Modelação da qualidade das águas superficiais ao nível de microbacias com base na ocupação por sistemas de produção agrícola.

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Dissertação para a obtenção do Grau de Mestre em

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Resumo alargado

A agricultura desempenha um importante papel na gestão de recursos hídricos, sendo responsável por cerca de 70% do uso global de água doce e constituindo uma relevante fonte de poluição. Contudo, estudos focados na avaliação dos impactos ambientais de práticas agrícolas específicas deparam-se frequentemente com dificuldades em fornecer informação prática relevante para o apoio à formulação de políticas públicas dirigidas à conciliação entre agricultura e sustentabilidade ambiental a longo prazo. Estas dificuldades levam à procura de abordagens alternativas que possam melhorar o custo-eficácia dessas políticas. Uma destas abordagens, que tem vindo a ser proposta recentemente por alguns autores, baseia-se na ideia de que é possível estabelecer uma relação entre sistemas de produção agrícola (SPA) e indicadores de qualidade ambiental, biodiversidade ou serviços de ecossistemas. De acordo com estas abordagens por SPA, explorações agrícolas classificadas no mesmo SPA apresentam padrões de uso e ocupação da terra e de atividades pecuárias semelhantes, utilizam aproximadamente os mesmos recursos e nas mesmas dotações e, por essas razões, são suscetíveis de causar idênticos impactes ao ambiente e de responder da mesma forma a alterações de políticas.

A partir de um estudo recente que estabeleceu uma tipologia de 22 sistemas de produção agrícola para a região do Alentejo, em Portugal, esta dissertação, apresentada em formato de artigo científico, foi elaborada com base em dois grandes objetivos: (a) testar a hipótese de que há diferenças entre os impactos na qualidade da água causados pela agricultura e pela floresta; e (b) testar a hipótese de que o predomínio de certos SPA na bacia hidrográfica pode ser um indicador de qualidade da água.

A escolha da região do Alentejo deveu-se à predominância da agricultura como principal uso da terra, enquanto as áreas não agrícolas são representadas maioritariamente por florestas, o que facilita a análise da primeira hipótese do trabalho, uma vez que reduz os ruídos que seriam causados por outros tipos de uso da terra não levados em consideração. O estudo não pretendeu, portanto, investigar os efeitos diretos de determinados contaminantes na qualidade da água, mas sim testar se os seus efeitos conjuntos podem ser detetados a partir de uma relação mais ampla entre os SPA e a qualidade da água, de modo a validar uma abordagem que poderá ser reproduzida em outros contextos e contribuir para a gestão de recursos hídricos, nomeadamente no contexto da Diretiva-Quadro da Água da União Europeia.

O estudo focou-se na qualidade das águas superficiais, especificamente rios e reservatórios (albufeiras), de modo a evitar a complexidade hidrogeológica que envolve as águas subterrâneas e que poderia prejudicar a identificação da relação entre o SPA e a qualidade da água (superficial) da bacia hidrográfica analisada. Foram utilizados dados de qualidade da água superficial classificados com base no *status* ecológico, segundo 5 categorias (Excelente, Bom, Razoável, Medíocre e Mau). Esta classificação serviu de base à construção da variável dependente do modelo, tendo sido reagrupada em 2 grupos de qualidade: "Desejada" ("Excelente" e "Bom") e "Indesejada" ("Razoável", "Medíocre" e "Mau"). A classificação ecológica teve como indicador o grupo das diatomáceas (fitobentos), a qual foi preferida em relação à classificação do *status* químico, não só porque este apresenta elevada incidência de classificações "desconhecidas", mas também porque os parâmetros aqui considerados estão frequentemente sujeitos a fatores externos não diretamente relacionáveis com os SPA. Estes dados, reportados aos anos de 2017 e 2019 (largamente coincidentes com os dados dos SPA), foram ajustados para o nível de microbacias de drenagem com áreas iguais ou inferiores a 2500 ha, as quais foram utilizadas como unidade de análise na estimação dos modelos. A escolha (arbitrária) do limite de 2500 ha deveu-se à convicção de que, para bacias de maior dimensão, a relação entre SPA e qualidade da água poderia tornar-se demasiado complexa, prejudicando os objetivos da análise. Este critério resultou na seleção de 140 microbacias que constituíram o universo amostral para as análises estatísticas subsequentes, as quais consistiram sobretudo na estimação de um modelo de regressão logística que teve a qualidade da água como variável independente (binária) e os SPA como variáveis independentes (peso dos SPA na área da microbacia, em %).

Os resultados alcançados revelaram um predomínio claro das áreas agrícolas no território (cerca de 70% da superfície total da área de estudo), onde os SPA de pastoreio de bovinos e ovinos com pastagens sob coberto de sobreiros e azinheiras representavam a maior parte da área agrícola. As áreas não ocupadas por SPA, interpretadas como correspondendo maioritariamente a floresta (não diferenciada), totalizaram aproximadamente 30% da superfície total. Os resultados foram ao encontro da hipótese inicial, revelando que em microbacias dominadas por usos agrícolas existe uma relação entre SPA e qualidade da água.

O facto de que todos os SPA estatisticamente significativos apresentaram efeitos negativos (coeficientes com sinal negativo), sugere que os usos agrícolas são mais prejudiciais do que os usos não agrícolas (floresta), os quais foram a categoria de referência do modelo. Além disso, os resultados também confirmam, quanto à segunda hipótese, que a informação referente ao peso relativo de diferentes SPA na microbacia pode ser usada, em considerável extensão, para predizer o nível de qualidade da água superficial. Quatro SPA foram considerados pelo modelo como estatisticamente significativos, apresentando coeficientes negativos: Cereais de sequeiro, Pastagens (com ausência de árvores e de gado), Ovelhas em pastoreio com pastagens e forragens, e o sistema Arroz. O modelo proposto resultou em 84,1% de predições corretas e mostrou um bom ajustamento aos dados. Um ponto interessante dos resultados é que, contrariamente ao esperado, os SPA que são tipicamente identificados como mais intensivos e/ou de regadio, não foram necessariamente aqueles que o modelo indicou como mais prejudiciais à qualidade da água, o que sugere que há outros fatores a serem considerados, entre os quais se poderá incluir a utilização de um nível tecnológico mais elevado, que permite uma aplicação mais controlada de agroquímicos, ou o facto de o nível de intensidade dos SPA se ter baseado nos preços dos produtos resultantes (*outputs*), em vez de exprimir o nível de inputs por unidades de área. O primeiro fator (tecnologia) pode ser exemplificado pelos SPA que envolvem olival intensivo de regadio, os quais se esperava que pudessem apresentar impactos negativos relevantes; o último fator pode ser exemplificado pelo SPA Floresta de Pinheiro Manso, classificado como intensivo em razão do valor de seus produtos finais. Além disso, também não é considerado na classificação atual o modo de aplicação destes inputs (se há aplicação única ou distribuída ao longo do tempo, por exemplo). Adicionalmente, fatores ecológicos e o delineamento do estudo também podem ter afetado os resultados, tais como o tamanho das microbacias utilizadas e as dinâmicas internas associadas, ou a condição ecológica do bioindicador utilizado nos dados de qualidade da água (diatomáceas). A alta mobilidade e a resposta rápida deste grupo às alterações ambientais podem contribuir para que seja mais utilizado em microescalas e em análises de curto prazo, mais relacionado a impactos de eutrofização (um processo que não varia claramente entre os sistemas de produção). Com exceção do SPA Arroz – que se revelou um sistema claramente impactante em termos ambientais, e do “Cereais de sequeiro” – o qual possui um histórico de associação à poluição de recursos hídricos na região do Alentejo causado por sobre-exploração do solo, a significância dos outros sistemas selecionados pelo modelo em relação aos sistemas restantes depende de análises e interpretações mais complexas. Dentre elas, destacam-se: (i) relativamente ao SPA Pastagens sem gado, pode estar a ocorrer a presença de animais provenientes de explorações vizinhas, por arrendamento de pastagens, o que levaria a uma interpretação enviesada quanto à real utilização da área; (ii) nos SPA de ovinos em pastoreio, as forragens (e mesmo os cereais de sequeiro) poderiam estar associados a altas taxas de aplicação de fertilizantes azotados, com uma maior concentração na sua distribuição espacial e temporal; (iii) práticas de gerenciamento inadequadas, incluindo a possibilidade de aplicação de insumos em excesso; (iv) perdas de nutrientes por escoamento superficial e/ou lixiviação de dejetos animais e; (vi) a aplicação de pesticidas. Neste sentido, uma importante conclusão do trabalho é que os efeitos da agricultura na qualidade da água superficial podem não ser tão previsíveis quanto frequentemente relatados na literatura. Em geral, considera-se que a abordagem proposta tem a vantagem de ser replicável noutras áreas, bem como de poder ser utilizada para apoiar o desenho de políticas mais eficientes e inovadoras no planeamento do uso da terra, de modo a encorajar os agricultores a adotar sistemas de produção menos propensos à degradação da qualidade da água.

