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The impact of the storage of nutrients and other trace elements on the degradation of a wetland

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Abstract

Wetland pollution and other changes have led to the serious degradation of wetlands worldwide. The Tablas de Daimiel National Park (TDNP) wetland is a unique wetland in a semi-arid region of Mediterranean climate (Central Spain) and it has suffered significant degradation. In an effort to evaluate the magnitude of this degradation, a total of 43 soil sampling stations were selected in the flood plain area of this wetland. Parameters such as pH, electrical conductivity (EC), dissolved oxygen (DO), calcium carbonate and nutrients (N, P, S, C, S) in the soil were measured along with other trace elements (Br and I). The results were analyzed and a significant spatial variability of the parameters was found. The results of the analysis indicate that the TDNP wetland has a significant capacity to retain and sequester carbon. The elements Br and I had the highest anthropogenic proportions in certain soils in the study area; Br was present in the range 7.7–375.7 mg/kg, with an average value of 74.8 mg/kg, whereas I was present in the range 20.0–277.0 mg/kg, with an average value of 39.4 mg/kg. Both of these average values are much higher than the reference levels in the region. N and P were also present and in some cases these also had higher values than the reference. Wastewaters from urban/industrial activities and from agricultural run-off are the cause of these anomalous levels released into this unique wetland and these concentrations may be harmful to living organisms.

Keywords

Semi-arid environment; wetland; spatial variability; nutrients; bromide; iodine

1. Introduction

Wetlands are ecosystems that are periodically or permanently flooded and they are characterized by the presence of hydrophytes and/or the development of hydric soils. Natural wetlands occupy between 700 and 1024 million hectares, which represents only 4–6% of the land surface (Mistch & Gosselink, 2000), but they are unique ecosystems that are recognized for their productivity and ecological value.

Wetlands are amongst the most productive ecosystems in the world (Whittaker & Likens, 1973) and they also provide flood control, fisheries production, carbon storage and water filtration, although there is some debate over the relative importance of these factors (Turner, 1997). Wetlands provide other tangible benefits and these include water supply and control, mining, the use of plants, wild-life, erosion control, education and training, recreation and reclamation (USEPA & USDA-NRCS, 1995; Cooper *et al.*, 1996; Vymazal *et al.*, 1998; USEPA, 2000; Sundaravadivel & Vigneswaran, 2001). Nevertheless, wetland ecosystems are fragile ecotones between terrestrial and aquatic habitats, especially in Mediterranean regions. It is therefore not surprising that, globally, an increase in the conservation of these areas has occurred – especially bearing in mind the irreplaceable ecological and environmental value of these zones (Mitsch & Gosselink, 2000). In this sense, Mol and Keesstra (2012) highlighted the role of the soil and soil science in helping to solve some of the most pressing global environmental issues: food security, water resources, biodiversity, and climate change.

In respect to the above, in the goals for sustainability the United Nations highlights that soil is a key component of the Earth System and is essential for sustainability. Keesstra *et al.* (2016) stated that Soil Science has a significant impact, as demonstrated by the functions of soils and the ecosystem services that are linked to these functions. Indeed, land management has a strong influence on the behavior of pollutants in soils because it affects the filter and buffer functions of the soil. In the same sense, Keesstra *et al.* (2012) evaluated the quality of soil water and the ability of soils to buffer and filter pollutants to prevent leaching to the ground water or surface water.

A common problem in wetlands downstream from agricultural and urban lands is eutrophication. Water eutrophication is an important environmental concern on a worldwide scale and it is typically linked to the increased anthropogenic input of nutrients. The dissolved elements include nitrogen (N), which plays a major role in the eutrophication of aquatic ecosystems (Smith *et al.*, 1999). In fact, nitrogen is considered by USEPA to be one of the primary stressors in aquatic ecosystems (USEPA, 2002). The subsequent environmental impacts include toxic algal blooms, oxygen depletion, fish death and loss of biodiversity (Vitousek *et al.*, 1997). Non-point-source pollution from agricultural areas is globally recognized as the largest single source of nitrogen emissions to aquatic environments (e.g., Carpenter *et al.*, 1998; Birgand *et al.*, 2007). Research has been carried out on the sources of pollutants and this includes irrigated agricultural soils (Trujillo-González *et al.*, 2017). Furthermore, the accumulation of certain elements in

road dust samples taken from urban sites with different land uses has been related to population density (Trujillo-González *et al.*, 2016). The increased adoption of intensive agricultural practices in recent decades has led to a degradation in water quality that is associated with nitrate (NO_3^-) leaching. However, nitrogen in wetlands can be removed by two main biologically mediated pathways: uptake by plants and denitrification (White & Reddy, 2003; De Laune *et al.*, 2005).

