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# WATER AND SEDIMENT QUALITY ASSESSMENT IN THE WETLAND PATEIRA DE FERMENTELOS (PORTUGAL)

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**Abstract:** We evaluated the water quality of the wetland ecosystem Pateira de Fermentelos (Portugal) within the Water Framework Directive 2000/60/EC and provide ideas for the wetland enhancement. For that purpose, surface water samples were collected in May 2011, at 5 selected sampling sites, and were analysed for physicochemical, chemical and biological parameters, namely temperature, conductivity, pH, nutrients, organochlorine pesticides, heavy metals and macroinvertebrates. An unacceptable water quality situation was observed for the index of macroinvertebrates in points 1 and 2 (Certima river and Ribeira do Pano), where pollution-tolerant *Chironomidae* and *Oligochaeta* were dominant taxa, indicating poor water quality. Total phosphors concentration measured in point 1 (Certima) exceeded the limit value three times. Sediments from the study area indicate contamination by zinc and lead and based on toxicity evaluation these metals could cause adverse effects especially in sediments from point 4 (east bank of the wetland). Higher concetrations of organochlorine pesticides (DDE and α-HCH) were detected in sediments from points 3 and 4 (Agueda and on east bank of the wetland), predicting sediment toxicity. The results of this study revealed the urgency of implementing restoration measures needed to restore water quality in the wetland Pateira de Fermentelos not only to meet WFD objectives, but also to guaranty sustainability and increase the resilience of the wetland ecosystem.

**Keywords:** Water Framework Directive, organochlorine pesticides, heavy metals, macroinvertebrates, restoration measures

## 1. INTRODUCTION

Wetland ecosystems are important habitats for flora and fauna and hence are of national and international importance for conservation. They comprise about six percent of the earth's land surface and have various ecology function, economy value and society value, including agricultural production, fisheries, provision of wildlife habitat and so on. However, with the economy development and the population growth, wetlands have undergone great changes. Wetlands previewed a downward trend during the past decades (Shi et al., 2008) due to the contamination of these ecosystems (in large part by urban and industrial effluents), eutrophication associated with intensive agriculture (pesticides and herbicides) and especially because of the poor management of natural resources (Cvetkovic & Chow-Fraser, 2011). These disturbances affect the level of services a wetland can provide.

Functions of a wetland depend on wetland water quality. Water quality is a primary factor from which derives the ability to subsequently offer other wetland functions and provide ecosystem services. A key initiative aimed at improving water quality throughout the European Union is the Water Framework Directive (WFD). This directive specifies quality elements for the classification of water bodies' ecological status that include chemical and physicochemical elements that support the biological elements.

The objective of this study was to conduct analyses of biological (macroinvertebrates), physicochemical (temperature, pH, conductivity, nutrients) and chemical parameters (heavy metals and organochlorine pesticides) to assess the current state of the wetland ecosystem Pateira de Fermentelos (Portugal) within the directive 2000/60/EC (Water Framework Directive) and to suggest ideas for improving wetland's conditions.

## 2. MATERIAL AND METHODS

### 2.1. Study Area and Sampling

Pateira de Fermentelos is a natural freshwater wetland ecosystem located at the central region of Portugal, being considered one of the largest natural wetland in the Iberian Peninsula. It is an area of high biological importance being protected by the Birds Directive and classified as a "Sensitive Area" in the Portuguese legislation (Decree-Law No. 152/97, of 19 July, Annex II), as it is an important and extensive wetland (Laranjeira, 2009). This wetland ecosystem (average depth 2.5 m, max. length 3.5 km, max. width 0.75 km) has a maximum surface area of approximately 5 $km^2$.

A major factor contributing to the degradation of the ecological, economical and social role of this wetland is the occurrence and spread of exotic weeds in Pateira (Laranjeira, 2009). In addition, in the last decade, the introduction of agricultural and industrial chemicals, domestic wastes, as well as eutrophication and incorrect utility of resources resulted in an increased water pollution (Ahmad et al., 2006) and consequently in the degradation of this ecosystem.

The sampling sites in Pateira de Fermentelos were chosen due to the possibility to determine the influence of water quality in inflows (the river Certima and Pano do Ribeira) on the state of wetland ecosystem and the outflow (the river Agueda, Fig. 1).

Field samples of sediments, water and macroinvertebrates were collected in May 2011. Sediment samples were collected using a plastic spade and then they were stored in plastic bags, properly identified and transported to the laboratory. Samples of macroinvertebrates were collected 6 times at each site using a benthic net. Water samples were collected using a polyethylene flask, previously washed with water from that site and then transferred to acid-washed polyethylene bottles and transported to the laboratory.