Resumo

A agricultura constitui relevante fonte de poluição hídrica, e a avaliação dos impactos ambientais de práticas agrícolas específicas dificulta a operacionalização de políticas públicas conciliadoras entre agricultura e sustentabilidade ambiental. Na busca por abordagens alternativas, os sistemas de produção agrícola (SPA) foram utilizados como variável independente: são explorações agrícolas que apresentam padrões de uso ou atividades semelhantes que utilizam os mesmos recursos e, por isso, são suscetíveis a idênticos impactes e respostas a alterações de políticas.

Através dos SPA identificados para o Alentejo, pretendeu-se responder: (a) há diferenças entre impactos na qualidade da água causados pela agricultura e pela floresta?; e (b) o predomínio de certos SPA pode ser um indicador de qualidade da água?

Os dados de qualidade de água superficial de 2017 e 2019 - variável dependente – foram agrupados em “Desejada” (Excelente, Bom), “Indesejada” (Razoável, Medíocre e Mau). Os indicadores biológicos foram diatomáceas e as unidades de análise foram microbacias até 2500 ha.

O modelo apresentou 84,1% de predições corretas e os SPA estatisticamente significativos (Cereais de sequeiro, Pastagens sem gado, Ovelhas em pastoreio com pastagens e forragens, e o sistema Arroz) apresentaram efeitos negativos, sugerindo que usos agrícolas são mais prejudiciais do que usos não agrícolas (floresta).

Também confirmou-se que o peso relativo de diferentes SPA pode ser utilizado para predizer o nível de qualidade da água superficial, e os mais intensivos e/ou de regadio não foram selecionados. Fatores que possivelmente afetaram estes resultados foram: (i) nível tecnológico, (ii) nível de intensidade dos SPA baseado nos preços dos *outputs* em vez de exprimir o nível de *inputs* por unidades de área, (iii) tamanho das microbacias, (iv) dinâmicas internas associadas, ou (v) condição ecológica do bioindicador utilizado (diatomáceas).

Portanto, os efeitos da agricultura não foram tão previsíveis quanto frequentemente relatados na literatura, e tal metodologia permite replicação noutras áreas e apoio ao desenho de políticas mais eficientes no planeamento do uso da terra.

Palavras-chave:

Sistemas de produção agrícola, Qualidade da água, Política agroambiental, Práticas agrícolas, Diretiva-quadro da água.

Abstract

Agriculture plays a major role in water resource management, accounting for c.a. 70% of the global use of freshwater and acting as an important source of water pollution. Studies assessing environmental impacts of specific agricultural practices may struggle to deliver practical inputs to support design of public policy aimed at reconciling agriculture and environment. This gives rise to seek an alternative and more cost-effective approach, such as the one based on Farming Systems (FS), which is based in the conception that a group of farms with similar land-use and livestock patterns, same resources and input endowments are likely to cause same environmental impacts and respond similarly to policy incentives. Departing from a recent study that set up a FS typology for Alentejo region, in Portugal, we aimed to test if there is a link between the prevalence of certain FS, at the watershed scale, and quality of water resources. Data were adjusted for the level of micro drainage basins up to 2500 ha and a logistic regression model was used to explore relationships through Beta coefficients. Results supported initial hypothesis that, in watersheds dominated by agricultural uses, there is such relationship between the FS and water quality. They also confirm that information on the relative weight of different FS in the basin can be used, to a considerable extent, to predict the level of surface water quality. Four FS were statistically significant with negative effect: Rainfed cereals, Pastures, Sheep grazing - pastures and forages, and Rice. Proposed model resulted in 84.1% of correct predictions and showed a good adjustment to the data. Unexpectedly, FS typically identified as more intensive or using irrigation practices were not necessarily the most detrimental to water quality, suggesting that other factors should be considered, such as (i) the level of technology and the use of more responsible and better management procedures, e.g., precision agriculture management practices, and (ii) current classification of farming intensity based in the output prices instead of level of inputs/outputs per area, and not considering if it is under a single or distributed application over time. Ecological and study design factors may also require adjustments, such as the ecological condition of the water quality bioindicators, or the size of micro-basins and internal dynamics associated to it. Despite of Rice FS – a clear environmentally impactful system, the significance of the other 3 FS over the rest could be explained by causes like presence of cattle due to the rent of pastures to neighbouring farmers, the association with high nitrogen fertilizer application rates, poor management practices, nutrient losses due to run-off, manure leaching and application of pesticides. In this sense, effects of agriculture on surface water quality may not be as predictable as often stated in the literature. The usefulness of the proposed approach is to be replicable in other areas and to contribute to support designing of innovative and cost-effective land use planning policies, encouraging farmers adopting FS less likely to contribute to water quality degradation.

Keywords:

Farming systems, Water quality, Agri-environment policy, Farming practices, Water Framework Directive.

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Abreviaturas

CAP - *Common Agricultural Policy*

ES - *Ecosystem Services*

FS – *Farming Systems*

IACS - *Integrated Administration and Control System*

LPIS - *Land Parcel Identification System*

PAC – *Política Agrícola Comum*

SPA – *Sistema de Produção Agrícola*

UAA - *Utilized Agricultural Area*

WFD - *Water Framework Directive*

1. Prefácio

Devido à atualidade e ao interesse científico do tema, bem como à abordagem adotada, em linha com diversos trabalhos de investigação recentemente publicados, optou-se por desenvolver a presente dissertação em formato de artigo científico. Assim, os capítulos seguintes correspondem ao manuscrito de um artigo científico já submetido para publicação no jornal científico *Land Use Policy*, do qual a aluna foi autora principal. Por esta razão, optou-se por manter o texto na língua original, em inglês.

