Chapter 32
Agricultural Intensification in the Alentejo Region: Effects on Water Quality and Water Suitability for Irrigation

Martinho Murteira, Maria Morais, and Maria Helena Novais

Abstract Agriculture is an important sector in southern Portugal, intensified in recent years by the construction of the Alqueva Dam on the Guadiana River. The Alqueva Multipurpose Project was designed and built to supply the driest region in Portugal, including the global irrigation system. This global change in the agricultural system (i.e. from dry to irrigated land) led to a significant increase in olive grove areas. Since 2009, olives have been the most representative crop, exceeding 50% in the entire irrigated area, and since 2013 Portugal has become self-sufficient in the olive oil sector. The Alqueva irrigation perimeter is expected to increase in the next years to 170,000 ha, with a predicted olive grove increase, if no restrictive measures are implemented at a national level. In this context, a temporal analysis of water quality for irrigation data is carried out (2010–2019), based on both the Portuguese regulations (DL 236/98) and the FAO guidelines. Therefore, the present work aims (i) to verify the effect of the land use change on the aquatic ecosystem integrity and (ii) to evaluate soil salinity risks and potential yield losses due to salinization of the most representative crops grown.

Our results show a possible degradation of the aquatic ecosystem integrity, given that persistent non-compliances were identified since 2011, for total phosphorus, pH, dissolved oxygen and chlorophyll *a* (biomass indicator), according to the Water Framework Directive guidelines. Furthermore, the breaches for bentazon, total phosphorus and chlorophyll *a* were more persistent in the last years (2018–2019), probably related to the olive grove super intensification in the irrigation blocks. Regarding the suitability of water for irrigation, most values were below the thresh-

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J. Muñoz-Rojas, R. García-Ruiz (eds.), *The Olive Landscapes of the Mediterranean*, Landscape Series 36,
https://doi.org/10.1007/978-3-031-57956-1_32

old of maximums recommended, even though some non-compliances were detected, namely, in the electrical conductivity, pH and bicarbonates.

32.1 Agricultural Changes in the Alentejo Region: The Alqueva Project

In recent decades, Europe has experienced great transitions in the rural landscape driven by multiple factors, perceived at different scales by a major change in the mode of agricultural production and land use (e.g. Carvalho-Ribeiro et al., 2013; Pinto-Correia & Kristensen, 2013). In the Portuguese context, the Alentejo region is experiencing a rapid agricultural intensification (from a predominantly extensive mode to an intensive production), mainly due to a long-standing public investment in the Alqueva irrigation system (Silveira et al., 2018).

The Alqueva project, with a long history (the first Alentejo Irrigation Plan dates to 1957), was designed and built to supply the driest region in Portugal, most prone to water scarcity and physical and human-induced desertification processes (Sanches & Pedro, 2006). The main objective of the initial project was the irrigation of the Alentejo region and to implement a productive agriculture, in order to combat desertification and underdevelopment of the region (Veiga et al., 2008). In fact, the long period that elapsed between the first studies (1957) and the closing of the dam floodgates in 2002 made "Alqueva" a myth for the local population, depressed since the 1930s "Wheat Campaign", through which the region was transformed into the "barn of the country" (Cutileiro, 2004). This campaign led to an intensive agricultural land use (cereal monoculture) with a consequent alteration of the landscape, soil depletion and erosion, simultaneously contributing to enormous social conflicts, repression, unemployment, poverty and migration to the coastal region and abroad. Consequently, the Alqueva project appears as a hope for Alentejo, with 1/3 of the Portuguese territory but with only 4.7% of its population and with high rates of human-induced desertification (PNPOT, 2018).

Currently, the Empresa de Desenvolvimento e Infra-estruturas do Alqueva, S.A. (EDIA) is responsible for the global irrigation system, based on the Alqueva Multipurpose Project (EFMA) that interconnects dams and covers an area of approximately 10,000 km^2, representing, therefore, a national strategic water reserve with the guarantee of water availability for a minimum of a consecutive period of 3 years. EFMA serves a total of 20 municipalities, supplying about 200,000 inhabitants, producing energy for 500,000 inhabitants and irrigating about 120,000 ha.

