

# A Big-Data-Analytics System for Supporting Decision Making Processes in Complex Smart-City Applications

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**Abstract.** Water is a fundamental element for the life of the ecosystem and of the human beings. Seas and oceans consist in the vastest available space on the planet. Water management is thus a critical issue in the context of smart-city applications, which maybe addressed via consolidated big data analytics methodologies. In addition to this, monitoring the quality of the water in order to decide current and future policy for having a high-quality ecosystem is today possible using connected and distributed devices. In such context, the relevant amount of data that can be acquired can be classified in order to create a big-data analytics-based Decision Support System (DSS) that represents a useful tool towards multiple purposes ranging from environmental monitoring and spatial planning to leisure activities, fishing and bathing. In this paper we propose a general design of a DSS for water quality management and we present several use cases that show how the system can be helpful to face operational, tactical and strategical decisions.

**Keywords:** Big data analytics · Smart city applications · Decision support systems · Water management

## 1 Introduction

Water is a fundamental element for the life of the ecosystem and of the human beings, thus becoming a global issue. Share water and identify it as a precious good it is unavoidable for all humankind. As the World Water Council [7] remembers "Together we make water a global priority", and this goal can be achieved by mobilizing actions on critical water issues at all levels and focusing on the political dimension of water security, adaptation and sustainability. Sharing water is non-questionable, but it is how to share the information related to it, because they are strictly connected to environment's and at the end to our health. The scientific knowledge tells us that water is the most widespread substance in our Planet. Water covers about the 71% of the Earth surface, the total amount of water resources is approximately of 1,386 million cubic kilometers, with more than 1,338 million cubic kilometers covered by Oceans, Seas, & Bays. A reliable

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evaluation of the global water resources was collected by Soviet scientists and presented by Igor Shiklomanov in a summarizing table called "Water reserves on the earth" [21], that follows, proposed in graphical version [1]. These are accurate but only approximate estimations, since water is a substance in continuous dynamism and in permanent motion. Increase and enhance the knowledge of this substance, which has a special role with respect to the others, is an arduous but essential mission, due to water vital influence on the natural environment.

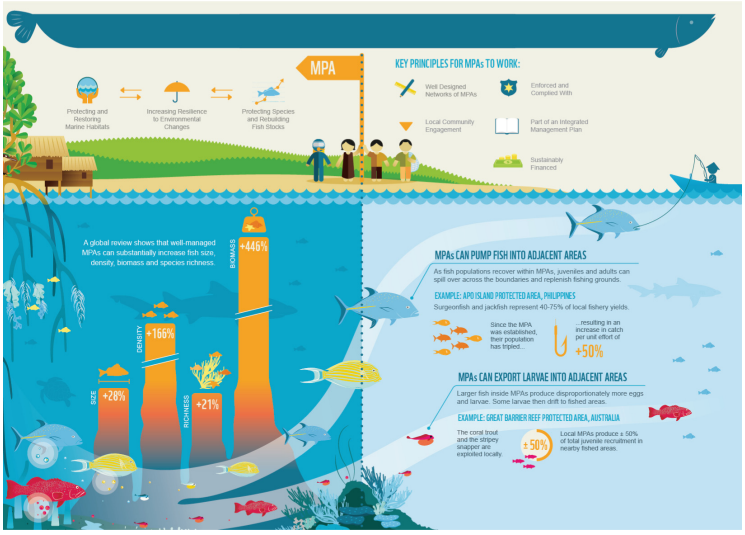


**Fig. 1.** Sea environment to be monitored

The World Meteorological Organization (WMO) [6], in order to satisfy the need of knowledge and consciousness relating to the water resources, proposes the "The Guide to Hydrological Practices" [5,9], that is almost the major output of the activities of the WMO Commission for Hydrology (CHy); the first edition of the Guide to Hydrometeorological Practices was published in 1965. This is just an example of document edited on the purpose to offer methodical guidelines to brave the challenge of the water issue. Another example is the one presented in the framework of the International Hydrological Programme [22] that focuses on the freshwater aspects proposing, at the same time, some basics consideration regarding water resources in general, some of them touched upon also in this article. A lot of conferences and activities in general focused in the water issue are promoted by many local and international, governmental and non-governmental organizations. Some of which have made a significant breakthrough in convincing humankind to tackle climate change as the agreement on the climate of Paris in 2015 promoted by Jen Schwartz. This put in evidence how the interconnection offered by the new devices and instruments of communication can sensitize and improve knowledge, transposing a local problem into a global issue, where every

