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Spatial and temporal variability of the water and sediments quality in the Alqueva reservoir (Guadiana Basin; southern Portugal)

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HIGHLIGHTS

- Evidence of a speeding up of the eutrophication process in the Alqueva reservoir.
- Major impacts were from agriculture activities and untreated wastewater discharges.
- Sediments at the Alqueva reservoir were characterized for the first time.
- Sediments were contaminated with As, with toxic concentrations for As, Cd and Pb.
- Multivariate statistics helped in the identification of the most polluted locations.

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ABSTRACT

The purpose of this work was to evaluate the dynamic of the water quality from the Alqueva reservoir (Guadiana River Basin, Portugal) and identify the most important parameters that influence its ecological and chemical status. The results could indicate preventive and/or remediation actions that are necessary to improve its quality and status. Water and sediment samples were collected between 2011 and 2012, at five sampling stations, and analyzed for: (i) water — pH, temperature, dissolved oxygen, electrical conductivity, chloride, total phosphorus, total nitrogen, ammonium, nitrate, nitrite, biochemical and chemical oxygen demand, total Fe, Mn, and As; and (ii) sediments — pH, electrical conductivity, organic matter, total nitrogen, total phosphorus, major and trace elements. The results from the water column showed that the organic descriptors exceeded the Portuguese guideline values for water quality for multiple uses at most of the sampling stations. As for nutrients, Ajuda is the station where the concentrations of the total nitrogen and total phosphorus exceeded the guideline values in most months. Ammonium achieved concentrations above the allowed, during the study, in all locations. Trace elements were more abundant in the sediments, surpassing the maximum levels for the protection of aquatic life for As, Cd and Pb, at Alcarrache, Lucefécit and Álamos, respectively. The use of multivariate analysis showed that the major parameters that explained the water quality variability were the nutrients in the water column, and trace elements in the sediments. Comparing the results from this study with results obtained since 2006, we can observe an obvious increment of the organic descriptors and nutrients in the water body. Further, several parameters and observations indicate an increase of the eutrophication process. So, it is urgent to develop preventive actions and remediation processes to stop the degradation so as to improve the quality of the water in this reservoir.

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1. Introduction

The European Water Framework Directive (WFD) (ECC, 2000) demands a "good ecological potential" and a "good chemical status" for all European heavily modified water bodies, by 2015. These waters are characterized by having an acceptably lower ecological status, resulting of hydromorphological pressures, which cannot be totally removed due to high social or economic costs (Borja and Elliott, 2007; Hering et al., 2010). Despite that, reports under the WFD indicate that a substantial proportion of the Europe's freshwaters are at risk of not achieving a good status by the year of 2015 (EEA, 2010).

Most of these heavily modified water bodies are reservoirs that were constructed for multiple purposes. Thus, currently, there is a need to

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focus the most immediate efforts of environmental management actions, which will allow the establishment of a balance between the ecological and the chemical status of the water, and its quality for a variety of practices and users.

Anthropogenic actions increment the amounts of nutrients, organic matter and hazards substances in water bodies, and, therefore, important driving forces for the insufficient status of many European freshwater reservoirs (Brack et al., 2007), as well as for the deficient quality of the water supplied to the populations. Thus, the variability of chemical parameters must be assessed and integrated in operational monitoring programs with the purposes of: (i) characterizing the present status of water bodies (Hoornbeek, 2004; Hering et al., 2010); (ii) detecting changes of water status (Borja et al., 2008); (iii) identifying the main parameters, which must be remediated to restore the good status of water bodies and guarantee its quality for supply to the populations; (iv) giving information, to the authorities of each state member, about the prioritization or ranking processes in order to allocate monitoring efforts towards relevant target compounds in each water body to achieve the objectives proposed by the WFD (Brack et al., 2007; López-Doval et al., 2012; Guillén et al., 2012).

In Alentejo (southern Portugal), one of the driest regions of Portugal, the low precipitation and the high temperatures highlight the importance of water reservoirs, built mainly with the purpose of water storage and for the smoothing of interannual precipitation variability (Silva et al., 2011). Nowadays, in Alentejo, about 69% of the water used is from surficial water (INE, 2010), which highlights the importance of the dams in the management plan of the water resources in this region. The reservoirs from Alentejo dams have their own dynamics, promoted by the clime, the over-exploitation, and the increment of the chemical and biologic pollution which induces the poor water quality (Rosado and Morais, 2010). So, it is urgent to define priority actions and establish sustainable management practices of the water resources. The Alqueva reservoir, in the Guadiana River Basin, located in Alentejo, was chosen as a case study since it constitutes the most important water supply source in southern Portugal, a semi-arid region with high levels of water scarcity and where agriculture is one of the main activities. Furthermore, it is the biggest artificial lake of the Iberian Peninsula, and it is intended to be a strategic water reserve for multiple uses, such as: (i) reinforcement of water supply to the Alentejo populations (drinking water); (ii) support to other Alentejo's reservoirs (e.g. Roxo, Enxoé, Monte Novo) when the Mediterranean conditions induce an extreme drought, with the consequent decrease of their water levels; (iii) agriculture application (irrigation); and (iv) electric energy generation (WWFN, 1995).