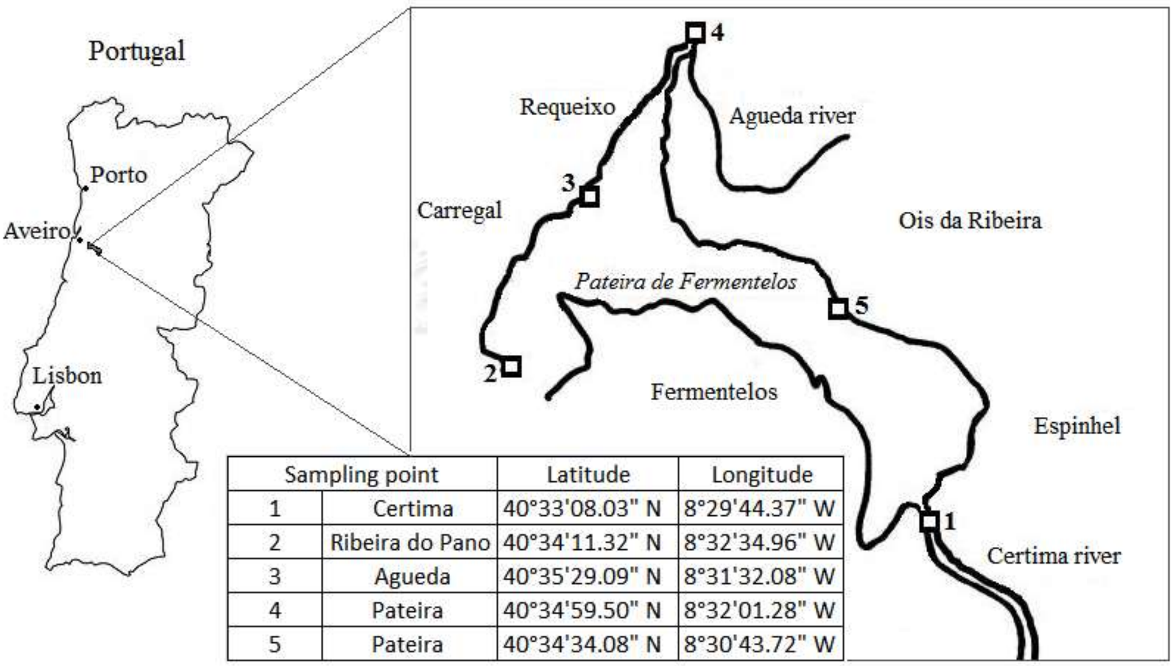
### 2.2. Methods

At each sampling site pH and conductivity were determined by electrometry and nutrients were determined by colorimetry after the arrival to the laboratory.

The process of determination of the biological index of benthic macroinvertebrates followed the method established by INAG (2008), the National Portuguese Institute of Water.

Heavy metals were transferred from sediments to solutions ($HNO_3$) using a high-pressure microwave digestion (MLS-1200 Mega, Millestone) and concentrations were determined by atomic absorption spectrometry with flame atomizer (PU 9200X, Philips) as described in Almeida et al., (2004).

Organochlorine pesticides (OCPs) in sediments were analysed using a microwave digestion (methanol), followed by headspace solid phase microextraction (HS-SPME) and gas chromatography (Varian CP 3800) with electron capture detector as described in Carvalho et al., (2008).




| Sampling point | | Latitude | Longitude |
|---|---|---|---|
| 1 | Certima | 40°33'08.03" N | 8°29'44.37" W |
| 2 | Ribeira do Pano | 40°34'11.32" N | 8°32'34.96" W |
| 3 | Agueda | 40°35'29.09" N | 8°31'32.08" W |
| 4 | Pateira | 40°34'59.50" N | 8°32'01.28" W |
| 5 | Pateira | 40°34'34.08" N | 8°30'43.72" W |

Figure 1. Location of the sampling sites within the area of interest

For the purpose of sediment pollution evaluation also a granulometric analysis was performed to determine the quantity of different granulometric fractions. Particle size distribution in sediments is an important parameter for chemical analysis of pollutants as they are absorbed in smaller grain size particles, mainly clay minerals. Furthermore, concentration of heavy metals in sediments is influenced by organic matter content. Organic matter content in sediments was determined by combustion at 500°C for 4 h.