2. Title

Modelling surface water quality at the micro-basin level based on farming systems shares.

3. Highlights

- Effect of agriculture on surface water quality are not as predictable as expected
- Farming system is a cost-effective and consistent approach to support policy
- More technological detail would help in designing payments to Farming Systems

4. Introduction

Reconciling agriculture with water resource management is a major challenge in many parts of the world. Global concerns about water quality and its availability has led the United Nations to include it among its 17 Sustainable Development Goals for 2030 (Grizzetti et al, 2016; UN, 2020). In Europe, such concerns were reflected in the Water Framework Directive (WFD 2000/60 / European Commission, 2000), which commits EU Member States to strive for good qualitative and quantitative status of all water bodies.

A growing number of studies have warned for a water demand increase up to 20-30% by 2050 in an optimistic perspective. Agriculture plays a major role in these outlooks since it accounts for c.a. 70% of the global use of freshwater (Boretti and Rosa, 2019; FAO, 2017). Moreover, a 60% increase in agricultural production is expected for 2025 globally, to meet the demands of a growing population, intensifying pressures on water resources (Alexandratos and Bruinsma, 2012; Dodds et al., 2013; WWAP/UN-Water, 2018).

In addition to the substantial water consumption, agriculture is also an important source of water pollution through the use of fertilizers, pesticides, and other inputs that, under inadequate management, can lead to harmful effects on water bodies and high socio-ecological costs (FAO, 2017; Stinner, 2016).

Reconciliation between agricultural practices and environmental conservation has been the subject of abundant research, frequently unveiling how the relationships between ecosystems and land uses are often non-linear (D'Amario et al., 2019; DeFries et al., 2004; Maes et al., 2009). Much of this research is focused on assessing the environmental impacts of specific agricultural practices (e.g., fertilization or pesticide use), but, at least partly, fails in delivering appropriate outputs to support the design of public policies aimed at reconciling agriculture and the environment (Bernués et al, 2016; Dale and Polasky, 2007; Valente et al 2021; Zhong et al 2020).

To overcome such shortcomings, Santos et al. (2020) have suggested a farming systems (FS) approach to link agricultural policies with the provision of ecosystem services (ES). This is based on the idea that finding a relationship between specific FS and ES indicators facilitates the design of effective policies to incentivize farmers to adopt environmentally friendly FS, without the need for more complex policy formulations to regulate agricultural activity.

Such a FS approach encompasses a tradeoff between highly tailored policy measures, designed to address specific environmental issues and often entailing high transaction costs and heavy control and monitoring requirements, and more broadly designed policies aimed at supporting particular FS, which are suggested to be more cost-effective. Under this approach, a FS refers to a group of farms with similar land-use and livestock patterns, using roughly the same resources and input combinations, which are therefore likely to cause identical environmental impacts and respond similarly to policy incentives (Darnhofer et al., 2012, Dixon et al., 2001; Ferraton and Touzard, 2009; Ribeiro et al., 2016a). This FS approach has already been successfully tested in previous works exploring links between FS and different dimensions of environmental quality, such as biodiversity conservation (Ribeiro et al., 2018; Ribeiro et al., 2016a) or landscape planning (Ribeiro et al., 2016b; Silva et al., 2020).

In this study, we aim to apply this FS approach to test the hypothesis that there is a link between the prevalence of particular FS in a given watershed and the quality of water resources (WFD *sensu*). As far as the authors are aware, this is the first study that seeks to directly relate FS with the environmental status of water resources. The establishment of these FS-water quality relationships could support the development of policy recommendations to encourage farmers to adopt FS less likely to contribute to water quality degradation.

For this purpose, we departed from a recent study that set up a FS typology for the Alentejo region, in southern Portugal (Ribeiro et al., 2021), and on water quality data collected under the WFD for the same region. Both data sets were adjusted for the level of micro drainage basins in the Alentejo region, which constituted the units of analysis for the empirical study. By relating the prevalence of different FS in the watershed with the level of water quality, we intend to test our research question on the existence of relationships between FS and water quality, and to establish the pattern of such relationships.

Taking advantage of the fact that this is a region where agriculture is the dominant land use, and where non-agricultural areas are mostly forest, we will also test the hypothesis of a differentiated impact on water quality between agriculture and forest.

It should be noted, therefore, that this study does not seek to investigate the direct effects of individual contaminants on water quality, nor to carry out a specific review of the impacts at the level of the study area, but to test whether effects can be detected within a broader FS-water quality relationship. Our focus is on validating the approach and its associated concepts, with the purpose of delivering a framework that can be easily reproduced in other areas, regardless of different FS compositions and water quality parameters. Results were eventually used to discuss the usefulness of the proposed approach to contribute to evidence-based policy-making aimed at water resource management at the micro-basin level, in the sense of the WFD.

5. Materials and Methods

5.1. Study area

The Alentejo region, in southern Portugal, corresponds to an area of 31605 km² - 34% of the Portuguese territory (Instituto Nacional de Estatística, 2019). About 5140 km² of this area are classified as Natura 2000 Sites and 1810 km² are part of the National Protected Areas Network (ADRAL, 2014). Climate is Mediterranean with dry and hot summers and moderately rainy winters (700 mm of average annual rainfall). Average annual temperature is 16.3 ºC and the relief is soft, with few mountainous areas. Hydrographic sub-basins are divisions of the watersheds of the main rivers: Guadiana, Mira, Sado and Tejo.

The Utilized Agricultural Area (UAA) of Alentejo is over 2.1 million hectares (57.7% of the total UAA in Portugal), of which the main uses are permanent pastures (58.5%), temporary crops (20.8%), permanent crops (10.5%) and fallow areas (7.6%) (Instituto Nacional de Estatística, 2017). Low incidence of industries and predominance of agricultural areas in 70% of the territory allow us to anticipate that the type of agriculture and the share of agriculture versus forest in land use will be decisive for the status of water resources in this region.

5.2. Water quality data

The water quality data were collected as part of the monitoring work carried out under the WFD. To reduce the effects of other factors on water quality, we focused the analysis only on rivers and reservoirs, discarding e.g. transitional and coastal waters. We also chose not to include groundwater, focusing only on surface water, as hydrogeological complexity could hinder the identification of relationships between existing FS and water quality at the micro-basin level.

The determination of water quality within the scope of the WFD comprises ecological and physical-chemical quality parameters. In the study area, data for chemical classification exhibited a high incidence of “Unknowns”. For this reason and the fact that these parameters can be subject to externally determined factors not easily relatable to existing FS (e.g., flow rate and flow conditions, depth and width variations), we chose to focus the analysis on the ecological status classification. This is categorized as Excellent, Good, Reasonable, Mediocre and Bad (Table 1).

Table 1. Definition of the five categories used to classify surface water ecological quality, adapted from WFD

Excellent - No (or very few) anthropogenic changes in the values of the physicochemical and hydromorphological quality elements of the surface water body type in relation to those normally associated with this type in undisturbed conditions. Values of the biological quality elements reflect those normally associated with that type in undisturbed conditions and do not present any distortion or show only a very slight distortion.

Good - The values of the biological quality elements of the surface water body present low levels of distortion resulting from human activities, and only deviate slightly from those normally associated with this type of surface water body in undisturbed conditions.

Reasonable - Values of the biological quality elements of the surface water body deviate moderately from those normally associated with that type of surface water body in undisturbed conditions. Values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good ecological status.