The Alqueva global irrigation system is divided into three subsystems, according to the different water sources and irrigating areas that belong to the hydrographic basins of the Guadiana and Sado Rivers (Fig. 32.1):

- Alqueva subsystem—origin at the Alqueva reservoir, with the water level raised 90 m at the Álamos pumping station, allowing the irrigation of ~64,000 ha (Guadiana Basin).

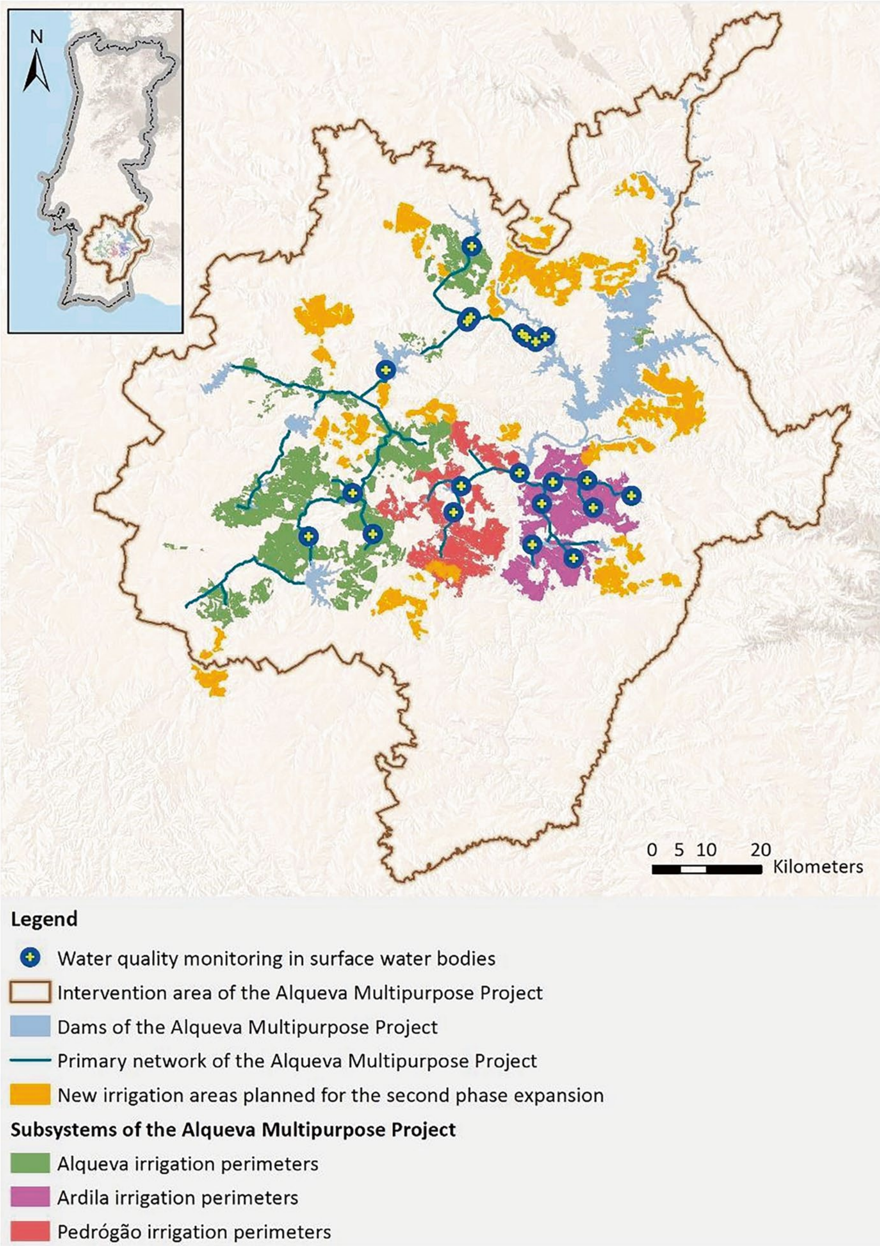

Fig. 32.1 The Alqueva global irrigation system in Portugal, showing the three subsystems: Alqueva, Ardila and Pedrógão. (This figure was produced by Martinho Murteira with original data from EDIA, 2020)

- Pedrógão subsystem—origin at the Pedrógão pumping station (right bank of the Pedrógão reservoir) and irrigating ~24,500 ha (Guadiana and Sado basins).
- Ardila subsystem—origin at the Pedrógão reservoir, Guadiana River left bank, and irrigating ~30,000 ha (Guadiana basin).

