expected, particularly from January to March. Comparing the obtained results, it is evident that as the Fervença River flows through the city of Bragança, the water quality indices decrease in most campaigns, particularly after point 5. This finding highlights the negative influence of the city on the river water quality. This study highlights the importance of assessing the water quality. Points 1 to 4 demonstrated good water quality, whereas point 5 showed reduced quality linked to the wastewater treatment plant. Drought and city influence affected the river's water quality.

Keywords—Environmental monitoring; water analysis; water pollution; water quality control.

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1. INTRODUCTION

In 2015, the United Nations established seventeen Sustainable Development Goals as part of the 2030 agenda for sustainable development. Goal number 6, "Clean Water and Sanitation," highlights the critical importance of monitoring and assessing the quality of groundwater and surface water. This imperative is aimed at ensuring a dignified future for future generations by safeguarding access to clean and safe water resources.

To achieve this, effective water quality control measures are necessary to monitor and identify pollution-causing agents, develop action plans, and minimize water pollution. Various chemical, physical, and microbiological parameters are used to assess water quality [1, 2].

Implementing a surface water quality control program across different locations and over time generated a significant amount of data and results. To transform these data into comprehensive, accessible, and simplified information, the calculation of the Water Quality Index (WQI) has become one of the most popular and effective methods [3, 4, 5].

The primary aim of a WQI is to provide a single value, such as a grade, that expresses the overall quality of a water body based on several water quality parameters. It is a simple and powerful tool that employs an aggregation function, enabling the evaluation of changes in water quality over time and across different locations [1, 5, 6]. Water quality indices (WQIs) are highly regarded by water management agencies because of their ease of use and understandability.

One widely recognized and utilized index for the classification of surface water quality is the National Sanitation Foundation Water Quality Index, created in 1970 by the National Sanitation Foundation (NSF) [6]. It is considered the most popular and widely employed index by researchers worldwide [7]. This index involves the analysis of nine parameters: dissolved oxygen (DO), pH, total solids (TS), biochemical oxygen demand (BOD_5), turbidity, total phosphate, nitrates, temperature, and fecal coliforms (FC) [3, 6, 8, 9].

Each of these parameters undergoes a conversion process to obtain dimensionless sub-indices that represent the individual quality variation. Weighting factors were assigned to each parameter to reflect their relative importance in determining the final WQI. These weighting factors are based on their significance in overall water quality assessments [3, 6, 8].

WQI was calculated using an aggregation function. The sub-indices obtained for each parameter, along with their respective weighting factors, were combined according to the aggregation function equation. The resulting index provides a single value that expresses overall water quality [5].

The WQI ranges from 0 to 100, with higher values indicating better water quality. It is categorized into five water quality levels, allowing for easy interpretation and understanding. These levels help to assess the health and suitability of water resources for various purposes [3, 6, 9].

The objective of this study was to assess the water quality of the Fervença River in Bragança, Portugal using a water quality index approach.

2. MATERIALS AND METHODS

Water samples were collected from the Fervença River, situated in the district of Bragança, northeast Portugal. Monthly sampling was conducted from January 2022 to June 2022, and water samples were collected at five distinct locations along the river.

Collection Point 1 (P1: 41˚47’37.6” N, 6˚47’15.3” W) is located in a rural area upstream, before reaching the most densely populated region. Point 2 (P2: 41˚47’54.9” N, 6°46’16.7” W) is situated within the city itself, adjacent to one of Bragança's major avenues, Avenida Sá Carneiro. Point 3 (P3: 41°47’54.6” N, 6°45’54.0” W) is located on the campus of the Polytechnic Institute of Bragança. Point 4 (P4: 41°48’17.0” N, 6°45’26.6” W) is situated in the central area, close to snack bars, shops, and areas with significant human activity. The final sampling location, Point 5 (P5: 41°48’04.5” N, 6°44’38.4” W), is positioned downstream after the river passes through the city center and receives effluent discharge from the wastewater treatment plant, encompassing the entire city area.

The selection of these distinct sampling points along the river provides a comprehensive representation of the water quality at various stages, from rural upstream areas to urbanized downstream regions. This approach enables the evaluation of potential variations in water quality influenced by different land uses, human activities, and point source pollution.

The collected water samples were analyzed in triplicate. The recommended analytical methods described in the Standard Methods for the Examination of Water & Wastewater Manual [10] were used to determine the pH, temperature, DO, turbidity, BOD_5, total phosphorus, nitrates, and TS.