Mediocre - Waters that exhibit considerable changes in the values of biological quality elements for the surface water body considered and in which the relevant biological communities deviate substantially from those normally associated with that type of surface water body under non-disturbed conditions.

Bad - Waters that exhibit serious changes in the values of biological quality elements for the surface water body considered and in which large portions of the relevant biological communities normally associated with this type of surface water body are absent under non-disturbed conditions.

Composition and abundance of phytobenthos (diatoms) is one of several elements included in the ecological status assessment. These organisms are highly responsive to environmental variables such as light, humidity, organic and inorganic contaminants; and chemical alterations of water, such as nutrients, temperature, pH and salinity (Instituto da Água, 2009; Lobo et al., 2010; Pfister et al., 2009). Therefore, they are often considered a potential indicator of water quality status (Pfister et al., 2017). For these reasons, and given the extensive availability of data, the classification of water quality status presented in this study was based on diatoms as a proxy of the impacts that different FS may have on surface water quality. These data were obtained from monitoring work carried out by the Portuguese Environment Agency (APA) in 2017 and 2019, within the scope of the WFD. Data were collected from 331 spatially explicit sampling points covering the study area of Alentejo. Since sampling points from both years were not spatially coincident, they were merged for the analysis allowing to substantially increase the number of observations, while assuming that the FS pattern in the region should have remained largely unchanged during this two-year period. Nevertheless, to investigate if the year of collection could interfere with the results, a corresponding dummy variable was included in the analysis.

5.3. Farming systems

The FS typology for the Alentejo region was derived from Ribeiro et al (2021). A total of 22 FS was identified and mapped for the entire area (Table 2, Figure 1). The FS typology was based on farm-level data describing land-use and livestock patterns in 2017 derived from the Integrated Administration and Control System (IACS), combined with spatial data from the Land Parcel Identification System (LPIS), provided by the Portuguese agency responsible for Common Agricultural Policy (CAP) payments (details in Ribeiro et al., 2021). The expected effects of each FS on water quality as compared to forest cover in Table 2 were inferred from the characteristics (e.g. irrigation, forages *vs* pastures, and under the cover of cork or holm oaks *vs* open field) of the FS (Ribeiro et al, 2021).

Table 2 . The farming systems identified for the study area (adapted from Ribeiro et al, 2021). Colours provide a legend for Figure 1.

Farming System	Description	Expected effect on water quality (0/-)[1]
Cattle grazing – CO[2]	Agroforestry system of high natural value (agricultural area placed under the canopy of sparse cork oak trees - an important income source for farmers, due to the production of cork). Composed by permanent pastures, it presents high livestock density (livestock unit - LU/ha)[3] but cork oak and holm oak covered areas extend over a large area (almost ⅓ of total UAA), which results in an extensive system (low intensity[4]). The main feature is UAA under CO (about 33%). It is expected a crucial performance in pollutants retention and prevention of undesirable transport of substances to water courses, regardless being less expressive than in sheep grazing systems (maybe due to cattle influence over regeneration of vegetation).	0
Cattle grazing – HO[5]	Agroforestry system of high natural value (agricultural area placed under the canopy of sparse holm oak trees - providing shade, firewood and food for animals on pastures). Composed by permanent pastures, it presents comparatively high livestock density, but cork oak and holm oak covered areas extend over a large area (almost 2/3 of total UAA), which results in a low intensity system. The main feature is the UAA under HO (59%). It is also expected to have a crucial performance in pollutant retention and prevention of undesirable transport of substances to surface water.	0
Sheep grazing – CO	Agroforestry system of high natural value (agricultural area placed under the canopy of sparse cork oak trees - an important income source for farmers, due to the production of cork). Composed of permanent pastures, it presents the lowest livestock density and clearly is a low-intensity system. The main feature is UAA under CO (about 69%). It is expected to have a crucial performance in pollutant retention and prevention of undesirable transport of substances to surface water.	0
Sheep grazing – HO	Agroforestry system of high natural value (agricultural area placed under the canopy of sparse holm oak trees - providing shade, firewood, and food for animals on pastures). Composed by permanent pastures, it presents one of the lowest livestock densities and clearly is a low-intensity system. The main feature is the UAA under HO (64%). It is also expected to show a crucial performance in pollutant retention and preventing undesirable transport of substances to surface water.	0
Grazing goats	Agroforestry system of high natural value, composed by permanent pastures and presenting 52% UAA under CO and HO. It does not demand much water from public irrigation systems, and has the 2nd highest livestock density, but still considered a low-intensity system because goats graze in non-declared areas, which leads to an overestimation of the livestock density indicator.	0
Sheep grazing – pastures	Massively composed by permanent pastures and it is one of the highest livestock densities, but it is considered a low-intensity system (non-	0

	declared grazing area may have led to overestimation of livestock density).	
Mixed Cattle and sheep – Irrigated forages	Mostly composed by irrigated forages (44% - watered by public systems and often fertilized), followed by pastures (22%) and rainfed forages (11%) too. There is a balance between cattle and sheep. It shows a low livestock density and is classified as a low-intensity system (although close to 1.2). The high presence of forages compared to pastures can make it prone to cause negative effects on the environment.	-
Sheep grazing – forages	Mostly composed of rainfed forages and grazing sheep (there are also grazing goats), it shows low livestock density, and it is a low-intensity system. Following land uses are pastures (13%) and rainfed olive groves (11%).	-
Cattle grazing – forages	Mostly composed by pastures (39%) and rainfed forages (24%), followed by rainfed cereals (14%). It is the 3rd highest livestock density (the highest among cattle FS), but it is considered a low-intensity system too (at least financially speaking, in terms of per hectare revenue). Areas occupied by rainfed forages (often fertilized) and rainfed cereals (total of 38%) may have negative effects related to the use of fertilizers and other agro-chemicals.	-
Sheep grazing - pastures and Forages	Mostly composed of permanent pastures used by sheep and, on, a lesser extent, goats. Occupation is followed by rainfed olive groves (16%), rainfed cereals (17%) and rainfed forages (14%). It shows a moderate to high livestock density, but it is considered a low-intensity system (probable non-declaration of all grazing area).	-
Rainfed olive groves with sheep	Remarkable presence of rainfed olive groves (66%) and the rest is filled by pastures. It shows the highest livestock density (sheep), but it is still considered a low-intensity system.	-
Rainfed olive groves	A permanent crop system massively occupied by rainfed olive groves. It is a clearly low-intensity system (economically speaking) but the high % UAA covered by this monoculture is considered environmentally unfriendly due to the production of pollutant oils in waste disposal and the run-off to surface waters of soil, fertilizers, and pesticides, when not carefully managed.	-
Irrigated olive groves	A permanent and intensive crop system massively occupied by olive groves irrigated by public irrigation systems. It is clearly environmentally unfriendly due to the production of pollutant oils in waste disposal, the run-off to surface waters of soil, fertilizers and pesticides and the exploitation of ground and surface waters for irrigation. Thus, when not carefully managed, it exhibits a high degree of degradation. On the other	-

