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Water Resources

PREFACE

The 2nd ICIEM 2016, **I**nternational **C**onference on **I**ntegrated **E**nvironmental **M**anagement for **S**ustainable Development seeks to create a tradition of a bi-annual gatherings of academia, industry and policy makers to build a series of environmental pollution monitoring systems and integrated management strategies. The conference will provide a forum for discussion amongst scientists, professionals and academia in different areas of the broader theme of environmental engineering and sciences. The wealth of information exchanged in this international meeting continues to be of great benefit to all involved in challenging environmental issues caused by the increase of pollutants loads discharged into natural environment ecosystems. Those challenges require the building of a regulatory framework and control strategies. This framework needs to be based on scientific evidence associated with exposure and health risk for pollution prevention and remediation strategies. The application of innovative remedial techniques and new scientific methods is key in order to reach sustainable development. It is therefore crucial to address the existing pollution problems, and protect public health as well as preserve the welfare of the environment.

The application of cost-effective technologies for waste treatment and controls is much needed in order to make possible the implement of appropriate regulatory measures that insure success of broader policy in pollution prevention.

Engineers and scientists working in this field need to be familiar with a wide range of issues including the physical processes of mixing and dispersion, and photochemical and biological developments. Hence, a continuous exchange of information between scientists in different parts of the world is essential.

In recent years, environmental protection has emerged as a requirement that goes beyond the state borders to reach a global dimension. This awareness has resulted in numerous treaties, directives and conventions and even changed the way we do business.

Protection of the environment, one of the pillars of sustainable development, is an absolute priority for the international community. In this context, the 2nd ICIEM conference aims to focus on relevant experiences, up-to-date scientific research and findings carried out all over the world to protect and preserve the environment. In addition, this meeting will allow the exchange of experiences to develop environmental protection strategies and pollution management tools.

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Optimization of Fluvıal Beaches Locatıon Based on a Multı-Crıterıa ApproachCombiningRıver Hydrodynamıcs and Water Qualıty

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Abstract.River basin management decisions arecomplex allocation processes that should be based on adequate decision support methodologies aiming at an efficient, rational and integrated use of water resources. The present study presents a site-specificmethodology designed toidentify and to rank potential fluvial beach locationscombininghydrodynamic comfort and water quality indexes. The concept was validated in Cavadoriver basinlocated in northern Portugal, where 73bathing locations were assessed and ranked.Results showed that only 8,3%presented a positive performance in terms of both water quality and hydrodynamic comfort, while16,3%present a favorable water quality performance but a low hydrodynamic comfort due toupstream hydropower plants.In conclusion, the multi-criteria methodology provided to be straightforward for water bathing sites identification, fostering the use of such licensingapproaches by local water authorities.

Keywords: Fluvial beaches, risk assessment, multi-criteria analysis, river modelling.

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58. Introduction

Rivers are structural territorial elements and their ecologicalvalues are the framework for a sustainable allocation ofhuman activities. Indeed, water functions and ecosystem services are the target of multiple human demands, naming water abstraction for public supply, food irrigation, hydropower generation and fishingactivities. Recently, rivers

and riparian zones play an increasingly supporting role for recreational activities, such as nature observationand pedestrian and bike trails.Bathing is another potential offer provided by many rivers. Bathingin river waters is a source of human well-being andan important leisure asset in inlandurban areaslocated far from coastal zones. However,dangersassociated with physical characteristics derived from river flows and water qualityshouldn't be disregarded. Physical conditions for bathing are dependent on water depth and flow velocities that may suffer short term pressures from upstream hydropower plants (Alexandre et al., 2013) or long term climate change impacts (Britoand Lacerda, 2011). Water quality is dependent ofdiffuse pollution sourcesat basin scale and direct wastewaters discharges (Vieira et al., 2013). Reference conditions in surface waters for direct contact are established by proper legislationand water authorities must license bathing sites accordingly (Pinho et al, 2011; Vieira et al, 2012).In 2015, near 6 500 bathing sites situated on rivers and lakes across Europe were identified, but only less 15 % were situated on rivers, most in lakes (EEA, 2016). Therefore, a significant trend towards more bathing sites in rivers is clearly expected for next years.

In this regard, regional water authorities need simplified yet accurate tools that are willing to contribute to better assessment and licensing procedures. Therefore, the design and implementation ofa multi-criteria methodology for river bathing zones selection was addressed, based on two indexes: (i) a physical index that reveals the adequacy of each site related with water depths and currents, and (ii) a second one that allows to rank the set of sites according the quality of the water. Model validation was carry out in Cavado river basin, located in the northern region of Portugal.