person, with regard to his skills and social role, can intervene. The question needs to be faced from all possible points of view, and the progress towards better water quality must be shared in a constructively competitive research race. The quality of the water can be monitored, in order to decide current and future policy for having a high-quality ecosystem, by using connected and distributed devices. Nowadays we have an enormous quantity of studies but also new technologies, that can make a further leap forward towards future actions to be taken. Due to the modern technology, for example, it is possible to compare a very extended amount of data, as NASA exalt "Big Data Helps Scientists Dig Deeper", with the phenomenon known as "big data", computers crunch vast quantities of information to identify useful patterns [1]. Another emerging use of the relevant amount of data that can be acquired, is to classify them in order to create a Decision Support System (DSS), which represent a useful tool towards multiple purposes.

In this paper, we will focus on purposes that range from environmental monitoring and spatial planning to leisure activities, fishing and bathing, like in so-called Marine Protected Areas (MPA) (Fig. 1). In particular, we propose a methodology to manage water quality that can be helpful to face operational, tactical and strategical decisions, putting in evidence the ones strictly related to surface water quality. In doing this, we recognize water management as a critical issue in the context of smart-city applications (e.g., [15,28,31]), which maybe addressed via consolidated big data analytics methodologies (e.g., [18,24,29]). We present a general architecture for a big-data analytics-based Decision Support System for surface water monitoring. Surface water are those that collect on the surface of the earth; waterways, lakes, wetlands, seas and oceans constitute surface water. The main goal of the proposed DSS is allowing to collaborate and reuse data inputs according to different business models, sharing and improving the data needed for different decision makers insisting on the same surface water facility. The main characteristic is the fusion of different data sources in order to enhance both the temporal sampling and the spatial sampling.

The rest of the paper is structured as follows. In Sect. 2 a literature review on existent decision support systems for water management is presented. Then, Sect. 3 introduces the Environmental parameters typically used to define water quality and the related KPI used to measure it. Section 4 describes the general architecture of the proposed DSS. Section 5 describes actors, business cases and related KPI, and Sect. 6 presents some preliminary experimental results. Finally, Sect. 7 outlines conclusion and future developments.

## 2 Literature Review

Decision Support System has been widely studied and applied in different field, as for example in logistics [16], mobility [13,17], security [14,19], comfort [20,26], etc. In the management of water and ecosystems, the concept of sustainability nowadays often named as a goal for businesses, nonprofit organizations and governments. Sustainability is the need of a constant and preferably growing well-being and the prospect of leaving future generations with a quality of life that

is not inferior to the current one. From this type of approach arises the development of the Triple Bottom Line (TBL) framework that involves three macro spheres of influence: social, environmental and financial [25]. This approach can be developed in different specific contexts and integrated in a Decision Support System. An example of the integration between biological information and modelling with the TBL approach will be briefly exposed in section V, in relation to the increasing complexity of fishery management [2]. Increasing the possibility of investigation increases also the complexity of the model used to understand a specific problem. The U.S. Geological Survey National Water Quality Assessment Program [3] uses the calibrated SPAtially Referenced Regression On Watershed attributes (SPARROW) models to investigate in stream-water quality in relation to human activities and natural processes [4]. The high level of experience necessary for its use has meant that this model could only be accessed through a DSS that simplified the processing and re-presented in tools that were easier to interpret [11]. Different approaches and methods of investigation are useful to describe the condition of the water and the environment in general. The tools for measuring, collecting and processing data improve in precision, quantity and quality, as the parameters of investigation. What is fundamentally essential to be more efficient and effective in terms of time and resources, and also up with the times and consistent with the efforts made is to be, as much as possible, collaborative.

## 3 Environmental Water Quality Parameters

To cope with quality of surface water, a wide set of parameters can be observed to evaluate the state of the water. In literature, the water pollutants can be classified into broad categories [10]. In Table 1 we have extended the broad categories of [10] to include also visual pollution and other perception based parameters. The resultant broad categories are marked in Table 1 with a letter for practical identification in the following:

The parameters introduced in Table 1 are variables that can be measured. Such measures can represent directly a Key Performance Indicator (KPI) to evaluate the quality of water or they can be combined to obtain more complex KPI. For example, in literature [10] several sets of KPI are defined to monitor the water quality, as for example:

- water stress index;
- total faecal coliforms;
- days of operation at required standards;
- repair times for high priority inoperative lines;
- percentage of total suspended solids;
- amount of potentially dangerous organisms (i.e., e. coli, naked amoebae, etc.);
- compliance in quality when compared to legal standards;
- dissolved air floatation performance;
- total cost of operations;
- metrics that measure specific systems and support vital to consistent operations.