	hand, the right use of technology could mitigate its negative potential (Cisternas et al, 2020; Silveira et al, 2018).	
Vineyards	A permanent and intensive crop system massively occupied by vineyards but also by rainfed olive groves (9%), pastures and fallows (12%). Considered an environmentally unfriendly system due to the use of pesticides and fertilizers, the high water consumption (especially during the vinification process) and the production of potentially contaminating waste water.	-
Fruit trees	A permanent and massively intensive crop system composed by fruit trees (55%) but also with a significant occupation by pastures (almost ¼ of area) and areas under CO and HO (18%). It is considered environmentally unfriendly due to the use of fertilizers and other agrochemicals, applied in a relatively small area.	-
Stone pine	A permanent and economically very intensive crop system massively occupied by Stone pines, but with a relevant area under CO and HO (26%) and pastures (19%). Intensity classification is assigned to Pine nuts, which are currently highly prized in international markets as it is one of the most important non-wood forest products that can be obtained from Mediterranean forests.	0
Rice	Annual and intensive monoculture system which demands the highest availability of public irrigation systems and extends its negative impacts on water for all the year. As it is mostly sowed with pre-germinate seeds directly on flooded terraces, it is intrinsically related and practiced along water courses.	-
Irrigated cereals and horticultural crops	Annual and very intensive crop system composed by irrigated cereals, but with horticultural and industrial horticulture in balanced proportions. It depends on public irrigation systems and fertilizers input, presenting high levels of mechanization.	-
Rainfed cereals and oilseeds	Annual and extensive crop system composed by cultivation of dryland cereals (rainfed) in autumn-winter and irrigated oilseeds in spring-summer. Both crops could demand input of fertilizers and pesticides, which are environmentally unfriendly.	-
Rainfed cereals	Annual and extensive crop system representing autumn-winter crops but also representative of the area occupied by a group composed of fallows, pastures and rainfed olive groves (47%). It exhibits no need of very high levels of nitrogen, but input in only one or two batches, or even a poor management of products and procedures, associated with rains, could enable carrying contaminants to water courses, causing pollution. In this context, improved technology could be determinant.	-
Pastures (no livestock)	Clearly an extensive system, it is massively occupied by pastures, but also by rainfed olive groves (15%). It is not expected to show negative	0

	effects since there are no inputs of fertilizers and pesticides, and it is supposed to not have permanent grazing.	
Fallows	Extensive system represented by smaller agricultural units filled with fallows.	0

[1] The effect of each FS on water quality (0/-) has taken as reference water quality under forest land cover.

[2] CO - Under cover of Cork oak.

[3] Livestock density data must be carefully considered in all cases, since it represents a ratio between animals and land when both are owned by the same farmer. It does not consider information about animals grazing and spreading over third party lands, which could reduce real livestock density.

[4] Intensity unit is 10^3 €/ha. Classification criteria: Intensive (>=1.2) and Extensive (<1.2).

[5] HO - Under cover of Holm oak.

5.4. Data analysis

Data preparation and analysis were carried out by running a sequence of procedures (Box 1). GIS tools were used to delimit the micro drainage basins (hereafter micro-basins) for the 331 water sampling points, from a digital elevation model of Portugal (mainland).

The FS and the micro-basins maps (Figure 1) were intersected to perform a pixel count for every micro-basin, producing a matrix where rows represented micro-basins (the analysis units) and columns included the share of each FS in the micro-basin total area (% of FS occupation), along with water quality information regarding ecological status classification.

Box 1. Step-by-step data preparation and analysis

1. Obtaining water quality classification for 331 sampling points (years 2017 and 2019) and FS data for Alentejo (2017).
2. Obtaining digital elevation model for Portugal (25m x 25m resolution) and delimitation for the Alentejo region.
3. Use of water quality points to generate drainage micro-basins polygons:

   Running the Fill Sinks (SAGA) algorithm in QGIS (QGIS Development Team, 2020).
   Running the Strahler Order (SAGA) algorithm in QGIS – resulted in 11 orders.

Running the Channel Network and Drainage Basins algorithm (with a threshold ≥ 5 to the order of basins).

4. Adherence of the points to the channel mesh generated in the previous step to adjust them just in case of possible small overlap differences:

   Running the “Snap points to lines” algorithm.
   Separation of points into individual vector layers.
   Running the Catchment Area algorithm for each point.

5. Polygon area was calculated based on the Attribute table in QGIS (command “add geometry attributes”).

6. Rasterization of the micro-basins, and identification of their FS compositions in R software (R Development Core Team, 2019).

7. Resulting table was edited in a spreadsheet editor to calculate area and corresponding % to each FS in the micro-basins (the output of R program reported the number of 25m x 25m pixels, which were multiplied by 625 to obtain area in m²).

5.5. Statistical model

Logistic regression was used to explore relationships between FS and water quality levels. To identify which FS contribute most to the water quality classification and accentuate the contrasts between the Desired (“Good” and “Excellent”) and Undesired (“Reasonable”, “Mediocre” and “Bad”) quality categories, they were regrouped, converting a dependent multi-categorical variable into a binary variable, with “1” assigned to the Desired group (“Good” and “Excellent”) and “0” to the other one (Figure 1).

A correlation matrix of the independent variables was used to check for multi-collinearity problems. Model accuracy and adjustment to the data was assessed based on an Omnibus test (to check that the explained variance is greater than the unexplained variance) and determination coefficient (Nagelkerke-R^2). Beta coefficients – value and sign – were used to investigate the effects of the independent variables on the dependent variable. The model was estimated in SPSS software (IBM Corp., 2019).

5.6. Analytical procedures

Micro-basins were used as the functional analysis units because they are representative of the geographic area receiving contributions drained to a specific point in a water body. As the size of the micro-basin increases, we can also expect greater complexity in the land use pattern and the water flow regime, and larger variability in luminosity, temperature, salinity, and other environmental parameters to which diatoms respond (Pfister et al., 2017; Wu et al., 2018). This can potentially mask the results of water quality classification and undermine the search for relationships between FS and water quality. For all these reasons, it was decided to restrict the analysis to micro-basins with up to 2500 ha of area, an arbitrary threshold based only on data examination. Under these criteria, 140 micro-basins were retained for further analysis.

It was also decided to compute the relative weights of each FS regarding the total area of the micro-basins, thereby creating a class of "unclassified" areas (i.e., areas not filled with FS), which were interpreted as mostly depicting forested areas. We anticipate these forested areas to have positive effects on water quality, when compared to FS areas. We thereby set to test the null hypothesis of an equality between agriculture and non-agriculture (forest) which, if rejected, would probably identify agriculture as a pressure factor on surface water quality, regardless of FS.