Recently, under the guidance of the Ministry of Agriculture, Forestry and Rural Development (MAFDR), the Alqueva perimeter is increasing to 170,000 ha, in order to optimize the funding of eligible investments for collective irrigation within the scope of the national irrigation program (PNRegadios) (EDIA, 2018b).

The new opportunities created by EFMA led to changes in the physical, chemical and biological characteristics of the natural hydrographic network in the Guadiana and Sado basins and, obviously, to changes in the type of crops, progressively explored more intensively as farmers adhere to the irrigation system.

On this basis, our guiding questions are the following:

- Could changes in land use patterns and agricultural intensification affect the environmental objectives of the Water Framework Directive (WFD, The European Parliament & European Council, 2000) and consequently the ecological integrity in the water sources for irrigation (i.e. reservoirs)?
- Could agricultural intensification increase the risk of salinization of soils and crops growing in the irrigation perimeters?

32.2 Olive Grove Evolution in the Alentejo Region

In order to know the irrigated areas of the main cultures on the different subsystems, the EFMA exploration indicators published by EDIA were consulted (EDIA, 2017a, b, 2018a, 2019a, b, 2020). The available data are only relative to 2011 onwards, since 2011 corresponds to the start of the first irrigation blocks, with payment of water usage fees by users (located on the Alqueva and Ardila subsystems), implemented in a phased manner until 2016, when all irrigation blocks were in operation.

Figure 32.2 shows the annual percent evolution of the main crops in each subsystem since 2011 for Alqueva and Ardila and since 2013 for Pedrógão (when the first irrigation blocks became operational in the latter). A decrease in the unused area is evident, from the beginning of the subsystems operation until 2019 (from 65% to 15% in Alqueva, from 66% to 19% in Ardila and from 72% to 9% in Pedrógão).

In all subsystems olive groves were the predominant crop, despite the type of plantations (traditional, semi-intensive, intensive, super-intensive), reaching a total percentage of land cover of 44, 60 and 59% on Alqueva, Ardila and Pedrógão, respectively.

It is worth noticing that the most representative plantation type is the intensive regime with a percentage cover of 21, 39 and 37%, respectively. Another interesting aspect is the almost complete disappearance of the traditional olive grove and its replacement by the super-intensive regime that had a significant presence since 2016, simultaneously with the almond groves that reach 14, 7 and 10%,

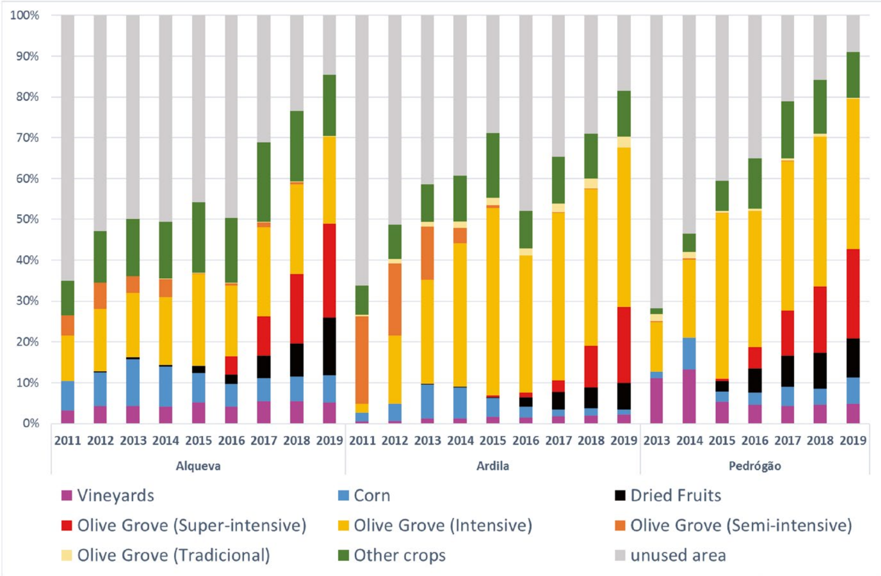

Fig. 32.2 Annual evolution (%) of the main crop change in the Alqueva, Ardila and Pedrógão subsystems, since the first irrigation blocks started operation

respectively, being the second most popular crop. Both groves (almond and super-intensive olive plantations) utilize a similar agricultural mechanization system.