59. Methods

59.1. Study site

River Cavado basin is located in the north-western region of Portugal. This basin occupies an area of 1589 km^2 and the river network considered in the model is about 360 km length corresponding to 16 rivers. The annual mean rainfall is 2200 mm, being 42% concentrated in December, January and February. Water is intensively used for hydropower generation, domestic and industrial water supply and irrigation. Six large hydropower plants are in operation with an installed power of 377.6 MW and an annual average production of 1535 GWh.Total reservoirs storage capacity is about 1170 hm^3, representing a high regulatory capacity for river flows (APA, 2015).

The lower part of the basin presents a relatively high population density (ranging from 317 inhab/km^2 at Barcelos to 990 inhab/km^2 at Braga municipality)distributed over five municipalities: Amares, Vila Verde, Braga, Barcelos and Esposende. These populations are supplied with water from river Cavado that, at the same time, is the receiving water body of WWTP discharges from those populations, which is a well-known challenging issue.Figure 1 depicts the Cavadoriver basin and the modelled river network. Thestudyareaincludestheriver Cávado, butalsoitsmaintributaries: Homem, Beredo, Borralha, Cabreira, Cabril, Cavadas, Caveiro, Covo, Febras, Gerês, Milhazes, Pontes, Rabagão, Toco, and Tojal.

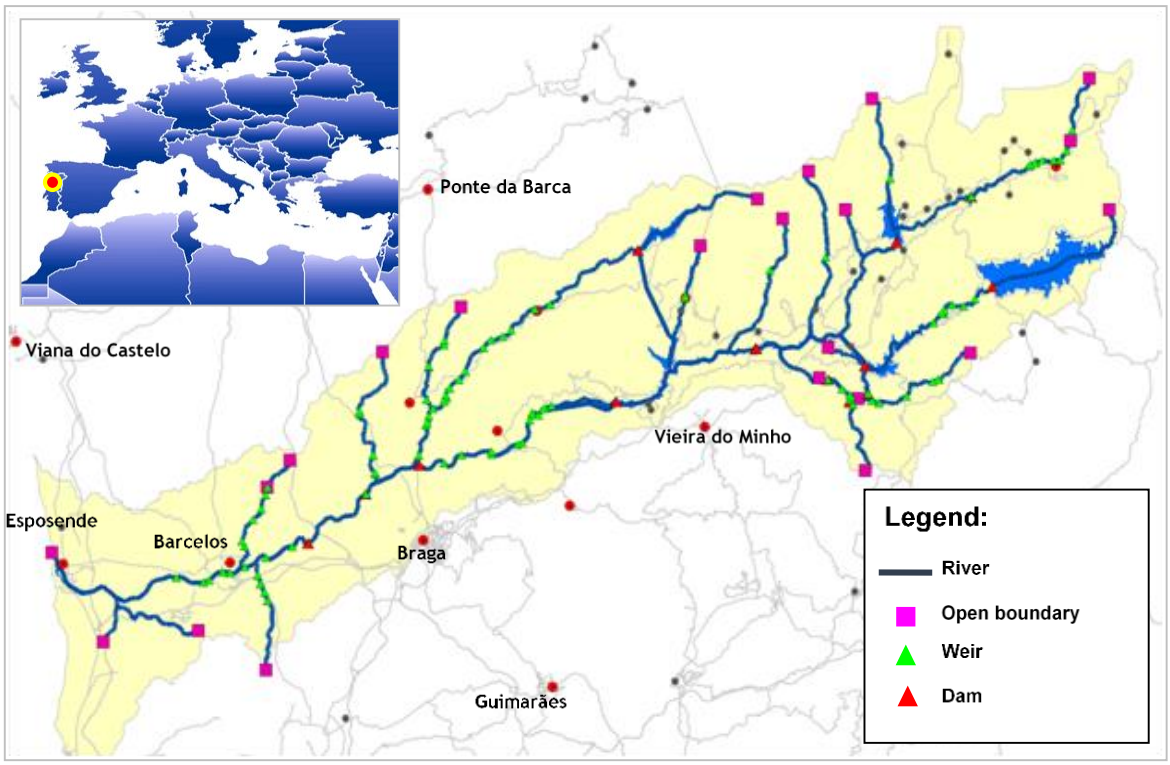

Figure 1. Study area location and river model.

