Enhancing citizen engagement in water resources management

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Abstract The world is currently facing serious water challenges that require an unprecedented global response. The present study proposes a multidisciplinary and dynamic approach to enhance citizen involvement in water resources management. It was conducted in Ave river, a medium-large sized river located in the Northwest region of Portugal, and the target groups were the inhabitants of Guimarães' parishes crossed by Ave river (45.000 inhabitants), particularly students (aged 6 to 18), the green volunteers of each parish, and parish council mayors. For a year, the ecological quality and the biodiversity of Ave river was monitored at 11 sampling sites, and mitigation and restoration measures to be done with the citizens were promoted. Additionally, more than 120 environmental education theoretical and practical actions were carried out to empower target groups with tools to track freshwater quality, to debate opinions, and to standardize procedures among parishes (e.g., clean-up and rehabilitation actions). Actions also included discussions with citizens, researchers, local authorities, and governmental entities about citizens' concerns, as well as proposing measures that reconnect citizens with local rivers. Citizens' engagement in water resources management has fostered good environmental practices and has increased society's awareness of green policies.

Keywords: Water Resources, Sustainability, Society, Water Policy, Community-based monitoring

1. Introduction

The world is facing serious challenges that require an unprecedented global response in order to protect our ecosystems. These challenges include the depletion of natural resources, environmental degradation and climate change (Gharesifard *et al*., 2019). Thus, to move towards a sustainable future solution should involve improved policies and more informed and participatory environmental decision-making processes. In fact, the importance of engaging the citizens in environmental science and policy has been emphasised by several international conventions and policy guidelines (UNECE, 1998; UNISDR, 2005; UN, 2015). Amongst the various examples, there is the so-called community-based monitoring of water and environmental resources which has mainly been spreading in Europe and North America (Conrad and Daoust, 2008; McKinley *et al*., 2017; Carlson and Cohen, 2018). The urgent need to involve citizens in these matters also emerged in the Northern Portuguese municipality of Guimarães, particularly in the management of water resources. Although there have been efforts since the 1980s for the depollution of Ave river, it is not yet fully recovered and there are still situations of illegal effluent discharges which might jeopardise all the work done so far. Furthermore, the lack of connection between the citizens and the river remains. Consequently, if people do not feel an emotional connection with the river, they will not be able to claim it as their own and probably they will not enjoy it. This situation has led to the need of establishing a more participatory process for river's management engaging not only the scientific community, the local authorities and the government entities in the river monitoring, but also the citizens. The main aim of this study was to showcase the importance of establishing a framework on river's management that promotes citizen´s participation and involvement supported by scientific research and educational programs.

2. Materials and Methods

2.1. Study area and sampling sites

This study was conducted in the hydrographic basin of Ave river located in the Northwest region of Portugal mainland. This river springs from Cabreira Mountain (Vieira do Minho municipality) and runs for approximately 85 km before flowing into the Atlantic Ocean (Vila do Conde municipality). It belongs to the "medium-large sized streams of the North" Portuguese river type (catchment area > 100 km^2) (INAG 2008a). Eleven sampling sites were selected (100 m long sections) for the evaluation of the ecological quality, according to the guidelines of national authorities (INAG 2008b, c, d) and they are distributed along several parishes within Guimarães municipality (± 30 km).

2.2. Assessment of the Ecological Status

Benthic macroinvertebrates, macrophytes and phytobenthos were monitored in the summer of 2019, due to greater flow constancy, lower turbidity and less disturbance to biotic communities. The sampling and laboratory analysis of the organisms followed the national guidelines for the Water Framework Directive implementation (INAG 2008b, c, d). The ecological status was assessed by determining the North Invertebrate Portuguese Index ($IPtI_N$), the Macrophyte Biological Index for Rivers (IBMR) as in Rodrigues *et al*. (2019), and the Specific Pollution Sensitivity Index (SPI; INAG, 2009). The final value of each index was expressed as Ecological Quality Ratio (EQR) and an ecological quality class was assigned (I-high to V-bad).

