Status of receiving bodies: from on-line measurements to the development of a quality index

Etat des milieux récepteurs : de la mesure en continu au développement d'un indice de qualité

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RESUME

La directive cadre sur l'eau (DCE) impose le «bon état» de toutes les masses d'eau d'ici 2015 et une mise en œuvre de programmes de surveillance pour évaluer la qualité des masses d'eau. Dans ce contexte, une station de surveillance spécifique DCE pour l'évaluation de la qualité chimique de l'eau a été développée sur le Rhône (Lyon, France), permettant la mesure directe de paramètres physico-chimiques tels que pH, température, oxygène dissous, conductivité, turbidité, Carbone Organique Total, nitrates et toxicité globale ainsi que la détection, et, dans certains cas, l'identification des substances prioritaires de la DCE, dans la gamme du µg/L. A partir des données obtenues, un indicateur, l'indice de qualité rivière (IQR) a été construit. Le rôle principal de l'IQR, basé sur une approche multicritères, est de permettre une interprétation plus facile des données de surveillance par agrégation des valeurs des paramètres mesurés sous forme d'indicateur. La méthodologie pour transformer les valeurs de tous les capteurs et analyseurs de la station de surveillance en un simple indicateur est décrite dans cet article. Les résultats obtenus confirment le bon état chimique des eaux du Rhône, en conformité avec l'exigence de la DCE. Cet état chimique prend en compte tous les rejets qui se produisent en amont de la station, y compris les rejets d'eaux pluviales provenant des systèmes d'assainissement urbain.

ABSTRACT

The Water Framework Directive (WFD) requires a "good status" for all water bodies by 2015 and the implementation of monitoring programmes to evaluate the water bodies' quality. In this context a WFD-specific monitoring station for chemical water quality assessment has been developed on the Rhône river (Lyon, France), comprising equipment for direct on-line measurement of parameters such as pH, temperature, dissolved oxygen, conductivity, turbidity, total organic carbon, nitrates and global toxicity and indirect on-line estimation of priority substances listed in the WFD, in the range of µg/L. From the data obtained, an indicator, the River Quality Index (RQI) was built. The main role of the RQI is to reduce the great amount of parameters to a simpler expression, to enable an easier interpretation of the monitoring data. The methodology to transform the actual values of all sensors and analysers of the monitoring station into a single indicator is described in this paper. The results obtained confirm the good chemical status of the Rhône water, in accordance with the WFD requirement. This chemical status takes into account all the discharges occurring upstream the station, including the stormwater discharges from the urban drainage systems.

KEYWORDS

Ordered weighted average, Priority substances monitoring station, Water framework directive, Water quality index

1 INTRODUCTION

Water pollution from micro-pollutants (MPs) is becoming more and more pressing on the environment. Most MPs are man-made organic chemicals being introduced to the environment by anthropologic inputs in a direct way, e.g. inputs from the wastewater system and indirect way, e.g. inputs from diffuse sources. Water quality is nevertheless not limited to the presence of micro-pollutants but can also be related to more global parameters. For instance, increasing river temperature have been associated with increased biological demand and decreased dissolved oxygen (Ozaki et al., 2003). Climate-related changes in rivers have affected species abundance, distribution and migration patterns. In the Rhône River, there have been significant changes in species composition, as southern, thermophilic fish and invertebrate species have progressively replaced cold-water species (Daufresne et al., 2004).

One of the driving forces for the monitoring of water bodies is the Water Framework Directive (WFD; 2000/60/EC). Its overall objectives are to achieve, by 2015, the "good status" for all the community waters, to prevent deterioration and enhance status of aquatic ecosystems, to promote sustainable water use and reduce water pollution and to contribute to the mitigation of floods and droughts. Beyond the regulatory constraints and the need for the development of River Basin Management Plans, which set out the actions required within each river basin to achieve environmental quality objectives, the implementation of the WFD is a real challenge for river basin stakeholders. The main reason is the limited amount of available information on these priority substances and their occurrence in the water bodies.