59.2. Mathematical models formulation

The water flow model used a one-dimensional formulation of free surface flows based on the conservation of mass and momentum equations. In addition to these equations, the flow discharges at hydraulic structures included in the model segmentation

was computed using specific expressions for each type of structure: bridges, culverts, siphons, orifices, pumps, and weirs. In these structures the flow depends on the upstream and downstream levels, on its dimensions and on a set of specific parameters. Water quality variables were modeled based on a one-dimensional transport equation.

$$\frac{\partial A_f}{\partial t} + \frac{\partial Q}{\partial s} = q_{lat} \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial s}\left(\frac{Q^2}{A_f}\right) + gA_f \frac{\partial H}{\partial s} + \frac{gQ|Q|}{C^2 R A_f} - W_f \frac{\tau_{wi}}{\rho} = 0 \tag{2}$$

$$\frac{\partial (A_f C)}{\partial t} = -\frac{\partial (QC)}{\partial s} + \frac{\partial}{\partial s}\left(DA_f \frac{\partial C}{\partial s}\right) + SA_f \tag{3}$$

where, Q = flow discharge, t = time, s = one-dimensional coordinate, A_f = wetted area, g = acceleration due to gravity, H = water level above plane of reference, C = Chézy's coefficient, R = hydraulic radius, W_f = superficial width, q_{lat} = lateral flow, τ_{wi} = wind shear force, ρ = water density, C= Substance concentration, D = Diffusion coefficient, S = Source, sink and reaction term.

Sources are considered as point sources using lateral discharges into the main rivers. River water quality parameters are: dissolved oxygen, biochemical oxygen demand and three bacteria indicators (total coliform, fecal coliform and streptococci). First order decay reactions were assumed in modeling microbial and chemical transformation mechanisms. Mechanisms include river water deoxygenation, reaeration and bacteria mortality rates (Chapra, 1997).The last term of Eq. 3 refers to the sources and sinks and the dependence on the processes occurring in the water column related with the modelled substance. Water quality processes library used in this work includes allrelevant processes allowing the establishment of either complex water quality processes or simple ones depending on data availability.

The river model (Figure 1) was implemented inSobekmodeling platform that solves the one-dimensional formulations of free surface flows based on mass and momentumconservation(Deltares, 2013). Cross sections of the river channels were

assessedfirst, using bathymetric and topographic data. The one-dimensional grid comprises 1722 computational nodes, 22 open boundaries, 51 controlled discharges at hydraulic structures and 105 non-controlled hydraulic structures. The rivers channels geometry was introduced considering 1854 cross sections. Pollutant sources are simulated considering 84 different locations identified in the river basin. All hydraulic structures with a significant influence in the rivers flows regime were considered with emphasis on dams and hydropower plants. The model segmentation was defined considering the impact of upstream reservoirs in the river flows and the occupation (industrial, agriculture and urban areas) in downstream areas.Bacterial contamination arising from discharges of point or diffuse sources wasmodelled by a 1st-orderreaction decay. The bacteria mortality coefficients were established recurring mainly to available field data.

In the calibration procedure a hybrid approach was followed. Several parameters were established either according to proposed values in the literature (Thomann and Mueller, 1987; Chapra, 1997), from previously developed works (Pinho et al., 2011) or derived from available field data.At the upstream open boundaries of the modelled rivers it was considered that the water presents characteristics of unpolluted water, with zero values of pollutants concentrations.

59.3. Spatial analysis approach

Multi-criteria spatial analysis approaches are frequent and well known for infrastructures location assessment studies. The definition of a set of relevant indicatorsis the first required step. In the present work, after a preliminary assessment,indicators were normalized and aggregated in two main indexes: a hydrodynamic comfort index and a water quality index. Hydrodynamic comfort index was based on two different indicators: local water depth variations for the river flow regime and local current velocities variations. The aim of this index is to translate the physical suitability of the site in relation to the behavior of the river flow. As the requirements of depth and velocity can vary widely depending on the recreational use of the water (a suitable place to perform jumps to the water is necessarily distinct from a comfortable place for swimming) and in the absence of specific legislation, it was considered these variations of depth and velocity as suitable indicators to quantify bathing comfort. There is no legislation regulating the adequacy of river waters to be used for bathing according their currents velocities except for diving that, whose regulation available for different countries, indicates that for this use river currents should be evaluated in qualitative terms.

The water quality index was buil-upupon microbiological indicators. The index score reflect the site vulnerability to bacterial pollution, considering water quality that is well defined in the bathing waters legislation.Three microbiological parameterswere used: total coliforms, fecal coliforms and streptococcus bacteria. The normalization attends the standard values defined in thebathing waters legislation.

