EFFECT OF LANDSCAPE METRICS ON WATER QUALITY OVER THREE DECADES: A CASE STUDY OF THE AVE RIVER BASIN, PORTUGAL

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ABSTRACT
Due to intense industrial and urban activity Ave River Basin, Portugal was once tagged as one of the most polluted in Europe. Besides point source pressures are the most evident threat to water quality in this river basin, in the present study, the effect of landscape on water quality was analysed. From a hydrological database, the concentration surface water parameters was extracted, comprehended between 1988 and 2016. The average concentrations in each sampling site for each hydrological year was calculated. The averages were correlated to 15 landscape metrics by using the Spearman's rank correlation coefficient, over the analysed hydrological years. For each landscape metric, the percentage of correlations with surface water parameters for each hydrological year that had statistical significance ($p \leq 0.05$) was counted, and the same analysis was made for each surface water parameter. The area occupied by artificial surfaces increased the contaminant concentrations in 65.3% of the correlations while the edge density increased by 62%. For forested areas, the edge density and occupied area had, respectively, 56.0% and 66.0%, of correlations that decreased contaminant concentrations. Conductivity was the parameter that has most linked to landscape metrics since, 52% increased the concentration, 21% decreased, while the remaining 27% did not have statistical significance. Oxygen demands, total suspended solids, different nitrates forms, total orthophosphate and coliforms were acceptably correlated, with percentages ranging from 20% to 44%. Only heavy metals were poorly correlated, since the percentage of correlations that varied the concentrations was lower than 8%. This study allowed us to understand that in an urbanised river basin, where point source pressures are the dominant pollution source, landscape metrics also have an effect on water quality and can become a threat to hydric resources.
Keywords: Spearman's rank correlation coefficient, water quality, ArcGIS, Ave River Basin, landscape metrics.

1 INTRODUCTION

The management of hydric resources is one challenge that has alongside humanity for thousands of years. Not only the availability of hydric resources but also the quality is a concern that emerged with demographic expansion and economic development. Since many threats to water quality have been arising, researchers have been conducting their studies in the scope of improving treatment technologies [1], prevention and mitigation strategies [2]. To study water quality (WQ) is necessary to comprehend that there is a multitude of interactions [3]–[7] and a vast type of different pollution sources that will end up releasing contaminants in hydric resources [8], which is essential knowledge to support the management of hydric resources [9]. In general, two types of pollution sources exist, point source (PS) and non-point source (NPS). Effluent discharges are the clearest point source pressures in hydric resources [10]. Besides the purpose of treatment stations is to reduce contamination loads, when treatment stations are not under proper functioning hydric resources become heavily contaminated. Commonly, effluents from domestic sewage contain high loads of organic compounds [11], while in industrial effluents, the composition is highly

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variable. Metallurgic and textile industries may release heavy metals [12], [13], pharmaceutical industries can release different chemical compounds [14], and food industries can release high loads of organic compounds [15], [16]. The diffuse sources (also called NPS) are large areas that can contain contaminants that are carried to rivers through surface runoff mechanisms. Such areas might be agricultural areas or livestock farms [17]. In agricultural fields, the pollution comes from the application of herbicides and pesticides [18], and in livestock areas, manure is a contamination source [19]. Many studies have been executed in the scope of the impact of NPS in WQ. In such studies, landscape metrics have been used as variables that characterise diffuse pollution sources. The composition of a landscape allows to interpret which are the dominant land uses, but the configuration,(for example, edge density and number of patches) are also key aspects to interpret if a landscape is vulnerable or not to diffuse pressures [20].

The present study takes place in an urbanised river basin located in the northwest region of Portugal, Ave River Basin (Fig. 1). Due to intense anthropogenic activity, during the second half of the 20th century, industrial effluent discharges without proper treatment. For such reasons, it became one of the most polluted in Europe [21]. This problematic caught the attention of several experts to study this problem. In pioneer studies, heavy metals concentration was measured in surface waters, aquatic fauna and sediments, to evidence the problem [13], [22]. Due to an ambitions remediation program, the concentrations dropped in the begging of the 21st century [23]. However, in more recent studies, it was revealed that PS was still contaminating the river basin and also diffuse pressures became another concern [24]–[26].