The communication on water quality data is challenging. Most river basin stakeholders are not directly interested in the values of the water quality data. They are more interested in the information that the water quality data conveys and are even more interested in the knowledge derived from the information. For example, a pH of 7 for a water sample collected from a river does not mean much to most stakeholders. However when the data is converted into information that the pH is within acceptable water quality guidelines, and thus the water quality is adapted for aquatic life, this is of interest for stakeholders and the value of the data is widely increased. Therefore, the current research aimed at contributing directly to the improvement of a new strategy for the evaluation of water and knowledge on the subject, and hence to produce a readable, concise and reliable communication tool.

Water quality monitoring networks can be found all over the world. For example, the GEMS/Water Global Network and its global water quality database GEMStat, is designed to share surface and ground water quality data sets and includes more than 3,000 stations. These data can be treated with different statistical analysis methods and are finally used in water assessments and capacity building initiatives around the world. Local monitoring networks can be found within Europe. In France, the French Administration controls biological, hydromorphological and physicochemical parameters as well as priority substances from different rivers basins in order to determine the ecological status of the river basin. This control is carried out by laboratory analysis of the samples taken. Other example can be found in Germany, where on-line measurements in different points of the river Erft are carried out to determine pH, turbidity, conductivity, dissolved oxygen and temperature. With these measurements, the quality of water is monitored in continuous to define management plans.

Internationally, there have been a number of attempts to produce a method that meaningfully integrates the data sets and converts them into relevant information (Nagels et al, 2001). Thus, Suez Environment and partners propose a system (a water quality index) integrating the results of water quality assessment. The index represents the level of chemical water quality in a given water basin. This paper defines the strategy adopted for monitoring of the Rhône River quality, and focuses mainly on the development of the Rhône river Quality Index (RQI).

2 MONITORING STRATEGY

The approach chosen in this study diverges from classical spot sampling, as it is based on continuous measurement and detection of pollutants in the Rhône River. Three categories of parameters have been defined:

- global parameters: pH, temperature, dissolved oxygen, ammonia, dissolved and total organic Carbone measured with physicochemical sensors from HACH Lange
- specific compounds: 13 organic micropollutants belonging to the priority substances listed in the WFD measured with the Aquapod MP analyser provided by HOCER

- global toxicity: toxicity measured with the TOXcontrol analyser from microLAN.

The list of parameters measured by the monitoring station is given in Table 1.

All sensors and analysers are connected to a supervision system (cf. Figure 1), managed by Topkapi®, a SCADA software for process control developed by Areal. Data archiving and edition of monthly monitoring reports are made through a Long-Term Data Base (BDLT), being developed in the context of this project. In case of an alarm, a 1L sample can be collected by a stationary sampler Bühler 4010, also controlled by the supervision system. This sample is then analysed in laboratory by reference methods (Barrek et al., 2009), for validation or further investigation on the priority substance(s) responsible for the alarm. The prototype station has been implemented on the Rhône River, in Ternay (France), located downstream of the Lyon town and downstream of a petrochemical complex. A more detailed description of the station can be found elsewhere (Barillon et al, 2010)

Table 1: Parameters analyzed by the monitoring station

Parameters	Alarm	Analyser
Temperature	> 30 °C	Aquapod
O2	< 3 mg/l	Aquapod
Turbidity	> 500 NTU	HACH
pH	< 7,5 or > 9,0	HACH
Conductivity	> 750 µs/cm3	HACH
Toxicity	25%	ToxControl
TOC	> 20 mg/l	HACH
Nitrate	> 1mg/l	HACH
Isoproturon, Atrazine, Diuron, Simazine, Trifluraline, Chlorophyriphos, Chlorofenvinphos , Octylphenol, Pentachlorophenol, 4-Nonylphenol, Trifluraline, Hexachlorobutadienne, Carbamazepine, Hexachlorobenzen,	0.1 µg/l	Aquapod