**Table 1.** Water pollutant categories

| | Categories | Parameters (some examples) | General use |
|---|---|---|---|
| *A* | Basic variables | Water temperature, pH, salinity, dissolved oxygen, and discharge | Used for a general characterization of water quality. |
| *B* | Organic pollution indicators | Dissolved oxygen, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonium | |
| *C* | Organic micropollutants | Such as pesticides and the numerous chemical substances used in industrial processes. PCB, HCH, PAH | |
| *D* | Specific major ions | Chloride, sulphate, sodium, potassium, calcium and magnesium. As essential factors in determining the suitability of water for most uses (eg. public water supply, livestock watering and crop irrigation) | |
| *E* | Microbiological indicator organism | Total coliforms, fecal coliforms and fecal streptococci bacteria | |
| *F* | Biological indicators of the environmental state of the ecosystem | Phytoplankton, zooplankton, zoobenthos, fish, macrophytes and birds and animals related to surface waters | |
| *G* | Suspended particulate matter | Suspended solids, turbidity and organic matter (TOC, BOD and COD) | |
| *H* | Metals | Cadmium, mercury, copper, zinc | |
| *I* | Indicators of eutrophication | Nutrients (eg. nitrogen and phosphorus), and various biological effect variables (eg. chlorophyll a, Secchi disc transparency, phytoplankton, zoobenthos) | |
| *J* | Indicators of acidification | pH, alkalinity, conductivity, sulphate, nitrate, aluminium, phytoplankton | |
| *K* | Indicators of radioactivity | Total alpha and beta activity, 137Cs, 90Sr | |
| *L* | Visual pollution | Tarry residues, glass, plastic, rubber | |
| *M* | Perception based parameters | Color, turbidity, smell | |

In general, KPI are not static and unchanging. Moreover, they strictly depend on the business context that they are applied.

## 4 DSS Architecture

The aim of this work is to propose a Collaborative DSS capable of aggregate and integrate different data sources regarding the measurement of the parameters affecting water quality (see Table 1) in order to produce added value in different application scenarios. The proposed Collaborative DSS can improve data to generate new information for a specific application domain using the related scientific knowledge.

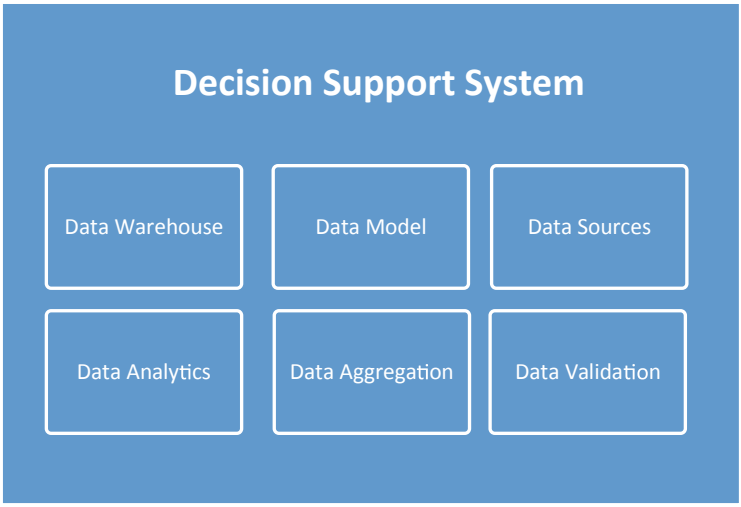


**Fig. 2.** DSS main features

The main objectives of the proposed Collaborative DSS are depicted in Fig. 2 and are described as follows:

1. Share information regarding data quality already acquire from public authorities;
2. Share information regarding specific measurement campaign in specific region;
3. Aggregate information around different data sources;
4. Provide evaluation and KPI for different specific application sectors;
5. Stimulate the citizen to evaluate the state of surface water and signal problems to the authorities by using the DSS.