The effects of landscape metrics on surface water parameters from 1988 to 2016 in Ave River Basin were studied, with the purpose of understanding which contaminants are related to landscape, and which landscape metrics are the one threat to WQ.

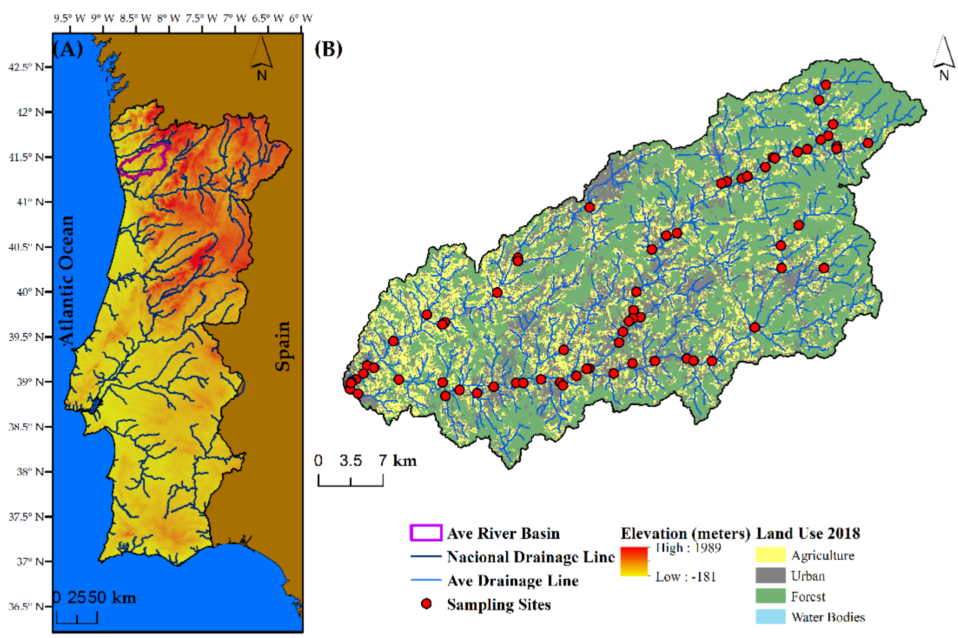

Figure 1: Ave River Basin location. (a) Portugal; and (b) Ave River Basin land use of 2018, and location of SWP sampling sites.

2 METHODOLOGY

The relation between landscape metrics and surface water parameters along different hydrological years (HY) was analysed by using Spearman's correlation rank coefficient. The first step was to delineate the Ave River Basin, drainage lines and also the drainage area of each WQ sampling site, by using ArcMap [27] and ArcHydro tools [28]. The location of the sampling sites and also the measurements of different surface water parameters (SWP) was downloaded from the Portuguese hydrological database SNIRH [29]. Table 1 represents the number of sampling sites for each SWP according to the HY.

The land cover was downloaded from the Portuguese Territorial database. For each year and drainage area, it was calculated landscape metrics by using a python toolbox [30]. Metrics were calculated for generic land uses, agriculture areas (AGR), artificial surfaces (ART) and also forest and semi-natural areas (FOR). The calculated metrics were the number of patches (npc), the percentage of area occupied (pz), the edge density (ed) and also the percentage of edges that are shared with two different types of land use (cce).