Phosphorus appears to act as a limiting nutrient for the primary production (Durga *et al.*, 2017). Wetlands can also act as phosphorus sinks (Fisher & Acreman, 2004; Wang & Li, 2010). Vepraskas & Faulkner (2001) reported that between 80 and 90% of the P in wetlands is present in the soil as a consequence of the long turnover time of nutrients in these environments (Kadlec & Hammer, 1988). Common sources of P include biogeochemical processes (Song *et al.*, 2007), sediment erosion and dredging (Reddy *et al.*, 1999), with smaller contributions from agriculture, households and industry, amongst others.

In terms of geochemistry, iodine and bromine can be classified as biophiles as they are concentrated in organic matter. Sulfur is of particular interest because it is a ubiquitous element, i.e., it occurs in soils and aquatic systems in both organic and inorganic forms. Although the total S content in soils varies depending on the nature of the soil, it is believed that most of the S present in soils (in humid and semi-humid regions) exists in organic forms (Stevenson, 1994). However, the availability of S decreases with submergence (depth of the water layer). Iodine is an essential trace element for human and animal health. The iodine found in nature has several valence states and it is present in a range of inorganic and organic forms (Liu *et al.*, 2007; Yang *et al.*, 2007; Yoshida *et al.*, 2007). The free form of bromine (Br) is not common in nature and its high solubility in water means that it moves through the courses of rivers and accumulates in wetlands or in the sea. Bromine has been used as a component of K-fertilisers (Kabata-Pendias, 2001).

Numerous wetlands close to agricultural, urban or industrial areas receive pollutants in the incoming waters and/or sediments and these can contain high concentrations of trace metals and/or nutrient-rich leachates. It has been demonstrated that both natural (Newman & Pietro, 2001; Rummer, 2004) and man-made (Knight *et al.*, 2000; Nairn & Mitsch, 2000; Braskerud, 2002a & 2002b; Poe *et al.*, 2003) wetlands are able to filter wastewater and nutrients from arable land.

Natural wetlands have been used by communities as wastewater discharge sites for many centuries. Observations on the wastewater depuration capacity of natural wetlands have led to a greater understanding of the potential of these ecosystems for pollutant assimilation and have stimulated the development of artificial wetland systems for the treatment of wastewaters from a variety of sources. In fact, one of the current issues in environmental science is the inefficiency of wastewater treatment plants to remove several xenobiotic organic compounds, such as pesticides and pharmaceutical residues, and the consequent contamination of the water bodies that receive the effluents.

The Mancha region (Central Spain) is a typical semi-arid Mediterranean area. Soil use in this region changed markedly during the final years of the 20th century due to the expansion of agriculture, especially dedicated to irrigation, and to population increases and the transformation of the landscape into urban and peri-urban areas. These changes led to the occurrence of numerous soil degradation processes. The concerns related to this phenomenon are evident in the case of the ‘Las Tablas de Daimiel’ wetland because, amongst other changes, the soils in the park have undergone a change of use due to intense irrigation aimed at increasing agricultural productivity. Despite the importance of this wetland, Las Tablas de Daimiel is now a threatened ecosystem that has been altered not only due to intensive agriculture, but also due to the burning of surrounding vegetation, urbanization, desiccation through trenching, pollution and other forms of human intervention. The ecological balance of Las Tablas is therefore under serious threat (Jiménez Ballesta, 2014) because the area receives water run-off from streams generated in the agricultural area that surrounds the park.

In wetlands, the primary pollutants that cause degradation are sediments, nutrients, pesticides, salinity, heavy metals and other elements, amongst others. The NPTD (Natural Park Tablas de Daimiel) receives effluents from two depuration stations, from the fertilization of surrounding soils and probably from the nearby industrial area. Reliable data on selected nutrients (N, P, S, C), and especially on bromine and iodine levels, in soils of the inundated flood plain of NPTD are very limited. As consequence, the main objective of the study reported here was to determine the levels of these elements in order to evaluate the status of the area.