The structure of the proposed Collaborative DSS, suited for managing the environmental quality of both salt and fresh water, is the following. The system

consists of a platform with which you can interact both via web pages and via smartphone Apps. Every user has to register to the Collaborative DSS giving his/her references. After the registration, typical power usage of the system can be guaranteed via log in. According to user liability assigned during the registration phase, the information he/she sends will have a different degree of reliability. The DSS can manage data coming from institutional bodies and individual citizens, from research areas and from economic bodies (for example, aquaculture companies) or even data from the marinas or managing institution, tour operators or from the tourists themselves. The collected data is geo-referenced. Some of the collected data are already certified if acquired from certified entities, some other are not certified if collected by causal users. Those data is managed by the Collaborative DSS taking into account the different degrees of reliability. Each user can send its own data to the Collaborative DSS: measurements made with expensive professional tools or with portable instruments or subjective perception and visual information related to the quality of the water. The Collaborative DSS can be tailored to different applicative scenarios. For each scenario, the platform provides an indication of the water status in the area of interest. The output of the Collaborative DSS aim at reducing the workload of the decision makers by providing a semaphore indicating the status of the water in the given scenario. The semaphore will be green if the quality in high, it is yellow if the quality is medium and it is red if the water quality is not acceptable. The best practices, derived from experts knowledge in the specific field, will drive the choice of the best decision-making policies to be realized.

## 5 Business Cases

### 5.1 Stakeholders Involved

For the Collaborative DSS a wide set of stakeholders can be outlined. We propose to consider the following categories of actors, that can include all the possible involved stakeholders:

1. Citizen: people that interact with surface water;
2. Active citizen: citizen that actively produces data to update data relative the region he/she is moving;
3. Private Company: private firm that operates near/on surface water, for example fishing company, maritime transport company, etc.;
4. Public Company: private firm that operates near/on surface water, for example environmental research company, wastewater management company, etc.;
5. Public Authority: police, territorial entity, etc.

### 5.2 Business Models

The actors introduced above can operate in different operative scenarios. In the following we define three business cases that point out that the same water parameter can have different evaluation in different scenarios. The business cases

considered in the following are Bathing, Fishing and Aquaculture, and Protected Natural Area. In Fig. 3 is represented the interconnection among the measured parameters (Table 1) and the applicative business cases considered. Note that in Fig. 3 the same parameter can be involved in different business cases with different evaluation criteria. The aim of Fig. 3 to show how the interconnection at different granularity levels can identify and characterize the specific business case.

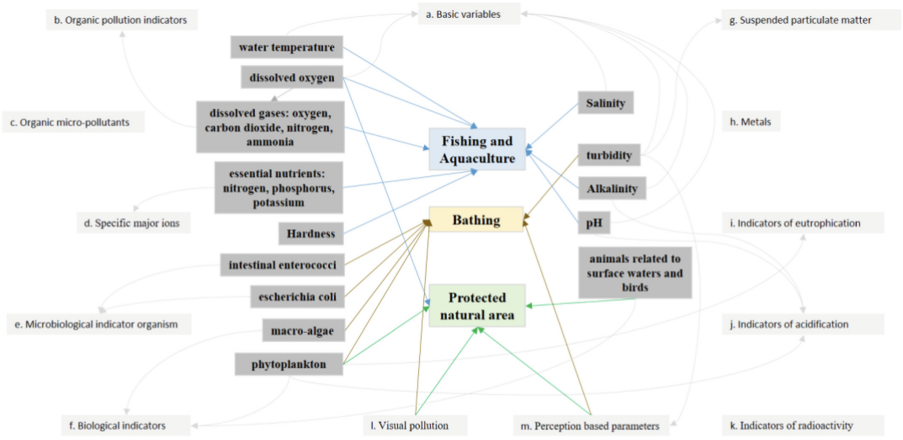


**Fig. 3.** Mind map of parameters for different business cases

**Business Case 1: Bathing.** In this case (see Fig. 4), we consider the typical behaviour of a tourist that during summer would like to have a bath at the sea/lake/river and he/she guesses about the status of the water of the region they are attending. The most observed parameters that prove the quality of bathing water are the presence of enterococci and escherichia coli, or the presence of cyanobacteria or microalgae but also other parameter could be taken into account. As European Commission directives remembers the waters are classified according to their level of quality: poor, sufficient, good or excellent. We knows, for example, that the activities to guarantee that the citizens are adequately informed are yet supervised.