## 3. RESULTS

### 3.1. Physicochemical parameters and distribution of macroinvertebrates

Physicochemical parameters of water (pH, temperature and conductivity) are shown in table 1. Temperature values ranged between 18ºC and 27ºC, with the highest values measured on the banks of the wetland as expected. The measured pH values fit within the limits set out in Portuguese legislation (Decree-Law No. 236/98, of 1 August, Annex 1) which is between 5.5 and 9. With regard to the electrical conductivity, the values ranged between 40 and 55 mS/m (at 20°C), lying also within the limits defined in the forementioned Portuguese legislation, ie. ≤100mS/m.

Results of nutrient concentration analyses are also shown in table 1. The threshold value established for the good ecological status in rivers of the North group in Portugal by INAG (2009) is for phosphorus ≤0.10mg/L. This upper limit was exceeded in sampling points 1 (0.3 mg/L), 4 (0.37mg/L) and 5 (0.15mg/L). For nitrate the threshold value is ≤25 mg/L and all the obtained values (3.54 – 7.09 mg/L) fit within the limit.

Table 1. Physicochemical parameters of water and nutrient concentrations in Pateira de Fermentelos

| Sampling point | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| pH | 7.53 | 6.86 | 8.55 | 8.75 | 8.81 |
| t (°C) | 18.2 | 23.3 | 24.1 | 27.3 | 26.3 |
| $\kappa_{20}$ (mS/m) | 55 | 40 | 50 | 47 | 46 |
| $NO_3^-$ (mg/L) | 7.09 | 0 | 3.54 | 0 | 6.2 |
| P total (mg/L) | 0.3 | 0.05 | 0.08 | 0.37 | 0.15 |

The value of electrical conductivity (55mS/m) and phosphorus concentrations (0.3mg/L) measured in point 1 (the river Certima) may be related to the influence of agricultural/livestock and/or domestic effluents along the Certima river, where most of the industries and the aggregate population is located.

One of the key biological components considered for the assessment of benthic integrity in the context of the Water Framework Directive are macroinvertebrate benthic communities.

These organisms are often used to assess water quality (Bartram & Balance, 1996) due to several advantages, in relation to other groups of organisms, as widely distribution and abundance in ecosystems, long life cycles and high number of species, which offers a broad spectrum of responses to environmental stress.

For the assessment of ecological status using macroinvertebrates the Iberian Biological Monitoring Party index (IBMWP) and the ecological quality ratio (EQR) was used. The IBMWP index is based on the principle that different aquatic invertebrates have different tolerances to pollutants. Certain species indicate the cleanest waterways and are given a tolerance score of 10 (e.g. *Ephemeroptera*). The number of different macroinvertebrates is also an important factor, because a better water quality is assumed to contain fewer pollutants resulting in a higher diversity. The IBMWP index classifies water quality into five classes: very good water quality (water not contaminated or water quality not significantly altered), good water quality (light contamination), moderate water quality (some contamination), low water quality (high contamination), bad water quality (very high contamination). EQR is the ratio between the value of the observed biological parameter for a given surface water body and the expected value under reference conditions. This ratio includes five quality classes too: excellent, good, moderate, poor and bad. High ecological status is represented by values close to one.

From the results obtained in this study (Table 2) it can be stated that the water is highly contaminated in inflow streams (Certima and Pano) and contaminated (very contaminated) in the Pateira de Fermentelos lagoon and in the outflow stream (Agueda). A total of 2180 macroinvertebrate individuals were collected, among which, 52% were *Chironomidae* and 24% *Oligochaeta*.

Low diversity of macroinvertebrates and the dominance of taxa resistant to pollution, such as *Chironomidae* and *Oligochaeta*, indicate poor water quality, especially in inflows Pano and Certima Both inflow rivers were also evaluated with the worst EQR class, meaning very high deviation from the reference conditions (0.086 EQR points for Certima, 0.053 EQR points for Pano), whereas Pateira de Fermentelos (points 4 and 5) and the outflow river (Agueda) had a poor EQR status, meaning high deviation from the reference conditions.

