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Management of Water Pollutants Based on Multi-Criteria Analysis and Fuzzy Logics

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Abstract This work has been developed in the frame of the MANPORIVERS research project funded by the European Commission. The goal is to identify effective and sustainable policies for the management of surface and ground water pollutants, taking account of their relationships with food production and human health. A methodology based on the combination of fuzzy logics and multicriteria analysis is proposed as a decision aid tool for the development of such policies. An example of application in the Huai river basin is given.

Key words: Rivers, pollutant, methodology, management, policy

OBJECTIVES AND ACTIVITIES

The goal of the MANPORIVERS project is to identify effective and sustainable policies for the management of surface and ground water pollutants, taking account of their relationships with food production and human health. The aim is the definition of policies with a very broad range of applicability that could be used for many river basins. They can be used interactively for different basins exchanging water. They can also be used at different scales in a recursive manner, from small tributary basins to large basins.

Table 1 Description of the tasks

Task number	Description of the tasks
	The different tasks develop methodologies for :
WP1.a	Evaluation of non accidental pollutant input
WP1.b	Evaluation of accidental pollutant input
WP1.c	Evaluation of input evolution in the future
WP2.a	Analysis and selection of surface water pollutant transport models
WP2.b	Analysis and selection of groundwater pollutant transport models
WP3.a	Identification and analysis of techniques for water cleaning
WP3.b	Identification and analysis of accident remediation techniques
WP4.a	Assessment of the use of drink water
WP4.b	Assessment of the use of irrigation water
WP4.c	Assessment of water used in food industries
WP4.d	Assessment of water used for fish breeding
WP4.e	Assessment of other uses of water
WP4.f	Evaluation of water use in the future
WP5	Analysis of the relationships of pollutants with health
WP6.	Pollution management priority policies by fuzzy logics and multicriteria analysis

The activities presented in this paper are summarized in Fig. 1 and Table 1. Although we mainly concentrate here on task WP6, it is worth giving some information on the work achieved in tasks WP1 to WP5 as they constitute a support for WP6.

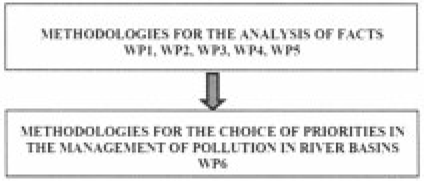

Figure 1: General Organization of the activities

METHODOLOGIES FOR THE ANALYSIS OF FACTS

1. Methodologies for the evaluation of accidental and non accidental pollutant input (WP1) [1] Pollutant sources are classified into two categories: non accidental pollutant input and accidental pollutant input.
The research work completed consists of two parts: (1) Development of evaluation methodologies for the two categories; (2) Application to the Xuyi County (Huai river basin) and to the Xizhijiang River basin (Pearl River delta).

2. Methodologies for the choice of models for the transport of pollutant by surface water and groundwater (WP2) [2-5] The objective is to evaluate existing models for pollutant transport, both for surface waters and groundwater, as tools contributing to the management policies of water pollutants.

1) *Transport of pollutant by surface waters* The analysis of different softwares has been performed. The following ones were considered and a methodology for their selection and use developed: (a) Mike 11 DHI Danish Hydraulic Institute from Denmark; (b) U.S. Geological Survey (USGS) from USA: a set of 42 sofwares for different purposes; (c) SOBEK Delft Hydraulics from Netherlands; (d) InfoWorks RS; Wallingford from Great Britain; (e) HEC-RAS (Army Corps of Engineer's Hydraulic Engineering Center (HEC)); (f) River Analysis System (RAS) from USA; (f) WOLF software from Belgium.

The required parameters, the basic characteristics and use limitations are examined.

2) *Transport of pollutant by groundwater* The application capabilities of several flow and pollutant transport models available on the Internet are studied, aiming at creating a methodology for their selection and use: (a) FEFLOW (Diersch, 1998); (b) MT3D (McDonald e Harbaugh, 1988); (c) ASMWIN (Chiang et al., 1998); (d) RBCA Tiers Analyser (Roy et al., 2000); (e) AQUA3D (Vatnaskil Consulting Engineers, 1988); (f) FLOWPATH II (Eviksov et al., 1998); (g) WINTRAN (Rumbaugh e Rumbaugh, 1995).

Conclusions on the possibilities, data requirements and accuracy corresponding to these softwares are summarized in tables that help decision makers to chose the appropriate model according to the site to be studied.

3. Methodologies for the choice of sanitation and remediation techniques (WP3) [6] The objective is to identify and evaluate existing techniques to decrease pollution levels in waters, due to accidental and non accidental input in order to support management policy decisions by appropriate selection charts and methodology.