Especially during the summer seasons warnings of danger to bathing are easily identifiable and they are managed by authorities. One of the possible way to extend the capability to prevent water quality contamination is enlarging the area of observation. The covered area can be improved by collecting different sources. The tourists can become a citizen science providing, for example, himself/herself with simple measuring instruments or engaging monitoring instruments to pleasure crafts. This kind of measure have to be evaluated by the proposed Collaborative DSS to appropriately enforce the knowledge of the surface water quality.

Relevant parameters to evaluate the water quality for bathing can be derived according to the Bathing Water Directive [8] and considering other relevant

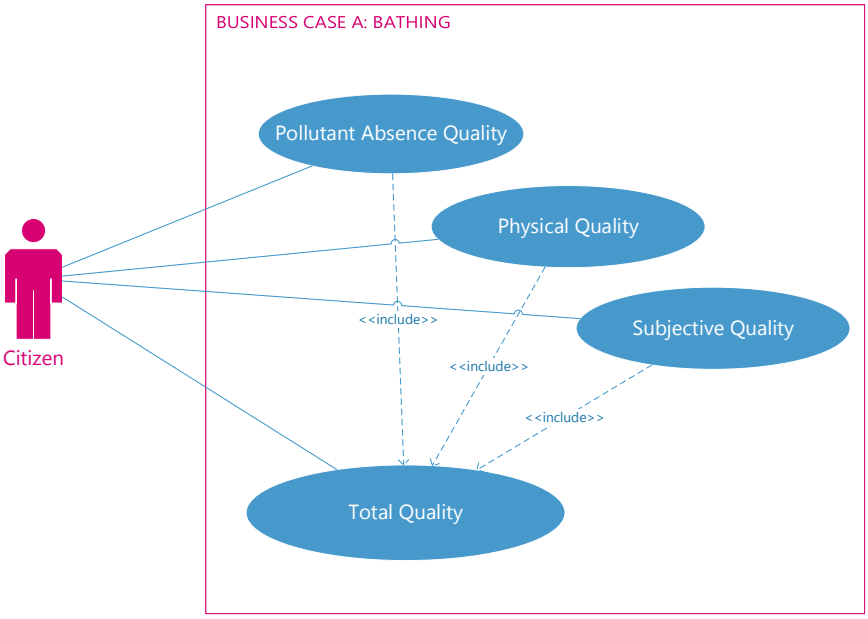


**Fig. 4.** Business Case 1 use case

**Table 2.** Water parameters for Business Case 1: BATHING

| Categories | Parameters BC1 |
|---|---|
| *A* | Temperature |
| *A* | Salinity |
| *G M* | Turbidity |
| *E* | Intestinal enterococci |
| *E* | Escherichia coli |
| *F* | Macro-algae |
| *F I J* | Phytoplankton |
| *L* | Tarry residues, glass, plastic, rubber |
| *M* | Color, smell |

human perception as shown in Table 2. Note that in Table 2 we have introduced some parameters belonging to visual pollution an perception based parameters.

**Business Case 2: Fishing and Aquaculture.** This business case (see Fig. 5) is considered due to the importance of the aquatic environment for fishing and aquaculture. The water quality requirements have different range for different fish species and this aspect has a strong impact on the fish under culture [27] (Table 3).

**Table 3.** KPI for Business Case 1: BATHING

| KPI BC1 | Name | Meaning |
|---|---|---|
| BC1_KPI1 | Water quality | Evaluation of the parameters described by the European legislation |
| BC1_KPI2 | Water perception | Perceived comfort of the water |
| BC1_KPI3 | Environment | Context in which the measurement is made |

