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Farming System Choice is Key to Preserving Surface Water Quality in Agricultural Watersheds

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Abstract: Despite much published literature on the impacts of agriculture on water quality, knowledge gaps persist regarding which farming systems are of most concern for these relationships, which could help water resource planners better target water management efforts. This study addresses these subjects, seeking to understand how this relationship varies across different farming systems. We used data on water quality status in watersheds of an agricultural region in southern Portugal and crossed it with a map of farming systems for the same region provided by a previous study. By overlaying both data layers, we characterized the areal shares of the farming systems in the watersheds and inspected how these shares relate with water quality status through logistic regression. Results support that the impact of agriculture on water quality is mostly related with specific farming systems. We believe this type of information can be of high interest for agricultural planners and policymakers interested in meeting water quality standards, and we conclude by suggesting innovative policy options based on payments to farmers operating selected farming systems, as a cost-effective way to reconcile agricultural and environmental policy objectives.

Keywords: water quality; farming system; Water Framework Directive; agricultural watershed

1. Introduction

Reconciling agriculture with water resource management is a major challenge in many parts of the world. Growing concerns about global water availability and quality have led the United Nations to include it among its 17 Sustainable Development Goals for 2030 [1,2]. In Europe, such concerns were reflected in the Water Framework Directive (WFD - Directive 2000/60/EC of the European Parliament and of the Council of 23 October 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 [3,4]. Furthermore, a 60% increase in agricultural production is expected in the coming years globally to meet the demands of a growing population, which will intensify pressures on water resources [5–8].

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 to socio-ecological costs [4,9].

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 [10–12]. 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, it fails in delivering appropriate insights to inform the design of public policies aimed at reconciling agriculture and the environment [13–16]. Moreover, studies comparing the impact of

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different agricultural crops on the quality of water resources also seem surprisingly virtually non-existent in the literature.

To overcome such shortcomings, Santos et al. [17] have suggested a farming systems (FS) approach to link agricultural policies with the provision of ecosystem services (ES) and environmental effects. This is based on the idea that finding a relationship between specific FS and ES or environmental indicators can facilitate the design of effective policies aimed at incentivizing farmers to adopt environmentally friendly FS, without the need for more complex policy formulations to regulate agricultural activity. Such a FS approach encompasses a trade-off 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 [18–21]. 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 [21,22] or landscape planning [23,24].

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). The establishment of these FS-water quality relationships could support the development of policy recommendations supporting the adoption of those FS that are less likely to contribute to water quality degradation.

With this purpose, we departed from a recent study that set up a FS typology for the Alentejo region, in southern Portugal [25], and from water quality data collected under the WFD for the same region. Both data sets were adjusted for the level of micro watersheds 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.

More specifically, we intend to answer the following questions: Can surface water quality be related to the prevalence of certain FS in the watershed? Which FS have the greatest impact on water quality, both positively and negatively? How much of the spatial variability in surface water quality can be explained by the spatial distribution of FS? Taking advantage of the fact that agriculture is the dominant land use in the study area, and non-agricultural areas are mostly forest, we will also test the hypothesis of a differentiated impact on water quality between forest and agriculture, also at the FS level.

Although there is vast scientific evidence on the effects of agriculture (as a whole) on water quality, to our knowledge this is the first study that seeks to establish a direct link between the FS pattern in the watershed and water quality, on a scale comparable to that of the water body, as recommended by the WFD.

The aim of this study, therefore, is not to investigate the direct effects of specific contaminants or agricultural practices on water quality, but to test whether these effects can be anticipated based on 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 where agriculture stands as a major land use. Results were eventually explored to discuss the usefulness of the proposed approach to contribute to evidence-based policymaking aimed at water resource management at the micro-basin level, in the sense of the WFD.

2. Materials and Methods

2.1. Study area

The choice of the Alentejo region, in southern Portugal, as our study area was based on three main reasons: 1) it is an extensive region (c.a. 31605 km², about 34% of the Portuguese mainland territory), covering areas included in 3 WFD river basin management plans (rivers Guadiana, Tejo

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and Sado&Mira), and therefore encompassing a high number of micro watersheds, in the sense of the WFD, and hereafter referred to as micro-basins; 2) the land use/cover is largely dominated by agriculture, and; 3) a recently developed farm-level mapping of farming systems is available for the entire region (see section 2.2).