1) *Non accidental pollutant input* Various sanitation techniques are examined according to the specific pollutants. Their working mechanisms and characteristics, the advantages and disadvantages, the suitable application domains, the equipments and technologies used as well as the costs are considered. The emerging innovative techniques are also identified and their potentials are evaluated. The technical specifications and the financial aspects are also taken into consideration so that they could be applied in real industrial cases.

2) *Accidental pollutant input* This part recapitulates and analyses some of the major accidents in drinking water as well as surface and groundwater pollution in order to gain a better understanding of the causes of accidental pollutant input. It is found that traffic accidents and vehicle overloads are the two main factors causing the release of some toxic chemicals into water body.

A variety of remediation technologies are recommended for hazard minimization, among which chemical and biological methods provide successfully techniques. Biological degradation methods are also holding promising perspectives.

4. Methodologies for the evaluation of water use (WP4) [7] In order to develop and apply an effective and sustainable policy for the management of water use, it is necessary to have clear and quantitative responses to the following questions: (a) What is this water used for? (b) Where does this water come from? (c) What are the quantities used for different purposes? (d) How do these quantities evolve in a year time? (e) What is the foreseen evolution in the future?

The objective of this work package is to develop methodologies to answer these questions and demonstrate their applicability in the chosen case areas. The following methodologies have been developed: (a) Methodology for evaluating the present water use; (b) Methodology for evaluating water demand in future; (c) Methodology for evaluation of the rationality of water use structure.

5. Methodologies for the evaluation of relationships of pollutants with human health (WP5) [8] The objective is to build a quantitative and qualitative database on the influence of various pollutants in river basins on human health.

To reach this goal different complementary approaches have been used.

(1) Various human health risk assessment methodologies have been evaluated. The data and information on human exposure to pollutants and their potential health effects have been catalogued. The realistic health risks that environmental pollutants impose on human have been evaluated by comparing their exposure concentration and their toxic potency, leading to a priority list of main pollutants in river basins.

(2) Considering that almost all data on health effect and toxicological information are based on animal studies and that there is great difference between animal and human beings, a short-term *in vitro* Micronuclei Assay based on human peripheral blood lymphocytes micronuclei has been developed and applied to directly evaluate the human health effect of pollutants. Toxic potencies of some aromatic compounds have been tested by this assay.

(3) Important efforts have been devoted to develop the Quantitative Structure Activity Relationships (QSAR) models. These are mathematical models that relate the biological activity (e.g. toxicity) of molecules to their chemical structures and to the corresponding chemical and physicochemical properties. This development aims at filling in the data gap for some pollutants. They can be used as indicators of the human health effect of pollutants and also for the development of to predict health effect of other pollutants.

METHODOLOGIES FOR THE CHOICE OF PRIORITIES IN THE MANAGEMENT OF POLLUTION IN RIVER BASINS BASED ON MULTICRITERIA ANALYSIS AND FUZZY LOGICS (WP6)

1. The MANPORIVERS methodology [9-11] Based on the combined use of multicriteria analysis and of fuzzy logics, a general methodology has been developed to help decision makers establish sustainable management policies for priority water pollutants and their effects on foods and human health. It is called the MANPORIVERS methodology (Fig. 2).

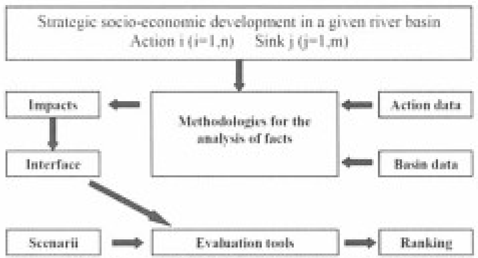

Figure 2: General Scheme of the MANPORIVERS Methodology

This methodology is a major original contribution of this research project and constitutes an efficient tool to help decision makers to undertake environmentally, socially and economically sustainable actions in a river basin.

It is applicable to any river basin and takes account not only of the environmental impacts (typically the concentrations of pollutants in water) but also of the social and economical aspects of the problem.

The MANPORIVERS methodology is a tool that is able to rank different Actions or Scenarii (i.e. combinations of Actions) in order to maximize their positive effects and minimize their negative effects.

The terminology used in Fig. 2 is detailed below.

Actions: any type of industrial, economical, political… action or event.

Sinks: different entities possibly affected by the impacts of the considered strategic socio-economic development in the region.

Action data: specific to a given action (economic, social, pollution data).

Regional data: specific to a region, we consider variable regional data (population, migration…) and permanent regional data (geology, rainfall, topography…).

Impacts: the different effects of actions, e.g. investment, annual cost, modification of pollutant levels, migration of population, aspect of landscape, …; each impact must be expressed by a quantifier which can be quantitative (e.g. amount of money invested, pollutant concentration or mass, …) or qualitative (e.g. good, neutral or bad effect on landscape).