59.3.1. Normalization and aggregation of indicators

Indicatorswere originally expressed in different scalesandin order toprovide a comparable and aggregated function a normalization operation was carried out. A normalization technique based on the sigmoid function was used, as follows:

$$x_n = \cos^2(a) \tag{4}$$

where, x_n, is the normalized value of the indicator. The value of$a$is computed with the following expression:

$$\begin{aligned} a &= \frac{\pi}{2}\frac{x - x_{1c}}{x_{2c} - x_{1c}} \\ a &= 0 \quad \text{for} \quad x \le x_{1c} \\ a &= \frac{\pi}{2} \quad \text{for} \quad x > x_{2c} \end{aligned} \tag{5}$$

being x_{1c} and x_{2c} control points values. These values were defined for each indicator, established through legal values, whenever possible.The aggregation of the indicators was done according the following expression in which is considered the possibility of exclusion, expressed in a binary scale:

$$I = \sum_{i=1}^{N} w_i x_{ni} \times \prod_{i=1}^{N} e_i \tag{6}$$

being I the index value, w_i the weight attributed to the normalized indicator x_{ni}, e_i the value of the binary variable associated to the x_{ni} indicator and N the number of indicators considered on the index construction.

59.3.2. Risk assessment model

The potential of river locations for bathing activities was evaluated considering safety risks associated with the hydrodynamic pattern of river waters and health risks due to their microbial quality. In the first case it was considered the (i) local water depth variations and (ii) the local water velocity variations combined in a hydrodynamic comfort index (I_{hc}). In order to evaluate water quality for each location it was considered either (i) real monitoring data and (ii) microbiological water simulationresults, aggregated in a water quality index (I_{wq}).The first index translates the physical suitabilyty of the location in relation to the river flow behavior. As the requirements of depth and speed vary widely accordingly the beach use (a suitable place to perform jumps to the water is necessarily distinct from a comfortable swimming place) and in the absence of specific legislation, it was assumed that the variations of depth and velocity are suitable indicators to quantify bathing comfort and safety.

Regarding the depth variation it was adopted a zero lower control point and an upper control point equal to 1,0 m for the normalization (Figure 2 a). Thus, locations that have variation in depth greater thant 1,0 m will have a null value after normalization (see Figure 2 a)).In the case of the river currentsvelocity there is no specific legislation regulating the beach use.It is possible to practice beach activities in very different river hydrodynamic conditions in terms of currentsvelocities. As velocitychanges in short periods of time may endanger the bather's safety, it was considered a null lower control point and a change of 0,5 m/s for the upper control point.

Figure 2 c) shows the result of the normalization for this indicator.Equal weights were assigned to each one of the preceding indicators in the construction of the hydrodynamic comfort index.Regarding the suitability of water quality of each location the normative values for bathing is well defined by several standards. It was decided to assess water quality bacteriologicalvariablesfor bathing waters: fecal coliform bacteria, total coliform bacteria and fecal streptococci. Besides historical monitoring data, the water quality index was also based on model results for those bacteria indicators.

The control points for the normalization procedure were adopted from the maximum recommend values (MRV) and maximum admissible values (MAV) considered EU

legislation. Table 1 and Figure 2 present the relevant data used to normalize and aggregate the indicators.

Table 1List of indicators,normalization control points and weights for risk indexes computations used in the multi-criteria analysis.

Indicator	**1st control point for normalization** (x_{1c})	**2nd control point for normalization** (x_{2c})	**Weight** (w_i)	**Indexes**
Water depth change x_1	0	1,0 m	0,5000	Hydrodynamic comfort index I_{hc}
Velocity change x_2	0	0,5 m/s	0,5000	
Fecal coliform bacteria (monitoring data) x_3	100	1000 (MAV/2)	0,1667	Water quality index I_{wq}
Total coliform bacteria (monitoring data) x_4	500	5000 (MAV/2)	0,1667	
Fecal Streptococci (monitoring data) x_5	0	100 (MRV)	0,1667	
Fecal coliform bacteria (modelling results)	100	1000 (MAV/2)	0,1667	

x_6				
Total coliform bacteria (modelling results) x_7	500	5000 (MAV/2)	0,1667	
Fecal Streptococci (modelling results) x_8	0	100 (MRV)	0,1667	