Climate in Alentejo is Mediterranean with dry and hot summers and moderately rainy winters (700 mm of average annual rainfall and an annual average temperature of 16.3 ⁰C). The relief is soft, with few mountainous areas. The Utilized Agricultural Area (UAA) of Alentejo is over 2.1 million hectares (about 2/3 of the total Alentejo area and 57.7% of the total UAA in Portugal), mostly corresponding to permanent pastures (58.5%), temporary crops (20.8%), permanent crops (10.5%) and fallow areas (7.6%). The low incidence of industries and high predominance of agricultural areas in 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.

2.2. Water quality data

Water quality data were collected as part of the monitoring work carried out under the WFD in the study area. 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 surface water quality status within the scope of the WFD comprises an assessment of the ecological and chemical water status. Ecological status is determined based on biological, hydromorphological, and physicochemical elements, from which a classification into 5 levels of quality is extracted (Table 1). Chemical status is based on the concentration of water pollutants specified in the Annex IX of the WFD, which must not exceed EU legal environmental quality standards, and which can lead to a classification of “good” surface water chemical status, or “insufficient” if it fails to achieve the required environmental objectives for surface water quality. Based on both criteria, the overall surface water status is determined by the poorer of its ecological status and its chemical status.

For the current research, we used surface water quality data made available by the Portuguese Environment Agency (available at https://snig.dgterritorio.gov.pt, accessed March 2023) for the year 2017, to match the same time period as the agricultural data used to derive the FS typology (see section 2.3). These data consisted of a GIS map of the micro-basins of the Alentejo region, with surface water status classified under five categories: Excellent, Good, Reasonable, Mediocre, and Bad (Figure 1).

Table 1. Definition of the five categories used to classify surface water ecological status (adapted from the EU Water Framework Directory).

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

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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.

2.3. Farming systems

The FS typology for the Alentejo region was derived from Ribeiro et al. [26]. A total of 22 FS was identified and mapped for the entire region (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 [26]). The expected effects of each FS on water quality described in Table 2, and taking forest cover as reference, were inferred from several characteristics of the FS, such as livestock density, irrigation, forages vs pastures or farmland under the cover of oak trees vs. open field [26].

Table 2. The farming systems of Alentejo, Portugal, in 2017 (adapted from [26]). Figures in brackets describe the livestock density, in livestock units per hectare of total agricultural area. Colours provide a legend for Figure 1.

Farming system description	Expected effect on water quality (0/–) [1]
Cattle grazing - CO: a low intensive agroforestry system, where farmland is mostly composed of permanent pastures under the canopy of scattered trees, mostly cork oak (CO), grazed by low-density cattle herds (0.78). 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: like the previous FS but with holm oak (HO) replacing cork oak and slightly lower livestock density (0.68). It is also expected to have a crucial performance in pollutant retention and prevention of undesirable transport of substances to surface water.	0
Cattle grazing – forages: a low-intensity system with farmland mostly composed by pastures, and rainfed forages and cereals. Higher livestock density, mostly cattle (0.97). 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 agrochemicals.	–
Grazing goats: a low intensive agroforestry system, dominated by permanent pastures under the canopy of cork and holm oaks (1.04 [2]) .	0