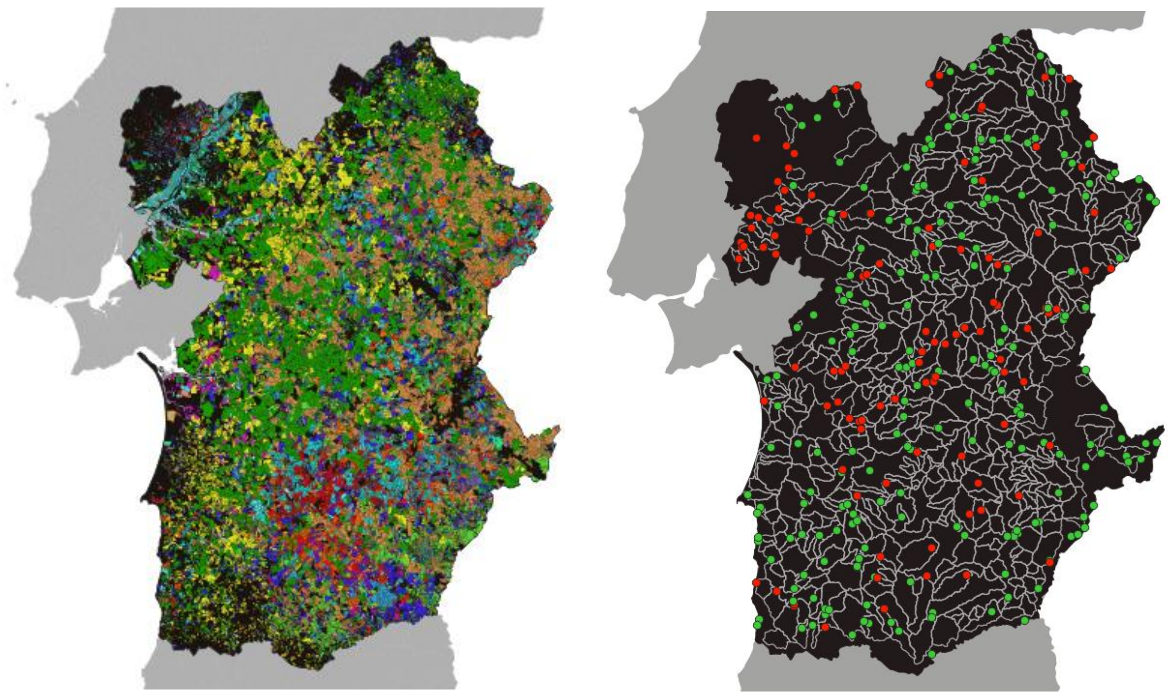

Figure 1. Farming systems map (left) and micro-basins (right) in the study area. Distinct colours in the FS map identify different FS according to the legend in Table 2 (for details on each FS spatial distribution refer to supplementary information in Ribeiro et al. 2021). Coloured dots on the micro-basins map identify water quality sampling points; green and red dots identify "desired" and "undesired" quality status (see text); light-grey polygons identify the micro-basins delimited for each sampling point.

6. Results

6.1. Farming system composition in the study area

Results showed that the overall FS pattern within the considered micro-basins exhibited a clear predominance of (i) agricultural areas under the canopy of cork and holm oaks, and (ii) pastures, as these FS covered more than 50% of the FS area, with emphasis on the association between cork oak and cattle. Areas not occupied by any FS totalized almost 30% of the total (Table 3).

Table 3. Overall area occupation by farming systems and non-classified areas ("Absence of FS") in the 140 micro-basins in analysis

Farming system / Land use	hectares	%
Absence of FS (mostly forest)	38019	29.4
Cattle grazing - CO	30942	23.9
Cattle grazing - HO	12531	9.7
Sheep grazing - CO	12316	9.5
Sheep grazing - HO	5813	4.5
Pastures – no trees and almost no cattle	5416	4.2
Irrigated olive groves	4682	3.6
Cattle grazing - Forages	3729	2.9
Sheep grazing – Pastures	3431	2.7
Rainfed cereals	2007	1.6
Rainfed olive groves	1676	1.3
Irrigated cereals and horticultural crops	1639	1.3
Rainfed cereals and oilseeds	1595	1.2
Sheep grazing – Pastures and forages	1219	0.9
Sheep grazing - Forages	1060	0.8
Rainfed olive groves with sheep	675	0.5
Mixed cattle and sheep - Irrigated forages	523	0.4

Stone pine	513	0.4
Grazing goats	403	0.3
Fruit trees	385	0.3
Fallows	347	0.3
Vineyards	242	0.2
Rice	127	0.1
TOTAL	129290	100

6.2. Water quality classification

Among the 140 micro-basins, the water quality status in 95 of them (68%) fall into the "Desired" group ("Good" or "Excellent") and 45 (32%) in the "Undesired" group (“Reasonable”, “Mediocre” and “Bad”).

6.3. Logit model

Eight outliers (cases with 2 or more standard deviations away from the mean, in the independent variables) were removed from analysis, which were thus performed with the remaining 132 micro-basins. The correlation matrix for the dependent variables (FS) has pointed out there was no relevant correlation (>0.5) between pairs of FS (only between “Cattle grazing - CO” and “Cattle grazing - HO” a value of 0.61 was identified which, nevertheless, was not considered sufficient to recommend the removal of one of the variables). Additionally, the dummy variable identifying the year of water quality data (2017 or 2019) was found not statistically significant, revealing the inexistence of significant differences in the data structure for the two years, so the data merging for the two years was kept.

The Omnibus test pointed the proposed model is significantly different from the null model, resulting in 84.1% of correct predictions (Table 4). Nevertheless, we found a high rate (almost 40%) of cases belonging to the “Undesired” group (0) but erroneously assigned to the “Desired” group (1), which could lead non-beneficial FS being masked with a false positive influence (Table 4). The model showed a good adjustment to the data, with a pseudo-R^2 (Nagelkerke) of 0.59 and a significant Hosmer-Lemeshow test (sig. 0.90).

Statistically significant variables affecting water quality classification were composed by 4 FS: Rainfed cereals, Pastures (no livestock), Sheep grazing - pastures and forages, and Rice (Table 5).

Table 4. Classification table for the proposed model.

		Predicted		
		Phytobenthos		Correct percentage
Observed		0	1	
Phytobenthos	0	26	17	60,5
	1	4	85	95,5
Overall percentage				84,1

Table 5. Variables in the equation. Lines in bold show statistically significant FS (sig. <0.05)

	B	Standard error	Sig.	95% C.I.for Exp(B)	
				Inferior	Superior
Cattle grazing - CO	-0.017	0.012	0.154	0.961	1.006
Cattle grazing - HO	-0.015	0.012	0.205	0.963	1.008
Cattle grazing - Forages	0.012	0.045	0.796	0.927	1.104
Grazing goats	0.199	0.376	0.597	0.583	2.552
Mixed cattle and sheep - Irrigated forages	-0.044	0.164	0.791	0.694	1.321
Sheep grazing - CO	0.039	0.029	0.173	0.983	1.101

Sheep grazing - HO	0.083	0.091	0.363	0.909	1.299
Sheep grazing - Pastures	-0.048	0.102	0.638	0.781	1.163
Sheep grazing – Pastures and forages	**-0.752**	**0.299**	**0.012**	**0.262**	**0.847**
Sheep grazing - Forages	0.037	0.056	0.513	0.929	1.158
Rainfed olive groves with sheep	-0.151	0.749	0.840	0.198	3.734
Rainfed olive groves	0.576	0.639	0.367	0.509	6.225
Irrigated olive groves	0.066	0.068	0.334	0.934	1.221
Vineyards	0.200	0.353	0.570	0.612	2.441
Fruit trees	1.064	0.547	0.052	0.992	8.463
Stone pine	0.130	0.217	0.550	0.744	1.743
Rice	**-6.972**	**3.194**	**0.029**	**0.000**	**0.491**
Irrigated cereals and horticultural crops	-0.033	0.028	0.248	0.916	1.023
Rainfed cereals and oilseeds	0.013	0.064	0.841	0.894	1.148
Rainfed cereals	**-0.438**	**0.165**	**0.008**	**0.467**	**0.892**
Pastures – no oak trees and almost no cattle	**-0.118**	**0.047**	**0.011**	**0.811**	**0.973**
Fallows	-0.279	0.263	0.289	0.451	1.267
Year	0.922	0.719	0.200	0.614	10.298
Constant	1.996	0.877	0.023		

Note: The omitted/reference category in the independent variables (FS shares), was the share of the area not classified in any FS. Thus, the signs and sizes of the B coefficients should be interpreted as the effect of that FS when compared to a land cover that would be predominantly forest.