The Spearman's correlation rank coefficient (r_s), measures monotonic relation between the paired variables. This coefficient varies from –1 to 1. When r_s is close to 0, the correlation is weak, while if the value is closer to –1 or 1 it means that the correlation is strong. In order to know if a correlation is statistically significant, is crucial to analyse the probability to reject the null hypothesis, which is dependent on the sample size. For two-tailed probabilities and a statistical significance of 0.05, the minimum sample size to achieve a statistically significant correlation is 5. Since for that sample size is necessary to have the maximum correlation (r_s=1 or r_s=–1) it was analysed only the correlations with at least six samples.

3 RESULTS AND DISCUSSION

For the present study, it was calculated the correlations between the 15 LSM with 14 SWP for the 29 analysed hydrological years. The correlations were counted, and it was calculated the percentage of correlations that had statistical significance. Tables 2 and 3 present the positive and negative correlations, respectively. For the percentage calculation, it was considered only correlations that had six or more samples. In Tables 2 and 3, the centred cells represent the percentage of hydrological years were the correlation was statistically significant. The last columns are the percentage of hydrological years among all metrics for the respective SWP, while in the last row is made the same analysis but for each LSM. For example, conductivity is a parameter that had more than five samples in 27 hydrological years. By looking to the percentage of correlations between conductivity with npc_(ART) in Table 2, the percentage of correlations is approximately 59.3%, which means that in 16 of the 27 analysed hydrological years, the correlation between this two variables is positive and statistically significant. In the last row of Table 2, the percentage of correlations among all LSM with conductivity is approximately 51.9%. Which means that in a total of 405 correlations (15 LSM in 27 HY), conductivity was positively correlated with statistical significance in 210 correlations, while 85 of the correlations (21% in Table 3) were negative and statistically significant, but the remaining 110 correlations were not statistically significant. By analysing the percentage of correlations of npc_(ART) in Table 2, is seen that the percentage of correlations is approximately 45.1%. This percentage is calculated by the total number of correlations among all SWP in the available hydrological years that had more than five measurements which is in total 297 correlations, and 45.1% of the total number of calculated correlations is 134.

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Table 1: Surface water parameters and the number of sampling sites with data.

Hydrological year	Total suspended solids	Conductivity	Biological oxygen demand	Chemical oxygen demand	Total nitrate	Ammonium	Ammonia	Orthophosphate	Fecal coliforms	Total coliforms	Chromium	Lead	Cadmium	Mercury
1988–1989	3	3	3	0	0	3	0	0	3	0	0	0	0	0
1989–1990	6	6	6	6	6	6	0	6	6	6	0	0	0	0
1990–1991	6	6	6	6	6	6	1	6	6	6	5	5	5	5
1991–1992	6	6	6	6	6	6	0	6	6	0	0	0	0	0
1992–1993	1	3	1	3	3	3	0	3	3	2	0	0	0	0
1993–1994	15	15	15	15	15	15	0	15	15	9	0	0	0	0
1994–1995	15	15	15	15	15	15	15	15	15	9	0	0	0	0
1995–1996	15	15	15	15	15	15	15	15	15	9	0	0	0	0
1996–1997	16	17	16	17	17	17	17	17	17	11	0	0	0	0
1997–1998	17	17	17	17	17	17	17	17	17	11	0	0	0	0
1998–1999	20	20	20	20	20	20	20	20	20	11	2	2	2	2
1999–2000	18	18	18	17	18	18	19	16	17	6	6	6	6	6
2000–2001	10	7	10	7	10	10	11	7	7	7	5	5	5	5
2001–2002	11	9	9	8	8	9	10	8	8	8	9	11	11	11
2002–2003	12	9	9	8	9	9	10	8	8	8	9	9	9	9
2003–2004	12	9	9	8	9	9	10	8	8	8	9	9	9	9
2004–2005	13	13	13	12	12	13	0	12	12	12	12	12	12	12
2005–2006	13	13	13	12	12	13	0	12	12	12	12	12	12	12
2006–2007	14	14	14	13	14	14	0	13	12	12	12	12	12	12
2007–2008	14	14	14	12	12	14	14	12	11	11	11	0	0	0
2008–2009	27	24	23	22	28	28	24	22	21	21	21	0	0	0
2009–2010	31	31	31	30	30	31	23	25	23	23	23	14	14	14
2010–2011	20	21	22	19	23	23	5	16	14	14	0	0	0	0
2011–2012	19	18	19	16	16	17	5	16	14	14	16	16	16	15
2012–2013	17	17	17	17	17	17	5	16	0	0	0	0	0	0
2013–2014	28	28	28	15	28	28	5	13	0	0	13	12	13	13
2014–2015	29	29	29	8	29	29	0	6	0	0	0	0	0	0
2015–2016	8	13	9	8	9	8	0	6	0	0	0	0	0	0
2016–2017	8	8	8	0	8	8	0	0	0	0	0	0	0	0

