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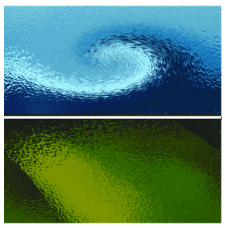

MONOGRAPH

Microbial contamination and management scenarios in a Mediterranean coastal lagoon (Etang de Thau, France): application of a Decision Support System within the Integrated Coastal Zone Management context.

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Abstract

1 - In the Thau lagoon (Southern Mediterranean Coast) the main anthropogenic pressure is represented by the urban development in the watershed, whilst oyster and mussel farming represents one of the main economical activities in the region.

2 - During the last decade, the increasing organic loads from watershed and urban settlements in the lagoon surroundings have caused a diffuse contamination by faecal bacteria. Also toxic algal blooms have been occurring, impairing water quality with major impacts on shellfish farming, fishery and bathing.

3 - In this study, indicators and scenarios identified for the lagoon have been integrated in a Decision Support System (DSS) to evaluate the best solutions for reducing pressures and improving both water quality and ecosystem status.

4 - The watershed has been analysed with reference to indicators of pollution sources and transfer rates to the lagoon. In parallel, socio-economic indicators and descriptors of urban growth and development have been assessed. Numerical models have been run in order to simulate the lagoon hydrodynamics in relation to both meteorological factors and watershed runoff. The impact of faecal bacteria contamination has been evaluated in terms of economical losses and social conflicts, arising from the restriction of shellfish farming and marketing during contamination events. Finally, the DSS prototype has been applied to the lagoon in support to management and future planning.

Keywords: Mediterranean lagoon, watershed, bacteriological contamination, scenario analysis, Integrated Coastal Zone Management (ICZM), Decision Support System (DSS).

Introduction

Mediterranean coastal lagoons are among the most productive aquatic ecosystems with a great biodiversity, but they are also intrinsically fragile and highly sensitive to external forcing (Kierfve, 1994). A brief review of the most common pressures and perturbations occurring in coastal lagoons is reported by Aliaume *et al.*

(this volume). Common features of lagoons in the Southern European Arc are also the strong anthropogenic pressures and severe threats, which pose the question of both sustainable exploitation and environment conservation.

Among the sites considered by the EU Project DITTY, the Thau lagoon (Southern France) has been studied for faecal bacteria contamination in relation with shellfish farming which is one of the main economical activity (www.dittyproject.org). Various scenarios were implemented considering ecological, economical and social implications in the context of both Integrated Coastal Zone Management (ICZM) and sustainable development. Particular attention has been given to the development and application of a Decision Support System (DSS) prototype. The DSS addressed environmental management policies and measures; priority has been given to either the mitigation of bacterial contamination or the recovery of the water quality as well as the improvement of the overall ecological status, with reference to the Water Framework Directive (2000/60/EC)

Study area

Main characteristics and threats

The Thau lagoon is located along the Mediterranean coast of Southern France (Fig. 1; see also Aliaume *et al.*, this volume). The lagoon surface is 75 km^2 with an average depth of 4 m (max 10 m) and a water volume of approximately 280 km^3. The lagoon is connected North to the sea by the "canal of Sète" (90% of sea water exchanges) and South by the "Grau de Pisse Saumes". The lagoon is under marine influence, and approximately one third of the lagoon water is exchanged with the adjacent sea each year. Hydrodynamics depends mainly on wind, tidal range being very narrow (< 10 cm). Strong North-West winds are blowing for more than 118 days per year, above level 5 on Beaufort scale. On average, water temperature and salinity range from minima of 5 °C and 27 in January and maxima of 29 °C and 40 in August, respectively.

The watershed surface is 280 km^2 and drained by a network of temporary small streams. Only the Vène river is permanent. Rainfalls show large inter-annual variations, from 500 to 1.100 mm y^{-1} (Tournoud *et al.*, 2000).

The watershed is densely populated (130,000 inhabitants, 465 inhabitants km^{-2}) and shows a positive and fast growing trend. Shellfish farming represents the main economical lagoon-based activity with an annual production of 13,000 t of oysters and 2,500 t of mussels . The Thau lagoon accounts for more than 10 % of the national French production of shellfish, the direct income of 750 small-scale producers and cooperatives is of 33,000,000 € y^{-1} (Rey-Valette, 2004).