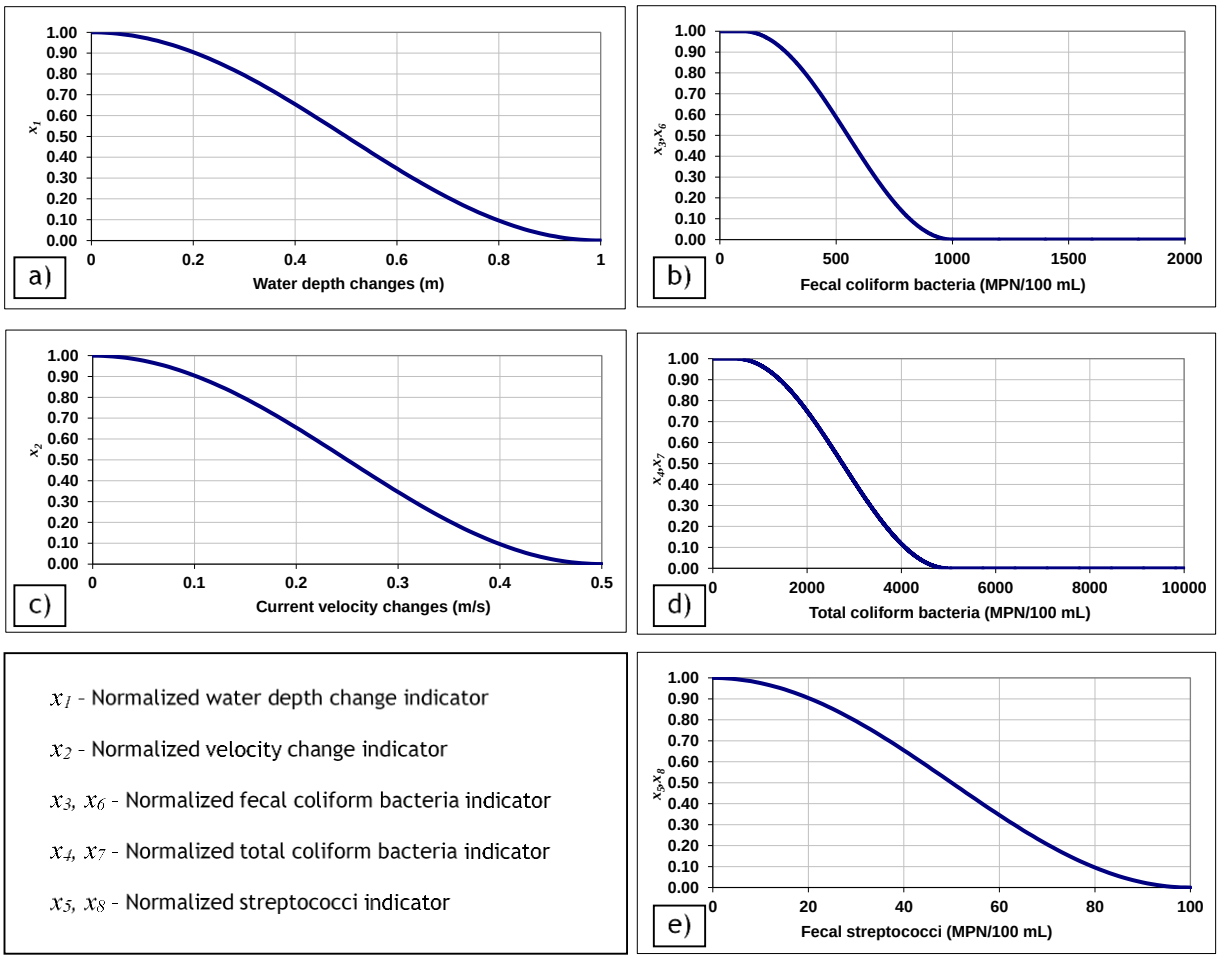

Figure 2. Normalization of indicators used in the multi-criteria analysis.

60. Results

Different hydrodynamic scenarios were implemented and the correspondent hydrodynamic comfort index for each location wasassumed equal to the minimum values obtained from those different scenarios. It were defined considering average discharge conditions for the tributary rivers and different operational conditions at the hydropower plants: (i) in the first scenario it was assumeda continuous production of energy at the three hydropowerplants during the simulation period(conditions at 3, 4 and 7inFigure 3); (ii) in the second scenario, the hydropeakingat Ponte doBico dam (condition at 4) was considered, which may occur during maintenance periods; (iii) in the third scenario it was assumedthe maintenance of Penidehydropower plant (condition at 7), which imply the opening of the floodgates, maintaining the energy production at the other two hydropower plants.The remaining conditions were kept constant for all scenarios.