By comparing Table 2 with Table 3, is seen in overall that landscape metrics have a stronger influence in the increase of SWP rather than in the decrease. For example, the percentage of correlations that increase conductivity (51.9%) is lower than the percentage that decreases it (21.0%), and in other SWP the percentages of positive correlations are also higher. According to Table 2 (last column), conductivity is mostly increased by landscape

Table 2: Percentage of positive correlations that had statistical significance.

	npc_(AGR)	npc_(ART)	npc_(FOR)	pz_(AGR)	pz_(ART)	pz_(FOR)	cce_(ART)_with_(AGR)	cce_(FOR)_with_(AGR)	cce_(AGR)_with_(ART)	cce_(FOR)_with_(ART)	cce_(AGR)_with_(FOR)	cce_(ART)_with_(FOR)	ed_(AGR)	ed_(ART)	ed_(FOR)	
Total suspended solids	44.4	51.9	22.2	59.3	66.7	0.0	63.0	0.0	0.0	0.0	22.2	66.7	63.0	66.7	0.0	35.1
Conductivity	88.9	88.9	59.3	77.8	88.9	0.0	88.9	0.0	0.0	0.0	25.9	85.2	85.2	88.9	0.0	51.9
Biological oxygen demand	48.1	48.1	37.0	55.6	77.8	0.0	77.8	0.0	0.0	0.0	14.8	63.0	70.4	74.1	0.0	37.8
Chemical oxygen demand	42.3	53.8	23.1	69.2	73.1	0.0	76.9	0.0	0.0	0.0	15.4	65.4	65.4	73.1	0.0	37.2
Total nitrate	25.9	40.7	18.5	85.2	88.9	0.0	88.9	0.0	0.0	0.0	40.7	88.9	96.3	88.9	0.0	44.2
Ammonium	70.4	70.4	40.7	55.6	77.8	0.0	77.8	0.0	0.0	0.0	14.8	74.1	74.1	77.8	0.0	42.2
Ammonia	23.5	23.5	23.5	11.8	52.9	0.0	52.9	0.0	0.0	0.0	0.0	41.2	35.3	41.2	0.0	20.4
Total orthophosphate	69.2	73.1	38.5	76.9	80.8	0.0	88.5	0.0	0.0	0.0	7.7	73.1	73.1	76.9	0.0	43.8
Fecal coliforms	18.2	22.7	9.1	59.1	77.3	0.0	63.6	0.0	0.0	0.0	0.0	63.6	59.1	68.2	0.0	29.4
Total coliforms	28.6	38.1	33.3	47.6	81.0	0.0	66.7	0.0	0.0	0.0	4.8	42.9	38.1	57.1	0.0	29.2
Chromium	14.3	14.3	7.1	7.1	14.3	0.0	14.3	0.0	0.0	7.1	0.0	0.0	14.3	14.3	0.0	7.1
Lead	0.0	0.0	0.0	0.0	8.3	8.3	8.3	8.3	0.0	16.7	0.0	0.0	0.0	16.7	8.3	5.0
Cadmium	0.0	0.0	0.0	0.0	0.0	8.3	0.0	8.3	0.0	16.7	0.0	0.0	0.0	0.0	8.3	2.8
Mercury	8.3	8.3	8.3	0.0	0.0	8.3	0.0	8.3	0.0	16.7	0.0	0.0	0.0	0.0	8.3	4.4
	40.7	45.1	26.6	51.9	65.3	1.0	64.0	1.0	0.0	2.4	13.1	56.6	57.2	62.0	1.0	