Methodologies: all the means (software, data bases, selection charts, recommendations …) by which the impacts quantifiers of different actions can be obtained.

Interface: integration of different impacts in three stages: a geographic integration, an integration within the set of all major pollutants and the integration within the set of sinks.

Scenarii: different combinations of Actions and different weights for the social, economical and pollution impacts.

Evaluation tools: softwares based on multicriteria analysis and fuzzy logics taking account of the impacts and their respective weights to give a classification of different actions.

Ranking: ordering from the best to the worst action.

Of course, this global methodology makes use of the specific methodologies for the analysis of facts presented in section 3 above.

In must be noted that the MANPORIVERS methodology is capable to take account of: (a) the different uses of water; (b) the effects of pollutants on human health; (c) the direct and indirect costs of Actions (investments, maintenance, functioning,..); (d) the effects of Actions on population (creation or loss of jobs, change of water price, change of water consumption, ...; (e) the effects of Actions on landscape, on the quality of life, …; (f) the coherence and feasibility of Actions.

It is able to consider not only deterministic quantitative criteria but also fuzzy criteria as well as qualitative criteria (such as linguistic statements).

The MANPORIVERS methodology is also characterized by the fact that it allows decision makers to estimate the robustness of their decision: by modify the weights given to the different criteria, they can see if their decision is modified by slight weight changes (no robust decision) or if, on the contrary, the decision is not affected by reasonable weight changes (robust decision).

To use this methodology, it is necessary to be able to evaluate the different scenarii on the basis of different criteria. In others words, it is necessary to quantify or qualify the impacts of the actions on a set of comparison indicators that must be defined by the decision makers. After having quantified/qualified these different impacts (using the specific methodologies presented in the last section), it is possible to use a decision aiding software based on multicriteria and fuzzy logics to select the best scenario according to the weight given to the different comparison criteria.

For complex management projects, it is necessary to have a global view, i.e. it is important to consider social, economic and environmental aspects but also, the concept of the coherence and the feasibility of the measures. The selection of the best scenario must be made according to these different aspects. We have to evaluate the different impacts of the measures on the criteria. However, the evaluation of some impacts is quite difficult because of the lack of data or the complexity of the reality. Then, the use of quantitative model is impossible and we have to use qualitative models.

This is where fuzzy logics enter into the picture: in classical multicriteria analysis, impacts are normally expressed by figures, usually some amount of money.

In the methodology, fuzzy logics has been introduced: it is possible to consider criteria expressed by fuzzy expressions and even to use linguistic scales (see Fig. 3).

Furthermore, the importance of the different comparison criteria is also essential in the selection. The decision makers will choose according to their convictions, their points of view. So, the methodology allows them to weigh the different criteria according to their convictions. Then, it is clear that the final choice will be different according to the specific weights given to each comparison criterion. In fact, we can say that the weighting is the mathematical translation of the convictions of the decision makers.

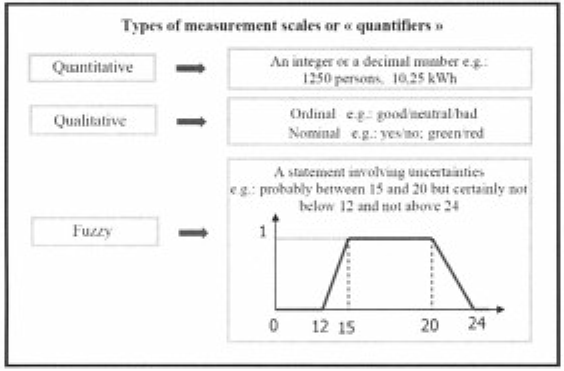

Figure 3: Examples of Measurement Scales or Quantifiers

Among the comparison criteria, the different pollutants of water constitute very important indicators for the final selection of a management strategy for the basin. However, there are many pollutants that are important in the analysis. The large number of pollutants could be an obstacle to the clarity of the reasoning.

That is why the MANPORIVERS methodology contains a functionality allowing to "integrate" the effects of the different pollutants. This functionality involves 3 levels of integration:

(1) Integration of the impact of a pollutant over the entire basin: this takes account of their potential danger of the pollutant over the considered period of time and of the population potentially affected.

(2) Integration on the pollutants : this takes account of the relative toxicities of the different pollutants present in the basin.

(3) Integration on the sinks: the sinks correspond to the different fields of water use: consumption, irrigation, fishing, food and domestic use. The methodology proposes a linguistic scale to give a weight to each of them.

Thanks to this functionality, it is possible to characterize the pollution of the considered basin by a simple result integrating not only the concentrations of the different pollutants but also their toxicity and the populations potentially affected.

For the economic criteria (direct cost, investments, maintenance costs, interest rates, …) classical methods of economy can be used to integrate them in order to get the global cost of an Action. So, this point is considered as classical and well known.