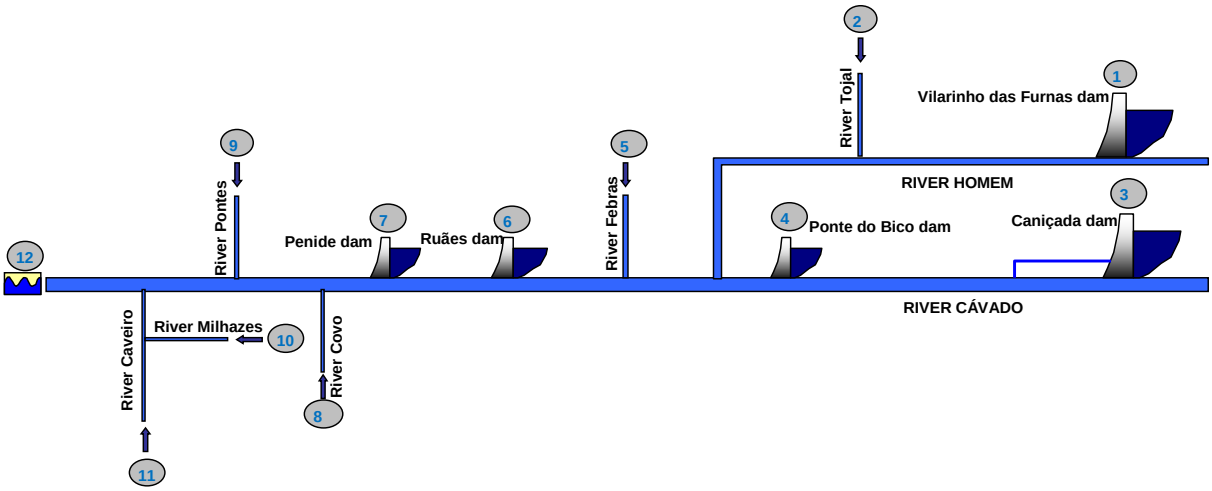

Figure 3. Open boundary conditions schematization for hydrodynamic scenarios definition.

Pollutant loads associated with industrial discharges were estimated (Table 2). In this area, most of the industrial effluents are received by the urban sewerage system and treated in municipal WWTP.Another pollutant sources are derived from livestock farms discharges. In this case, effluent loads were estimated considering the number of livestock per farm (Pinho et al., 2011).

Table 2.Most relevant pollutant point sources.

Model ID	Name	Discharge (m^3/s)	BOD (mg/L)	Bacteria 1 (MPN/m^3)	Bacteria 2 (MPN/m^3)	Bacteria 3 (MPN/m^3)
FT_ETAR14	Frossos	0,15332	101	4,2E+08	4,2E+09	8,4E+09
FT_ETAR5	Vila Frescainha	0,04686	92	3,8E+08	3,8E+09	7,7E+09
FT_ETAR9	Esposende	0,02002	81	3,4E+08	3,4E+09	6,7E+09
FT_VAC16	Sociedade Agro-Pecuária Barbosas, Lda	0,00010	12857	7,9E+06	7,9E+07	2,2E+08
FT_ETAR13	Palmeira	0,00959	101	4,2E+08	4,2E+09	8,4E+09
FT_ETAR29	Vila Verde	0,01142	69	2,9E+08	2,9E+09	5,7E+09
FT_ETAR28	Prado	0,01065	52	2,2E+08	2,2E+09	4,3E+09
FT_ETAR3	Amares	0,00558	84	3,5E+08	3,5E+09	7,0E+09
FT_VAC17	Sociedade Agro-Pecuária Irmãos Marques, Lda	0,00003	12857	2,4E+07	2,4E+08	6,7E+08
FT_VAC13	Manuel Sá Faria	0,00003	12857	2,8E+07	2,8E+08	7,8E+08
FT_VAC1	Albino Martins Branco	0,00002	12857	3,4E+07	3,4E+08	9,5E+08
FT_ETAR12	Caldelas	0,00085	341	1,4E+09	1,4E+10	2,8E+10
FT_VAC3	António José Pereira Ferreira	0,00002	12857	3,8E+07	3,8E+08	1,1E+09
FT_VAC2	António Eugénio Costa Maciel	0,00002	12857	4,7E+07	4,7E+08	1,3E+09
FT_VA12	Manuel Novais da Silva	0,00001	12857	6,3E+07	6,3E+08	1,8E+09
FT_ETAR26	Barcelinhos	0,00139	92	3,8E+08	3,8E+09	7,7E+09

Figure 4 presents the results for the rivers Cavado and Homem, where 73 locations were evaluated. As a general observation, bathing potential revealed a decreasing trend towards downstream locations. The river Homem presents a favorable performance in terms of both water quality and hydrodynamic comfort. This performance is supplemented with interesting landscape values. Note that the results obtained allow us to infer a water quality also favorable at the upstream section of the river Cavado till the confluence with the River Homem. However, the hydrodynamic comfort is very low resulting from intense flow fluctuations that result from the operation of the upstream hydropower plant.