Table 2. Distribution of macroinvertebrates in the study area and water quality assessment

| Sampling point / Family | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| *Ephemeroptera* (order) | | | | | 5 | |
| *Leptophlebiidae* | | | | 2 | | |
| *Aeshnidae* | | | | | 1 | |
| *Atyidae* | | | | 53 | 156 | 17 |
| *Isopoda/Amphipoda* (order) | | | | | 1 | |
| *Glossiphonidae* | | | | | 3 | 17 |
| *Naucoridae* | | | | | 2 | |
| *Physidae* | | | | 19 | 7 | 113 |
| *Ferrissiidae* | | | | | 40 | 5 |
| *Planorbidae* | | | | | 1 | |
| *Corbiculidae* | | 1 | | | | |
| *Chironomidae* | | 139 | 21 | 656 | 145 | 145 |
| *Thaumaleidae* | | 1 | 3 | 68 | | 4 |
| *Oligochaeta* (subclass) | | 139 | 190 | 59 | 93 | 93 |
| IBMWP | Points | 5 | 5 | 38 | 42 | 23 |
| | Water quality | Bad | | Moderate | | Low |
| EQRs | Points | 0.086 | 0.053 | 0.29 | 0.35 | 0.248 |
| | Quality level | Bad | | Poor | | |

The inflows Certima and Pano are most probably the source of the pollution in the wetland, where the water quality improves, very slightly though.

### 3.2. Metal content in sediments

The results of analysis of metals in sediments are summarized in table 3. Cadmium was below the limit of detection (<0.35ng/g) in all samples. The highest deposition of Fe, Cu, Pb and Cr was observed in points 2 and 4, whereas for Mn, Ni and Zn it was in points 3 and 4. The highest metal concentrations were determined in sampling points 2 and 4. This is probably related with the higher percentages of organic matter (cca. 25 and 14%) and of fine grains (8 and 12%) found at these points.

Ecological risk posed by metals can be evaluated using different sediment quality standards. MacDonald et al., (2000) concluded that the consensus-based SQGs provide a reliable basis for assessing sediment quality conditions in freshwater ecosystems. Therefore, for each contaminant of concern, two consensus-based sediment quality guidelines were developed from the published SQGs, including a threshold effect concentration (TEC) and a probable effect concentration (PEC) (Table 4). Values below TEC indicate that adverse effects are not expected to occur, predicting the absence of sediment toxicity. Values above PEC indicate that adverse effects are expected to occur more often than not, predicting sediment toxicity.

In all sediment samples Mn and Zn were the most abundant metals in all sediment samples (about 62%), but there are no TEC or PEC values for either of them. These two metals are widely distributed in the earth's crust and are not considered toxic.

In this study all metal concentrations were below PEC but concentration of Cu in points 2 (58 μg/g), 3 (44 μg/g) and 4 (73μg/g), of Pb in points 2 (46μg/g) and 4 (65μg/g) and of Zn in point 4 (152μg/g) the values exceed TEC values predicting possible sediment toxicity, in accordance with the classification of heavily and moderately polluted sediments (US EPA).

On the other hand, metal values in points 1 (Certima) and 5 (northeastern bank of wetland) were lower than TECs, suggesting no toxicity in accordance with the classification of non polluted sediments (US EPA). The concentrations of Cd (<0.35μg/g), Cr (5.8-25.2μg/g) and Ni (3.3 – 18.7μg/g) indicate absence of sediment toxicity at all sampling points.

Several studies have been carried out in the main wetlands throughout Portugal, like Ria Formosa lagoon in the south coast of Portugal, Sado and Tagus estuary in the southwest coast of Portugal, and "Ria de Aveiro" lagoon and Douro, Cavado, Minho and Lima estuaries in the Portuguese northwest coast (Almeida et al., 2008 and reference therein). These studies concluded that some of those areas, like Douro, Tagus and Sado estuaries or Ria Formosa lagoon, suffer from anthropogenic contamination, namely by metals.

The natural occurrence of metals in the environment complicates the identification of a

Table 3. Metals in sediments in μg/g of dry mass, except Fe in mg/g

| Metals | LOD | Sampling point | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Pb | 0.099 | 15 ± 2 | 46 ± 3 | 35 ± 4 | 65 ± 4 | 22 ± 4 |
| Cu | 0.046 | 6 ± 1 | 58 ± 1 | 44 ± 2 | 73 ± 2 | 11 ± 1 |
| Ni | 0.38 | 3 ± 1 | 8 ± 2 | 16 ± 2 | 19 ± 2 | 7 ± 3 |
| Zn | 9.1 | 24 ± 5 | 76 ± 3 | 118 ± 8 | 152 ± 6 | 60 ± 3 |
| Cd | 0.35 | <LOD | <LOD | <LOD | <LOD | <LOD |
| Cr | 5 | 5.8 ± 0.8 | 20.9 ± 0.4 | 15 ± 1 | 25 ± 2 | 9.7 ± 0.2 |
| Fe | 0.25 | 7 ± 2 | 21.0 ± 0.3 | 16 ± 0.6 | 23.8 ± 0.7 | 11.9 ± 0.4 |
| Mn | 4.1 | 52 ± 12 | 43 ± 2 | 81 ± 5 | 174 ± 14 | 101 ± 4 |
| Organic matter (%) | | 5.6 | 25.1 | 14.5 | 13.5 | 6.4 |
| Grain size <0.063 mm (%) | | 2.71 | 7.94 | 1.1 | 12.33 | 1.95 |

