Aggregated indicators from an optimized groundwater monitoring network : examples in Walloon region of Belgium for implementation of the European Water Directive

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Abstract

Following prescriptions of the recent European Water Framework Directive, a groundwater quality evaluation system must be adopted for checking the groundwater status with respect to different contaminants. A screening evaluation system (based on a system developed by the French Water Agencies) has been adapted to the specific conditions in the Walloon Region of Belgium. Groundwater quality data are aggregated into indicators with respect to different water uses such as drinking water standards, thresholds values for preserving dependent surface ecosystems, or the groundwater 'natural or patrimonial state'. A global groundwater quality indicator can also be calculated. Different aggregation techniques are discussed with their respective influence on the final indicator.

In relation to this evaluation, the monitoring network must be adapted for being (as far as possible) representative of the global quality of water in each groundwater body. Existing knowledge and understanding of the actual hydrogeological conditions were used in priority for choosing an adequate network of monitoring points. At the same time, the spatial density of points was checked in order to obtain a statistically representative network.

Applications were performed in five different GWBodies belonging to the hydrographic district of the Meuse River in the Walloon Region and with different contrasted geological conditions: Cretaceous chalks, Carboniferous limestones and Pleistocene gravels of the alluvial plain of the River Meuse. These examples provide a good opportunity for further discussion and work about the main related issues: optimization procedures, aggregation methods and estimation of the reliability of indicators.

Keywords

Quality indicators; aggregation; groundwater quality; monitoring network; european Water Framework Directive

1. Introduction

The European Water Framework Directive 2000/60/CE establishing a framework for Community action in the field of water policy aims to coordinate the Member states' water management within the international river basin districts. The directive sets three general objectives concerning the groundwater: (1) to prevent their deterioration, (2) to enhance and restore them to achieve good water status at the latest in 2015, and (3) to reverse any significant and sustained upward trend of any pollutant inside them. Member States are requested to establish monitoring programmes of the chemical and quantitative groundwater status. All the substances resulting from the impact of human activity must be controlled. Wallonia has adopted a groundwater quality assessment system named SEQESO (for 'Système d'Evaluation de la Qualité des Eaux SOuterraines'),, originally developed by the French Water Agencies (Agences de l'Eau, 2002). The main principles of this system will be described hereunder. In order to satisfy the requirements of the water-framework directive, this system has been developed for qualifying the general hydrochemical status of groundwater bodies (GWBodies) by means of aggregation techniques from a representative monitoring network.

2. The groundwater quality assessment system SEQESO

Basically, the SEQESO provides an interpretation grid of a complete protocol analysis related to a single water sampling point. The system is based on the establishment of parameter thresholds defining quality classes. One of the difficulties of groundwater quality assessment lies on the fact that it can be considered as a relative concept depending on water use. As far as groundwater is concerned, the SEQESO system considers 3 essential functions :
1) Water use : human consumption, industry, agricultural uses (animal watering and irrigation), energy (heat pumps),etc. "Drinking water supply" (ADE for 'Aptitude à la Distribution de l'Eau') is recognized as the main use introduced in the SEQESO. For this use, 4 quality classes are defined with the 3 following :

- ADE-S1 (blue/green) : guide level values of DIR/80/778/CEE relating to the quality of water intended for human consumption, or expert judgement based on the statistical distribution of the quality values for water supplies.
- ADE-S3(*) (green/orange) : parametric value of DIR98/83/CE when relevant for raw water.
- ADE-S4 (orange/red) : guide or imperative values of DIR/75/440/CEE concerning the quality required of surface water intended for abstraction of drinking water, or expert judgement on the maximum level of treatability of raw water.