The watershed-lagoon system is exploited for other activities which are in competition with shellfish farming ; it should be stressed that conflicts are often caused by the lack of resource allocation. Recreational and leisure activities are enhanced by a huge development of traditional and health tourism, water sports, scuba diving and hunting. Industrial and commercial activities are linked to Frontignan and Sète ports, the later being the first fishing port in the Mediterranean coast of France. Finally, the coastal zone is subject to a rapid urbanisation due to the vicinity of Montpellier city, which is of regional importance. Moreover, the Languedoc-Roussillon region is facing the country's highest population flux.

Identification of environmental threats and related policies

The main environmental concerns for shellfish farming and fishery in the lagoon are the harmful algal blooms of *Alexandrium sp*. and *Dinophysis sp*., faecal bacteria contamination, anoxia, alien species invasion, biodiversity loss and eutrophication.

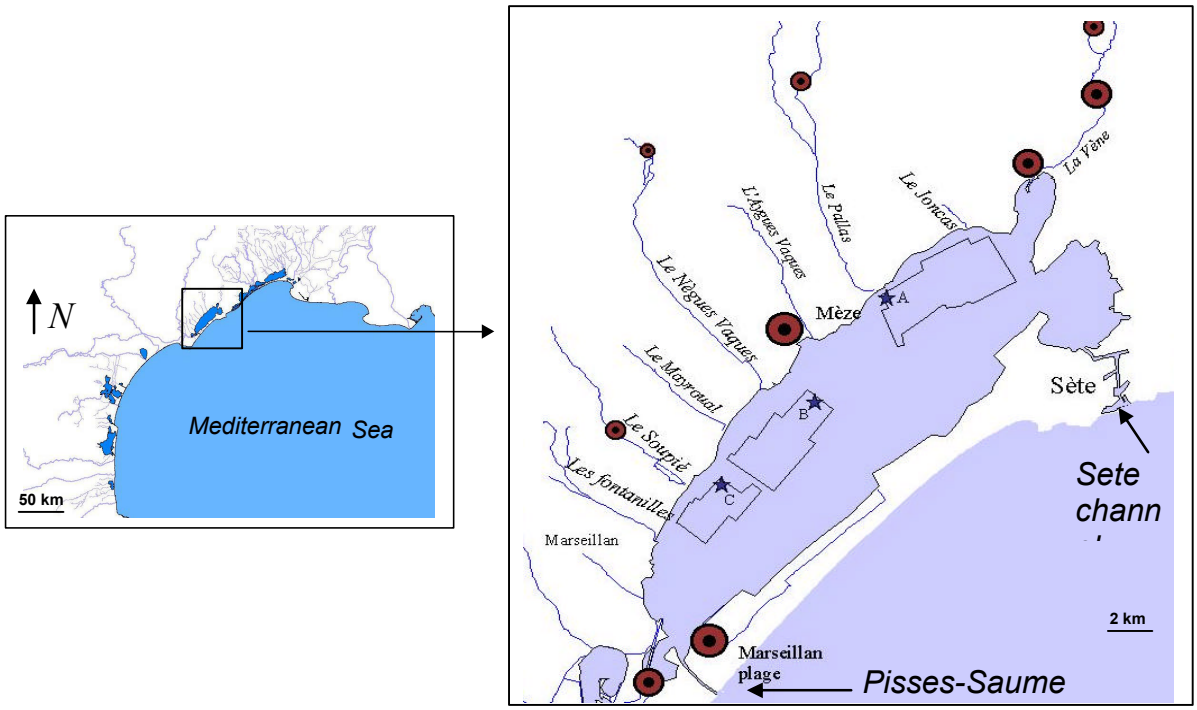

Figure 1. Thau lagoon location and major characteristics : hydrographic network, wastewater treatment plants (circles), shellfish farming zones (A, B and C) and connections to the sea (Sète and Pisse-Saumes channels).

The fact that the development of watershed-based activities could threaten the lagoon has been taken into account in the sector-based policy which was developed in an agreement between 19 municipalities around the Thau lagoon site (Vigne-Etang agreement). During the last decade, bacterial contamination from urban wastewater required an integrated watershed-lagoon management plan, which was established in 1995 (SMVM - Schéma de Mise en Valeur de la Mer). The SMVM focused on shellfish farming among priorities and options for the development of activities in the lagoon and its watershed. In order to reduce the microbial contamination, the implementation of wastewater processing plants was put in the frame of two agreements (Contrat d'Etang) among the main stakeholders. Notwithstanding the above mentioned actions, bacterial contamination of the lagoon water increased as well as gaps in knowledge and shortages in microbiological pollution control. A third contract (Contrat Qualité) was set up and implemented with reference to environmental management procedures (ISO 14001) and to water quality standards for both bathing water quality (regulation IT 178/2002) and production and marketing of bivalve molluscs (2006/7/EC Directive).