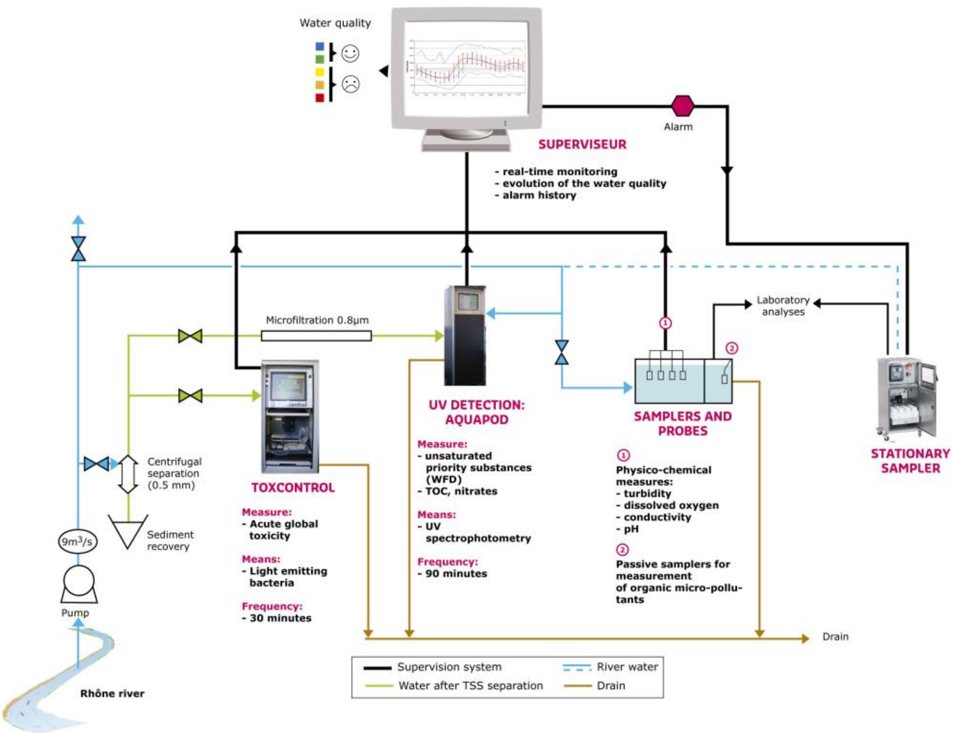

Figure 1: P&ID of the monitoring station

3 WATER QUALITY INDEX

A Rhône River Quality Index (RQI) for the classification of the Rhône river chemical status was developed as a way to integrate the monitoring station data into a simple descriptor of water quality. Generally a number, a range, a verbal description, a symbol or a colour are used to represent the indices. In our case the output interface of RQI is based on a colour coding system.

The water quality being a multidimensional concept (Schultz, 2001), its evaluation can naturally rest on the construction of a data fusion model or "multicriteria evaluation" (Grabisch et al,2000). The stake thus is to be able to merge and to combine the information collected by the monitoring station and develop a model evaluating the chemical quality of Rhône water on the basis of the parameters available on the station while keeping a function of alert when the values of the parameters exceed the thresholds indicated in Table 1. The methods developed in operational research for the multicriteria evaluation were privileged, to the detriment of the methods based on the fuzzy logic. Indeed this last approach requires more elaborated and expensive tools (computer software).

The model developed is enough generic and stable to be transposed, afterward, into other applications (drinking water, WWTP outlet). The general structure to calculate the RQI is mainly based on the following 3 steps: (i) Determination of the function of satisfaction for every parameter, transforming the parameter into a sub-index. Sub-indices are then transformed into non dimensional scaled values, (ii) Sub-indices aggregation with mathematical equation, (iii) Classification of the water quality from the final value of the sub-indices aggregation.

3.1 Satisfaction functions

The representation of the measures is crucial because the global index of the water body quality depends on it. The measured parameters in programs for water quality monitoring (spot monitoring or alarm network) are often represented within the framework of the Boolean logic (good = 1 / bad = 0): in other words, the state of the parameter is good if its value is below the warning threshold, conversely its state becomes bad if it is exceeded. This representation presents drawbacks, especially when the measured parameter displays values close to the threshold. In order to overcome the limitations of Boolean logic, the measures are represented by fuzzy sets, defined by satisfaction functions (Bellman and Zadeh, 1970).