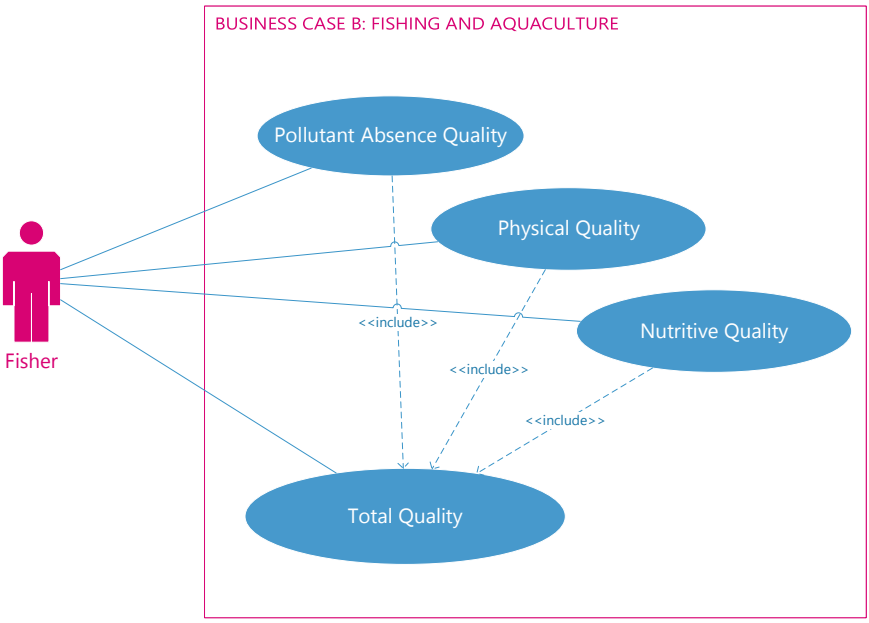


**Fig. 5.** Business Case 2 use case

In Table 4 relevant parameters to evaluate the water quality in case of Fishing and Aquaculture are presented. It is worth to note that, analyzing Table 4, the parameters considered are related to presence of pollutants and the nutritional characteristics of the water and that visual and perceptional parameters are not considered.

Starting from the measured parameters of Table 4 we propose the relevant KPI for the Fishing and Aquaculture business case. In Table 5 we propose to consider water quality, nutritional proprieties and abundance of fish KPI.

**Business Case 3: Protected Natural Areas.** With the term protected natural area (see Fig. 6) we include all those natural areas characterized by heterogeneous landscapes and of particular importance regarding wildlife, flora and fauna, including anything that makes them of special environmental interest. Due to their beauty and uniqueness the tourism is promoted but always in respect to the preservation of the environment. Protected natural areas can be designed

**Table 4.** KPI for Business Case 2: FISHING and AQUACULTURE

| Categories | Parameters BC2 |
|---|---|
| *A* | Temperature |
| *A J* | pH |
| *A* | Salinity |
| *G M* | Turbidity |
| *A B* | Dissolved oxygen |
| *B* | Other dissolved gasses: carbon dioxide, nitrogen, ammonia |
| *J* | Alkalinity |
| *I* | Essential nutrients: Nitrogen, Phosphorus, Potassium |

**Table 5.** KPI for Business Case 2: FISHING and AQUACULTURE

| KPI BC2 | Name | Meaning |
|---|---|---|
| BC2_KPI1 | Water quality | Presence pollutants in the water |
| BC2_KPI2 | Nutritional properties | Presence of nutrients |
| BC2_KPI3 | Abundance of fish | Presence of organisms influencing fish life |

by public institutions or private individuals, such as charitable or research institutions. Coastal protected areas are constantly monitored in regards of water quality to be sure that the eligible standard values of quality are not exceeded, then compromising the status of all the investigated area. Those values can be shared to all the people interested in, because it is usually an information of public domain. Conversely, the measures analyzed and elaborated from researchers can be shared with the legal entity responsible of the protected area and, after validation, shared in the appropriate form to all the people interested in the results. At the same time a tourist can stumble upon some evident anomaly in the water surface quality, for example an oil stain, and alert immediately the authority sending some simple kind of messages to the Collaborative DSS. When the tourist identifies some generic anomalous event, the Collaborative DSS decides on the status of the water and what kind of action has to be taken. The warning can be of different kinds and starts from different users with different reliability. For this reason, in a such delicate context, the communication interface of the Collaborative DSS has to be adequate for different users. This permits to weight at the same time the warning and the information in relation to their origin. In such context the measures taken by researchers, with a high level of reliability, can effectively turn from local into global consistency and collaborate to the aim of the global environment issue.

In Table 6 relevant parameters to evaluate the water quality in case of Protected natural area are proposed. Note analyzing Table 6 that visual pollution and perception based parameters are considered relevant to define the KPI for this business case.