32.3 Olive Grove Intensification Effects on Aquatic Ecosystems

Data from the EFMA "Primary Network Surface Water Resources Monitoring Program" conducted by the EDIA since 2002 in all the subsystem reservoirs were analysed taking into account the compliance with the WFD good ecological potential (The European Parliament & European Council, 2000) and the guidelines for Portugal (APA, 2016).

An analysis of the WFD supporting parameters for the ecological potential assessment of the reservoirs integrating the three subsystems revealed non-compliance for total phosphorus (> 0.07 mg P/L), pH (> 9), dissolved oxygen, DO (> 140%) and chlorophyll *a* (> 9.5 mg/mm^3), systematically from 2011 to the present (Fig. 32.3), whilst nitrate concentrations were always within the limit for the good ecological potential (≤ 25 mg NO_3/L). These breaches were mostly detected in the summer during periods with high temperatures (e.g. 42.0 °C Tmax in July, 2019) and absence of precipitation. To test for differences in these parameters between hydrological years, a Kruskal-Wallis one-way analysis of variance on

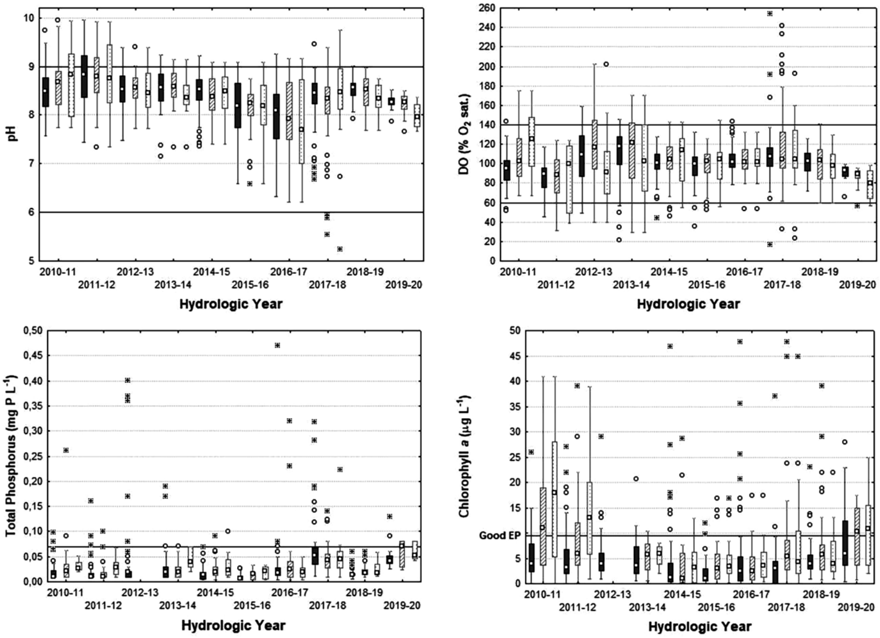

Fig. 32.3 *Box and whiskers* graphs for pH, DO (% O_2 sat.), total phosphorus and chlorophyll *a* (parameters that present values in non-compliance with the WFD requirements) along time (between 2010/2011 and 2019/2020) in the three subsystems. Dark grey, Alqueva; diagonal lines, Ardila; dots, Pedrógão. Median, box, 25–75%; whiskers, non-outlier range; ○, outliers; cross, extremes; horizontal lines, WFD limits for the good potential quality

ranks (Kruskal-Wallis test) was carried out (since the data did not pass the normality and/or the equal variance tests), using SigmaPlot 12.0 (Systat Software Inc., Chicago, IL). The Kruskal-Wallis tests revealed differences for the non-compliance parameters (pH, dissolved oxygen, total phosphorus and chlorophyll *a*) in the three subsystems, when all years were considered, but no clear pattern could be observed in the pairwise multiple comparison analysis (Dunn's method). However, in Fig. 32.3 it is possible to notice an increasing pattern for total phosphorus and chlorophyll *a,* for the last year in all the subsystems, with median values higher than the threshold for the good ecological potential, particularly in the Pedrógão and Ardila subsystems.