Table 4. SQGs used for assessing sediment toxicity of heavy metals in μg/g of dry mass

| Heavy metals | MacDonald et al.(2000) | | US EPA | | |
|---|---|---|---|---|---|
| | TEC | PEC | Non polluted | Moderately polluted | Heavily polluted |
| Pb | 35.8 | 128 | <40 | 40-60 | >60 |
| Cu | 31.6 | 149 | <25 | 25-50 | >50 |
| Ni | 22.7 | 48.6 | <20 | 20-50 | >50 |
| Zn | 121 | 459 | <90 | 90-200 | >200 |
| Cd | 0.99 | 4.98 | - | - | >6 |
| Cr | 43.4 | 111 | <25 | 25-75 | >75 |

potential source of anthropogenic contamination of sediments. An adequate approach is the normalization of metal levels by a reference element not associated with anthropogenic contamination, like Fe (Almeida et al., 2008 and Reis et al., 2009). Normalizations of the concentrations of Pb, Cu, Cr, Ni and Zn by Fe are shown in Fig. 2.The presence of outliners (points that do not fit the linear regression, marked with triangles in graphs in Fig. 2) was indicative of anthropogenic contamination and were excluded from linearization.

Sediments from sampling point 2 indicated anthropogenic contamination by Zn and Ni. At this point the Pano water flows into the wetland, fine-grained sediments that bind more metals to their surface could accumulate. Based on the comparison of Zn and Ni concentrations with the limit values TEC and PEC no toxic concentrations were measured. Sediments from point 4 (northwest bank of Pateira) also showed indication of anthropogenic contamination, by Pb. These sediments with higher silt and clay (13 %) and also organic matter content (14%) than other sediments from the study area, acting like an "ideal" deposit of fine sediments that retain Pb from the the inflow Pano. Furthermore, the concentration of Pb in sediments from the sampling point 4 exceeded the limit value TEC, posing possible toxic threat to organisms living in sediments.

On the other hand, the normalization to Fe indicated that the metal levels observed in sampling points 1 (Certima) and 5 (east bank of Pateira) were probably associated to the natural characteristics of the sediments of this site.

Metal levels in our study were similar to areas considered not polluted, like Minho (Reis et al., 2009), with the exception of Cu, Pb and Zn. In this "clean area" the values of Cu ranged from about 3 to 22μg/g, Pb 5 to 15μg/g, Zn 38 - 92μg/g. In Pateira de Fermentelos these metals presented slightly higher levels (especially in points 2 (Pano) and 4 (northern bank of wetland), where the concentration of Cu was about 58 and 73μg/g, Pb 46 and 65μg/g, Zn 76 and 152μg/g. This finding corresponds with their toxicity evaluation.

### 3.3. Organochlorine pesticides in sediments

The levels of OCPs observed in sampling points are presented in table 5. In this case study 15 OCPs were surveyed: α-lindane, γ-lindane, β-lindane, δ-lindane, heptachlor, aldrin, heptachlor epoxide, endrin, endosulfan I and II, DDE, dieldrin, DDD, DDT and methoxychlor.

From the 15 OCPs investigated only 3 were found in the samples: α-lindane, DDE and DDD. Data were examined to document sediment quality guideline exceedances. A variety of attempts have been made to set numerical sediment quality guidelines (SQG), not only for metals as mentioned above but also for organic contaminants like pesticides. Long & Morgan (1991) suggested effects range-low (ER-L) and effects range-median (ER-M) concentrations for sediment sorbed contaminants. Theses limit values were derived using both freshwater and marine data.

Comparison of these reference values with the obtained results indicates that at sampling point 4 the concentration value of α-lindane (2.2ng/g) exceeded the ER-M (1ng/g), the value above which adverse biological effects are frequently observed, and the concentration of DDE (4.3 ng/g) exceeded the ER-L (2.2ng/g), the value above which adverse biological effects can be observed.

The evaluation of the probability of toxicity occurrence of these pesticides can also be done by comparision with TEC and PEC values as mentioned above for metals. This evaluation indicated that sediments from sampling point 4 presented a probable toxic threat in terms of DDE (4.3ng/g).