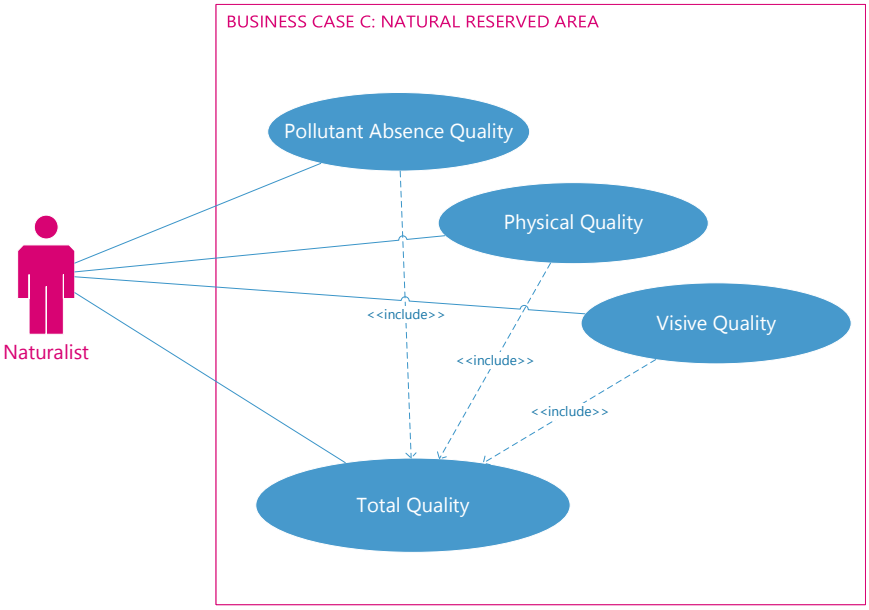


**Fig. 6.** Business Case 3 use case

**Table 6.** Water parameters for Business Case 3: PROTECTED NATURAL AREA

| Categories | Parameters BC3 |
|---|---|
| *A B* | Dissolved oxygen |
| *F I J* | Phytoplankton |
| *G M* | Turbidity |
| *F* | Birds and animals related to surface waters |
| *L* | Tarry residues, glass, plastic, rubber |
| *M* | Color, smell |

**Table 7.** KPI for Business Case 3: PROTECTED NATURAL AREA

| KPI BC3 | Name | Meaning |
|---|---|---|
| BC3_KPI1 | Water quality | Presence pollutants in the water |
| BC3_KPI2 | Water affinity | Congruence with the environmental attitude of the neighborhood |
| BC3_KPI3 | Flora and fauna | Well-being and biodiversity of the environment |

Starting from the parameters listed in Table 6 we have defined relevant KPI for the protected area business case. In Table 7 we propose to consider water quality, water affinity and flora and fauna KPI.

## 6 Preliminary Experimental Results

The proposed system has been tested by feeding in information from different data sources. Business Cases presented in Sect. 5 have been considered. In the preliminary experimental results presented in this Section, the Gulf of Trieste region of the Adriatic Sea in Italy has been analyzed.

More precisely, in Fig. 7 an example of quality evaluation of the water for bathing is reported.

Figure 8 shows an example of aquaculture water quality evaluation is presented. In this example, some artificial problematic values of pH of the water has been added, in order to show that the proposed DSS generates warning in case of water parameters out of ranges.

Finally, Fig. 9 illustrates the water quality analysis of reserved areas.