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Mixed Cattle and sheep - Irrigated forages: mostly composed by irrigated forages, and rainfed permanent pastures and forages. Livestock includes both cattle and sheep (0.62). The high presence of forages compared to pastures can make it prone to cause negative effects on the environment.	–
Sheep grazing - CO: like Cattle grazing - CO but with livestock mostly composed by sheep instead of cattle (0.25). %). 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: like Cattle grazing - HO but with livestock mostly composed by sheep instead of cattle (0.39). It is also expected to show a crucial role in pollutant retention and preventing adverse transport of substances to surface water.	0
Sheep grazing - pastures: low intensive system dominated by rainfed permanent pastures grazed by sheep (1.00), with few or no trees.	0
Sheep grazing - pastures and forages: mostly composed by permanent pastures (no trees), but including olive groves, and rainfed cereals and forages. Livestock dominated by sheep but may include some goats (0.71).	–
Sheep grazing - forages: mostly composed by forages, but also including permanent pastures and olive groves. Livestock dominated by grazing sheep, but possibly including goats (0.38).	–
Rainfed olive groves with sheep: olive groves dominate, with some pastures grazed by sheep (1.21).	–
Rainfed olive groves: a permanent crop system largely dominated by rainfed olive groves. No livestock (n.e. [3]).	–
Irrigated olive groves: a permanent and intensive crop system, massively occupied by olive groves irrigated by public irrigation systems (n.e.). It is potentially harmful to the environment due to the disposal of pollutant oils in its wastes, the run-off to surface waters of soil, fertilizers and pesticides, and the exploitation of ground and surface waters for irrigation.	–
Vineyards: a permanent and intensive crop system dominated by vineyards but also including rainfed olive groves, pastures, and fallows (n.e.). 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 intensive crop system composed mostly by fruit trees, but also with pastures under cork and holm oaks (n.e.). It is considered potentially harmful to the environment due to the high use of fertilizers and agrochemicals.	–
Stone pine: a permanent and intensive crop system massively occupied by Stone pines, but with relevant pasture area under cork and holm oaks (n.e.).	0
Rice: an annual and intensive monoculture system, often depending on public irrigation systems (n.e.). Due to its close location with water streams, it is expected to have a strong effect on surface water quality.	–
Irrigated cereals and horticultural crops: an annual and very intensive crop system, composed by cereals, horticultural, and industrial horticulture irrigated by public irrigation systems (n.e.).	–

Rainfed cereals and oilseeds: an annual and extensive crop system, composed by rainfed cereals and irrigated oilseeds (n.e.).	–
Rainfed cereals: an annual and extensive crop system, including autumn-winter crops, fallows, pastures and rainfed olive groves (n.e.). Although typically not subject to high levels of nitrogen use, this is often applied in a single treatment, which can lead to the contamination of water bodies.	–
Pastures (no livestock): a very extensive system dominated by pastures, occasionally including also small areas of rainfed olive groves, but without any livestock declared (n.e.) . The use of pesticides and fertilizers is predictably low or non-existent.	0
Fallows: extensive system represented by small farms that were under fallow in 2017 (n.e.).	0

[1] The expected effect of the FS on water quality: Low/null (0), or negative (–); [2] The livestock density in this FS is likely overestimated because goats often graze outside the farm's area.; [3] The livestock density in this and subsequent FS is virtually zero, so they are marked "n.e." (non-existent).

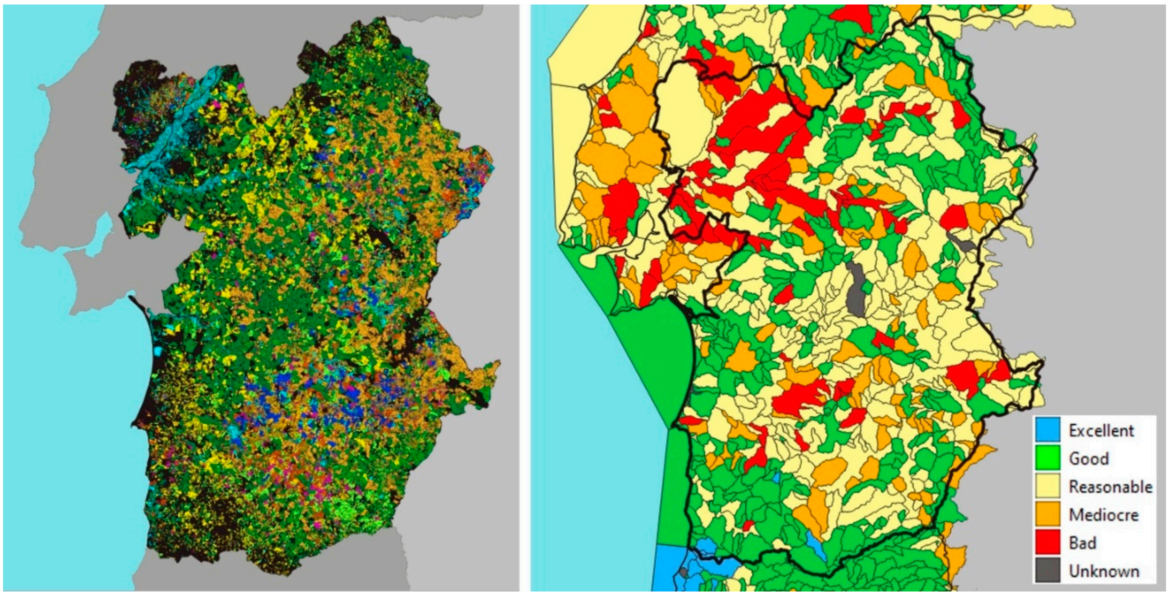

Figure 1. Farming systems map (left) and micro-basins (right) in the Alentejo region, Portugal. Distinct colours in the FS map identify different FS, according to the legend in Table 2 (for details on each FS spatial distribution refer to supplementary information in [26]). Micro-basins are coloured according to its quality status (see legend in figure).