An integrated management of the lagoon and its watershed was also developed aiming at a better land use planning (SCOT - Schéma de COhérence Territoriale) and water management (SAGE - Schéma d'Aménagement et de Gestion des Eaux). Furthermore, most of the actions taken in the watershed-lagoon system were in agreement with the goals of the Water Framework Directive (WFD, 2000/60/EC), namely the achievement of a good ecological status of the lagoon ecosystem within 2015.

Overall, actions and management options allowed to identify the main threats and their causes. Among these, at present, the bacterial contamination is the main concern and depends on the influence of Mediterranean heavy rainy events associated to wastewaters works malfunctioning.

Considering the regulation context and the strong economic and social pressure on the watershed-lagoon system, the recovery of water quality standards and ecological status of lagoon and adjacent marine ecosystems

constitutes a real scientific, technological, socio-economical challenge, that requires the development of new tools and approaches in an Integrated Coastal Zone Management context. Along with sustainable solutions for the main environmental problems, an integrated system for early warning becomes necessary to manage issues which cannot be solved in an economically acceptable fashion.

Most of those issues have been framed and analysed in the DITTY project. Specifically, for the Thau lagoon, the main objective was to support environmental policies and management in order to find out sustainable solutions for shellfish farming and bathing.

Methods and tools

Diagnosis of environmental and economical contexts

Based on the actions and studies mentioned above, the economic activities in the watershed-lagoon system were classified in three categories taking into account their pressures and impacts on lagoon and aquatic resources (Rey-Valette and Valette, 2005) :

- Specific activities related to the exploitation of the lagoon are shellfish farming, professional and non professional fishing, harbour activities, tourism, bathing, but also hunting , water sports, diving, nature discovery and watching,
- Activities in the watershed are mainly linked to agriculture and urban development in relation with the demographic trends and fluxes,
- Commercial and industrial activities are connected to the development of Sète harbour.

The assessment of present status and future trends was performed assuming different socio-economic and environmental factors which are summarised below :

- The urbanisation of the lagoon surroundings is leading to the development of a residential economy which depends on the daily migrations of about 14 % of the population to and from Montpellier city,
- Demographic dynamics vary among areas according to five sub-zones, which foreseen growth rates range from 8 to 72 % until 2020 (Fig. 2), - The lagoon surroundings provide up to 40 % of the tourist accommodation facilities of the Hérault department. An equivalent tourist flux is also related to second houses,
- Life quality and environmental standards are perceived in a different way by different population sectors,
- Agricultural areas cover 44% of the watershed surface, of which 80% are used for vineyards,
- The sanitary standards for waters used for shellfish farming and bathing are the main constraint for the lagoon exploitation. For example, since June 2004, due to faecal bacteria pollution the Thau lagoon was downgraded from A to B sanitary class according to European Directive 91/492/EC; as a consequence, to be put on the market purification of molluscs is compulsory.

Data handling and definition of index of bacterial contamination

Since bacterial contamination has been identified as the main concern for water quality and local economy, the first step in the DITTY project consisted in setting up of a logical scheme which summarises the main issues exposed hereupon (Fig. 3). According to the logical diagram the main factors involved in bacterial contamination were identified and assessed, namely watershed characteristics, typology of meteorological events, identification and characterisation of pollution sources, evaluation of wastewater infrastructures in the watershed, definition of a transfer index of pollutants from the watershed to the lagoon, identification of lagoon areas which are sensitive to bacterial contamination and contaminant transport within the lagoon. Impact and risk assessment, economical evaluation of risks and management options were also considered.

The main goal was to build up a set of indicators to assess the pollutant/bacterial contamination in the watershed and its transfer to the lagoon. The methodology used was based on a Geographical Information System (GIS) application with the support of a multicriteria analysis of the data sets (Fig. 4). A full description of methods used is reported in the technical reports of the DITTY project (www.dittyproject.org).