2) Patrimonial status (PAW for 'état PAtrimonial en Wallonie'): measures the degree of quality deviation from the natural status due to anthropic pressures. For this use, 5 quality classes are defined with the 4 following thresholds :

- PAW-S1 (blue/green) : corresponds as closely as possible to a "natural" status. In practice, it is a "reference" status set as : the usual analytical detection limits for organic compounds, an expert judgement value for nitrates (10 mg NO3/l) or reference values for minerals and metals according to Wallonia Soil Policy(**) based on estimated natural geochemical background in aquifers.
- PAW-S2 (green/yellow) : calibrated so as the set S1, S2, S3, S4 fits to an arithmetical or geometrical series according to the kind of variations of the pollutant.

(*) The ADE-S2 threshold does not exist.

(**) Decree of April the 1st 2004, concerning the remediation of contamined soils and the economic activity sites to be restored .

- PAW-S3 (yellow /orange) : according to the proposal for a directive on the protection of groundwater against pollution, a starting point for trend reversal must be set. That point, also called the "action" point wherefrom prevent/control are required by the WFD, is not allowed to excess 75% of the community quality standards discussed in the same proposal (50 mg/l for nitrates and 0,1 µg/l for individual pesticides) or the proposed threshold value for the other pollutants (these limits between good and bad status, that will be enforced into law before end 2005 by the Member States, are the definition of the ADE-S3). PAW-S3 is thus proposed in a first draft as equal to 75% of ADE-S3.
- PAW-S4 (orange/red) : refers to the remediation threshold of the soils policy. A distinction is made here between the diffuse (or occurring often in many places) pollutants like nitrates and pesticides, and the point source pollutants like hydrocarbons and heavy metals. For mineral pollutants, the remediation value to clean-up has been introduced from soils policy. That value is based on criteria concerning the mobility of the pollutants in the aquifer, the human health and ecotoxicity.

3) <u>Ability to sustain biology in the associated water courses</u> (BIO) (groundwater dependant ecosystems). For this use, 5 quality classes are defined. The 4 corresponding thresholds are exactly the same as for surface water, assuming that a 100% feeding from groundwater can occur, which of course is a strong assumption.

In order to examine all parameters at the same scale for each use, each value corresponding to a particular concentration for a parameter is converted into an non-dimensional index according to simple interpolation lines and curves between the thresholds. The parameters are then gathered into consistent packages called "alterations". The quality class for each alteration is given by the index of the most problematic parameter. This allows to greatly synthesize the concept of groundwater quality.

A great advantage of the SEQESO (focused by the French Water Agencies) consists in combining the ADE use and the PAW function to obtain a general expression of the groundwater quality (GQW = General Quality in Wallonia). The mechanism is illustrated at the figure 1 for the general case of nitrates (there are of cause several exceptions). As a general rule, 5 quality classes are defined : the PAW induces the 2 better classes and the ADE the 3 worse classes. The boundary for bad status is the yellow/orange limit GQW3.

Figure 1 : Building mechanism for the General Quality (GQW) : example for nitrates

Drinking water use:		**General quality**			**Patrimonial status:**	
Best quality for drinking water; DIR/80/778 guide value	DWS1 = 25 mg/l	Index = 80	GQ1 = 10	Very good	PS1 = 10 mg/l	**Pristine or natural** quality content; geochemical background; no detection of organic compounds
Drinking water (before the supply network); in many cases the DIR 98/83/CE parametric value for human consumption		60	GQ2 = 25	Good	PS2 = 25 mg/l	Anthropogenic **contamination** detected
	DWS3 = 50 mg/l	40	GQ3 = 50	medium	PS3 = 37,5mg/l	**Significative deterioration** from "natural" status
Water **unsuitable** to a drinking water supply	DWS4 = 100 mg/l	20	GQ4 = 100	bad	PS4 = 50 mg/l	**Important deterioration** from "natural" status
Water **unsuitable** to a treatment to produce drinking water		0		very bad		**Very important deterioration from "natural" status;** contaminated sites cleanup required

Every GQW threshold is then converted into a general quality index (Ig) as showed at the figure 1. According to simple interpolation lines and curves between 0, GQ1, GQ2, GQ3 and GQ4 points, and ω, the general indicator range from 100 (best quality) to 0 (worse quality). The general quality indicator allows the comparison between different water sampling points.