2.4. Data analysis

The share of the different FS in each micro-basin was computed on a GIS environment by overlaying the FS and the micro-basins maps (Figure 1). The proportion of pixels identifying each FS in the total number of pixels inside each micro-basin determined the value of the FS share in the micro-basin. This procedure resulted in a two-entry matrix where rows correspond to the micro-basins (the analysis units for the statistical modelling) and columns show the areal share of each FS in the total area of the micro-basin (proportion of FS occupation), along with the classification of the micro-basin in terms of its surface water quality status. All micro-basins with 50% or more of its total area outside the Alentejo region were rejected for the analysis, due to lack of agricultural data.

Since not the entire micro-basin area is classified in any FS (as not all micro-basin area is necessarily farmland), a new category was set to identify "unclassified" areas, which was interpreted as largely referring to forested areas (roughly corresponding to the black colored areas in the FS map,

Figure 1). We anticipate these forest areas to have positive effects on water quality, when compared to FS areas.

To identify which FS contribute most to the water quality status within the micro-basins and accentuate the distinction between the socially Desired ("Good" and "Excellent") and Undesired ("Reasonable", "Mediocre" and "Bad") quality categories, these were regrouped, converting the dependent multi-categorical variable into a binary variable where "1" was assigned to the Desired group ("Good" and "Excellent") and "0" to the other Undesired categories.

A binary logistic model was used to explore the relationships between FS and water quality status, where the (binary) water quality variable was used as the dependent variable, and the FS shares were the predictor variables. Since the 22 FS predictors plus the "unclassified" category (mostly forest) make up 100% of the micro-basin area, causing linearity problems in the modelling (a common problem with compositional data), it was decided to leave out the "unclassified" (forest) category, thereby serving as the reference category in the models. As all candidate independent variables have the same metric and range of values (proportions, from 0 to 1), no normalization procedure was adopted. A correlation matrix crossing all independent variables was also computed to check for multi-collinearity problems.

The pseudo-R^2 (Nagelkerke) was computed to evaluate how much of the spatial variability of water quality is explained by the spatial distribution of FS. Model coefficients – values and signs – were used to investigate the effects of the independent variables (FS) on the dependent variable (a FS with a significant negative coefficient identifies it as a detrimental FS for water quality).

3. Results

3.1. Surface water quality and farming system composition in the study area

The Alentejo region encompasses a total of 674 micro-basins. Of these, 70 have more than half the area outside the Alentejo region and were therefore excluded for subsequent analyses, leaving a total of 604 valid micro-basins, all of them inland waters (rivers or reservoirs).

The surface water quality data revealed that 41% of the 604 micro-basins in the Alentejo region achieved a Good or Excellent status in 2017, which were thereby classified under the Desired category. The remaining 59% of the micro-basins did not meet the legally required water quality status and were thus classified in the Undesired category.

Agricultural data showed that in 2017 about 70% of the total area of the 604 micro-basins used in model estimation was classified under one of the 22 FS. The remaining 30% related to unclassified areas (forest). About 35% of the area was being managed by cattle grazing specialized farming systems, particularly the Cattle grazing – CO (21%) and the Cattle grazing – HO (12%). It should be noted that more than half (ca. 55%) of the area of these micro-basins was being managed by some type of livestock FS.

Table 3. Overall forest and farming system areal composition in the 604 micro-basins in the Alentejo region.