The water general physico-chemical parameters were monthly monitored, from August 2019 to July 2020. Water temperature (Temp.), pH, dissolved oxygen concentration (DO) and percent saturation (% DO), total dissolved solids (TDS), conductivity (Cond.), salinity (Sal.), chemical oxygen demand (COD), nitrates (NO_3^-), nitrites (NO_2^-), ammonium ion (NH_4^+), total phosphorus (P) were determined as in Rodrigues *et al*. (2019). Total suspended solids (TSS) were determined by the gravimetric method, and the biochemical oxygen demand (CBO_5) was determined by measuring the concentration of dissolved oxygen before and after five days of incubation at 20 °C (± 1 °C) in the dark with the addition of a nitrification inhibitor. These parameters were classified considering the thresholds established for the good ecological status in Northern Portuguese rivers.

The hydromorphological quality assessment of the Ave river was carried out in the summer of 2019, when the biological quality elements were collected. The indices and methodologies for this assessment were the same used by Rodrigues *et al*. (2019), namely the Habitat Quality Assessment (HQA), the Habitat Modification Score (HMS), and the Riparian Vegetation index (RVI).

1.3. Statistical analysis

All statistical analysis was performed with GraphPad (GraphPad Prism version 9.0.0 (121) for Windows). All the data sets followed the D'Agostino & Pearson, Shapiro-Wilk, and Kolmogorov-Smirnov normality tests to assess gaussian distribution. When normal distribution was verified, an ordinary one-way ANOVA and Tukey's multiple comparison test were performed. When it was not verified, the data followed the non-parametric Kruskal-Wallis test. A significance level of 0.05 was considered for all tests.

2.5. Environmental awareness and education actions

Environmental awareness and education actions occurred from September 2019 to September 2020. The target groups were the inhabitants of all the parishes crossed by Ave river in Guimarães municipality (45.000 inhabitants), particularly students (aged 6 to 18), the green volunteers of each parish, and parish council mayors. Five sessions took place in every school (24 schools, from primary to secondary school) from the parishes crossed by Ave river, with at least one class per school. The sessions comprised: i) a discussion with students about the importance of water resources and biodiversity, ii) in making a joint SWOT analysis of Ave river, iii) simulating a parliamentary assembly to discuss the problems and solutions; iv) a field trip so that students could learn to visually evaluate different quality indicators of the river. Five sessions were also carried out, targeting green volunteers, parish council mayors, researchers on different fields, local authorities and governmental entities. These sessions aimed to co-create solutions to the problems encountered based on civic empowerment and public participation, and to standardize procedures among parishes.

Non-target groups of citizens could also somehow be involved in the Ave River monitoring (e.g., theoretical-practical sessions, biodiversity campaigns, social network updates).

3. Results and Discussion

The global ecological status of Ave river varied between moderate (class III, AR1 to AR4 and AR10) and poor (class IV; AR5 to AR9 and AR11). Regarding the biological quality elements, the $IPtI_N$ was the index that revealed a stronger response of organisms to anthropogenic disturbances (Table 1). Only AR4 and AR10 showed good ecological status with $IPtI_N$, while the remaining sites presented moderate to poor ecological status (Table 1). The IBMR and IPS indices revealed that the sampling sites have good or high, or moderate ecological status, respectively (Table 1).

Table 1. EQR values and corresponding ecological quality classes of the IBMR, the SPI, and the $IPtI_N$ indices determined at the sampling sites of Ave river (AR1 to AR11) in the summer 2019.

Sites	Biological Quality Elements		
	IBMR	IPS	$IPtI_N$
AR1	1.12 (I)	0.71 (III)	0.51 (III)
AR2	0.82 (II)	0.64 (III)	0.57 (III)
AR3	0.80 (II)	0.64 (III)	0.52 (III)
AR4	0.70 (II)	0.63 (III)	0.76 (II)
AR5	0.75 (II)	0.63 (III)	0.40 (IV)
AR6	0.75 (II)	0.62 (III)	0.42 (IV)
AR7	0.75 (II)	0.63 (III)	0.38 (IV)
AR8	0.85 (II)	0.64 (III)	0.30 (IV)
AR9	0.83 (II)	0.55 (III)	0.31 (IV)
AR10	0.83 (II)	0.59 (III)	0.58 (II)
AR11	No indic. sp.	0.59 (III)	0.28 (IV)

Note: Nº ind. sp. means no indicator species were found.