2. GWBodies qualitative management

In order to satisfy the requirements of the water framework directive, the SEQESO system has been developed to assess the global quality of groundwater in the whole GWBody. The SEQESO uses aggregation techniques through a simple arithmetic mean as imposed by the directive. These techniques aggregate data from each site of the GWBody monitoring network into a single global quality indicator (with respect to the water use). Two different techniques have been worked out : (1) the "parameter aggregation" calculate the global quality indicator as the minimum of the mean parameter index of every site and (2) the "alteration aggregation", calculate the global quality indicator as the mean of the minima alteration index per site. Four steps are considered for these two techniques (the first two steps are identical for both techniques) :

1. An index I relative to every measured value is calculated (by converting every parameter concentration into an non-dimensionnal index according to interpolation lines and curves between the thresholds).
2. For each parameter, and for each water sampling point an arithmetic mean of index I over a considered period of time is calculated to find the PMI (= Point Mean Index).

Parameter aggregation

3. For each parameter, a BMI (Body Mean Index) is calculated averaging the PMI from the different points.
4. For each alteration, the minimum among the BMI is selected.

Alteration aggregation

3. For each monitoring network point, the minimum among the PMI of all parameter belonging to an alteration is selected (⇒PMA= point mean alteration).
4. The PMA arithmetic mean of every monitoring network point is calculated for each alteration.

In order to improve the understanding, an example is given : lets consider a monitoring network composed of 4 points (*X1*, *X2*, *X3* et *X4*) and an alteration composed of 3 parameters (*P1*, *P2* et *P3*). All PMI obtained after the first 2 steps are given in the following table :

PMI	***X1***	***X2***	***X3***	***X4***
P1	82	85	19	75
P2	76	74	78	69
P3	54	42	55	40

Parameter aggregation

- Step 3 : BMI(*P1*)=65 ; BMI(*P2*)=74 ; BMI(*P3*)=48
- Step 4 : BMImin=48 (*P3*)

⇒ Medium quality class (yellow) with *P3* as the global problematic parameter.

Alteration aggregation

- Step 3 : PMA(*X1*)=54 (*P3*) ; PMA(*X2*)=42 (*P3*) ; PMA(*X3*)=19 (*P1*) ; PMA(*X4*)=40 (*P3*)
- Step 4 : PMAmoy=39 (*P1*)

⇒ Bad quality class (orange) with *P1* as the local most problematic parameter.

This example clearly shows the difference between both approaches. The results are similar when an alteration contains only one parameter, in all the other cases the second technique (alteration aggregation) is penalizing because it takes account of the worst situation. The indicator calculated by this technique will always be smaller then the one calculated by the first technique, which is accentuated if the points measurement variability is high. The parameter aggregation gives an insight of the global contamination problem, whereas the alteration aggregation emphasizes a possible local contamination not necessarily representative of the GWBody.

3. Applications of the SEQESO system

A test of the SEQESO system has been performed on five very different GWBodies belonging to the hydrographic district of the Meuse river in Wallonia (Rentier et al., 2004) and with different contrasted geological and hydrogeological conditions : Cretaceous chalks, Carboniferous limestones and Pleistocene gravels of the alluvial plain of the river Meuse. In relation to this evaluation, the monitoring network has been adapted for being (as far as possible) representative of the global quality of water in each GWBody. Existing knowledge and understanding of the actual hydrogeological conditions were used in priority for choosing an adequate network of monitoring points. At the same time, the spatial density and distribution of points were checked in order to obtain a statistically representative network. Results obtained with the SEQESO for Cretaceous chalks of the Hesbaye GWBody is given in example at the figure 2 as a summary quality sheet and main results are provided in the table 1 for the five GWbodies. The water framework directive requires the European Member States to provide a synthesis of the groundwater qualitative status as a conclusion (‘good’ or ‘bad’ status) for each GWBody. Considering that bad status is reflected by an Ig value lower than 40 and moreover that a risk -which must be assessed by a trend analysis on the monitoring data- of failing to achieve the quality objectives in 2015 exists from a Ig value lower than 60 , this can be done by using the general quality indicator calculated with the SEQESO system.