For the social criteria and for the criteria of coherence and feasibility, no attempt is made to try to "integrate" them. They are considered one by one. Indeed, the "aggregation" of criteria like number of jobs created or lost, modification of water consumption, change of water price, change of land use, ….does not seem reasonable and is not easily feasible in practice since linguistic scales are often used for some of these criteria.

Once all the criteria defined, evaluated on the basis of the methodologies for the analysis of facts and integrated if necessary, a multicriteria table is obtained (see an example in Table 8).

Then, a multicriteria decision aiding software can be used. In this research, we use the software Decision Lab using the PROMETHEE methodology. It is a multicriteria decision aiding software including fuzzy logic aspects. It allows the ranking of different Actions or Scenarii taking account of the different criteria and of their respective weights.

2. Integration of pollutants: the global Environment Pollution Risk Criterion (EPRC) Among the comparison criteria, the different pollutants of water constitute very important indicators for the final selection of a management strategy for the considered river basin. However, there are many pollutants that are important in the analysis. The large number of pollutants could be an obstacle to the clarity of the reasoning.

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(3) Integration on the sinks: the sinks correspond to the different fields of water use: drinking water, irrigation, fish breeding, water for food industries and water for non food industries. The methodology proposes a linguistic scale to give a weight to each of them.

Thanks to this EPRC, it is possible to characterize the pollution of the considered basin by a simple result integrating not only the concentrations of the different pollutants but also their toxicity and the populations potentially affected.

1) *Geographic integration* The goal of this first step is to evaluate the effect of each pollutant on the considered basin.

It is suggested to divide the basin in different zones in order to determine the impact of a pollutant on the basin with precision. Actually, it would be dangerous to consider the basin as a whole because, in that case, the calculated impact would show an unrealistic homogeneity. We have to take the diversification of the area into account, particularly for the density of population and for the pollutants concentration. The proposed methodology is based on these basic considerations. The ideal would be to have a division highlighting zones with various pollutants concentrations and densities of population in order to have an optimal representation of reality.

Concerning the pollutants concentration distribution and the evolution of these concentrations with time, they can be obtained by the complementary use of pollutant transport models and in field data analysis. Given the pollutant input data, they enable to predict the concentration $c(x, y, t)$ of a given pollutant at point (x,y) of the considered basin at time t. These models can be calibrated with the help of in situ measurements.

Geographic integration formula In order to aggregate the impact of a pollutant over the entire basin, we propose the following expression in which the notation « *year* » indicates the considered year (we cannot forget the evolution with time; the "sustainable development" concept is very important).

$$I_{ijk}(year) = \int_A D_{ijk}(x, y, year) \times F_p^m(x, y, year)\, dA$$

Let us clarify the content of this expression:

(1) The subscripts i, j and k represent the action or scenario i, the sink j, and the considered pollutant k.

(2) A is the area of the considered basin entire basin.

(3) $D_{ijk}(x, y, year)$ defines the « potential danger » of pollutant k for one year. It is based on the concentration of the considered pollutant $c_{ijk}(x, y, t)$ and is expressed in $\mu g / l$; it is defined below;

(4) $F^m{}_p(x\ y\ ,year)$ is a function of the distribution of population density in the considered year expressed in $pers./km^2$; it is also defined below;

(5) The integrated impact is expressed in: $pers \times \mu g / l$

Definition of function $D_{ijk}(x, y, year)$ The definition of the potential danger of a pollutant must be considered with care.

A first idea is be to integrate the concentration over 1 year: this gives an idea of the average amount of pollutant to which the population is exposed during the year under consideration. However, this approach erases potential concentration peaks presenting severe danger for human health. That is why we propose to consider another element: the maximum of the pollutant concentration.

Then, the questions to answer are: "When should we use the maximum?" "When should we use the average?"

Usually, each pollutant is characterized by a critical threshold that cannot be exceeded: over this critical threshold, the consequences for human health could be very serious.

This threshold is used as discriminant.

Let us consider the two following cases for a given pollutant.

First, we consider the case where the yearly trend of the pollutant concentration is quite stable (Fig. 4).

In this case, there is no reason to include the maximum of the concentration because it is lower than the critical concentration, and therefore, the average represents fairly enough the reality.

Then, we consider the following case (Fig. 5).