2. Material and methods

2.1. The site area

The study area (NPTD) is one of the most important wetlands in Central Spain and it plays an essential role in conserving fauna and flora in this area. The area is located at the western end of the plains of La Mancha (Figure 1), specifically at the bottom of a sector of the Paleozoic reliefs of the Montes de Toledo. The area is approximately 20 km², of which only 17 km² are flooded (Sanchez-Carrillo *et al.*, 2001). However, a substantial part of the Tablas has been virtually dry during various periods (especially in the final years of the last two prolonged periods of drought, i.e., 1980–1995 and 1999–2009). The total area is representative of a characteristic ecosystem called wetlands. The wetlands in this case are formed by the overflow from the Guadiana and Cigüela rivers in a process that is favoured by the phenomenon of endorheism.

The surface area data, according to MAGRAMA (2016), are as follows: gross area: 3,030 ha; peripheral protection area: 5,272.59 ha; socioeconomic influence area: 82,174 ha. The GPS coordinates are 39° 11' 19" N, 3° 46' 25" W - 39° 06' 39" N, 3° 38' 53" W. The flood plain of the wetland currently covers 1,735 ha in the park zone area and 285 ha in the protection zone (Mejias, 2014). In the past, the park covered over 15,000 ha (Sanchez-Carrillo, 2000; Sanchez-Carrillo & Alvarez-Cobelas, 2001).

The space occupied by the NPTD lies on tertiary materials in the southern Plateau and these mainly consist of lacustrine carbonates and sands, gravels and alluvial conglomerates (Santisteban *et al.*, 2009). According to Sanchez-Carrillo (2000), the morphology of the environment of Tablas de Daimiel corresponds to a number of developed geological-geomorphological and anthropic processes from the Pliocene-Pleistocene limit (1.6 m), and this hydrological behaviour can be understood by considering the data reported by Aguilera *et al.* (2013). The weather, as in the rest of the La Mancha plain, is continental, with a maximum temperature in summer of over 40 °C and minimum temperature in winter close to –10 °C. Rainfall is rare and irregular, with maximum rainfall in spring and an annual rainfall of 400–500 mm. The emerging vegetation is dominated by *Phragmites australis* and, to a lesser extent, *Cladium mariscus* and *Thyphadomingensis* along with another series of unique plants such as *Ranunculustrichophyllus* (locally known as ‘Manzanilla’), *Anagallis-aquatica*, *Limoniumdichotomum*, *Limonium costae*, *Limoniumlongebracteatum*, *Juncusmaritimus*, *Tamarixgallica*, *Tamarixcanariensis*, *Salsolavermiculata*, and *Lathyrumsalicaria*, amongst others. In the most superficial part of the wetland, which is developed on peat soils, one can find ‘masiega’ (*Cladiummariscus*), which is perhaps the most

representative species in this area. The dominant associated vegetation includes common reed and cattail (Cirujano *et al.*, 1996; Alvarez-Cobelas *et al.*, 2001).

2.2. Soil sampling

Samples were collected during October and November of 2015. The sampling sites was selected according to the spatial distribution of the wetlands shown in Figure 2. Attempts were made to fit a series of transverse transects and to cover the entire area of inundation. The soil samples were collected at each site at depths of 0 to 30 cm and the exact location was recorded by GPS in each case. For each soil sample, a description of the soil 'colour' was recorded with reference to the appropriate Munsell Colour Chart. All soil samples were air-dried at room temperature immediately after collection and sieved through a 2-mm nylon sieve to remove coarse debris.

Sampling was carried out using a Van Veen Drag. Dissolved oxygen was measured during sampling. As a consequence of the high humidity, samples were dried in a forced air oven at 40 °C for around 7 days. Once the samples had been dried, aggregates were broken using a wooden roller and sieved through a fine 2 mm mesh. The coarser fraction was discarded and the finer fraction was retained for analysis. All analyses are referred to the dry weight and they were carried out in duplicate.

The samples were transported to the laboratory under quality control standards and the main parameters were measured as follows: Soil pH was measured in a 1:1 soil:water suspension (Peech, 1965) and electrical conductivity was determined in a 1:5 soil:water suspension (Richards, 1974). The soil organic matter was determined by the method of Anne (1945), total nitrogen was measured by Kjeldahl's method (AENOR, 2007) and available phosphorus was measured by the Olsen method (Olsen *et al.*, 1954). The total CaCO₃ content was determined by the Bernard calcimeter method using 4 M HCl, and the total contents of N, P, S, Br and I were determined by X-ray fluorescence spectrometry on a total reflection fluorescence system (TXRF Philips, Model PW 2404).