All water physico-chemical parameters showed spatial (Temp., $p = 0.0212$; CBO_5, $p = 0.001$; NO_3^-, $p = 0.0002$; TSS, $p = 0.0001$; pH, OD, % OD, COD, Cond., Sal., TDS, P, NO_2^-, NH_4^+, $p < 0.0001$) significant differences in Ave river. This river presents good ecological status for all parameters analysed, except for total phosphorus, whose annual mean exceeded the limit value for the establishment of good ecological status (P > 0.10 mg/L) in all sampling sites, especially in AR9 and AR10 (Table 2), both located downstream of the confluence of Selho and Ave rivers. The discharge of phosphates of agricultural origin, urban and industrial effluents can cause the growth of large amounts of photosynthetic aquatic micro and macro-organisms, triggering eutrophication processes. Therefore, field trips were carried out along the river to identify and georeference possible sources of contamination.

Table 2. Spatial variations (mean ± standard deviation) of physico-chemical parameters determined at the sampling sites of the Ave river (AR1 to AR11) from August 2019 to August 2020. Different characters indicate significant differences between sites ($p < 0.05$), as indicated by the Tukey's multiple comparison test.

	Sampling Site										
Parameter	**AR1**	**AR2**	**AR3**	**AR4**	**AR5**	**AR6**	**AR7**	**AR8**	**AR9**	**AR10**	**AR11**
Temp.	15.52	15.37	15.82	15.94	15.91	16.49	16.75	16.80	17.06	17.43	17.60
(C°)	±4.11	±3.67	±4.08	±4.11	±4.01	±4.56	±4.98	±5.01	±5.26	±5.11	±5.34
pH	6.71	6.93	6.98	7.00	7.20	7.26	7.22	7.19	7.11	7.35	7.58
	±0.54 a	±0.31 a	±0.26 a	±0.30 ab	±0.40 ab	±0.45 ab	±0.41 ab	±0.32 ab	±0.27 ab	±0.29 ab	±0.39 b
OD	7.90	8.32	8.59	8.63	8.98	8.78	8.85	8.67	8.49	9.38	8.76
(mg O_2/L)	±1.19 a	±0.95 a	±1.11 ab	±1.09 ab	±0.94 ab	± 1.11 ab	±1.04 ab	±1.13 ab	±1.03 a	±0.98 b	±1.21 ab
% OD	79.31	84.26	88.89	90.21	92.97	91.72	92.79	91.47	90.05	99.5	93.54
	±14.35 a	±11.32 a	±11.71 ab	±11.91 ab	±11.46 ab	±12.52 ab	±10.48 ab	±10.92 ab	±11.82 ab	±16.22 b	±14.61 ab
BOD_5	2.19	2.15	2.44	2.37	2.79	2.69	2.65	2.47	2.48	3.32	2.76
(mg O_2/L)	± 0.90 a	±0.76 a	±0.91 a	±1.02 a	±1.13 ab	±1.18 ab	±1.02 ab	±0.99 ab	±1.09 ab	±1.53 b	±1.56 ab
COD	4.39	7.89	6.33	10.69	9.81	5.31	5.11	10.92	10.36	13.06	13.03
(mg O_2/L)	±7.77 a	±11.66 ab	±12.03 a	±11.95 ab	±10.17 ab	±6.64 a	± 5.47 a	±11.70 b	±7.46 ab	±10.54 b	±9.17 b
Cond.	55.89	46.11	45.92	47.14	48.14	51.39	57.08	55.39	60.44	101.8	188.3
(mg/L)	±17.35 a	±10.26 a	± 9.71 a	±10.90 a	±11.06 a	±9.84 a	±9.41 a	±11.23 a	±9.44 a	±73.36 b	±97.00 c
Sal.	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.09
(PSU)	±0.01 a	±0.01 a	± 0.01 a	±0.01 a	±0.01 a	±0.01 a	±0.01 a	± 0.01 a	±0.01 a	±0.04 b	±0.05 c
SDT	27.94	22.61	22.44	23.25	23.33	26.31	27.92	27.92	30.47	48.52	96.28
(µS/cm)	±9.09 a	±4.17 a	±4.01 a	±4.51 a	±3.76 a	±6.41 a	±4.38 a	±5.77 a	±5.74 a	±37.29 b	±48.11 c
SST	2.60	1.00	0.90	0.30	0.50	0.40	0.90	7.30	1.70	2.56	7.60
(mg/L)	±7.28 a	±1.58 ab	±1.24 ab	±0.65 a	0.82 a	±0.93 a	±1.61 ab	±16.13 ab	±2.32 ab	±4.64 ab	±15.01 b
P	0.16	0.13	0.11	0.13	0.18	0.13	0.16	0.09	0.20	0.30	0.35
(mg/L)	±0.21 a	±0.09 a	±0.11 a	±0.09 a	±0.16 ab	±0.12 a	±0.14 a	±0.08 a	±0.16 ab	±0.23 b	±0.29 b
NO_3^-	6.85	9.10	8.19	9.27	9.39	7.55	9.38	7.84	11.00	11.54	11.58
(mg/L)	±3.58 a	± 4.58 ab	±3.82 ab	±4.34 ab	±4.41 ab	±2.60 ab	±5.22 ab	±4.74 ab	±5.33 ab	±5.13 b	±6.37 b
NO_2^-	0.03	0.03	0.04	0.13	0.04	0.04	0.04	0.04	0.05	0.06	0.09
(mg/L)	±0.01 a	±0.01 a	±0.02 a	±0.32 b	±0.02 a	±0.02 a	±0.02 a	±0.03 a	±0.02 a	±0.06 ab	±0.09 ab
NH_4^+	0.19	0.28	0.20	0.18	0.15	0.18	0.17	0.21	0.21	0.53	0.47
(mg/L)	±0.19 a	±0.25 a	±0.10 a	±0.15 a	±0.11 a	±0.11 a	±0.09 a	±0.11 a	±0.17 a	±0.41 ab	±0.30 ab