Farming system / Land use	Area (ha)	Area (%)
Forest [1]	963 736	30.6
Cattle grazing - CO	668 861	21.2
Cattle grazing - HO	361 788	11.5
Sheep grazing - CO	279 303	8.9
Pastures – no trees and almost no cattle	149 865	4.8
Sheep grazing - HO	122 321	3.9
Sheep grazing – Pastures	87 118	2.8
Cattle grazing - Forages	83 539	2.7

Irrigated olive groves	75 496	2.4
Rainfed cereals	54 308	1.7
Irrigated cereals and horticultural crops	54 183	1.7
Sheep grazing – Pastures and forages	41 542	1.3
Rainfed olive groves	28 704	0.9
Rainfed cereals and oilseeds	27 140	0.9
Vineyards	25 619	0.8
Sheep grazing - Forages	23 608	0.7
Stone pine	22 173	0.7
Rice	17 685	0.6
Grazing goats	15 657	0.5
Fallows	15 122	0.5
Fruit trees	10 420	0.3
Mixed cattle and sheep - Irrigated forages	9 918	0.3
Rainfed olive groves with sheep	9 751	0.3
Total	3 147 858	100.0

[1] Forest areas were assumed to roughly correspond to the non-FS areas of the micro-basins.

3.2. Farming systems impacts on surface water quality

The correlation matrix for the dependent variables (FS) indicated no relevant correlations (>0.5) between pairs of FS (only between the Rainfed olive groves FS and the Rainfed olive groves with sheep FS a value of 0.57 was found which, nevertheless, was not considered sufficient to recommend the removal of one of the variables). The model presented a 0.21 pseudo-R^2 (Nagelkerke), revealing that about 21% of the spatial variability of the surface water quality in the Alentejo region can be explained by the spatial patterns of the FS within the micro-basins. The overall predictive accuracy of the model was 66%, which can be considered an acceptable value since the model is only using the FS composition of the micro-basins to predict surface water quality status. It should also be noted that the aim was not to obtain a model with high predictive accuracy, as the intention was not to use it to make predictions, but rather to explore the relationships between the candidate independent variables (the FS) and the dependent variable (the surface water quality status).

Among the 22 FS predictor variables included in model estimation, only 7 revealed to be statistically significant in the model, at the 95% confidence level (Table 4). All these significant predictors presented a negative sign, indicating that their effect on surface water quality is more harmful than that of forest, which was the reference category left aside to prevent collinearity problems. Altogether, these 7 FS cover around 34% of the total area of the Alentejo micro-basins (cf. Table 3). A similar area (35%) was therefore occupied by FS whose pressure on surface water resources did not show significant differences from that of forest, which occupies the remaining area of the micro-basins (30%).

The FS showing a negative coefficient with the highest absolute value was the Rice FS, suggesting that it has the greatest impact on water quality, probably due to its typical contiguity with surface water bodies, meaning that any agrochemical application in the crop field can more easily drain to the nearby water stream. The Vineyards FS presented the second highest absolute value of the coefficient, indicating that a high prevalence of this FS in the micro-basin is likely to decrease the quality of surface waters. The Rainfed olive groves with sheep FS presented the third highest value, also revealing a significant negative effect on surface water quality.

Other FS with statistically significant negative coefficients were Rainfed cereals, Pastures, Cattle grazing – forages, Irrigated olive groves, and Cattle grazing – CO, by decreasing order of the absolute value of the coefficient. It is noteworthy that the 7 FS with significant coefficients divide in similar parts between FS specialized in livestock and in crop production, suggesting that there is no obvious difference between the two types of productive orientations in their impacts on surface water quality. Nevertheless, the 3 FS with higher coefficient absolute values are all crop specialized FS which, on the other hand, represent a mere 3% of the total area of the micro-basins.

Table 4. Estimated coefficients of the binary logistic regression

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)	
Intercept	0.899	0.378	2.378	0.017	*
Cattle grazing - CO	-1.901	0.564	-3.372	0.001	***
Cattle grazing - HO	-0.478	0.597	-0.801	0.423	
Cattle grazing - Forages	-3.600	1.614	-2.23	0.026	*
Grazing goats	-0.918	4.631	-0.198	0.843	
Mixed cattle and sheep - Irrigated forages	-0.031	6.597	-0.005	0.996	
Sheep grazing - CO	0.958	0.971	0.986	0.324	
Sheep grazing - HO	0.247	1.157	0.213	0.831	
Sheep grazing – Pastures	-1.567	1.821	-0.861	0.389	
Sheep grazing – Pastures and forages	3.263	3.394	0.961	0.336	
Sheep grazing - Forages	-4.203	4.65	-0.904	0.366	
Rainfed olive groves with sheep	-19.893	14.431	-1.378	0.168	
Rainfed olive groves	2.287	4.119	0.555	0.579	
Irrigated olive groves	-3.057	1.339	-2.283	0.022	*
Vineyards	-24.662	8.693	-2.837	0.005	**
Fruit trees	8.699	9.595	0.907	0.365	
Stone pine	0.424	2.596	0.163	0.87	
Rice	-33.323	12.322	-2.704	0.007	**
Irrigated cereals and horticultural crops	-2.469	2.345	-1.053	0.292	
Rainfed cereals and oilseeds	-2.799	3.068	-0.912	0.362	
Rainfed cereals	-10.163	4.152	-2.448	0.014	*
Pastures – no trees and almost no cattle	-4.233	1.52	-2.785	0.005	**
Fallows	2.675	5.919	0.452	0.651	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