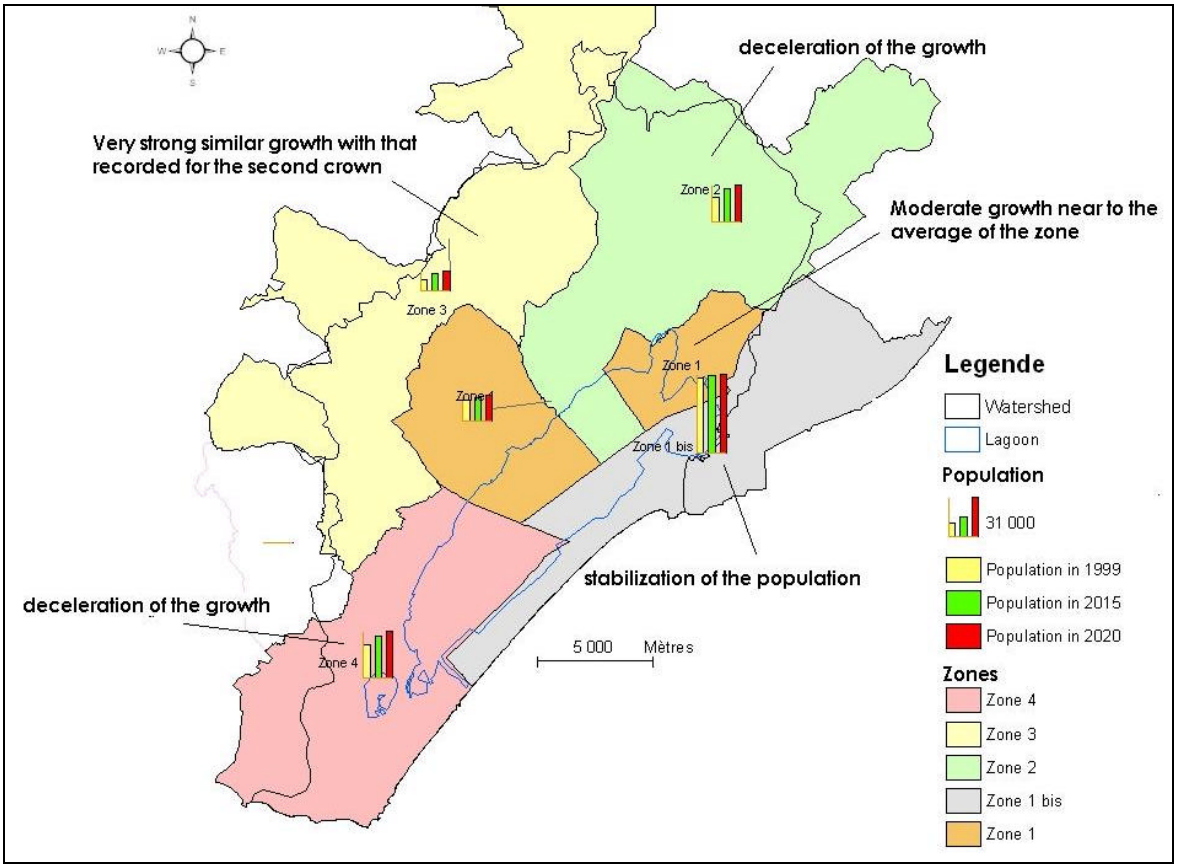

Figure 2. Demographic dynamics in the watershed of the Etang de Thau. Five zones were identified with different trends.

The transfer index of pollutants from watershed to the lagoon was defined by identifying critical environmental issues in the watershed (Musy, 2003). It is based on the availability of a slope map derived from a Digital Terrain Model of the watershed (Fig. 5a) and land use (Fig. 5b) and soils pedology types maps (Fig. 5c). The integration of slope, land use and pedology is realised using spatial analysis with GIS algebraic map computed in raster format (Fig. 5d) in order to obtain a first transfer index to the watershed. This index is then weighed according to the distance from the lagoon using GIS spatial analysis ; distance buffers of one km from the lagoon (Fig. 5e) was computed to produce an integrated transfer index from the watershed to the lagoon (Fig. 5f).

The Thau Basin Agglomeration Community (CABT) and the Northern Basin Community (CCNBT) are the bodies in charge of the wastewater processing for the Thau lagoon. A diagnosis protocol is performed for assessing the critical functioning of water treatment plants, aiming at identifying the infrastructure shortages which lead to sewages releases and bacterial contamination. The inventory and the location of infrastructures susceptible to cause a sanitary impact on the lagoon are archived in a georeferenced database. Using these data, indices of critical functioning have been calculated according to ISO 9001 and 14001 standards and based on the AMDEC methodology (Analyse des Modes de Défaillance, de leurs Effets et leur Criticité). The wastewater infrastructures and their critical indices are then mapped using the cartographic module of the GIS (Fig. 6). The combination of the integrated transfer index with the index of critical functioning gives an index of the lagoon sensitivity to bacterial contamination (Fig. 7). Here, the sensitivity is assessed in terms of potential risk linked to wastewater discharges into the lagoon.