The maximum concentration of pollutant k is higher than the critical level. By itself, the average does not represent correctly the reality because it doesn't reflect this peak. Then, the use of the maximum of the concentration would be favourable. That is why; we propose the following expression to calculate the potential danger of pollutant k:

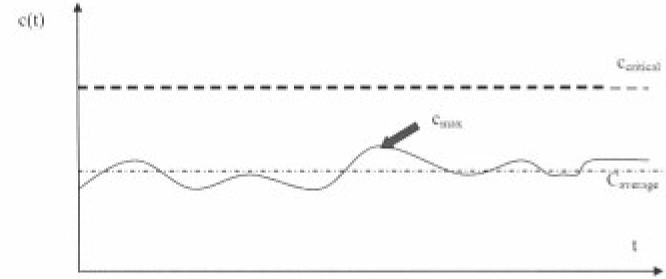

Figure 4: Stable evolution of pollutant concentration

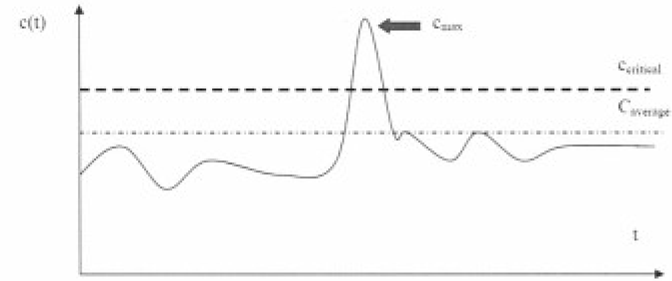

Figure 5: Evolution of pollutant concentration with peak

$$D_{i,j,k}(x, y, year) = \alpha \frac{1}{\Delta t} \int_{\Delta t} c_{i,j,k}(x, y, t)\, dt + \beta \max_{\Delta t}\ c_{i,j,k}(x, y, t)$$

$$\Delta t = 1 year$$

$$(\alpha, \beta) = \begin{cases} (0,1)\ if\ \exists\, t : c_{i,j,k}(x, y, t) \geq c_{critical} \\ (1,0)\ if\ \forall t : c_{i,j,k}(x, y, t) < c_{critical} \end{cases}$$

This means that we propose to estimate the potential danger by the average if the yearly trend of the pollutant concentration does not exceed the critical concentration, or by the maximum of concentration if the trend exceeds the critical threshold.

Definition of $F_p^m(x, y, year)$ A power function of the density of the population is chosen to take account not only of the number of people exposed but also of the epidemic risk enhanced by high population density.

$$F_p^m(x, y, year) = d_0 \times \left[\frac{d(x, y, year)}{d_0}\right]^m$$

where $d(x, y, year)$ is the population density at point (x,y) for the considered year, d_0 is a normalizing factor: $d_0 = 100\,pers/km^2$, and $m = 1$ if the pollution does not lead to an epidemic risk(e;g; mineral pollution), $m > 1$ if there is a risk of epidemy (e.g. viral pollution).

We stress the fact that m depends on the subscipts j and k since the type and importance of contamination is a function of the pollutant nature (k) and of the sink (j) considered (e.g. a pollutant is considered differently in drink water or in water used for car wash).

Then, we obtain the impact $I_{ijk}(year)$ of pollutant k on sink j for the entire basin, for the studied year and for the considered action i.

2) *Integration over the different pollutants* In this paragraph, we propose to calculate the impact of all the pollutants on the basin. Having the individual impacts of each pollutant on the whole area, we can perform a weighted integration of these impacts.

$$I_{i,j}(year) = \sum_{k \in K} I_{i,j,k}(year) \times T_k$$

As a weighting factor, we propose to use the toxicity factor T_k representing the toxicity of pollutant k.

Due to the limitation of time and money, the toxicity spectrum of most chemicals is still unknown and there is not enough information on their hazards and their potential health effect. How can we know which pollutants are toxic? Which chemical are dangerous? What levels do we expose to a pollutant? What are the potential health risks of human exposure to pollutant? To answer these questions, a health risk assessment must be performed. The key points of health risk assessment are:

Effect assessment examines the capacity of an agent to cause adverse health effects in humans or animals. It is a qualitative description based on the type and quality of the data, complementary information (e.g. structure–activity analysis, genetic toxicity, pharmacokinetic), and the weight of evidence from these various sources.

Effect assessment uses animal data (toxicological methods), human data (epidemiological methods when groups of people are involved, or toxicological methods when using case studies and acute chamber studies) or other data (structure-activity data or *in vitro* data).

Dose–response assessment examines the quantitative relationships between exposure and the effects of concern. There are often limited human exposure data and animal bio-assay data are most often used for dose-response assessment. The use of these data requires extrapolations from animals to humans and interpolations from high doses to low doses.

Risk characterization is the final step in the risk assessment process, it (a) integrates the information from effect assessment and exposure assessment; (b) provides an evaluation of the overall quality of the assessment and the degree of confidence the risk assessors have in the estimates of risk and conclusions drawn. This approach is the classical basis on which toxicity data can been obtained.

In the present work, existing data have been collected from literature, from commercial or non-commercial database, from laboratory studies, from properties or toxicity estimation methods and from Quantitative Structure-Activity Relationships (QSAR) approaches.