4. Discussion

4.1. Farming systems and surface water quality

Our results support the hypothesis that, in watersheds dominated by agricultural uses, there is a relationship between the prevalence of specific FS and the quality of surface water bodies, which is not extensible to all agricultural areas or FS. They also confirm that information on the relative weight of particular FS in the micro-basin can be used, to a considerable extent, to infer about surface water status. 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.

Our findings indicate that only about 1/3 of the FS in the study area exhibit a significant negative relationship with micro-basin surface water quality. This result should not be surprising, since there was no reason to assume at the outset that all FS should necessarily have negative impacts on the water environment, but rather that this relationship could emerge only in a few relevant FS, as it turned out.

In our modelling approach, forest areas were taken as the reference land use (left outside in the land use compositional data computed for the micro-basins area to avoid collinearity problems). Forest areas can be taken as closer to natural environments, since they are areas where fertilizer or pesticide use is virtually absent (exceptions aside), and where the level of disturbance caused by any possible forest management operations is generally much lower than in agricultural areas, also because they typically occur at much wider intervals of time than in agriculture. Therefore, the fact that most of the FS in the study area (2/3) did not prove significant in the model, suggest that their impact on surface water quality is not significantly different from that of forest. This result questions the idea widely stated in the literature that agriculture is generally more harmful to water quality than forests [27–29], by showing that this may only be true for some FS which, for this reason, should be prioritized in efforts to reconcile agriculture and water resources management. The interest of this result is particularly notable given the lack of studies focused on comparing the impacts of different agricultural crops on water quality, as most studies consider agriculture as a whole, without distinguishing between different crops or activities (or at most distinguishing only cropping and livestock systems).

Although it was not the objective of this study to explain the reasons behind the negative relationships found between the FS and surface water quality, some conjecture can be made from the available literature, also as a validity test of our results. The Rice FS proved to be the one that potentially causes the greatest negative impact on surface water quality (coefficient with the highest absolute value). This FS, dominated by rice crop, is subject to intensive cultivation in shallow areas along riverbanks in the Alentejo region, and it has been acknowledged as an environmentally impactful crop, 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 [30–32]. The significant negative impact of the Vineyards FS in surface water quality can be related to the high use of pesticides in these crops, particularly in the Mediterranean regions [33,34]. The Rainfed cereals FS presented the third highest (absolute) coefficient, which constitutes an unexpected result since it is typically an extensive FS, with low use of inputs with potential impact on water quality (e.g. fertilizers or pesticides). Despite the lack of supporting data, we can speculate that this may be due to poor agricultural practices, such as the application of fertilizers in a single operation, rather than distributed over time, conducting to possible leachable surpluses to water courses. Indeed, there is evidence that differences in the fertilization planning can lead to different impact on water quality [35]. In contrast, the intensive Irrigated olive groves FS, although also revealing a significant negative impact on water quality, the absolute value of the coefficient was much lower, suggesting that the relationship between the level of agricultural intensity and the impact on water quality may not be as straightforward as suggested by many studies [36–40]. In fact, there seems to be evidence that in more intensive agricultural systems the knowledge and technological level applied in the use of inputs is much higher, so that fertilizers and pesticides are applied to minimize runoff losses [41].