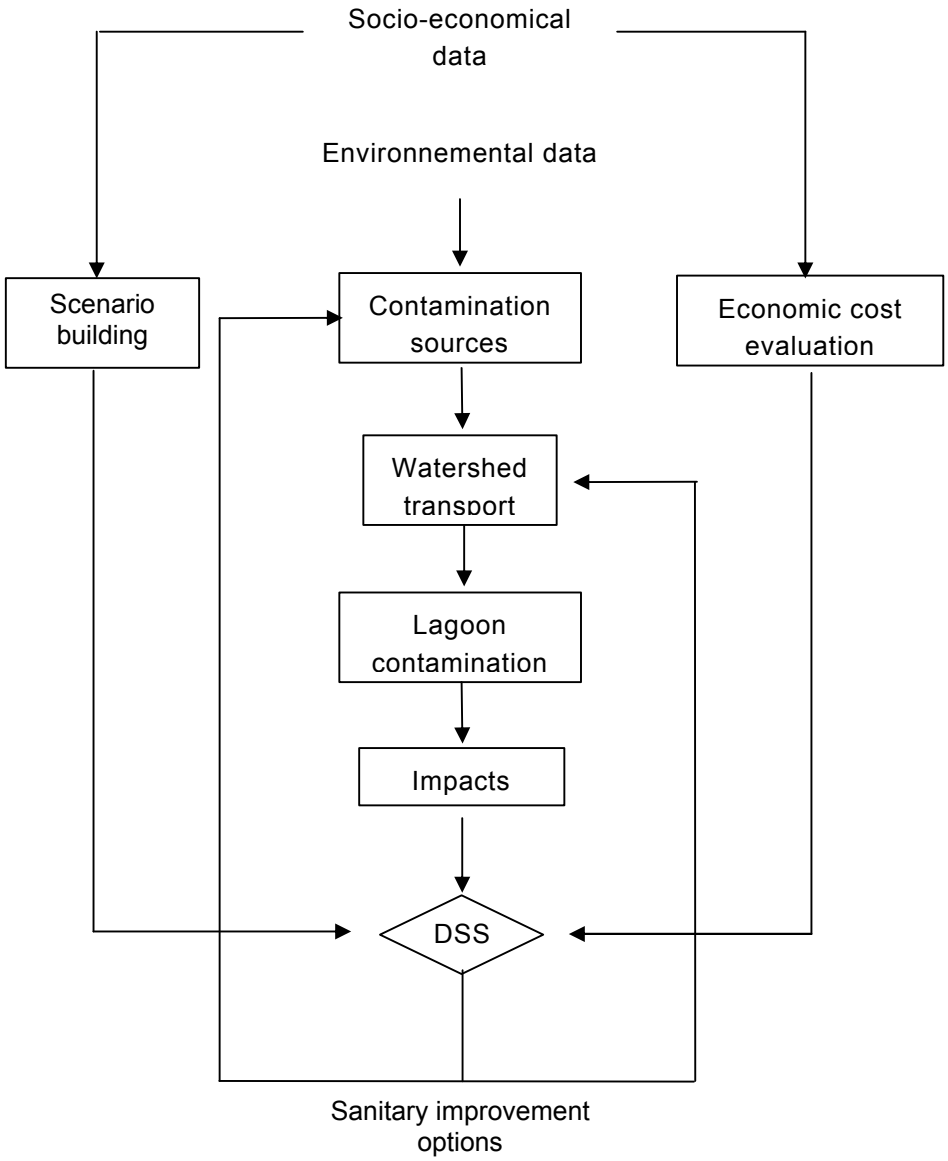

Figure 3. Conceptual scheme representing factors and processes involved in the bacterial contamination of the Thau lagoon.