Up to this date, in partnership, with the regulatory agency responsible for the management of Portuguese water bodies (Agência Portuguesa do Ambiente — APA) and the Portuguese enterprise responsible for the Alqueva management (Empresa de Desenvolvimento de Infra-estruturas do Alqueva — EDIA), our team has developed monitoring studies in the reservoir, during the periods of 2006–2007 and 2011–2012, with the main aim of obtaining the physical and chemical characteristics of the water body. From the studies conducted in 2006–2007, some water quality problems were identified, such as: (i) high amounts of nutrients and organic matter, originated from water runoff of intensive agriculture, pasture activities and untreated wastewater discharges (Palma et al., 2010a); (ii) some pesticides, classified as hazardous substances according to the Directive 2008/105/CE (ECC, 2008), surpassed its environmental quality standard values (Palma et al., 2009); and (iii) quantification of high values of As, Fe and Mn, that appear mainly at the rainy season, probably due to the geological nature of the soils and to the acid mine drainage (AMD) derived from abandoned mines located around the reservoir (Palma et al., 2010a). From the abovementioned studies, the most contaminated areas of the reservoir were at the upstream, near the border to Spain, and at tributaries near the large agriculture fields (Palma et al., 2010a,b). Nevertheless, these studies were only performed in the water column, emphasizing the need to characterize the sediment compartment in order to allow an integrative and an appropriate environmental management of this aquatic environment (Carere et al., 2012). To our best knowledge, the physicochemical characterization, and the quantification of the major and trace elements of the sediments, in the Alqueva reservoir, have never been performed before.

In this scenario, the main aims of the present study were: (1) to assess the spatial and temporal variability of the water and sediments quality at the Alqueva reservoir; (2) to identify the most important chemical parameters that explain the variability of the water and sediment quality and that are responsible for the increment of the deterioration of this resource; and (3) to group the sampling locations according to their water and sediment characteristics, which is very important in order to optimize the number of monitoring sites and, consequently minimizing the sampling and the analysis cost. To achieve these goals, a group of physical and chemical analyses was performed, during two years (2011–2012) in the Alqueva reservoir: (i) in the water column (pH, temperature, dissolved oxygen, electrical conductivity, chloride, total phosphorus, total nitrogen, ammonium, nitrates, nitrites, biochemical oxygen demand, chemical oxygen demand, iron, manganese and arsenic); and (ii) in the sediments (grain size, pH, electrical conductivity, organic matter, total nitrogen, total phosphorus, and the quantification of potentially hazardous trace elements, namely As, Cd, Cr, Cu, Pb, Ni and Zn). The results of this study, together with the outcomes obtained in previous researches, may prove to be important tools for the water resource management as to help the authorities to establish priority actions in this water body, bearing in mind the objectives proposed by the Directive. Furthermore, these results are extremely important in order to establish the direct implications that the water quality of the Alqueva reservoir could have in the different systems eventually supplied by its water.

2. Materials and methods

2.1. Study area and sampling sites characterization

The Alqueva reservoir is located in southern Portugal, along 83 km of the main course of the Guadiana River Basin. The hydrologic regime of the Alqueva reservoir reflects the regional expression of the Mediterranean climate, which is characterized by dry and hot summers as well as mild and wet winters with concentrated rains (Morales, 1993). During the study period, the clime was characterized by an average atmospheric temperature of 16 °C, ranging from 3 °C in January to 33 °C in August (www.snirh.pt, 2010/2011; 2011/2012). The average monthly precipitation for the hydrologic year of 2010/2011 was 46.5 mm (www.snirh.pt, 2010/2011), and for the hydrologic year of 2011/2012 was 20.3 mm (www.snirh.pt, 2011/2012). So, the values of precipitation at the hydrologic year of 2011/2012 were extremely low comparing with the years before. The land uses obtained from CORINE land cover classes (2006) identify agriculture activities as the most ubiquitous in the Alentejo region (68.8%) followed by semi-natural areas (28.1%) (ARHAlentejo, 2011). The description of the main point and diffuse sources of pollution around the Alqueva reservoir is reported elsewhere (Palma et al., 2010a).

Five sampling sites were established at the Alqueva reservoir: three upstream, Ajuda (Aj; 38°46′28.56″N, 7°10′47.00″W), Alcarrache (Ac; 38°19′1.53″N, 7°19′51.10″W), Álamos (Al; 38°20′30.00″N, 7°34′40.00″W), and two at the middle, Mourão (Mr; 38°23′60.00″N, 7°23′25.80″W) and Lucefécit (Lf; 38°33′6.32″N, 7°17′52.86″W), of the reservoir (Fig. 1). Ajuda was the only location with lotic conditions, and was chosen to provide information about the input flux to the Guadiana River coming from Spain. The other sites, with lentic conditions, were chosen taking into account the Alqueva's monitoring program, developed by EDIA, and previous results for the reservoir water quality assessment, which indicated these sites as those with worst water quality (Morais et al., 2007; Palma et al., 2009, 2010a,b).

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