3. Results and discussion

The average, minimum, maximum and standard deviations for the concentrations of N, P, C, S, Br and I are provided in Table 1. The values of pH, electrical conductivity (EC), dissolved oxygen (DO), and calcium carbonate content are also listed in Table 1. The pH values are in the range 7.03–8.48, the electrical conductivity values are in the range 0.29–7.64 dS/m (i.e., very variable), and the dissolved oxygen is in a wide range of

5.5–143.3% (once again very variable). The carbonate content is also very variable and is in the range between 2.2 and 72.4%. This finding is consistent with the carbonated nature of the parent material. All of the data outlined above show a clear variability and this is reflected in the resulting maps (Figure 3).

The organic matter (OM) contents are in the range 3.0–65.3%, with a mean value of 20.54% (Table 1). The very high OM contents are consistent with the large number of plants that live in the wetland. These values are very different to those found by Aguilera *et al.* (2009), which were in the range 0.99–24.05%. This trend for the accumulation of organic matter is historic (Domínguez-Castro *et al.*, 2006). Therefore, these soils are rich in organic matter and are mostly peaty in character (Histosols in Soil Survey Staff, 2006; and in FAO-ISRIC-ISSS, 2006). As far as the spatial variability of the organic matter is concerned (Figure 4), it should be noted that preferential accumulation occurs in the downstream area and, in some cases, at high levels. The entrance area by the Gigüela river has the lowest OM percentages.

Wetlands are often colonized by compact stands of vegetation and these play an important role in the accumulation of organic matter. The resulting high bioproductivity ultimately gives rise to the development of soils with a peaty chemical composition. It is therefore not surprising that there are numerous points within the area with high concentrations of organic matter, because there is also an intense development of vegetation (mainly reed) in conjunction with the presence of a permanent layer of water. Aguilera *et al.* (2009) identified a similar trend and noted that all areas with abundant plant development, mainly reed beds, are rich in organic matter. It therefore appears that this perennial rhizomatous plant (with a ground biomass that is of the same order or even higher than the surface biomass and which has annual renewal) is currently one of the main sources of organic matter and nutrients for the environment and these are provided by the decomposition and mineralization of plant remains (Sanchez-Carrillo & Alvarez-Cobelas, 2001). The data discussed above suggest that high biomass production favours carbon sequestration in plant biomass. Net primary production in this wetland is closely linked to soil-forming processes, which in turn are related to the hydroperiod and landscape. These factors control organic matter decomposition and nutrient cycling.

High concentrations of a range of different nutrients were also found in the NPTD wetland. The N contents varied between 0.075 and 1.012%, with an average value of 0.340%, and these values range between medium and, on occasion, high (according to Brady & Weil, 1999). The variability of the N content (Figure 5) is similar to that found

for organic matter. This result is due to the quality of the plant waste and, in particular, the effect of the more or less permanent water layer. The data obtained in this study are consistent with those reported by Rodriguez-Murillo (2001) and are indicative of an increase in the input of nutrients in the wetland in recent years. The main pollutants from domestic wastewater are nitrogen and phosphorus, which are usually present in concentration ranges of 20–85 mg/L and 4–15 mg/L, respectively.

Phosphorus is present in wastewater as phosphate and this is either dissolved or particulate. Inorganic phosphorus from wastewater generally originates from cleaning products. Another possible source of phosphorus is agricultural fertilizers. Therefore, the existence of high phosphorus values in some areas (such as the area located in the north and centre of the park) is attributed to excess nutrients from urban wastewater, excessive N fertilization carried out in surrounding soils and possible nearby industries. Eutrophication is visible in the field and it has emerged as a key human stressor on the world's ecosystems (Cloern *et al.*, 2007). Wetlands are widely recognized as ecosystems that are effective against this type of pollution due to their capacity to act as green filters and thus contribute to an improvement in water quality (Mitsch & Gosselink, 2000).

The C/N ratio varies between 7.5 and 96.4 and this finding indicates conditions of very divergent humification. This situation is interpreted as a function of the nature of plant materials and other environmental factors such as the depth of the water layer and the nature of the mineral medium, amongst others. As a result, the spatial distribution map for this parameter shows very significant variations in trends, with higher values observed closer to the park exit (Figure 5). The values are substantially different to those found by Aguilera *et al.* (2009), who reported a ratio between organic carbon and nitrogen (C/N) that is generally between 6 and 12, thus indicating a slight tendency towards mineralization. In contrast to our findings, these results are similar to the criteria established by Rodriguez-Murillo *et al.* (2009), who also reported that 'humification' was usually scarce. In our case, the average value (38.3) indicates a low level of humification, as one would expect for an anaerobic environment.