Integration of socio-economic and demographic data in the environmental context

Pressures and impacts on the lagoon have to be analysed in the context of the recent demographic trend, which has been characterised by an annual average increase of 1500 inhabitants during the last 15 years (Valette and Rey-Valette, 2004). The overall demographic growth corresponds to a supplementary land occupation of 100 ha y^{-1}, of which 90 % is made of urbanised areas. Considering the watershed zones (Fig. 2) and a Business as Usual (BAU) scenario, one can foresee a saturation in the Eastern area and a demographic increase in the Western area which has been basically rural until now (Table 1). Due to the different degree of sensitivity to bacterial contamination, an increase of residential population in the Western area will have a greater impact on the lagoon followed by an increase of water pollution (Fig. 8). We also considered two options, based on different policy targets (Table 2). A more restrictive policy will increase environmental protection, whilst a support to the economic development of this zone, where the unemployment rate is among the highest in the department, will cause further impacts.

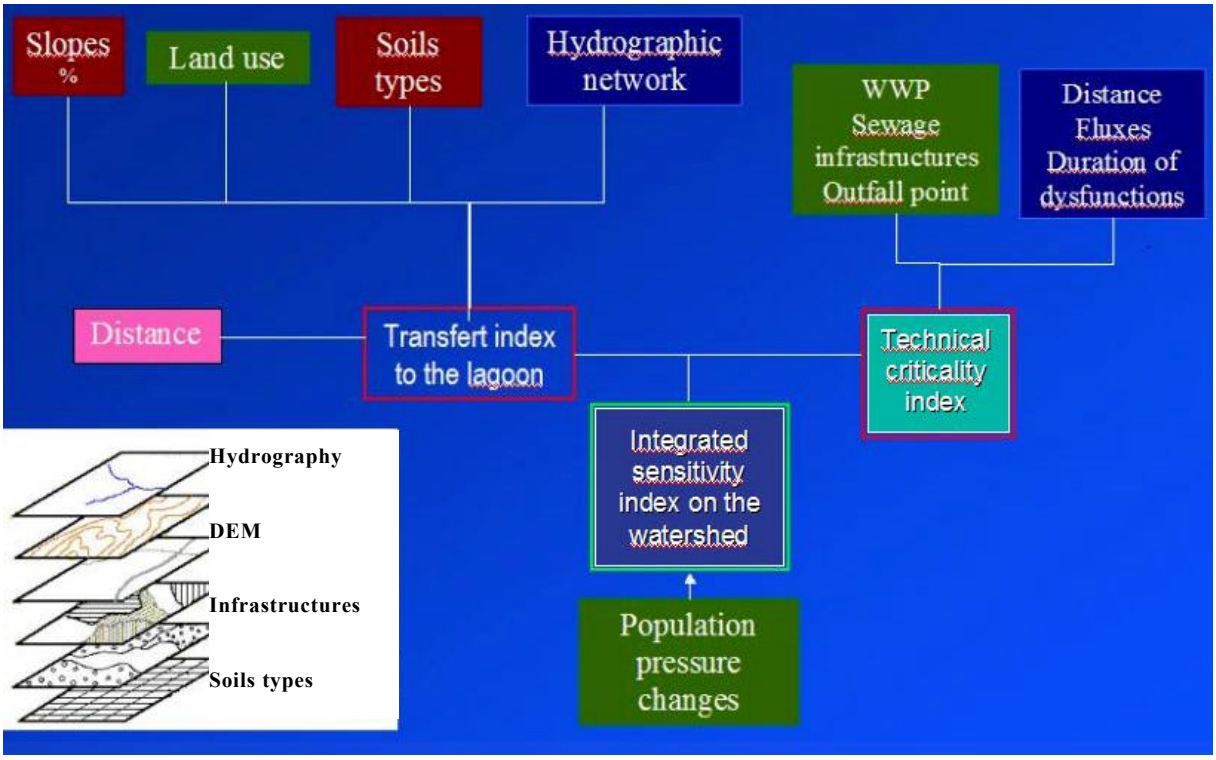

Figure 4. Flow chart describing the methodology developed to define an integrated sensibility index of the watershed.

Table 1. Demographic evolution *vs* wastewaters outlets. N: number of inhabitants, %: relative population increase as percent of the population in 2004.

		Wastewaters outlets		Total
		Lagoon	Sea	
Population in 2004	N	36,172	93,333	129,505
Population increase by 2015	N	47,394	104,426	151,820
	%	+ 31	+ 12	+ 17%
Population increase by 2020	N	53,004	109,972	162,977
	%	+ 47	+ 18	+ 26%

Table 2: Demographic trends under different economic development options

	Economic development	Population forecasts by 2015
Average hypothesis	Business as usual	151,820
Low hypothesis	Environmental issues, low population growth, increase of the social disparities	141,191
High hypothesis	Incentives to economy, strong population growth, employment increase, improvement of socio-economic conditions	182,220