For each parameter, a satisfaction function was defined, so as to transform the different units and dimensions of water quality variables to a common scale. This function indicates the satisfaction degree of a flexible constraint imposed on the parameter. It equals to 1 if the constraint is totally satisfied, 0 if it is not at all satisfied and it takes a value between 0 and 1 if the constraint is satisfied with a certain degree. In the end, a value between 0 and 1 is assigned to each parameter.

In Figure 2, the satisfaction functions for TOC, dissolved oxygen, pH, toxicity and priority substances are shown.

As there are no recommended ranges of values for TOC in the WFD, the value “1” of the satisfaction function for TOC arbitrarily corresponds to TOC concentrations lower than 15 mg/L and the value “0” to concentrations higher than 20 mg/L. The same logic was applied for toxicity, with the value “1” for toxicity values lower than 20% and the value “0” for toxicity values higher than 25%.

For dissolved oxygen and pH, recommended ranges of values exist in the WFD. These ranges were used to define the value “1” and the thresholds from Table 1 were used for the value “0” of the corresponding satisfaction functions.

The satisfaction function of the specific parameters analysed by Aquapod is binary: it equals to 1 if the parameter is lower than the detection threshold and 0 in the contrary case. The parameters (sub-indices) so represented can be then aggregated between them by means of aggregation operators.