Table 3: Percentage of negative correlations that had statistical significance.

	npc_(AGR)	npc_(ART)	npc_(FOR)	pz_(AGR)	pz_(ART)	pz_(FOR)	cce_(ART)_with_(AGR)	cce_(FOR)_with_(AGR)	cce_(AGR)_with_(ART)	cce_(FOR)_with_(ART)	cce_(AGR)_with_(FOR)	cce_(ART)_with_(FOR)	ed_(AGR)	ed_(ART)	ed_(FOR)	
Total suspended solids	0.0	0.0	0.0	0.0	0.0	74.1	0.0	59.3	37.0	7.4	0.0	0.0	0.0	0.0	66.7	16.3
Conductivity	0.0	0.0	0.0	0.0	0.0	88.9	0.0	81.5	51.9	7.4	0.0	0.0	0.0	0.0	85.2	21.0
Biological oxygen demand	0.0	0.0	0.0	0.0	0.0	77.8	0.0	74.1	48.1	7.4	0.0	0.0	0.0	0.0	66.7	18.3
Chemical oxygen demand	0.0	0.0	0.0	0.0	0.0	73.1	0.0	61.5	23.1	7.7	0.0	0.0	0.0	0.0	61.5	15.1
Total nitrate	0.0	0.0	0.0	0.0	0.0	88.9	0.0	85.2	40.7	14.8	0.0	0.0	0.0	0.0	96.3	21.7
Ammonium	0.0	0.0	0.0	0.0	0.0	77.8	0.0	74.1	51.9	11.1	0.0	0.0	0.0	0.0	63.0	18.5
Ammonia	0.0	0.0	0.0	0.0	0.0	47.1	0.0	58.8	11.8	17.6	0.0	0.0	0.0	0.0	47.1	12.2
Total orthophosphate	0.0	0.0	0.0	0.0	0.0	80.8	0.0	73.1	34.6	0.0	0.0	0.0	0.0	0.0	76.9	17.7
Fecal coliforms	0.0	0.0	0.0	0.0	0.0	77.3	0.0	68.2	22.7	13.6	0.0	0.0	0.0	0.0	50.0	15.5
Total coliforms	0.0	0.0	0.0	0.0	0.0	85.7	0.0	52.4	33.3	9.5	0.0	0.0	0.0	0.0	33.3	14.3
Chromium	0.0	0.0	0.0	0.0	0.0	14.3	0.0	7.1	7.1	0.0	0.0	0.0	0.0	0.0	7.1	2.4
Lead	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	0.0	0.0	0.0	8.3	8.3	8.3	8.3	6.7
Cadmium	8.3	8.3	8.3	8.3	8.3	0.0	8.3	0.0	0.0	0.0	0.0	8.3	8.3	8.3	0.0	5.0
Mercury	8.3	8.3	8.3	8.3	8.3	0.0	8.3	0.0	8.3	0.0	0.0	8.3	8.3	8.3	0.0	5.6
	1.0	1.0	1.0	1.0	1.0	66.0	1.0	58.6	31.3	7.7	0.0	1.0	1.0	1.0	55.9	

metrics 51.9%, followed by parameters related to nutrients (N and P), nitrate (44.2%), total orthophosphate (43.8%) and also ammonium with (42.2%). With lower percentages, oxygen demands, both BOD_5 and COD are still affected by landscape metrics with a percentage of 37.8 and 37.2%, respectively. Total suspended solids percentage is 35.1%, coliforms are also increased in 29.4% and 29.2, faecal and total respectively. Ammonia is the parameter related to N forms that is less influenced by landscape metrics with a percentage of 20.4%, and heavy metals are less correlated to LSM since the percentage of positive correlations are the lowest, ranging from 7.1% to 2.8%.