Among the livestock FS that revealed a significant relationship with surface water quality, these included the Cattle grazing – Forages, the Cattle grazing – CO, and the Pastures without trees and livestock FS (this later FS, although it is described as a FS without livestock, we have reasons to assume that a large part of these pastures is used by animals from neighboring farmers, under lease [25]). It can be admitted that in these FS, the high stocking rates, some use of fertilizers (especially in Cattle grazing – Forages FS) and vegetation with a very low structure during much of the year due to grazing pressure, could lead to soil erosion and runoffs which easily impact surface waters [42]. Interestingly, the Cattle grazing – HO FS did not prove to be significant in this analysis, which may be related to a lower animal density in this FS compared to the other cattle grazing FS [25]. Equally interesting is the fact that all sheep-grazing FS also did not prove to be significant in the model. Although literature comparing the effect of cattle and sheep grazing on water quality is scarce and often presenting unclear results [42,43], there appears to be evidence that nitrate leaching is significantly lower in sheep farming than in cattle systems [44–46], which could help explain our results.

4.2. Implications for water quality management in agricultural watersheds

A variety of different public policies have been suggested or implemented to address the reconciliation of agriculture and water quality. The polluter pays principle has been a common approach to reduce polluting emissions. However, this option is difficult to apply in the case of non-point pollution, as is typically the case in the agricultural sector [47]. Regulatory approaches have also been proposed to restrict certain agricultural practices, such as the use of pesticides, agrochemicals, and other water pollutants, or to prohibit uncontrolled discharges of environmental contaminants. These approaches, however, usually imply high implementation, control, and inspection costs to ensure compliance, so their practical enforcement remains a challenge. Both the polluter pays principle and the regulatory approach place the burden of pollutant emissions on the polluter's side, recognizing society's right to environmental quality.

More recently, approaches based on payments for ecosystem services have been proposed, to reward the adoption of good practices and remunerate the provision of environmental public goods [48]. Under these approaches, the financial burden is placed on the recipients of the ecosystem service. In practice, payments for ecosystem services generally do not pay for the service itself, but rather for proxies that provide these services, such as certain land uses [48]. Such policy options have been implemented based on voluntary agreements with farmers who adopt environmentally friendly practices, as under the EU's Common Agricultural Policy and the European Green Deal [49]. The framework we propose in this study tends to align with these approaches.

In watersheds where agriculture is the dominant economic activity and land use, the greatest pressure on water resources can be expected to come from diffuse pollution from agriculture. Regarding water quality, this study supports the existence of such a relationship, by identifying a statistically significant negative association between certain FS and the quality of surface waters. This finding that the impact of agriculture on water quality is not generalized across the entire industry, but is mostly of concern to certain FS, may constitute valuable information for water management planners, as it allows focusing efforts to preserve water quality in those FS that effectively put greater pressure on water quality, discouraging its adoption or promoting the improvement of their agricultural practices. For example, water management at the water body level (the micro-basins, in this study), as recommended under the EU WFD, may involve preventing certain FS from assuming an area share above certain limits in the micro-basin.

The choice of the FS is a decision made by farmers, subject to environmental, biophysical, and socioeconomic constraints. Market and policy drivers play a substantial role in this decision-making process [26], so there is room for the implementation of public-policies encouraging farmers' decisions towards more environmentally friendly FS, such as agri-environmental payments, a policy-design approach that has been suggested by previous studies [17,47,50].

4.3. Limitations and uncertainties

Although our framework proved to be adequate to explore our hypotheses, some research options may deserve future review to improve the methodology. For example, it is possible that the high variability in the size of the micro-basins in the study area may have caused some noise in the statistical analyses, as it can be expected that larger watersheds present higher landscape heterogeneity (both in composition and configuration), making it more difficult to capture the relationship between FS and water quality. A pre-selection of micro-basins with an area not exceeding a certain threshold could be tested to minimize this possible effect. Also, the average distance of each FS in the micro-basin to the water sampling points could have influenced 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.

The proposed approach requires classifying farms according to the FS in an expeditious, efficient, and easily updatable way. In the EU, this can be accomplished by resorting to data such as that annually collected through farmers' applications for CAP payments (IACS/LPIS data), as proposed by Santos et al. [17] and recently applied by Ribeiro et al. [26]. But this may be a limitation for the generalization of the methodology here proposed, since this type of farm-level spatially explicit data may not always be available.

5. Conclusions

This study consisted largely in an implementation of the approach proposed by Santos et al. [17] to relate FS with ecosystem services and environmental indicators, in this case adjusted to explore links between FS and surface water quality in farmland-dominated watersheds. This may be of interest, for example, for agricultural planners and policymakers interested in meeting 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 high-tech or precision agricultural practices, capable of mitigating its effects on the environment.

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. For example, a policy paying a premium to farms operating selected farming systems 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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