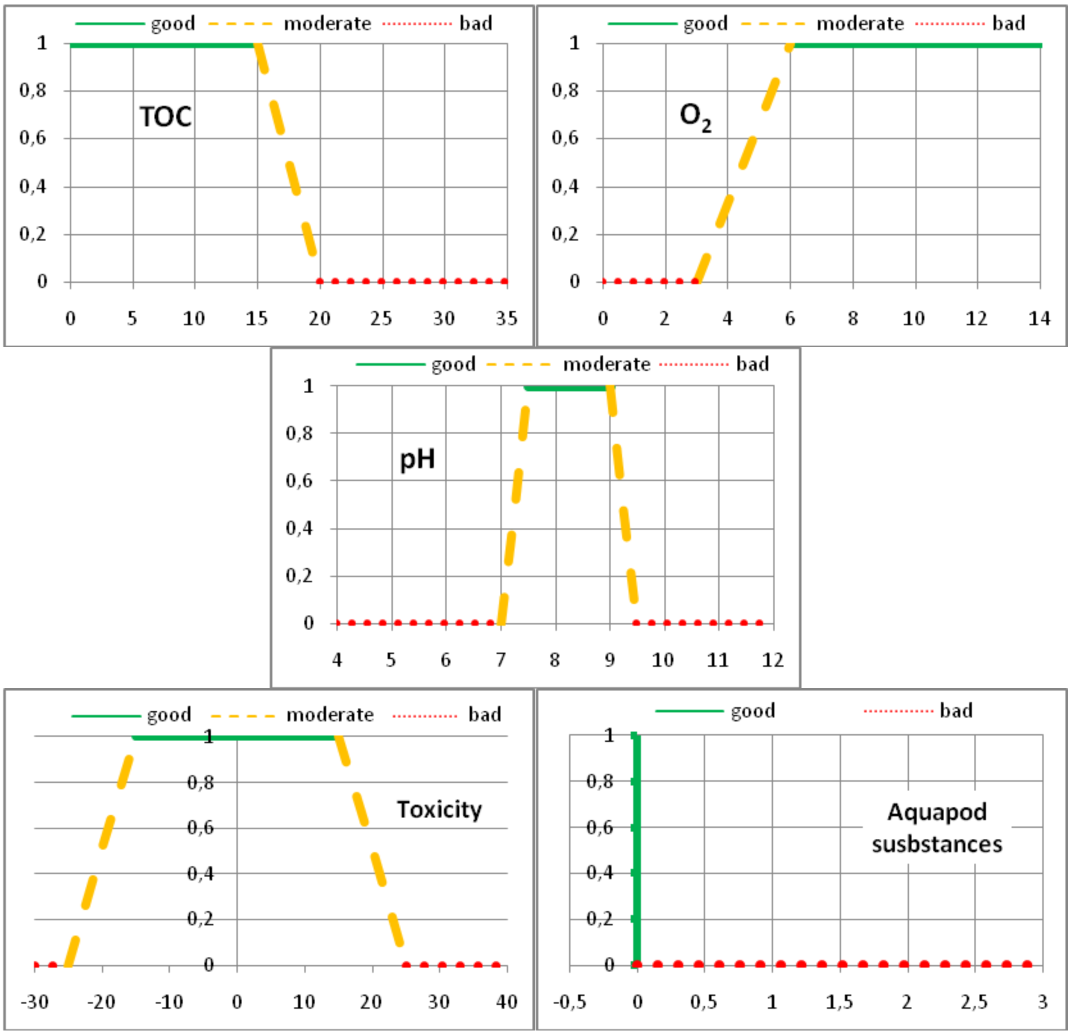

Figure 2: Examples of satisfaction functions.

3.2 Aggregation parameters (sub-indices)

While aggregating the parameters, it was found important, on the one hand, to keep the possibility to consider the relative importance attached to the different sub-indices. For example, the sub-index a_1 (turbidity) with its frequent fluctuations is more important than sub-index a_2 (pH). In this case, to reflect this significant impact, the chosen method to aggregate a_1 and a_2 should allow to put more weight on g_1.

On the other hand, it also appeared necessary to give more importance to the worst scores and limit the possibility of compensating bad grades on some criteria (sub-index) by good grades for some others. A solution was to focus on the worst component a_i in the vector (a_1, …, a_n) and then to use the other components as secondary criteria (sub-index). This led to the minimum weighted operator (Dubois and Prade,1986) defined by:

$$W_{min}(a_1, \dots, a_n) = \bigwedge_{i=1}^{n} [(1 - w_i) \vee a_i]$$

Where ai is the score obtained by the monitoring of a water body at time (t) on criterion (sub-index) i, and $w_i \in [0,1]$ are weights, such as $\bigvee_{i=1}^{n} w_i = 1$

One known problem with this operator is over pessimism in the evaluation. An alternative choice that gives a better control of the relative impact of good and bad evaluations is the Ordered Weighted Average (OWA) introduced by Yager (1998) and defined as follows:

$$OWA_w(a_1, \ldots, a_n) = \sum_{1}^{n} w_i a_{\sigma(i)}$$

Where {(1), . . ., (n)} is a permutation of {1, . . . , n} such that $a_{(j-1)} \leq a_{(j)}$ for all j = 2, ..., n. To get the desired behaviour in the aggregation, it is sufficient to use weights defined so that the lower is the score, the higher is the weight. Formally it gives: $w_j > w_{j+1}$, j = 1, . . ., n – 1.

The 22 physicochemical parameters measured continuously by the monitoring station are used to calculate the value of the RQI. The OWA operator considered is:

$$OWA = RQI = \sum_{1}^{3} w_i a_{\sigma(i)}$$

$$RQI = 0{,}75 a_{\sigma(1)} + 0{,}20 a_{\sigma(2)} + 0{,}05 a_{\sigma(3)}$$

Its definition shows that the calculation of the global index of the Rhône water quality is based on the three worse satisfaction scores among the 22 parameters measured by the station; their weighting is as follows: 75% for the worst, 20% for the second worst and 5% for the third worst. The other indices of satisfaction have a no weighting and thus have no influence on the calculation of the satisfaction global index (RQI). The choice of three weighting weights refers to the three state levels of the sub-indices (good, average and bad). As for their values, they are the result of optimization tests. The vector (0.75, 0.20, 0.05) turns out to be the most relevant because it presents the most advantageous offer in term of sensibility of index quality. This vector has been chosen after several trials.

3.3 The classification of status

The RQI produces a score between 0 and 100. The higher the score is considered to reflect the better the water quality. The RQI values are then converted into classes/categories by using the categorization scheme presented in Table 2. The goal of these classes is to improve communication with the public and increases public awareness of water quality conditions.