FC bacteria were quantified using the membrane filtration method with m-FC base agar, as outlined in the ISO 9308 standard. The water samples were incubated at 44°C during the analysis to facilitate the growth and enumeration of fecal coliform bacteria [11].

The WQI is determined using the aggregation function expressed in Eq. 1, as referenced in previous studies [8, 3, 6].

$$WQI = \sum_{i=1}^{n} q_i w_i \qquad \text{Equation 1}$$

where: WQI represents the water quality index, qi denotes the sub-index evaluated for each parameter, obtained from the quality variation slope of that parameter, w_i corresponds to the weight assigned to each parameter, and *n* represents the number of parameters being considered.

The sub-index (q_i) for each parameter is calculated using a specific mathematical equation that varies according to the limits associated with that particular parameter. The mathematical expressions used in this study are presented in Table I.

For the w_i term in Eq. 1, the weights assigned to each parameter were determined based on their significance in determining the overall water quality. The sum of all weight factors must be equal to one. In this research, the weights assigned to each parameter were as follows: 0.17 for DO, 0.15 for FC, 0.12 for pH, 0.10 for BOD_5, 0.10 for nitrates, 0.10 for total phosphorus, 0.10 for temperature, 0.08 for turbidity, and 0.08 for TS [4, 7, 13].

Table I: Representative NSF Quality Equations [4, 12].

Parameter	**Min. limit**	**Max. limit**	**qi Equation**
FC (UFC 100 mL $^{-1}$)	0	10^5	$98.24034-34.7145*(logFC)+2.614267*(logFC)^2+0.107821*(logFC)^3$
pH	7	8	$-427.8+142*pH-9.695*pH^2$
	8	8.5	216-16*pH
BOD_5 (mg L^{-1})	0	30	$100.9571-10.7121*BOD_5+0.49544*(BOD_5)^2-0.011167*(BOD_5)^3+0.0001*(BOD_5)^4$
	30		2
Nitrates (mg L^{-1})	0	10	-5.1*(N)+100.17
T. Phosph. (mg L^{-1})	0	10	$79.7*(PO_4+0.821)^{-1.15}$

Temperature			93
Turbidity (NTU)	0	150	$100.17-2.67*Turb+0.03775*Turb^2$
	150		5
TS (mg L^{-1})	0	500	$133.17*e^{(-0.0027*TS)}-53.17*e^{(-0.0141*TS)}+$ $[(-6.2*e^{(-0.00462*TS)}*\sin(0.0146*TS)]$
	500		32
DO (%sat)	50	85	$3-1.166*(\%sat)+0.058*(\%sat)^2$ $-3.803435*0.0001*(\%sat)^3$
	85	100	$3+3.7745*(\%sat)^{0.704889}$

By determining all the sub-indices (q_i) and weights (w_i), the final WQI can be calculated using Eq. 1.

3. RESULTS AND DISCUSSION

The sampling campaign started in January on a sunny day with a recorded temperature of 8 °C. In February, the weather was cloudy, and the temperature was 10 °C. Despite the low rainfall in the preceding days, river flow remained unaffected. However, March sampling encountered extraordinary weather conditions. On March 15, 2022, a dust storm originating in the Sahara Desert reached Portugal. Although no rainfall was recorded on that day, the absence of rain potentially facilitated the transportation of debris into the Fervença River. The sampling was performed at a temperature of 12 °C. Notably, this campaign marked the last campaign conducted during the winter.

In April, the fourth sampling campaign was conducted at a temperature of 13 °C. The preceding days were relatively warmer, with temperatures peaking at 25 °C and no rainfall. River flow remained low during this period. Similarly, the May campaign took place at a temperature of 14 °C, with the preceding days recording temperatures of up to 25 °C with no rain. In mid-spring, the riparian forest along the river flourished, serving as a physical barrier to sediment retention.

Finally, the sixth and final sampling campaigns took place in June, coinciding with the second day of the summer. The temperature recorded during this campaign was 16 °C, with the previous week seeing temperatures as high as 35 °C. No rain was recorded on the days leading up to the sampling, and the river flow remained low.

Decree-Law n.° 236/98, in Annex I, establishes the classification of the quality of surface fresh water intended for the production of water for human consumption based on the maximum values found for each analyzed parameter [14]. According to this classification, surface water can be categorized into three distinct treatment classes.