The collected data were stored in an internal database that can also be enriched through public participation. In order to ascertain the causes and find definitive solutions to prevent further degradation, the collected information was forwarded to local authorities and governmental entities directly linked to the licensing, monitoring, surveillance, management and exploitation of water resources and economic activities.

Although more than half of the sampling sites have high physical heterogeneity of habitat (HQA, class I; Table 3), none showed the riverbed and banks in natural condition (all sites with HMS < class I; Table 3). AR2, AR5 and AR9 were the sites that showed the greatest modification of the riverbed and banks, with artificial structures in the riverbed (e.g., bridges, weirs) and high modification of the riverbed and banks (e.g., bank and bed reinforcement, resectioning, channel realignment). Therefore, they were categorised as severely (HMS category 5; AR9) or significantly (HMS category 4; AR2 and AR5) modified (Table 3).

According to the RVI assessment, only AR4 and AR6 showed riparian vegetation quality below good, i.e., moderate (class III) and poor (class IV), respectively (Table 3), which was mainly due to the low coverage and proportion of endemic species. It should be noted that all sites except AR1 showed high proportion and cover of exotic species according to RVI. Some of these are included in the national list of invasive species (DRE, 2019), namely: *Acacia dealbata* (AR1, AR3, AR7, AR8, AR10), *A. melanoxylon* (AR7, AR9, AR11), *Ailanthus altissima* (AR2, AR5, AR6, AR8), *Amaranthus hybridus* (AR3), *A. powelii* (AR3, AR5, AR11), *A. retroflexus* (AR7), *Bidens frondosa* (AR1 to AR11), *Calystegia silvatica* (AR4), *Conyza canadensis* (AR2, AR7), *Crocosmia* x *crocosmiiflora* (AR3, AR7), *Datura stramonium* (AR11), *Egeria densa* (AR3 to AR6, AR8, AR10), *Erigeron karvinskianus* (AR9), *Ipomoea indica* (AR8), *Myriophyllum aquaticum* (AR2, AR4), *Paspalum paspalodes* (AR4 to AR6), *Phytolacca americana* (AR2 to AR8, AR10, AR11), *Setaria parviflora* (AR7) and *Tradescantia fluminensis* (AR9, AR11).