The parameters that are mostly decreased by LSM (Table 3 last column) are total nitrate (21.7%) and conductivity (21.0%). Other parameters have percentages that vary from 18.5% to 12.2%, expect heavy metals that have lower percentages, ranging from 6.7% and 2.4%.

In the last row of Tables 2 and 3 the percentage of correlations associated with each metric is shown. Some contrast metrics might look identic when applied to the same pair of land uses, for example, cce_(AGR)_with_(FOR) and cce_(FOR)_with_(AGR). However, they are different since in the first case is the percentage of forested edges that are shared with agriculture edges, while the second metric is the percentage of agricultural edges that are shared with forestry edges. From the 15 LSM only four have a notorious impact in the decrease of contaminants concentrations, pz_(FOR) (66.0%), cce_(FOR)_with_(AGR) (58.6%), ed_(FOR) (55.9%) and unexpectedly the cce_(AGR)_with_(ART) (31.3%). There are eight metrics that increase the SWP: pz_(ART) (65.3%), cce_(ART)_with_(AGR) (64%), ed_(ART) (62%), ed_(AGR) (57.2%), cce_(ART)_with_(FOR) (56.6%), pz_(AGR) (51.9%), npc_(ART) (45.1%) and npc_(AGR) (40.7%). The remaining three metrics, npc_(FOR), cce_(AGR)_with_(FOR) and cce_(FOR)_with_(ART), can be assumed as non-effective since the percentages that increase and decrease SWP are much lower when compared to the other LSM.

In the main matrix of Tables 2 and 3, it can be seen in detail which SWP are related to LSM. For heavy metals the percentages of correlations are quite low, varying from 16.7% to 0.0%, so there is not any particular LSM that can be related to heavy metals. The npc_(AGR) and npc_(ART) are both related to the increase of conductivity, orthophosphate and ammonium. The pz_(AGR) is linked to SWP with the expectation of ammonia and heavy metals, while the pz_(ART) and cce_(ART)_with_(AGR) are not linked to heavy metals. The cce_(ART)_with_(FOR) and ed_(AGR) are less linked to ammonia and total coliforms, and not linked to heavy metals, while ed_(ART) is more linked to the increase of total coliforms.

The pz_(FOR) is the metric that is mostly related to the decrease of SWP, and it decreases all SWP (except heavy metals) since the percentage of correlations ranges from 88.9–47.1%. The cce_(FOR)_with_(AGR) also decreases the SWP but with a shorter range of 85.2–52.4% (except heavy metals). The cce_(AGR)_with_(ART) decreases, in general, the SWP but seen in detail there are SWP that are more related to this metric, specific conductivity and ammonium both with 51.9% and BOD with 48.1%. The ed_(FOR) is another LSM that had a strong influence in the decrease of SWP. However, it has high variability in the percentages of particular SWP, since in the decrease of nitrates the percentage is 96.3%, for conductivity is 82.5%, orthophosphate is 76.9%, and for the reaming SWP is lower than 70%, and also has no influence in heavy metals.

4 DISCUSSION

The used methodology allowed to understand which are the effects of landscape metrics in Ave River Basin. The analysis consisted in summarize the correlations between LSM and SWP in during many hydrological years, in order to treat the effects for an extended period.

In general, the metrics have a substantial effect on the increase of contaminant concentrations rather than in the decrease. This is an expected result since there were used only three types of land use, of which ART and AGR usually have a negative impact on WQ, while FOR increases WQ [31].