Class A1 refers to water that requires only physical treatment and disinfection to become suitable for human consumption [14]. Class A2 includes water that requires physical, chemical, and disinfection treatments to ensure its quality for consumption [14]. Finally, Class A3 encompasses water that requires physical treatment, chemical refinement, and disinfection to meet the standards required for the production of water intended for human consumption [14].

Table II presents the microbiological characterization, specifically the determination of FC, for the water samples collected from the Fervença River at each collection point throughout the 6-month study period. The results showed the presence and levels of FC at each sampling location.

According to Decree-Law n.° 236/98, for the water to be suitable for the production of water for human consumption, points P1, P2, P3, P4 (except in January), and P5 (except in January, March, April, May, and June) would need to undergo physical and chemical treatment, as well as disinfection.

Table II: Concentration Of Fecal Coliforms (CFU Mg 100 Ml-1) Along The Length Of The Fervença River From January To June 2022.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
P1	1,117	1,370	1,243	16,133	1,117	79,000
P2	1,707	89	1,820	5,700	1,707	330
P3	667	370	2,280	5,167	667	513
P4	7,067	263	1,340	4,500	7,067	140
P5	20,367	1,763	87,000	566,667	20,367	86,000

However, there are points that exceed the maximum allowable value and are not recommended for producing water for human consumption, even after undergoing physical and chemical treatment, refining, and disinfection. For instance, in January, March, April, May, and June, P5 showed FC concentrations above the recommended limit of 20,000 CFU mg 100 mL^{-1}. P1 exceeded this limit in June.

Figure 1 and 2 illustrate the physicochemical parameters determined for the water samples. These parameters provide valuable insights into various physical and chemical aspects of river water, including pH, temperature, DO, turbidity, BOD_5, total phosphorus, nitrates, TS, and FC. The graphical representation helps to visualize the variations and trends in these parameters over the study duration.

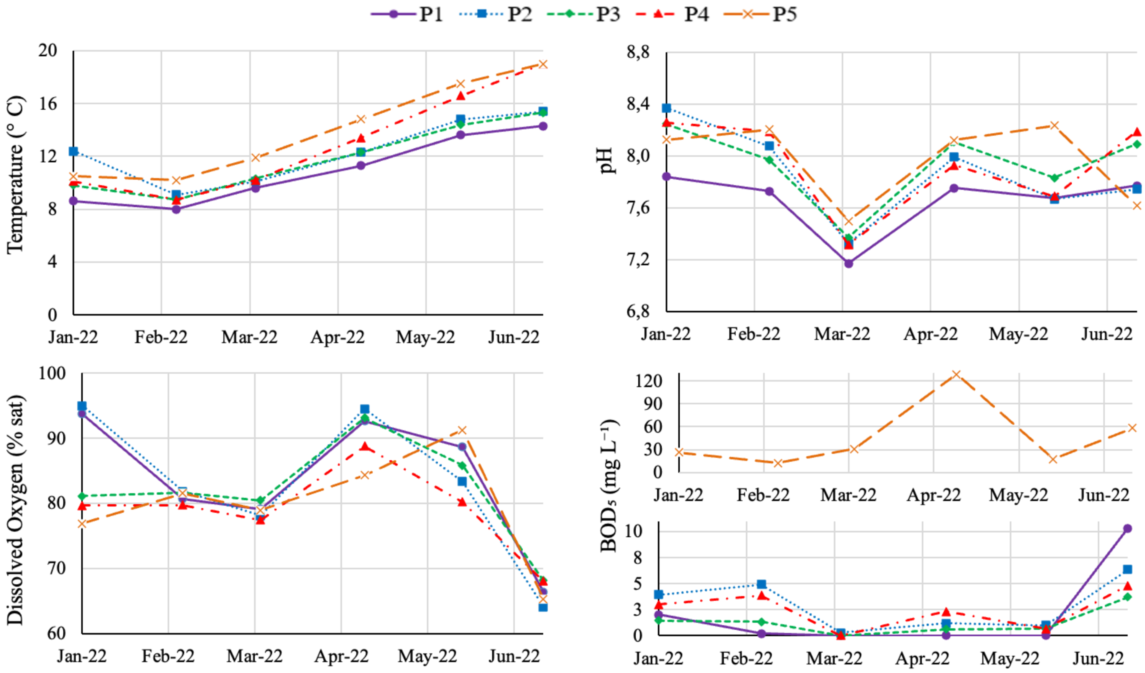

Fig. 1. Water Quality Parameters (temperature, pH, dissolved oxygen, and BOD_5) of the Fervença River (January – June 2022).