The soluble phosphorus (P), expressed as P_2O_5 , is in the range 10.4–56.2 mg/kg and the average value is 34.1 mg/kg (i.e., regular). The spatial variability map (Figure 5) shows that the lowest values are found at the entrance to the park and the highest values were measured in the starting area. The total content has an average value of 1070 mg/kg, with a maximum value near to the industrial wastewater treatment of Villarrubia (6370 mg/kg). In the entrance area, the total phosphorus (P) also appears to be more

concentrated and this is also the case in certain focal environments, with the lowest values related to the output area. The retention of P is mainly controlled by soil physicochemical conditions but other factors may also have an influence, such as vegetation, plant debris and detritus accumulation, water-table depth and water-flow velocity, hydraulic retention time and hydrological fluctuations (Reddy *et al.*, 1999). The retention of P by soil in wetlands is related to P loading and various physicochemical properties of the soil, including the pH, Eh, mineralogy, clay content, Fe, Al and Ca contents, organic matter content and P content (Reddy *et al.*, 1996; Reddy & DeLaune, 2008). The wastewaters that flow from industrial treatment plants at Villarrubia and Daimiel (samples 37 and 39, respectively), or Navaseca lagoon linked to the sewage treatment plant of Daimiel, are important inputs of phosphorus, nitrogen and dissolved organic carbon into the wetland, as reported by Alvarez-Rogel *et al.* (2006, 2007). Detergents are also commonly found in wastewater (Gunatilaka *et al.*, 1988).

The dynamics of phosphorus in wetlands involve complex biogeochemical processes. Gomez-Cerezo *et al.* (2001) reported that *Phragmites australis* is highly effective in removing phosphorus from water in a constructed wetland but the presence of a high density of plants did not lead to a significant improvement in nutrient retention. Meuleman *et al.* (2002) studied *Phragmites australis* and found a translocation of nutrients from shoots and leaves to roots in autumn – a change that decreased the efficiency of this species for nutrient removal. The latter finding indicates that the response of the vegetation in a marsh can be influenced by factors such as the season of the year.

The sulfur (S) content ranges from 1.85 to 37.15 g/kg, with an average value of 13.71 g/kg. The S content varies markedly in the corresponding map (Figure 5). In the area in question there is a freshwater input in the East from the Guadiana, with low sulfate contents, and also the entry of brackish water in the Northwest, with a richer sulfate environment. As a consequence, it can be seen that the highest values are found at the entrance of the park by the Gigüela River and the lowest levels were measured by the output. The trend between these two points was a relatively uniform change in values. It should be noted that sulfur can influence the distribution of other elements in soils.

Bromine (Br) is a non-metal that is present in the Earth's crust. There is some debate concerning the global average values for this element. Yamada (1968) reported values of 1–40 mg/kg whereas Martin *et al.* (1999) reported a range between 2.4 and 11.9 mg/kg, with an average of 5.9 mg/kg, in some Australian soils. Bowen (1979) reported

an average concentration of 10 mg/kg, whereas the Br content in soil varied from 5 to 40 mg/kg according to Kabata-Pendias (2001). Furthermore, Martinez Cortizas *et al.* (2016) found high bromine concentrations in deep, acidic, organic-rich soils. Maw & Kempton (1982) and Biester *et al.* (2004) reported that atmospherically deposited Br is preferentially retained in humic compounds due to its incorporation by microbial activity or by abiotic mechanisms. Furthermore, it was stated that Br absorption by vegetation is not a relevant process in the formation of organo-bromine compounds in peat. In the study area Br is present in the range 7.7–375.7 mg/kg, with an average value of 74.8 mg/kg (Table 1). In some cases the values are much higher than the reference levels cited by Jimenez-Ballesta *et al.* (2010) for soils in the same region.

Bromine has commonly been used to produce ethylene dibromide, a lead scavenger used in the production of antiknock compounds in petrol. However, this source of bromine has decreased dramatically due to concerns over the amount of Pb in the environment. Bromine is also used in the manufacture of fumigants (methyl bromide) for agricultural purposes, flame-proofing agents, water purification compounds and dyes, as well as in the production of photographic chemicals and as a component of K-fertilizers (Kabata-Pendias, 2001).