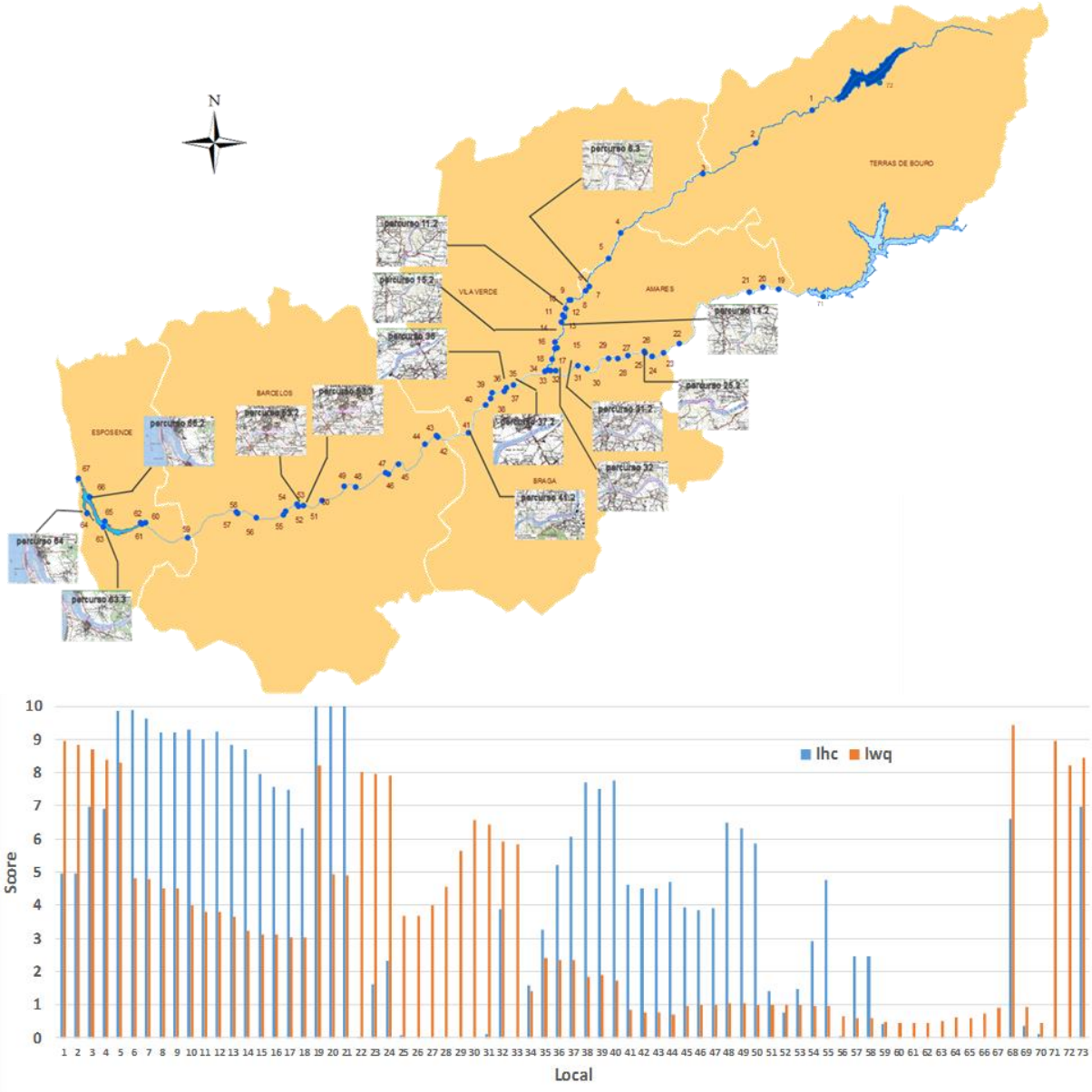

Figure 4. Results obtained for risk indexes (hydrodynamic comfort and water quality) at 73 locations.

Results indicate that only half of the river sites revealed a good performance in terms of water quality index, including sites 71 and 72 at two different artificial reservoirs, Vilarinho das Furnas and Caniçada. Therefore, an additional approach should be considered in order to increase decentralized wastewater treatment capability in small communities, as prescribed in the adjacent river basin Minho-Lima (Costa et al, 2009). In addition, 16,3% presents a favorable water quality performance but a low hydrodynamic comfort due to

upstream hydropower plants. Hydrodynamics is a major problem in two thirds of the bathing sites.For instance, sites 25 and 29 are downstream the main hydropower plant in Cavado river (Caniçada dam) and present a low score in terms of hydrodynamic comfort (Figure 5). Hydropeaking has negative impacts on bathing safety, as well as in river biofilm communities (Rodrigues et al, 2010)and fish populations(Alexandre et al, 2013). In artificial reservoirs the significant water level fluctuations constrain recreational uses and bathingalso.Furthermore, only 8,3% presented a positive performance in terms of both water quality and hydrodynamic comfort.