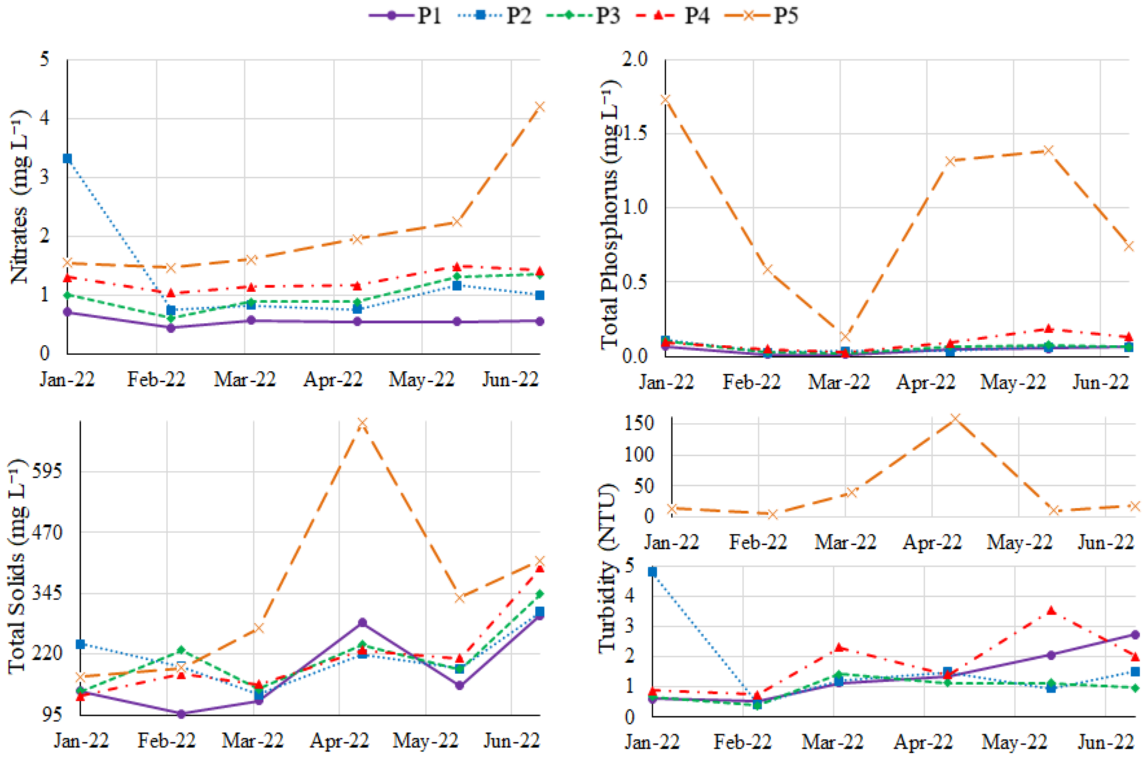

Fig. 2. Water Quality Parameters (nitrate, total phosphorus, total solids, and turbidity) of the Fervença River (January – June 2022).

Despite the tendency for water temperature to increase over the study period, none of the Fervença River sampling points exceeded the maximum value recommended by Decree-Law n.° 236/98.

The pH values measured from January to June 2022 ranged from 7.2 to 8.4 at all sampling points, indicating that the water quality, based on this parameter, falls within Class A1 for surface freshwater intended for production of water for human consumption. Therefore, physical treatment and disinfection are sufficient before water can be used for human consumption.

In terms of DO, all the points had a concentration that fits into Class A1 (up to 70% O_2 saturation) from January to May, while in June, the collected points belonged to Class A2 according to the % of O_2 sat (up to 50% O_2 saturation) in accordance with Decree-Law n.° 236/98.

Regarding BOD_5, P1 to P4 belong to Class A2 from January to May, with the exception of P2 in January and February, and P4 in February. However, all P5 samples exceeded the maximum BOD_5 concentration, even for Class A3. As a result, water from this point is not recommended for the production of water for human consumption. In June, after physical and chemical treatment and disinfection, P3 and P4 could be used for the production of water for human consumption, but the water collected from P1 and P2 in the same month is not recommended for use even after these treatments.