Iodine (I) was present in the range 20.0–277.0 mg/kg, with an average value of 39.4 mg/kg (Table 1). This element is generally an outlier, although some samples had elevated levels. The iodine concentration in soil is typically in the range from < 0.1 to 10 mg/kg (Kabata-Pendias & Pendias, 1992). Bowen (1979) reported the average concentration on a world-wide basis as 5 mg/kg. The retention of Br and I in soils is largely influenced by organic matter and sesquioxides (Whitehead, 1979; Kabata-Pendias & Pendias, 1992).

Soils within the NPTD wetland had moderate levels of pollution by Br and I. There is very little industrial activity around the park and, as a result, the major sources of contamination are probably urban sewage effluents and the use of fertilizers and pesticides for agricultural operations. The possibility of bromine contamination of the soil due to the application of agricultural chemicals must therefore be highlighted (Figure 6). The natural dynamics of the NPTD have been disrupted, especially in recent decades. The current state of this area depends on the scarce contributions of both the Guadiana and Gigüela Rivers, as well as the contributions of the transfers and nutrients derived from other sources, such as the wastewater treatment plants of Villarrubia de los Ojos, Daimiel and Manzanares. Excess nutrient loading is linked to algal blooms, which were observed

in some areas and are a symptom of the aforementioned nutrient sources. However, the effects of these processes on biological resources are unclear in the long term, possibly due to rapid recycling after accumulation.

The soil below the water table is the key hydrological filter (Keesstra *et al.*, 2012) and it is worth noting that the wetlands act as an interface that is essential to understand the processes by which the studied elements are accumulated. As a consequence, it is necessary to assess the riparian zones around the sediment and the water movement to understand the distribution of pollutants (Keesstra *et al.*, 2012).

Farmers can help to solve some of the problems associated with pollution by employing more environmentally friendly management techniques, such as the use of straw mulch, because this can reduce soil and water losses (Cerdá *et al.*, 2017). Policy makers can also help to solve the aforementioned problems by implementing appropriate agriculture policy aimed at reducing runoff discharge and pollutants. In this sense, Parras-Alcantara *et al.* (2016) described a number of strategies that have been employed in olive plantations. The presence of vegetation can also contribute to solving the problems outlined above (van Hall *et al.*, 2016). A more natural solution is organic farming, which could be key to finding solutions for the problems outlined above as a cost-effective long term remedy to avoid hydrological risks and land degradation (Keesstra *et al.*, 2018).

It should be highlighted that the NPTD acts as a buffer due to its ability to confine the aforementioned nutrients. It is envisaged that the results obtained in this study will bring awareness to government agencies to assist them – and farmers – in taking necessary precautions to protect this area.

4. Conclusions

The results obtained in the study described here show that there is a clear spatial variability in the various measured parameters. Specifically, compact colonization by vegetation in conjunction with water plays a vital role in the accumulation of organic matter, which ultimately leads to high bio-productivity and generates peaty soils. The NPTD wetland therefore has an important role to play due to its capacity to retain and sequester carbon.

The presence of phosphorus and nitrogen in the soils can be attributed to natural processes linked to the accumulation of organic matter and leaching of such matter from anthropogenic sources. It can be concluded that the soil of the NPTD wetland can be considered as a sink for C, N and P.

Soils within the NPTD wetland had moderate levels of pollution by Br and I. These results suggest that human activities have led to an increase in the Br content and, to a lesser extent, transportation of I from surrounding areas. The causes of this type of pollution include urban, industrial and agricultural activities. The NPTD wetland acts as a filter to reduce nutrient concentrations before the polluted water flows into other areas and therefore it is necessary to take precautions to protect this area.

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Table and figure captions

Table 1. Results: pH, electrical conductivity (EC), dissolved oxygen (DO), organic matter (OM), C, N, C/N, Br, I, total phosphorus, soluble phosphorus and CaCO₃

Figure 1. Location map of TDNP wetland (39° 11' 19" N, 3° 46' 25" W - 39° 06' 39" N, 3° 38' 53" W). <http://centrodedescargas.cnig.es>

Figure 2: Location map of the study area showing sampling points. Samples 1, 21, 37, 38, 39, 41 and 42 are located outside the flood zone, but are located in potentially polluting sources; Sample 43 represents the starting area.

Figure 3. Spatial variability of pH, EC, DO and CaCO₃ content.

Figure 4. Organic matter content and its spatial variability.

Figure 5. N, P (total and available) and S contents. The C/N ratio is also shown.

Figure 6. Spatial variability of I and Br.