Table 2 below gives an example of data collection on the cancer potency of organic pollutants present in the Huai River in 2003.

The cancer ranking score (last column) means the ranking of a chemical based on its cancer potency results, Ames assay results and of its presence in the US EPA list or CPB list.

In detail, if for a chemical, the Ames assay result is negative, there is no evidence indicating that it is carceinogenic and it belongs to neither of the priority lists, it is ranked as 0;

If for a chemical, the Ames assay result is negative, there is no evidence indicating that it is carceinogenic but it belongs to either of the priority lists, it is ranked as 1;

If for a chemical, WHO's opinion on its carcinogenicity is either canceinogenic or non-carcinogenic and it belongs to either of a priority pollutants list, it is ranked as 2;

If for a chemical, there is one evidence of carcinogenicity but it does not belong to either of priority list, it is ranked as 3;

If for a chemical, there is one carcinogenic evidence, and it belongs to either of a priority list, it is ranked as 4;

If for a chemical, there are 2 carcinogenic evidences and it belongs to either of a priority list, it is ranked as 5;

Table 2 Cancer potency for the organic pollutants in water of Huai River (2003)

Organic pollutants (k)	US EPA list[1]	CPB List[2]	Ames assay[3]	*Cancer potency*[4]		WHO[5]	Cancer ranking score $(CRS)_k$
				Rat	Mouse		
1,2-dichlorobenzene			–	–	–		0
1,3-dichlorobenzene			–	–	–		0
1,4-dichlorobenzene			–	644	398		4
1,2,4-trichlorobenzene							1
hexachloroethane			–	55.4	338		5
bis(2-chloroethoxy)methane							5
4-chlorophenylphenyl ether							5
hexachlorobenzene			–	3.86	65.1		5
2,4-dinitrotoluene			+	6.21	29.4		5
N-Nitro-N-propylamine			+	0.186	+		5
3,3-dichlorolBidine			+	28.1	.		5
Isophorone			–	1210	–		4
2,4-dichlorophenol			–	–	–		1
2,4,6-triclphenol			–	405	1070		5
2,4-dimethylphenol			–	–	–		0
2-methyl-4,6-dinitrophenol			–		–		1
pentachlorophenol			–	13.1	23		5
2-nitrophenol							2
2,4-dinitrophenol			–				2
4-nitrophenol			–	–	–		1
butyl benzyl phthalate			–	–	–		1
di-n-octyl phthalathene			–	–	–		1
fluorene			–	–	–		1
acenaphthene			–	–	–		1
phenanthrene						WHO(+–)	3
anthracene			–	+	–	WHO(–)	3
pyrene						WHO(+–)	3
benzo(a) anthracene			+	.	+	WHO(+–)	5
chrysene					+	WHO(+)	5
indeno(1,2,3-cd) pyrene						WHO(+)	5
dibenz (a,h)anthracene			+		5.88	WHO(+)	5
benzo(g,h,I) perylene			–	–	–	WHO(–)	1
α-HCH			.	11.2	6.62		5
β-HCH			–		27.8		5
γ-HCH			–	–	30.7		4
4,4'-DDD			–	–	30.7		4
2,4'-DDT			–	84.7	12.8		5
4,4'-DDT			–	84.7	12.8		5
Heptachlor			–	–	1.21		4
Aldrin			–	–	1.27		4
HE							4
α-Endosulfan			–	–	–		1
Dieldrin			–	–	0.912		4
Endrin			–	–	–		1
β-Endosulfan			–	–	–		1
Methoxychlor			–	–	–		0

1. US EPA list refers to the priority organic pollutant list of US Environmental Protection Agency, the unit in blue means this pollutant belongs to US EPA list.
2. CPB list refers to the priority organic pollutant list of Environmental Protection Agency of China, the unit in blue in this column means this pollutant belongs to CPB list.
3. Ames assay means the mutagenicities of these pollutants based on Ames assay's results. "+" refers to positive, and "–" refers to negative.
4.Cancer potency refers to the carcinogenic potency of these chemical from CPDB, in detail, is the TD 50 of a chemical. Rat or mouse means the experimental results is obtained based on rat or mouse. "–" refers to negative.
5. WHO refers to World Health Organization, means WHO's opinion on the cancer potency of a chemical.

If for a chemical, there in no carcinogenic experimental data but it belongs to either of a priority list, it is ranked as 5 (principle of precaution).

Based on the Cancer Ranking Score, the toxicity factor T_k of pollutant k is calculated by:

$$T_k = \frac{(CRS)_k}{5}$$

Of course, the authors are aware that the cancer risk is not the only one to be considered to characterize the toxicity of a pollutant. On the other hand, the list of chemicals considered in the table above is not exhaustive.