All points analyzed fell within the maximum concentration limits for nitrates as defined by Decree-Law n.° 236/98, falling under Class A1, which specifies a maximum concentration of 25 mg L^{-1} for surface fresh water.

Regarding phosphorus concentration, all points analyzed, except P5, were within the maximum limit of 0.4 mg L^{-1} for Class A1 of surface fresh water intended for the production of water for human consumption. P5 exceeded the limit for Class A2 in February and June, while in the other months (January, April, and May), the water at this point exhibited excessive concentrations, making it unsuitable for the production of water for human consumption based on this parameter.

Decree-Law n.° 236/98 does not establish specific maximum values for TS and turbidity in surface freshwater intended for the production of water for human consumption.

By combining the results of microbiological characterization and physicochemical parameters, a comprehensive understanding of the water quality in the Fervença River can be obtained. This information is crucial for assessing the overall health of a river and its potential environmental impact.

By analyzing the parameters based on Decree-Law n.° 236/98, the results from the January sampling show that P1 and P3 fit into Class A2 for the production of drinking water, as pH, DO, temperature, FC, BOD_5, nitrates, and total phosphorus values all fall within acceptable ranges. P4 could be considered as an option for producing potable water after undergoing physical, chemical, disinfection, and refining treatments (Class A3). However, P5 is not recommended for drinking water production because of the high FC and BOD_5 values.

In the February sampling, P1 to P4 were considered acceptable for the production of water for human consumption after the Class A2 treatment. However, with a high BOD_5 value, P5 was not a suitable option for potable-water production after any class of treatment.

In March, water from P1 to P4 can be used to produce water for human consumption after the Class A2 treatment. All measured parameters, except for FC, were within limits, even for the less severe treatment (Class A1). P5 showed significantly higher turbidity, FC, BOD5, and TS values than the previous campaigns.

During the April collection, an increase in the measured values of TS, temperature, total phosphorus, and FC was observed at all points. This increase may be influenced by factors such as temperature and TD, which affect the number of FC in the water owing to the tendency of phosphorus and fecal bacteria to be associated with particles [15]. Typically, elevated TS values in surface water are associated with external causes such as runoff from the drainage basin and resuspension of sediments [15].

The results from April indicate that water from P1 to P4 could be used as a source of drinking water only after the Class A3 treatment. The water from P5 was not suitable for human consumption under any circumstances, with some values (BOD_5) exceeding the wastewater discharge limits stated in Annex XVIII of

Decree-Law n.° 236/98.

In May, P1, P2, and P3 could be used as sources of drinking water after undergoing A2 treatment. P4 fell within the limits of treatment A3, and some parameters of P5 (total phosphorus and FC) exceeded the limits for any class of treatment, making it unsuitable for this purpose.

The results from the May sampling campaign showed a reduction in DO rates and an increase in BOD_5 values for all five points compared to the last five campaigns. This may represent an increased activity of bacteria that decompose organic matter and may be influenced by rising temperatures [16].

Additionally, this campaign showed an unusual increase in FC, BOD_5, and nitrates at P1. Being located in a rural area, this could be attributed to the presence of animal feces and may indicate agricultural activities as sources of organic matter and nitrogen [17].

In June, considering only the measured parameters, P1 and P5 could not be used as drinking water sources. P2 would only be suitable after Class A3 treatment, and P3 and P4 after Class A2 treatment, based on Annex I of Decree-Law n.° 236/98. Similar to the April campaign, the BOD_5 values at P5 (downstream of the city's wastewater treatment plant (WWTP)) exceeded the wastewater discharge limits set out in Annex XVIII of Decree-Law n.° 236/98

Additionally, the collected data were used to calculate the WQI for each sampling point during the campaigns conducted from January 2022 to June 2022, as presented in Figure 3.

Based on the WQI results, the classification can be divided as follows: Excellent for WQI scores ranging from 91 to 100, Good for scores between 90 and 71, Regular for scores from 70 to 51, Bad for scores from 50 to 26, and Very Bad for scores ranging from 0 to 25 [3, 6, 9].