Analysis of all data available on OCPs levels on Portuguese coastal areas (Carvalho et al., 2009) indicated that the OCPs detected in our studied area were among those commonly found in the Portuguese coast. Levels of lindane (0.91 and 2.2ng/g) were similar to those generally found in estuaries of the north of Portugal. But DDE levels, namely at point 4 (4.3ng/g) were identical to those found in more polluted areas, like Sado and Tejo estuaries or Ria Formosa lagoon, where the concentration of DDE ranged from 0.07 to 9.64 ng/g with the highest value measured in Tejo estuary.

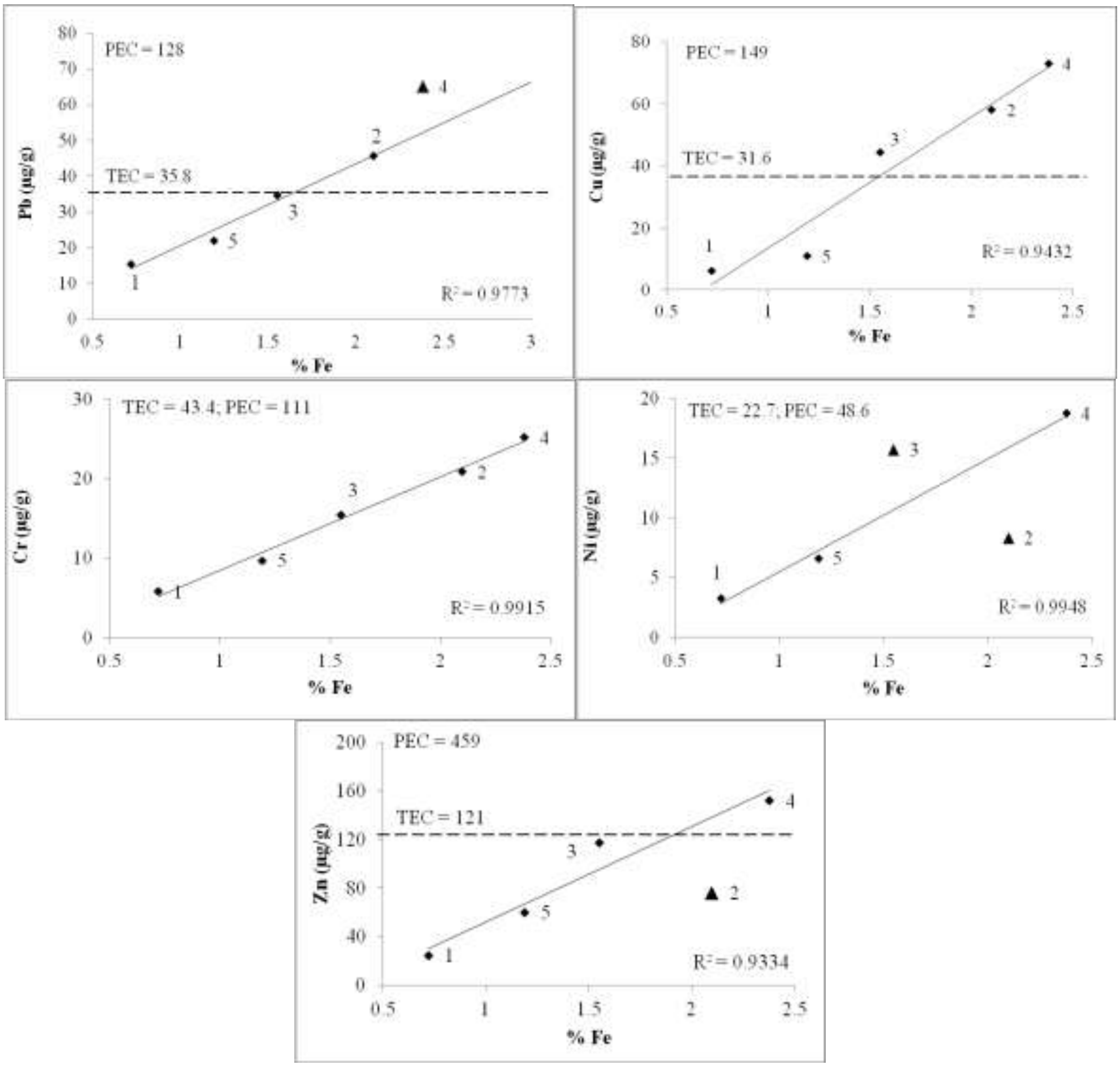



Figure 2. Normalization of Pb, Cu, Cr Ni and Zn concentrations by Fe. The numbering of data indicates sampling sites. TEC and PEC values (in µg/g) are also included.