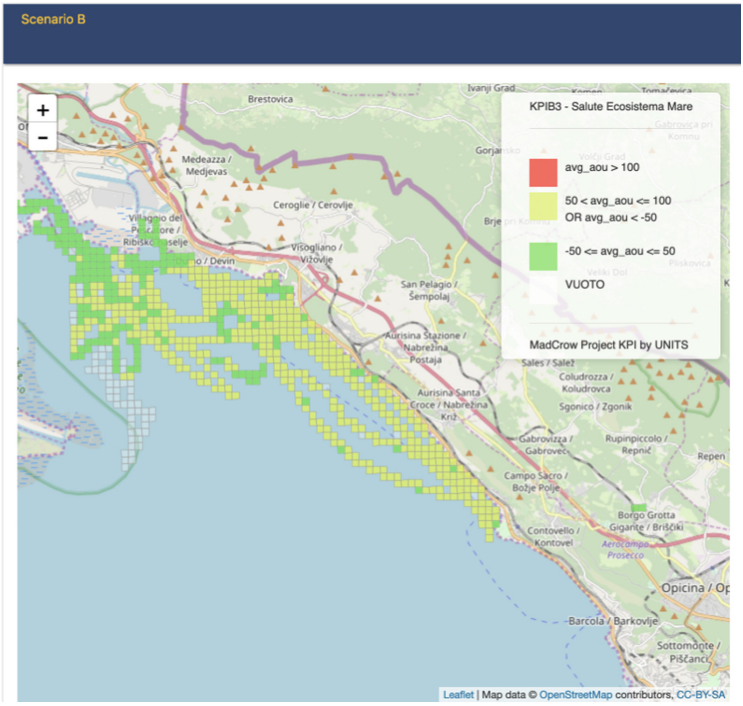


**Fig. 7.** Business Case 1: experimental results

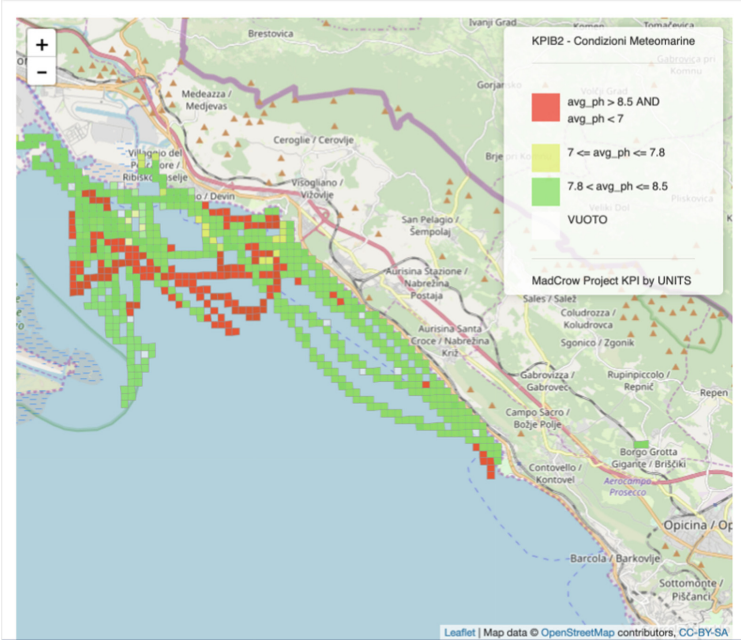


**Fig. 8.** Business Case 2: experimental results

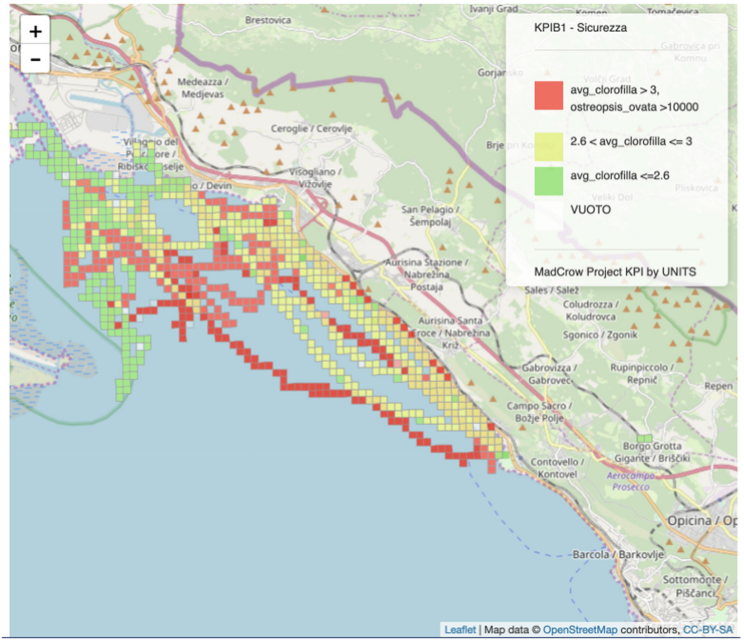


**Fig. 9.** Business Case 3: experimental results

## 7 Conclusions and Future Work

In this paper we have analyzes the potentiality of a Collaborative DSS approach in order to face the problem of the reuse of water quality data in different applications. DSS input variables have been collected into broad categories to simplify their interpretation. Starting from the parameters belonging to such broad categories we have outlined three relevant business cases and related KPI that reuse and reinterpret the meaning of the common parameters adapting them to the specific application. Note that the same parameter can affect mere than one KPI and can be interpret in different way in different business cases. Future work will be conducted for implementing this approach using real data collecting from public institution and voluntary measurement from citizen scientist. Also, performance issues in the context of the underlying big data processing layer will be considered (e.g., [12,23,30]).

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