7. Discussion

Overall, the results support our initial hypothesis that, in watersheds dominated by agricultural uses, there is a relationship between the prevalence of certain FS and the quality of surface water. They also confirm that information on the relative weight of different FS in the basin can be used, to a considerable extent, to predict the level of surface water quality. This type of knowledge can be very useful to support the design of innovative and cost-effective land use planning policies aimed at complying with legal water quality standards at the river-basin level, such as those under the WFD.

7.1. Farming systems and water quality

As mentioned before, of the 22 FS identified in the Alentejo region, only 4 exhibited a (statistically significant) relationship with the quality of surface water in the micro-basins: Rice, Sheep grazing pastures and forages, Pastures without trees and livestock, and Rainfed cereals. This apparently small number of significant FS should not be seen as a weakness of the model, as there was no reason to assume at the outset that a significant number of FS should have a clear relationship with water quality, but rather that this relationship could emerge only in a few relevant FS, as it turned out.

The fact that all significant FS presented negative effects (negative signs in the coefficients), suggests that agricultural land uses are more detrimental to water quality than non-agricultural uses, namely forests, which was the reference category in the model, so partly validating our hypothesis of an overall negative effect of agriculture when compared to forest.

The Rice FS proved to be the one that potentially causes the greatest negative impact on water quality (coefficient with the highest absolute value), clearly standing out from the other significant FS in the model. This FS accounts for an intensive cultivation placed in shallow flooded areas and practiced along the banks of the largest rivers in Alentejo. It is acknowledged as an environmentally impactful system, especially related to greenhouse gas emissions, soil degradation and pollution through the input of fertilizers and pesticides that can be directly washed away to contiguous water streams (Kimaro, 2019; Miranda et al., 2015; You et al., 2011).

Sheep grazing - pastures and forages points out potential impacts caused by the presence of animals and forages. Nutrient losses due to run-off, manure leaching and application of pesticides in the sheep immersion baths can contribute to degrade water quality, besides the possibility of other biological contaminations (Hooda et al., 2000). Nevertheless, losses of nitrogen and phosphorus in sheep farming are recognized as smaller than in cattle farming, as well as their impact on water bodies (Drewry et al., 2000; McDowell and Wilcock, 2008).

As the Pastures without trees and livestock FS, although it is described as a FS without livestock, we can assume that a large part of these pastures is used by animals from neighbouring farmers, under lease, possibly with high stocking rates, so it is therefore advisable to analyse the results on this basis. Thereby, its environmental impacts can be largely related to the presence of grazing animals (whose droppings have high nitrogen contents and can be spatially concentrated), but also with high nitrogen fertilizer application rates, which can yield surpluses capable of eutrophication. Pastures requiring these inputs are subject to quick and long-lasting periods of nitrogen mineralization, which increases the loss potential (Vendramini et al., 2007).

Rainfed cereals, despite of being less intensive in fertilizer inputs and water irrigation than some other FS, is recognized as an environmentally impacting system since it can encompass poor management practices, as discussed in the next section.

The dominant FS in the study area, namely the cattle systems with oaks and other low-intensity FS, had not significant effects in the model, which is possibly related to the fact that, for these low-intensity FS, the impact on surface water quality is indeed not significantly different from that of forest cover.

Against expectations, many irrigated FS, in particular irrigated olive groves, have not also revealed to have a significant effect on water quality. A possible explanation for this result is that FS using great extensions of land could encompass more internal heterogeneity, thereby generating statistical noise and hindering the measurement of the average effect sign and size of each FS. This heterogeneity, in particular in the case of FS with intensive irrigated crop, may be connected with different technological levels within the same FS, e.g., irrigated olive groves. Some farms may e.g., be using fertilizer in a way that prevents leachable surpluses to develop in the soil, whereas others do not.

7.2. Farming intensity and water quality

High levels of agrochemicals use and artificial irrigation can affect water quality and availability downstream, potentially contributing to a greater concentration of salts, other chemicals, and leaching nutrients (Kimaro, 2019). Santos et al (2020) reported production intensity as one of the main causes of

FS impacts on biodiversity and ecosystem services. However, it did not seem to be a determinant criterion in this case (as the most intensive FS were not selected by the model), and rice was the only high impact FS depending on irrigation and substantial water input. A possible explanation is that the current classification of farming intensity was not based directly on the level of inputs/outputs per unit area but instead on the per-hectare output values, which are affected by output prices. In addition, it does not reflect the frequency level in the application of inputs (single application or distributed over time) or the quality of management developed, e.g. application of all the fertilizer in a single moment, conducting to possible run-off of agrochemicals to water courses, depending on the usage cycle of the nutrients by the crop and the consequent production of leachable surpluses at particular phases. In practice, differences in the fertilization planning and in the design of farm requirements lead to different impacts (Löw et al, 2021). This could also be a possible explanation for the selection of low-intensity FS like the Sheep grazing - pastures and forages, and Rainfed cereals.

7.3. Hidden features and possible justifications

Some FS that were expected to be chosen by the model (based on their negative effects described in the literature) in fact were not, while others were an intriguing novelty, challenging a deeper reflection in interpreting the results.

Irrigated olive groves was one of the FS expected to be significant in the model (but it was not), as it is generally intensive in pesticides and fertilizers inputs. The possible justification for its exclusion could be the current level of technology reached, such as drip watering and other precision farming approaches, enabling mitigation of its negative effects on water quality. Internal heterogeneity may be assigned to different technological levels within the same FS, and this lack of control for technology in intensive FS may also explain why a high proportion (40%) of micro-basins with undesirable levels of water quality are predicted as having desirable levels based on their FS composition. This would advise the use of more farm-level technology variables when classifying farms by FS, so as to improve the predictability of water quality based on shares of FS in land use at the micro-basin level.

Another possibility is that impacts could be more readily evident on soil and biotic environments (fauna and flora) because of their slower resilience processes. The opposite can happen with water, which may show signs only in the future.

The Stone pine FS was also identified by Ribeiro et al. (2021) as among the most intensive FS in the region and, for this reason, it was anticipated as potential candidate for the model. However, this was not the case, possibly because this FS was marked as intensive based on the high market prices of its outputs (pine nuts), and not due to particularly high input levels that could be associated with negative environmentally impacts.

Similarly, also the intensive Fruit trees FS was expected to have a significant effect, which could have been attenuated by the presence of a relevant area under cork oak and holm oak (18%) and pastures (24%), in addition to the incorporation of advanced technologies and more responsible and better management procedures. The importance of incorporating all land uses (including the low-input ones) at the FS level is a strength of the proposed approach when it comes to assess the responsibility for water quality impacts at the farm level.

In the group of systems not expected to be chosen by the model, the apparently odd selection of FS Pastures without trees and livestock is probably related to the abovementioned fact of the presence of grazing livestock from neighbouring farms, in addition to the fact that pastures are often complemented with forages that are usually fertilized, thus contributing to possible negative impacts.