This study allowed to understand which SWP are associated to LSM. By summing the respective percentages of Tables 2 and 3, is calculated the total percentage of statistically significant correlations. Therefore, conductivity and total nitrates are the variables that are more influenced by landscape metrics, since the sum of percentages is the highest, respectively 72.8% and 65.9%. Since electrical conductivity is a measure of ions is a parameter that portrays many contaminants surface water, which are linked to landscape metrics. The presence of nutrients is commonly accessed in landscape metrics studies [32], and also, in this case, the concentration of nitrates is linked to landscape metrics, and also total orthophosphate, which is one of the phosphorous. Oxygen demands are also linked in other studies with landscape metrics [33]–[35], in the present study BOD (56.1%) and COD (52.3%) are linked to LSM. The total suspended solids is also another parameter that is related to LSM, since the total percentage is 51.4%, while the others have percentages lower than 50%, possibly because they are more linked to point source pressures, which reflects in low correlations with LSM [36]. Total coliforms and faecal have total percentages of 43.5% and 44.9%, respectively, besides this contaminant can be from livestock origin, it can be more linked to domestic sewage [37]. Ammonia can be released into surface water from different sources, such as fertilizer and also from industrial applications [38]. Since the total percentage is 32.6%, it can be assumed that in the Ave River Basin is more linked to point source pressures rather than to diffuse emissions. The total percentage of the studied heavy metals ranges from 11.7% (lead) to 7.8% (cadmium), which means that the presence of this SWP is intrinsically linked to point sources pressures, as other studies have revealed for the studied river basin [13], [22], [39].

The results led to understand that the landscape metrics that play a dominant role in the river basin WQ are, the pz_(FOR) and pz_(ART), since pz_(FOR) decreases the concentration of SWP in 66% of the correlations while pz_(ART) increases the SWP in 65.9%. Clearly, these variables expose the effect of natural areas vs anthropogenic regions, because in forestry areas found freshwaters with high quality [40]. Besides, urban areas can also be linked to point source pressures, urban areas are impervious, and the drainage can be routed surface waters, which is a form of diffuse urban pressure [41]. Besides the composition of artificial surfaces and forestry areas has an impact in Ave River Basin, other metrics evidenced influence on SWP, and also the ed_(ART) increases SWP with a percentage of positive correlations of 62.0%. The percentage of agricultural edges that are shared with artificial surfaces, cce_(ART)_with_(AGR) has a strong impact, since the percentage of correlations that decrease WQ is 64.0%. This was expected since agricultural areas, and artificial surfaces are land use types that commonly decrease WQ [31]. On the other hand, the cce_(AGR)_with_(ART) revealed 31.3% negative correlations which is hard to explain. Separately the ed_(AGR) also revealed a degradation effect with 57.2% positive correlations. Nevertheless, the percentage of agricultural edges that are shared with forestry, cce_(FOR)_with_(AGR), revealed a positive impact on WQ, since the percentage of negative correlations (58.6%). It is curious that edge density of forests, ed_(FOR), has a slightly lower percentage, (55.9%). Other authors have reached a similar result [42], and this shows that agricultural fields that are surrounded by forests might not be harmful to hydric resources, by function as sinks for the contaminant flow. However, the percentage of forested areas that are shared with urban areas cce_(ART)_with_(FOR), has a negative impact on WQ, possibly because the effect of urban areas overcomes forestry regions.

5 CONCLUSION

The results, clearly evidenced that the relations between LSM and SWP is highly variable depending on the metric and the parameter. The results clearly showed that in Ave River Basin, urban areas and also agricultural surfaces degrade WQ, while forestry land use can improve WQ. In practical terms, is necessary to increase forested areas in spread shapes, increasing edge density and total area. While for urban areas besides, it is hard to decrease the area occupied, is necessary to at least reduce the urban sprawl. In agricultural areas is essential to surround them with forests, in order to promote a natural barrier for the contaminant flow. For the biggest part of the analysed SWP, conscious land use changes might reduce the contamination into sustainable values. However, to reduce the contamination of ammonia and heavy metals is necessary to implement measures that are beyond landscape metrics, which can be the implementation of improved effluent treatment technologies.

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