Therefore, the proposed formula must be considered as a temporary result that should be improved as the knowledge on the toxicity of pollutants increases.

3) *Integration of the sinks* The sinks considered in this paper coincide with the different water uses classified as follows: $j=1$: drinking water; $j=2$: irrigation; $j=3$: fish breeding; $j=4$: water for food industries; $j=5$: water for non food industries.

The method to give a weight V_j to each of them is inspired from the risk management approaches where the weight associated with a category of accidental events is given by:

"weight" = "frequency of occurrence" x "importance of the consequences"

In the present context, the weight V_j associated with sink j is defined by:

$V_j = Q_j \times (SEF)_j$

where Q_j is the amount of water used for sink j during the considered year (in m^3 per year). This data is indeed an adequate quantitative measure of the "frequency of occurrence"

$(SEF)_j$ is a socio-economic factor measuring the "importance of the consequences" on human population of the pollution of the water used by sink j. This factor is chosen in a scale from 1 to 5. Table 3 gives a proposal that, of course, can be modified by local experts to take account of the socio-economic particularities of the considered basin.

Table 3 Proposal of the socio-economic factors

j	Sink	Importance of the consequences	$(SEF)_j$
1	drinking water	very high	5
2	irrigation	high	4
3	fish breeding	high	4
4	water for food industries	very high	5
5	water for non food industries	low	2

The relative weight of sink j is then given by:

$$v_j = \frac{V_j}{V_1 + V_2 + V_3 + V_4 + V_5}$$

Hence, the Environment Pollutant Risk Criterium is defined by:

$$EPRC_i(year) = \sum_{j \in J} I_{i,j}(year) \times v_j$$

This expression calculates the global impact of all the pollutants for all the water use fields (the sinks) on the considered river basin for a given action i.

3. Application to a case study in the Huai river basin The case area is the Xuyi County in the Huai river basin. Three types of actions to manage the pollution in the basin are considered. In each type, various sub-actions are considered (Tables 4-6), including a reference situation ("business as usual") corresponding to the current situation. The list of considered criteria is given in Table 7.

Each action is evaluated according to the above mentioned methodology (Table 8). This evaluation is be made for three time horizons 2001, 2005 and 2010.

The last step is thus the construction of scenarii, i.e. is different combinations of Actions in order to manage the pollution in the basin. The following ones are considered: (a) Scenario S0: A0 + BC0 + D0 (the present situation with no change), (b) Scenario S1: A2 + BC1 +D1, (c) Scenario S2: A2 + BC1 +D2, (d) Scenario S3: A1 + BC2 + D2, (e) Scenario S4: A1 + BC4 + D2.

Table 4 Sub-actions A: wastewater treatment in industries

N°	Short Title	Short description
A0	Business as usual	Don't change anything to the present situation; the environmental management strategy in the future is the same one as now.
A1	All industries	Impose stricter regulations on wastewater treatment (advanced) to all industries in the region, which means the plants must adopt technical renovation to meet both stricter discharge amount and discharge standards.
A2	Certain types of industries	Impose advanced wastewater treatment to chemical industry* in the region and primary treatment to the other types of industries

* In the sub-action A2, the distinction between the chemical industry and the others lies in the fact that simply the chemical industries represent the most important part of the industrial life in this county.

Table 5 Sub-actions BC: agriculture regulation

N°	Short Title	Short description
BC0	Business as usual	Don't change anything to the present situation. The pesticides and fertilizers management situation in future is the same one as now.
BC1	Resources reuse	Application of resources reuse such as full usage of dejections in order to limit the use of chemical pesticides and limit the use of chemical fertilizers with no change in agricultural mode (keep the same kind of crops) and no change of farm drainage treatment.
BC2	Suppress the usage of pesticides/fertilizers	Suppression of chemical fertilizers and pesticides with no change in agricultural mode (keep the same kind of crops).
BC4	Change the irrigation method	Only change the irrigation method and nothing else

Table 6 Sub-actions D: Wastewater treatment outside industries

N°	Short Title	Short description
D0	Business as usual	Don't change anything to the present situation
D1	Renovation	Renovation in sewage treatment technology, from primary to secondary treatment technology.
D2	Secondary treatment for all big cities	Create wastewater treatment plants for all big cities. The plants will be designed for secondary treatment level.