Same issue regarding fertilized forages could be raised for FS Sheep grazing - pastures and forages, in addition to the potential impacts arising from presumed presence of animals. Despite this, there does not seem to be a clear explanation to specifically classify this FS as negatively differentiated from others that also have the presence of animals in pastures (e.g., cattle systems). A reason that could be highlighted is the relevant occupation in area (47%) by other crops with expected negative impacts, like rainfed olive groves, rainfed cereals and rainfed forages.

On the other hand, Rainfed cereals was expected to have negative effect (along with Rice FS) since it is already related to pollution of underground aquifers caused by soil overexploitation, which prevents the replacement of fertility, leading to instability of watercourses and aquifers in some regions of Alentejo (Gonçalves, 2017). The main causes seem to be the low-technology use of fertilizers and their easy transport to nearby water bodies.

7.4. Research gaps and generalisability

Although our hypotheses were confirmed by the results achieved (some FS have an effect on water quality as compared to forest, and these effects are always negative), it is possible that these were influenced by research options or specificities of the study area. For example, factors affecting the ecological condition of diatoms (e.g., precipitation events, microenvironments of the sampling points or seasonal variability) may interfere with the mobilization pattern, the origin of the contributing diatoms (riparian or aquatic), the transport of nutrients and the representativeness of the drained area (partial or total). For that reason, suitability of using diatoms as the single biological indicator should also be verified, since their high mobility and fast response to environmental changes contribute to stressors analysis that are mainly focused on local scale and short-term periods. Thus, chances of them reflecting influence of factors from farther locations are less. They are more linked to impacts related to eutrophication, an environmental process that may not clearly vary between FS (Bielczyńska, 2016). In fact, some authors suggest that methods involving this group should be complemented with others using phytoplankton, macrophytes and/or benthic macroinvertebrates (Desianti et al., 2019), an option that was not available to us due to lack of data.

Other important factors possibly affecting the results and demanding further research can include the size of the micro-basins. The arbitrary threshold of 2500 ha that was imposed for the maximum size of the micro-basins should be faced with caution and recommends additional investigation.

Finally, it could also be ascertained whether the average distance of each FS in the micro-basin to the sampling point would have an influence on the results, since it can be assumed that FS closer to the sampling point will have, under other circumstances, greater influence on the water quality parameters.

8. Conclusions

This study consisted, to a large extent, in an adaptation of the approach proposed by Santos et al. (2020) to relate FS with ecosystem services and biodiversity conservation, in this case applied to explore links between FS and surface water quality in farmland-dominated micro-basins. This may be of interest, for example, to meet the objectives of the EU Water Framework Directive.

The study showed that the effects of agriculture on the environment, and particularly on surface water quality, may not be as predictable as often stated in the literature. In fact, we found that FS typically identified as more intensive or using irrigation practices are not necessarily the most detrimental to water quality, suggesting that there are other factors to be considered. A possibility is that more intensive FS can be associated with precision agriculture management practices, capable of mitigating its effects on the environment. Technology is another relevant factor to be taken into consideration, as this may possibly contribute to further split the FS so as to solve the internal heterogeneity problem and thus reach clearer relationships between FS and water quality.

The proposed approach requires classifying farms according to the FS in an expeditious, efficient, and easily updated way. In the EU, this requirement can be put into practice by resorting to data such as that annually collected through farmers' applications for CAP payments (IACS/LPIS data), as proposed by Santos et al. (2020) and recently applied by Ribeiro et al. (2021).

The evidence of a clear relationship between certain FS and surface water quality that emerged from this study supports the recommendation of policy alternatives focused on water resources management in areas where agriculture can be assumed as an important source of diffuse water pollution. A policy paying a premium to farms operating a particular Farming System could prove to be the right way to reconcile agricultural and environmental policy objectives, by allowing to influence farmers' decisions towards socially desirable objectives, while reducing the high administrative costs of policies based on agricultural practices and the associated burden of controlling and monitoring them.

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10. Considerações Finais

Tendo em conta os resultados alcançados, e conforme referido na discussão e conclusões da proposta de artigo científico que está na base desta Tese, considera-se que a abordagem adotada constitui uma alternativa viável para explorar opções de conciliação entre objetivos de política agrícola e política ambiental.

Ambas as hipóteses a serem testadas no estudo foram validadas, comprovando, por um lado, a existência de uma relação diferenciada entre agricultura e floresta na qualidade da água e, por outro lado, a existência também de uma relação diferenciada entre distintos SPA e o seu impacte na qualidade da água.

Os resultados alcançados vão ao encontro de propostas anteriores que defendem políticas de pagamentos por SPA, que incentivem os agricultores a adotar sistemas mais amigos do ambiente – neste caso da qualidade da água – com vista a melhorar o custo-eficácia das políticas públicas interessadas nestes objetivos, nomeadamente através de uma redução dos custos associados às ações de controlo e monitorização de práticas agrícolas individuais.

Esta opção pressupõe a existência de um sistema de recolha de dados ao nível da exploração com regularidade suficiente para acompanhar de perto das decisões dos agricultores, nomeadamente na escolha do sistema de produção. É o caso da Política Agrícola Comum (PAC) que requer que os agricultores europeus que se candidatam a pagamentos PAC sejam obrigados a declarar anualmente os usos e ocupação das suas terras, ao nível da (sub)parcela, bem como a composição e dimensão dos efetivos pecuários, entre outros dados (e.g. regadio/sequeiro). Conforme proposto por outros autores, esta informação poderia ser usada para classificar, todos os anos, as explorações agrícolas de uma determinada área de interesse, segundo uma tipologia de sistemas de produção previamente definida. As explorações identificadas a praticar os SPA recomendados pela política seriam automaticamente selecionadas para um pagamento premium, constituindo um incentivo à manutenção da escolha desses SPA.

O estudo aqui desenvolvido mostrou, pelas limitações encontradas, que a eficácia da abordagem por SPA proposta poderia ser melhorada se, no âmbito das declarações anuais dos agricultores, fosse possível recolher mais e melhor informação acerca de práticas agrícolas (e.g. sobre aplicação de agroquímicos).

Importante ensinamento extraído das análises realizadas é que os efeitos da agricultura no ambiente, nomeadamente na qualidade da água, podem não ser tão previsíveis quanto frequentemente são considerados pela literatura. Esta conclusão fundamenta-se, por exemplo, no facto de o modelo ter identificado como significativos SPA que à partida, não se esperaria que estivessem entre os mais impactantes, tendo em conta o seu nível de intensidade ou o regime de irrigação (regadio *vs* sequeiro), o que também sugere uma mais-valia da abordagem integrada por sistemas, em detrimento de uma análise por práticas isoladas.

Discutiu-se, portanto, a importância que a ponderação de outros aspetos possui nesta abordagem, como o uso de tecnologias mais avançadas e a aplicação de práticas de gestão mais eficientes que envolvam, por exemplo, a agricultura de precisão. Estes fatores podem ser capazes de permitir uma reorganização dos sistemas de produção de modo a solucionar possíveis interferências que as heterogeneidades internas de cada sistema possam ter ao afetar as conclusões do modelo quanto aos sistemas mais impactantes na qualidade da água. Ainda assim, a conclusão deste estudo é de que a abordagem demonstra grande potencial de aplicação e bons resultados práticos para o futuro.

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