Figure 2 : Summary sheet relative to the Cretaceous chalks of the Hesbaye GWBody (RWM040) obtained with the parameter aggregation technique

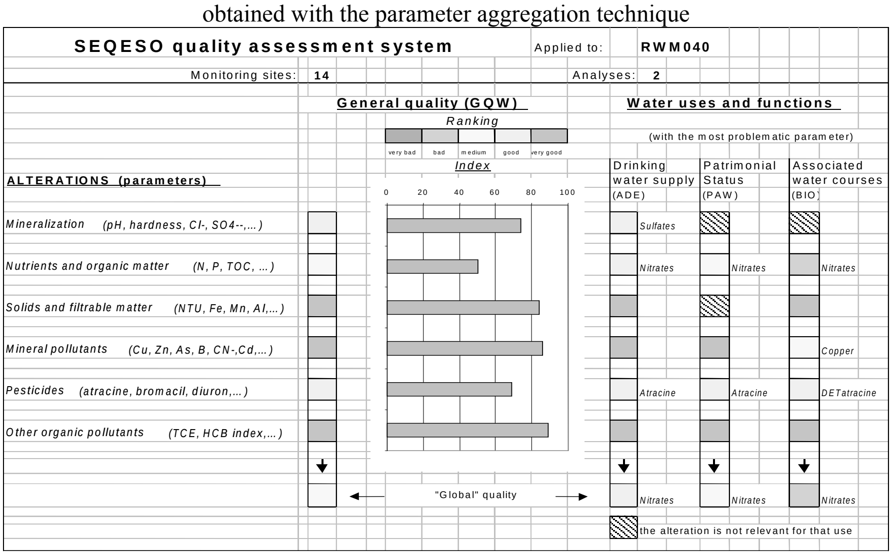

Table 1: SEQESO results for the five GWBodies providing a global quality class, the most problematic parameter, and conclusions about the GWBody qualitative state.

Table 1 : SEQESO results for the five walloon GWBodies

	GWBody	Quality class	Ig	Most problematic parameter	GWBody qualitative state
Cretaceous chalks of Hesbaye	RWM040	Medium (yellow)	50	Nitrates	"at risk"+ action threshold reached
Cretaceous chalks of Herve	RWM151	Medium (yellow)	56	Nitrates	"at risk"
Alluvial plain of the River Meuse (between Namur and Lanaye)	RWM072	Medium (yellow)	56	Sulfates	requires a trend analysis
Alluvial plain of the River Meuse (between Engis and Herstal)	RWM073	Bad (orange)	30	Manganèse	"at risk"+ action threshold reached
Carboniferous limestones of Néblon bassin	"RWM021 "	Medium (yellow)	55	Nitrates	"at risk"

Conclusions

The SEQESO is a powerful tool to evaluate the chemical status of a groundwater body in accordance with the new concepts of the water framework directive and the subsequent proposal for a groundwater directive. A first set of thresholds corresponding to the different quality levels distinguished by these directives are operational. The methodology used to aggregate these 5 quality classes indicators was validated on five different GWBodies. The SEQ-ESO assessment will be applied to the remaining 28 walloon GWBodies. It might also be improved for some parameters by taking more into consideration through the BIO function the water courses and other groundwater dependent ecosystems, with the consequence of tightening the GQW thresholds. The main result is the official threshold value for groundwater that Wallonia has to fix into force before implementing its first river basin management plans.

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