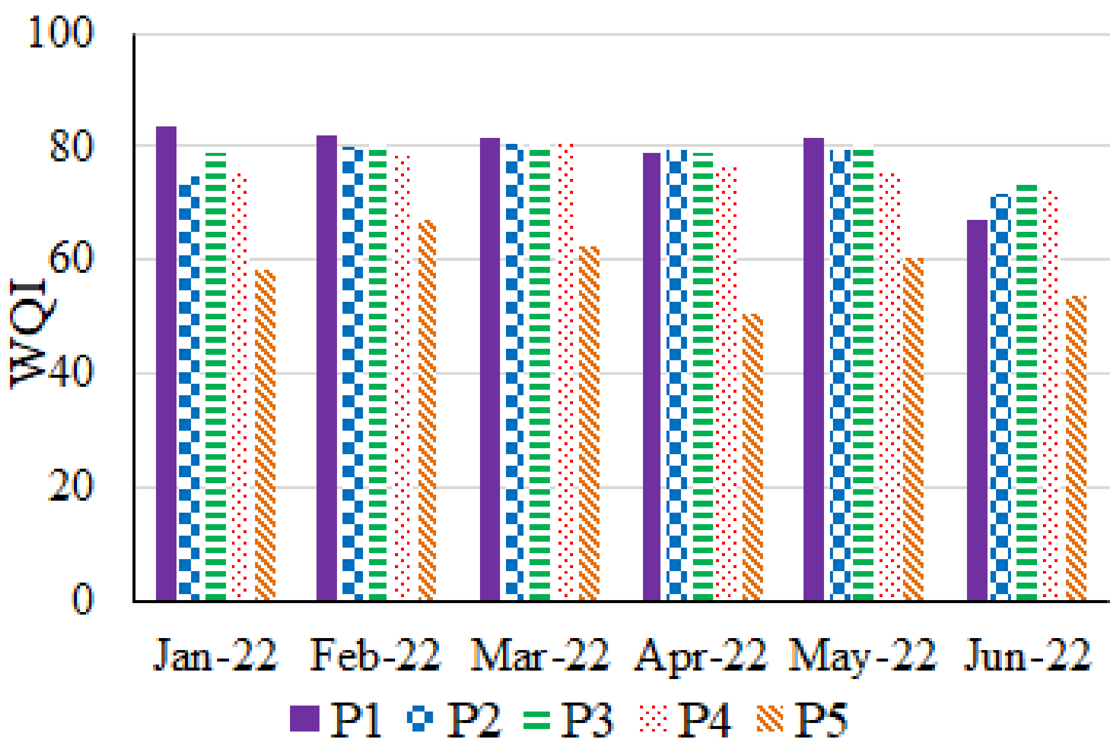

Fig. 3 Monthly WQI score of the Fervença River (January – June 2022.

Table III presents the rankings for each sampling point during the study period, indicating the corresponding classification for each month.

Table III: Monthly WQI Classification Of The Fervença River (January – June 2022) [3, 6, 9].

	Jan-22	**Feb-22**	**Mar-22**	**Apr-22**	**May-22**	**Jun-22**
P1	Good	Good	Good	Good	Good	Regular
P2	Good	Good	Good	Good	Good	Good
P3	Good	Good	Good	Good	Good	Good
P4	Good	Good	Good	Good	Good	Good
P5	Regular	Regular	Regular	Bad	Regular	Regular

In general, the water quality of the Fervença River was good throughout the study period, except for P5. P1 to P4 consistently demonstrated high WQI values with minimal variations in both space and time from January to May 2022.

However, June stood out as the month with the poorest water quality index results for most sampling points along the river. Specifically, there was a lower DO score and higher BOD_5 and TS parameter scores. This decline in water quality can be attributed to the natural increase in water temperature, which negatively affects DO levels, and the potential increase in bacterial activity responsible for decomposing organic matter.

Unfortunately, the winter period experienced a severe drought, which hindered the expected improvements in water quality over time. Figure 4, obtained from the Portuguese Institution of Sea and Atmosphere (IPMA), illustrates a comparison between the total rainfall volume in 2022 and the average volume recorded from 2011 to 2021 [18]. The data clearly demonstrate a significant deviation in rainfall volumes for January and February, with 2022 receiving only 6.5% and 6.9% of the expected average, respectively [18]. Additionally, March, April, May, and June also exhibited substantially lower rainfall volumes than the anticipated levels [18].

These climatic conditions likely contributed to the observed variations in the water quality during the study period. Nonetheless, except for P5, the Fervença River generally maintained a good water quality throughout the study period.