Table 5. OCPs concentrations in sediments and SQGs (in ng/g)

| OCPs | | α-Lindane | DDE | DDD |
|---|---|---|---|---|
| Sampling points | 1 | <LOD | <LOD | <LOD |
| | 2 | <LOD | 1.06 ± 0.03 | <LOD |
| | 3 | <LOD | 0.3 ± 0.2 | 0.9 ± 0.2 |
| | 4 | 2.2 ± 0.7 | 4.3 ± 0.8 | <LOD |
| | 5 | <LOD | <LOD | <LOD |
| LOD | | 0.09 | 0.02 | 0.03 |
| SQGs | TEC | 6 | 3.16 | 4.88 |
| | PEC | - | 31.3 | 28 |
| | ER-L | 0.32 | 2.2 | 2 |
| | ER-M | 1 | 27 | 20 |

## 4. DISCUSSIONS

Physico-chemical parameters of water, such as temperature, pH, conductivity and nitrate ion were within the limit values (Decree-Law No. 236/98, of 1 August, Annex 1 and INAG, 2009). Our pH values were rather in the alkaline area. This might be due to the presence of carbonate rocks in the study area. Anyway, slightly higher pH values can be also the result of greater photosynthetic activity in spring, greater use of carbon dioxide, followed by the increase of the concentration of dissolved oxygen and reduction of the water acidity and final increase of pH values (Harper, 1992).

Regarding the total phosphorus concentrations measured in sampling points 1 (Certima), 4 (northern bank of the wetland) and 5 (eastern bank of the wetland) exceeded the limit value of 0.10 mg/L. It is possible to say, that the inflow river water rich in total phosphorus affects the quality of water in the wetland itself.

The results of physico-chemical monitoring should be regularly reviewed with the results of biological monitoring, e.g. the state of macroinvertebrates community. Many species of macroinvertebrates found in the studied area are able to live in anaerobic conditions. For example *Chironomidae* have a high tolerance to oxygen deprivation, which suggests that there could be a problem with the oxygen content in water. Therefore this parameter should be considered for future monitoring purposes.

The state of the wetland was assessed also by studying sediment pollution with heavy metals and organochlorine pesticides. It was very clear, that the highest total concentrations of metals were found in the sediments of sampling points 2 (inflow river Pano) and 4 (northern bank of wetland), where the clay-sized sediment fraction (<0,063 mm) was the highest from all sediment samples (8 and 12%) and organic matter content was also high (25 and 14 %). Given these characteristics of the sediments, points 2 and 4 seem to be an appropriate storage for monitored pollutants which was also confirmed by the results of chemical analyses.

Sediments from sampling point 2 (Pano) showed indication of anthropogenic contamination by Ni and Zn, but these metal concentrations were lower than TEC values (threshold effect concentration), which means that there were no significant indications that those metals can cause negative effects in organisms living in sediments. On the other hand, Pb concentrations measured in point 4 (northern bank of wetland) could cause negative effects in organisms living in these sediments (these concentrations exceeded TEC values) that also showed indication of anthropogenic pollution (as well as Cu concentrations measured in sampling points 2, 3 and 4). The source of higher (possibly toxic) concentrations of metals in the sampling point 2 and 4 might be industrial zones situated along the river Pano.

When comparing our results with the study of the author Reis et al., (2009), it can be stated that the sediments from our study area indicated contamination with Cu, Pb and also Zn and based on the sediment toxicity evaluation using limit values TEC, which were exceeded in this case, these metal concentrations could pose a toxic threat for organisms living in sediments.

Highest concentrations of pesticides were measured in sediments from point 4 (northern bank of wetland) and were six times higher than the ones in sampling point 2 (inflow river Pano) and 3 (outflow river Agueda).

Sediments from sampling point 4 contained the highest percentage of fraction smaller than 0.0063mm (12.3%), while sediments from point 2 and 3 less (about 8 and 3%). However, the content of organic matter from point 2 and 3 was almost twice as high (25 and 21%) than in sediments from point 4 (13%). Increase of organic matter in sediments may result in increase of microbial biomass and thereby cause degradation of organochlorine pesticides, but in our study, organic matter content in sediments from points 1 (inflow Certima) and 5 (northeastern bank of wetland) was low (about 6%) and no OCPs were detected. On the contrary in the other sediments (from points 2, 3 and 4), with much higher organic matter content, OCPs were detected. This problem with biodegradation of OCPs may be due to the decreased water quality and oxygen conditions. Therefore, differences in sediment characteristics (grain size and organic matter content) do not have to correspond with different levels of sediment contamination. The results of our analyses are very clear though as OCPs are synthetic and anthropogenic pollutants and each sampling point can be contaminated by various sources and sediments can contain different concentrations of OCPs.