Table 3. Scores or EQR values of the hydromorphological quality indices determined at the sampling sites of the Ave river (AR1 to AR11) in the summer of 2019. Corresponding quality classes (I to V) for HQA and RVI indices' scores or EQR values, corresponding HMS categories of artificialisation of river channel morphology, and the number of species (Nº sp.) in the riparian zone, are also given.

Site	**HQA Score (class)**	**HMS Score (category)**	**RVI EQR (class)**	**RVI Nº sp.**
AR1	54 (I)	110 (2)	1.56 (I)	51
AR2	44	530 (4)	0.67 (I)	53
AR3	53 (I)	270 (3)	0.78 (I)	57
AR4	43	380 (3)	0.33 (III)	41
AR5	67 (I)	960 (4)	0.67 (I)	41
AR6	44	370 (3)	0.22 (IV)	31
AR7	34	50 (2)	0.56 (I)	49
AR8	60 (I)	360 (3)	0.78 (I)	57
AR9	53 (I)	1620 (5)	1.11 (I)	36
AR10	49 (I)	370 (3)	0.67 (I)	44
AR11	41	250 (3)	0.44 (II)	50

Based on these results, a set of environmental awareness and educational actions, open to the community, were carried out. Their aim was to increase the width of riparian zones and restore the connectivity with the riparian forest, as well as to eliminate invasive species and fostering the native ones. These actions were entitled: Importance of the Riparian Gallery, Life under Water, Solid Urban Waste Collection, Opportunities and Threats of the Riparian Vegetation, Identification and Control of Invasive Plant Species, and Plant a Native Tree in Ave River. Since prevention, early detection and rapid response are essential for invasive species eradication, priority was set in areas with isolated specimens. In October 2019, the eradication (physical control, namely hand-pulling and debarking) with volunteers started in AR1, the site with the lowest proportion and cover of exotic species (8% and 3% respectively) which is located in Arosa and Castelões parishes, under the guidance of experts in this field. The riparian forest of AR1 is dominated by *Alnus glutinosa*, followed by *Fraxinus angustifolia* and *Salix atrocinerea* in tree stratum and it belongs to the priority natural habitat 91E0 – Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) (EEC, 1992). A total of 165 species of plants were identified in the different sampling sites (Table 3), being mostly native (119). Additionally, a set of theoretical and practical sessions open to the public were organised to promote biodiversity. These were: Aquatic Organisms and Water Quality Assessment, Amphibian Prospection, Mycological Trail, Scientific Bird Ringing, Identification and Control of Invasive Plant Species. In these field activities several species of fungi, birds and mammals were identified (53, 20 and 5, respectively) and added to the biodiversity database of Guimarães municipality, through the mobile app BiodiversityGO!, a local tool of citizen science.

Sessions targeting green volunteers of each parish, parish council mayors, researchers, local authorities and governmental entities, provided the discussion of citizens' concerns regarding Ave river (e.g., cleaning and monitoring, invasive species, operational problems), and allowed the co-creation of solutions to recover the nexus between citizens and the river. The Municipality of Guimarães and the Landscape Laboratory have already initiated some of them, including: i) an application for a river beach at Caldelas parish; ii) the construction of a walking trail along the river (the first phase of this project started in October 2020). Furthermore, after all the lessons in schools, 700 Ave river ambassadors were able to recognise both the threats and the positive indicators of the river and to spread good practices and name solutions for the conservation of the riverbed and banks to the whole community. For that, students carried out actions where they could express their creativity (e.g., exhibitions, Ave river mockups, drawings, biodiversity mural), and share them at school, in public spaces and on the website of the Landscape Laboratory. Therefore, citizens' engagement in water resources management has proven to foster good environmental practices that improve the ecological quality of rivers, and has increased society's awareness of green policies.

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