In addition, the results for specific pollutants showed non-compliance for bentazon (broad-spectrum herbicide) in the Alqueva and Pedrógão reservoirs, during 2018 and 2019. Palma et al. (2009), working in the Alqueva reservoir, had already detected values of the pesticides atrazine and diuron that were above the annual average proposed by the European Union legislation.

These findings could explain the effect of an agricultural intensification on the water quality of reservoirs (i.e. the origin of water for the irrigation system), which could compromise the compliance of the environmental objectives in the context of the Water Framework Directive. The water quality degradation could also affect the irrigation system by the corrosion and scale formation in pipelines and irrigation equipment, due to an increase in organic matter from primary production and eutrophication processes.

32.4 Olive Grove Intensification Effects on Water Suitability for Irrigation and the Salinization of Soils

Data from the EFMA "Primary Network Surface Water Resources Monitoring Program" conducted by the EDIA since 2002 in all the subsystem reservoirs were also analysed taking into account the compliance with the water quality for irrigation purposes, following the requirements and thresholds established by Annex XVI of the Decree-Law No. 236/98 and the FAO guidelines (salinity of water, EC, sodium risk, sodium adsorption ratio (SAR), residual sodium carbonates (RSC) and ion toxicity) (Ayers & Westcot, 1985).

Regarding the suitability of water for irrigation purposes, most values were below the threshold of maxima recommended. However, there were some non-compliances: the conductivity is over 700 μS/cm in about 5% of the samples, without ever exceeding 3000 μS/cm; pH exceeds the recommended maximum in about 10% of all samples; and bicarbonates are over 90 mg/L in about 18% of the total samples analysed.

In relation to ionic toxicity, the results of boron and chloride did not exceed the established thresholds (0.7 mg/L and 14 mg/L, respectively) with no risk for the cultures. The diagrams proposed by the US Salinity Laboratory (USSL) (Richards, 1954 *in* Zamna et al., 2018) showed that the majority of samples were in class C2-S1 (danger of medium salinity (C2), low sodium levels (S1)), indicating that water can be used in all soils for the crops currently practiced in the blocks with no risk of salinization.

In order to assess the sodium risk, associated with calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) precipitation, the residual sodium carbonates (Na_2SO_3, RSC) were analysed. The obtained results confirmed that all values were below 1.25 me/L, indicating good-quality water for irrigation (Wilcox et al., 1954 method *in* Zamna et al. 2018).

Finally, the Langelier index with values between −0.8 and 0.9 (variations among slightly corrosion but non-scale forming, balanced/neutral and smooth corrosion) revealed the absence of risk of calcium carbonate ($CaCO_3$) film deposition or scales in the pipes.

32.5 Conclusions

The results for water quality for irrigation in all the subsystem reservoirs revealed that, despite the fact that no relevant breaches were detected, there were persistent non-compliances, according to the good ecological potential guidelines (WFD criteria) for total phosphorus, pH, dissolved oxygen and chlorophyll *a*. In the latest years (2018 and 2019), the situation seems to be getting worse since breaches for bentazon, total phosphorus and chlorophyll *a* were more persistent. These non-compliances may be related to the intensification of agriculture in the irrigation blocks, particularly with the super intensification of olive groves, which showed a > 50% increase compared to 2016 in the three subsystems.

In fact, several studies have demonstrated the existence of a direct relationship between olive groves (under-intensive and super-intensive monoculture cultivation) and ecosystem integrity (e.g. Silveira et al., 2018; Matono et al., 2013), compromising the fulfilment of the WFD environmental objectives and accelerating ecosystem degradation.

This situation may worsen with repercussions on soil degradation, given climate change scenarios for the region predicting a decrease in precipitation and an increase in temperature (IPCC, 2018). In this sense, it is necessary to implement a more sustainable agricultural system, with a greater diversity of cultures. Otherwise, we can relive the environmental situation of the beginning of the last century (1930s), now with soil depletion and erosion due to the escalation of an intensely fertilized monoculture of olive trees.

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