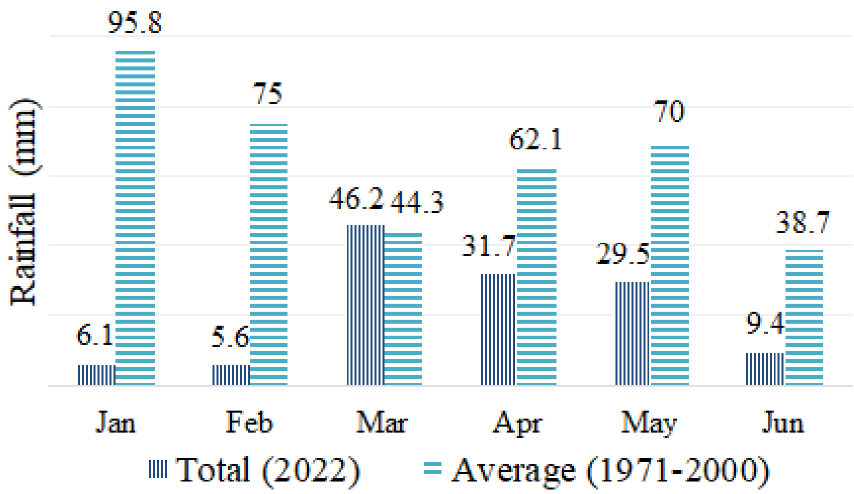

Fig. 4 Rainfall for 2022 (total volume) compared to the average for 2011 – 2021 [18].

Rainfall plays a direct role in surface water quality and is one of the most influential seasonal factors [2]. The low rainfall rates observed throughout the analyzed period, especially during the typical rainy winter season, can be considered the primary reason for the relatively consistent water quality index results [2]. Overall, no significant influence of rainfall on the results was observed.

Similarly, the growth of riparian forests, which are expected to protect the river from sediment-laden runoff, particularly during the spring season, did not appear to have a noticeable impact on the water quality index results [19]. This lack of impact could be attributed to the scarcity of rainfall during this period.

In terms of land use influence and location comparison, P5 consistently exhibited the worst water quality index scores every month [17]. Located approximately 200 m downstream from the Bragança wastewater treatment plant, it is evident that its water quality status is closely related to the "Regular" and "Bad" classifications observed during the analyzed period. Furthermore, the "Regular" status of P1 in June, characterized by lower indexes in parameters such as FC, DO, and BOD_5, is likely influenced by the sources of organic matter prevalent in the region.

Additionally, a slight superiority in WQI was observed in P1 (except in June) compared with P4. This difference was expected, considering that P1 is situated in a rural area, whereas P4 is located in the central area of Bragança, with a higher potential for exposure to urban pollutants.

In conclusion, based on the obtained water quality index results, it can be inferred that the city of Bragança has a direct negative influence on the water quality status of the Fervença River during the first six months of 2022.

4. CONCLUSIONS

The application of the WQI to assess the water quality of the Fervença River in Bragança, Portugal proved to be successful. The results enabled comparisons over time, different locations, and compliance with Portuguese legislation regarding water-use requirements.

In general, the water quality results indicated "good" quality for P1 to P4 based on the water quality classification. Considering the analyzed parameter (9), the water from P2, P3, and P4 in all six sampling campaigns could be used as a source for drinking water production after undergoing treatment Class A2 or A3, as defined in Decree-Law n.° 236/98. However, for P1, water could not be used for this purpose in the last campaign because of the high values of FC and BOD_5.

P5 consistently showed a "regular" to "bad" water quality status based on the QWI; located just a few hundred meters downstream from the Bragança WWTP, confirmed the negative influence it has on the water quality of the Fervença River. In two campaigns, some water quality parameter values exceeded the limits set for wastewater discharge according to Decree-Law n.° 236/98.

The June campaign resulted in the lowest overall water quality. This decline may have been influenced by the higher temperatures during this month. Temperature directly affected DO, which had the highest weight value in determining the WQI. However, the influence of rainfall on the results could not be observed because of the low precipitation recorded in Bragança during the first six months of 2022, which was marked by an intense drought.

This study confirms the expected negative influence of Bragança City on the water quality of the Fervença River. While the water quality remains relatively good from P1 to P4 as the river flows into the city, it significantly deteriorates after P5, when it receives discharges of treated effluents from the WWTP.

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