The final ecological and chemical status evaluation of the study site in terms of selected parameters, according to the WFD, which applied the principle "one out - all out" is shown in table 6. This means that the overall status of surface water is evaluated based on the biological or chemical parameter that presents the worst results.

Through evaluation of the ecological and chemical status of the lagoon major problems of water contamination were identified, especially in the two main inputs of water, points 1 and 2, the levels of phosphorus and the biological index for macroinvertebrates.

In the other points, 3, 4 and 5, there were also problems not only with the levels of phosphorus and the biological index of macroinvertebrates but also problems with the quality of the sediments in terms of metals and pesticides. The presence of phosphorus can be related with deposition and runoff of fertilizers from the fields surrounding the study area, discharges of nutrients from animal husbandry (manure and slurry), wastewater treatment stations, among other.

The increase of this compound causes an anthropogenic impact that induces the decrease of environmental status ecosystem, involving the development of macroinvertebrates tolerant species (Brown, 2005; Novotny et al., 2005) and the progressive loss of intolerant species (Newman & Medmenham, 1992), as observed in this case study. However, source of phosphorus may be difficult to control.

In the case of sediments, which can represent a toxicological threat to organisms that inhabit them given the existing levels of metals and pesticides, a measure to be applied would be the removal of sediment through dredging processes. However, if the physicochemical conditions of water and sediments undergo any changes, as usually happens in the dredging process, contaminants can be released from the sediment into the water and become easily bioavailable to the organisms that inhabit the lagoon. For this reason extracting the surface sediments of the lagoon may not be an option, because such action can lead to a secondary pollution that will certainly aggravate the current situation.

To minimize the two problems described above a recovery measure could be the creation of purification zones, through, for instance, the development of green filters. These filters would be applied on the two principal inputs of water to the lagoon, Pano and Certima rivers, since these rivers are the principal source of pollutants to the lagoon. These green filters are based on floating water plants with a dense root system that could effectively eliminate nutrients and contaminants with low installation and maintenance costs.

In this case, it can be suggested as a possible plant to be used in the green filter the water-hyacinth (*Eichhornia crassipes*). This plant is abundant in the lagoon margins, particularly in the two entrance points and its removal was already considered necessary. This macrophyte is considered as one of the worst pests of aquatic plants globally, because it can be easily spread, which implies that it should be mechanically removed and then it could be used to fertilize fields. Mechanical removal is economically demanding, but if we take into account the fact that

Table 6. Evaluation of the ecological and chemical status in terms of WFD

| | Parameters | Sampling Points | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Water quality | $NO_3^-$ | Good | Good | Good | Good | Good |
| | $P_{total}$ | Moderate | Good | Good | Moderate | Moderate |
| | Macroinvertebrates | Bad | Bad | Poor | Poor | Poor |
| Sediments quality | Metals | Good | Moderate | Moderate | Moderate | Good |
| | OCPs | Good | Good | Good | Moderate | Good |
| WFD evaluation | | Bad | Bad | Poor | Poor | Poor |

farmers improve the yield of their fields by using artificial fertilizers, using water hyacinth as a fertilizer would be an environmentally more acceptable method (cycling of nutrients).

Water hyacinth has high capacity for accumulation of metals and organic contaminants and high tolerance to environmental variations (Rommens et al., 2003). In fact it has a high ability to grow in polluted areas, therefore it has been now identified as an effective water treatment for nutritionally rich water bodies (Tripathi & Upadhyay, 2003). Use of water hyacinth as a fertilizer is only possible provided it does not contain unacceptable concentrations of contaminants that the plant can accumulate.

## 5. CONCLUSION

The results of this work indicated problems with the current state of Pateira de Fermentelos wetland meeting the main objective of the Water Framework Directive. Based on the results of statistical evaluation of data gathered from analyses of certain biological, physicochemical and chemical parameters, the wetland water quality does not reach good ecological nor chemical status and restoration of the wetland ecosystem is needed to restore the functions and values it can provide.

It is very important for the wetland to reduce its pollution through the two main inflows - the river Certima and Ribeira do Pano, to promote sustainable water use, encouraging the adoption of specific measures for the gradual reduction of effluent discharges, emissions of substances that present a significant risk to the aquatic environment ensuring the progressive reduction of pollution of groundwater, prevent worsening of their pollution and ultimately contribute to mitigating the adverse effects of episodes of flooding and droughts.

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