Table 2 : RQI category descriptions

class	colours	RQI
high	blue	90 to 100
good	green	60 to 89
moderate	yellow	40 to 59
poor	orange	20 to 39
bad	red	0 to 19

The RQI can be however adjusted when the data of the descriptor are in insufficient number (due to a malfunction of probes). All operations (the satisfaction functions representation, parameter aggregation and the establishment of the evaluation grid of the quality index) defining the RQI have been programmed in an Excel file in order to have an immediate calculation of the RQI from on-line measurements.

4 APPLICATION OF THE RQI

The proposed water quality classification scheme was applied to assess the chemical water quality status of the Rhône River. The water quality data of the monitoring station presented in section 2 were considered for estimation of RQI.

It has to be noticed that only a few alarms were detected by the analysers and probes, due to the fact that the Rhône River is a receiving body with a high dilution potential, thereby limiting the range of values taken by the monitored parameters and consequently by the RQI. As a result, the RQI could not be tested in its full range on the Rhône River.

Despite that, to overcome this difficulty and to assess the performance of the RQI, a sensitivity study was done by considering different theoretical scenarios in which some of the monitored parameters were set to specific values, close to the alarm threshold. Six of these scenarios are shown in Table 3.

In these examples, the values of the monitored parameters led to RQI values ranging between 0 and 100, highlighting the fact that RQI index is able to give a coherent image of chemical quality of a water body.

Table 3: Application example of the RQI.

Case	Constraints	RQI value	Class
1	a priority substance (Aquapod) > 0	0	bad
2	toxicity = 30	25	poor
3	TOC = 17	70	good
4	pH = 4	25	poor
5	all measures are good	100	high
6	pH = 7,5; Toxicity = 19; Turbidity = 485	29,5	poor

In case n°6, the quality index displays a poor water quality despite the fact that no parameter has exceeded thresholds of alarm, but only three parameters (pH, turbidity and toxicity) have values close to the alarm threshold. By using the traditional method (i.e., the alert is activated, if one of the parameters exceeds the threshold of alarm), no alert would have been triggered because all the parameters are below the threshold of alarm.

In this study, the calculation methods are very easy to implement and simple to use. The aggregation model was performed for this purpose using the Excel programming, accessible to everyone. Moreover, a correlation between the calculated indicator and result of spot sampling has been verified, since the two methods display a good chemical status of the Rhône.

5 CONCLUSION

The River Quality Index (RQI) developed in this study is an indicator assessing the water quality of a river or a water body by aggregation of the measurements of twenty two quality parameters. The methodology used to build this indicator from data collected by a monitoring station was based on a multicritera approach and the use of an OWA operator. The RQI was developed with the purpose of providing simple, concise and valuable information to the river basin stakeholders. The assessment of the water quality was done through five classes: high, good, moderate, poor and bad.

This indicator can be used for the:

- Follow-up the water quality of a river downstream of an agglomeration.
- Follow-up the quality of a specific discharge.
- Evaluation of the impact of an agglomeration on the river water quality.
- Evaluation of the effectiveness treatment of a wastewater treatment plant.

This index does not depend on the type of water to evaluate: the general methodology can be applied to all types of receiving bodies. As a result, it is possible to have a general evaluation system to assess the quality of water in European bodies of water.

Thanks to the monitoring station and the formalisation of the aggregation process, the evaluation of water quality can be performed routinely in an objective way.

This monitoring strategy, on-line measurement and water quality assessment, compared to the conventional one consisting in spot sampling and laboratory analyses, provides information on the quality of the water, in a real-time basis, allowing the detection of transient pollution events and compatible with the spatial and temporal variability of the pollutants in the water bodies.

The RQI can identify water quality trends and problem areas. These can be screened out and evaluated in greater detail by direct observation of the data, thus increasing efficiency. Consequently, the RQI provides a basis to evaluate the effectiveness of water quality improvement programs and can be considered as an aid decision tool for establishing priorities in watershed management. It can help watershed managers to understand their final result, and to orientate the identification of causes of "bad status" in the best time, while encouraging them to take efficient remedial measures.

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