Table 7 List of Criteria

C1	Annual water consumption of rivers in the case area (10^6 m^3/year)
C2	COD discharge intensity (kg/10^4 yuan GDP)
C3	Ratio of urban sewage discharged after treatment (%)
C4	Ratio of country side sewage discharged after treatment (%)
C5	TN discharge intensity (kg/10^4 yuan GDP)
C6	Coherence with historic landscape (linguistic scale)

C7	Agricultural sources (land use changes) (linguistic scale)
C8	Water consumption per unit GDP ($m^3/10^4$ yuan)
C9	Water price for domestic use / industrial use / irrigation (yuan/m^3/sink)
C10	Employment (person)
C11	Increased demand for water (Δm^3/person/year)
C12	Public health risks (linguistic scale)
C13	Dependence on public founds and subventions (linguistic scale)
C14	Risk of conflit between neighbour zones (linguistic scale)

Table 8 Example of Evaluation Table

(Year) Senario	Environmental Criteria						Socio-Economic Criteria						Coherence Feasibility	
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
(2001)														
S0	310.0	66.0	0	0	7.9	3	1	719.0	0.0473	82550.0	0.0	4	2	4
(2005)														
S0	372.4	38.3	0	0	4.7	3	1	435.5	0.0473	82550.0	0.0	4	1	4
S1	360.1	36.2	66	70	3.1	3	1	421.2	0.0473	82616.7	−16.8	3	4	3
S2	360.1	26.9	100	70	3.0	3	2	421.2	0.0473	83283.3	−16.8	2	5	2
S3	357.0	35.3	100	70	2.9	3	2	417.6	0.0473	83000.0	−21.0	2	5	2
S4	265.4	26.8	100	0	4.3	3	2	292.5	0.0473	83183.3	−146.0	3	5	2
(2010)														
S0	372.4	18.5	0	0	2.5	3	1	435.5	0.0473	82550.0	0.0	4	1	4
S1	360.1	12.4	66	70	1.6	3	1	421.2	0.0473	82616.7	−16.8	3	4	3
S2	360.1	12.0	100	70	1.6	3	2	421.2	0.0473	83283.3	−16.8	2	5	2
S3	357.0	16.2	100	70	1.3	3	2	417.6	0.0473	83000.0	−21.0	2	5	2
S4	265.4	12.0	100	0	2.1	3	2	292.5	0.0473	83183.3	−146.0	3	5	2

Fig. 6 illustrates the final ranking of the scenarii for the horizon 2005 if we give all the criteria the same weight. We can observe that the best scenario is the fourth one.

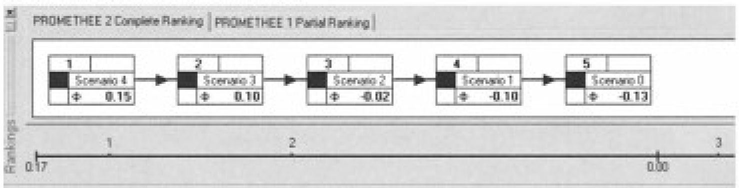

Figure 6: The final ranking of the scenario for the horizon 2005 with all criteria in same weight

We can continue the analysis and compare the ranking of the scenarii if we change the weights of the criteria.

For example, if we put emphasis on the social point of view, we give more importance to the social criteria. It is just an example to illustrate the possible different final results according to the different points of view of the decision makers. In fact, we keep the weight 1 for all the criteria except for the three social criteria: we give the weight 3 to the employment and the increased demand of water, and 5 to the public health risks. The result for the horizon 2005 is shown in Fig. 7.

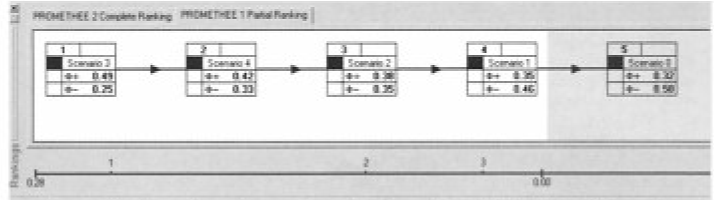

Figure 7: The final ranking of the scenario for the horizon 2005 with all criteria in different weight

In the present case, the best scenario is the scenario 3 while scenario 4 is placed at the second rank. The result is different compared to a homogeneous distribution of weights.

This demonstrates that the MANPORIVERS methodology makes it possible to analyze the robustness of the best scenario.

To summarize, we can say that the MANPORIVERS methodology makes possible to construct pollution management scenarii, to compare them according to criteria defined previously and to propose a final ranking indicating which scenario is the best.

CONCLUSION

The MANPORIVERS methodology is based on the combined use of multicriteria analysis and of fuzzy logics. It constitutes a decision aid tool to help decision makers establish environmentally, socially and economically sustainable management policies for priority water pollutants taking account of their effects on foods and human health.

It is applicable to any river basin and takes account not only of the environmental impacts (typically the concentrations of pollutants in water) but also of the social and economical aspects of the problem.

This methodology can be used interactively for different basins exchanging water. It can also be used at different scales in a recursive manner, from small tributary basins to large basins. These properties constitute a strong incentive to harmonize and coordinate the policies of different basins but these policies can be applied progressively according to the circumstances and available budgets, starting from small basins, since the results of small basins can be directly utilized for larger ones.

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