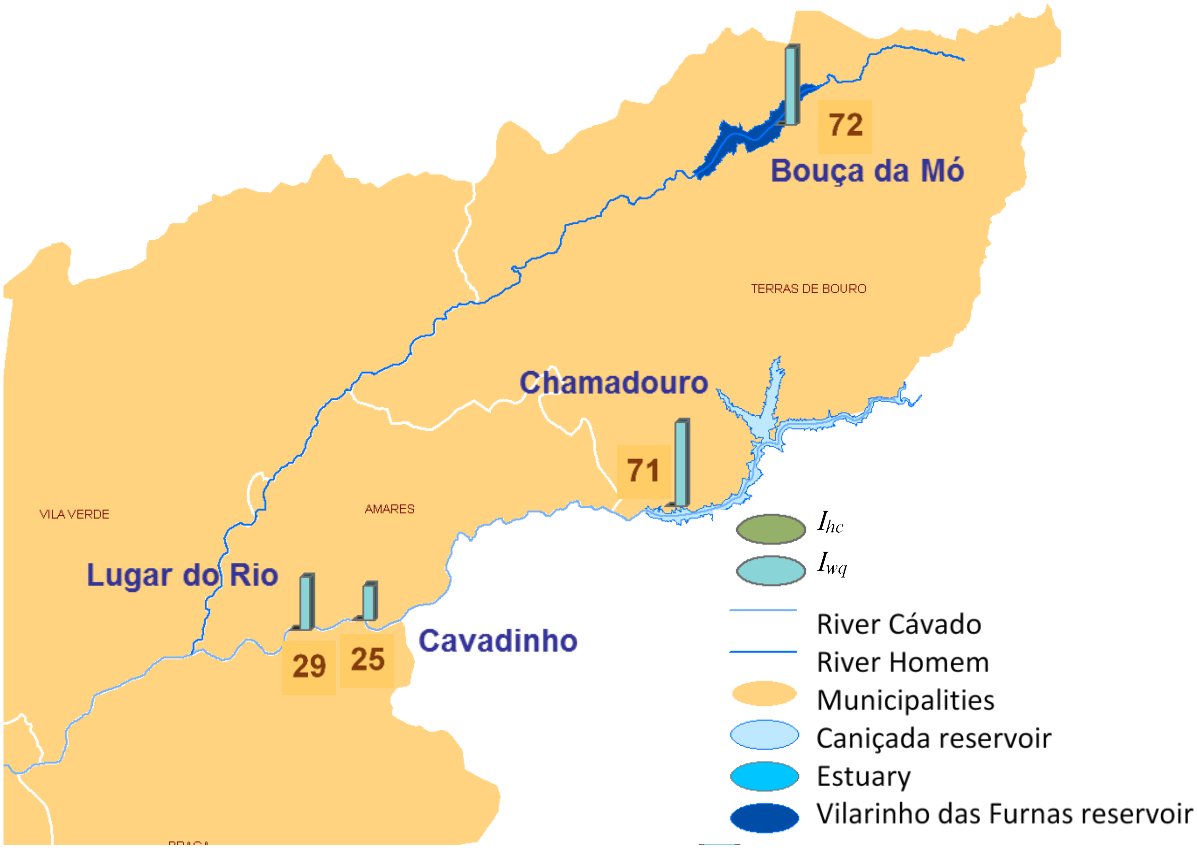

Figure 5. Examples of sites revealing high score in terms of water quality but demonstrating bad performance in terms of hydrodynamic comfort.

61. Conclusions

Hydrodynamic and water quality indicators wereintegrated into asimplifiedmodeling methodology in order to scopefluvial beaches locationsinCavadoriver basin.Indicators were based on both historical monitoring data and a hydrodynamic and water quality numerical model.Wastewater treatment performance imposed a significant pressure on bathing sites selection. In addition, the attenuationof hydropeakingphenomena was considered asa key factor to minimizerisks in recreational fluvial beaches downstream hydropower plants. This study proved that simplified multi-criteria methodologies that allow water recreational activities identification and ranking are useful in decision making processes towards anintegrated water resources management.

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