Decision Support for Water Quality Management

Emil G. Bournaski, Leoneed M. Kirilov, Rossen St. Iliev, Ivan Diadovski

Abstract: *We consider the application of Multiple Criteria Decision Analysis (MCDA) in solving problems for water quality management. A realization with Mesta river catchment in Bulgaria is demonstrated. A set of alternative actions for sustainable improving of water quality are presented. They are evaluated according to a number of eleven ecological and economic objectives. The formulated MCDA problem is solved with the help of computer Interactive Decision Support System.*
Key words: *Decision Support, Multiple Criteria, Mathematical Modelling, Water Quality.*

INTRODUCTION

Multiple Criteria Decision Analysis (MCDA) is a very powerful tool for solving problems where someone has to choose the "best" solution among a finite set of possible alternatives according to several objectives – [11]. An example of such applications is water quality management – [2], [3], [4]. To start with we have to formulate a number of criteria or objective functions and to formulate a set of alternatives (actions for achieving the objectives).

Let us denote the objectives as f_i, i = 1,…,k and the alternatives with a_j, j = 1,…n and the value of alternative a_j according to the objective f_i as v_{ij} . Then the formulation of MCDA problem becomes in matrix form (e.g. rows as objectives and columns as alternatives) to choose an alternative according to some rule (method) [9] that satisfies all objectives as much as possible.

The following scheme could be used for water quality management problems:

1) Defining of a set of objectives for water quality;
2) Defining of a set of possible actions (alternatives, solutions) for solving the problem – for example construction of treatment stations and/or reservoirs;
3) Filling the cells of decision matrix;
4) Choose the best alternative by using appropriate method for Multiple Criteria Decision Analysis;
5) The selected alternative could be investigated further by using sensitivity analysis;
6) If the chosen alternative is not satisfying due to some possibly unknown reasons then the model could be changed – the set of objectives and/or the set of alternatives. Also Group Decision Making can be applied.

Steps 1) and 2) can be performed in reverse order or simultaneously. Steps 3), 4), 5), 6) are usually performed with the help of Decision Support System and by participation of an expert – Decision Maker (DM). In our case we use the Mulino DSS – [3].

This task was performed in the framework of completed in February 2006 TRANSCAT Project of the 5^{th} framework programme of EC - [10]. A TRANSCAT DSS was developed in help of integrated water resources management of transboundary catchments. Mulino DSS is one of the systems incorporated in TRANSCAT DSS.

INPUT DATA

The following water-quality parameters were used: water temperature, pH, dissolved oxygen, NO_2, BOD_5, electric conductivity, permanganate oxidizability, chloride, sulphide, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, phosphates, calcium, magnesium and water hardness. The data are available from the Mesta river monitoring stations – Spirka Gen.Kovachev (1998-2002), Momina Kula (1998-2003), and Hadjidimovo (1981-2003). Similar data are available from Fillipovo monitoring point (1981-1998), the Razlozhka river before flowing into the Mesta river (1981-1998), and for cadmium at Hadjidimovo (1993-2003).

The data analysis shows that the most recent observations do not reveal aggravated ecological parameters.

The older observations from the 80-ies of the last century exhibited certain worsening of some parameters as BOD_5 and N - NO_2 in the section from the Iztok River mouth in the Mesta River to Momina Kula (the Gospodintsi village). The presumptive pollution sources are (see [5]):

1) household wastewater from the settlements in the catchment area;

2) industrial wastewater – mainly from wood industry. It cannot be predicted exactly which branch of industry will be developed in future.

3) uranium mines that are already closed and out of operation and measures have been taken for preventing wastewater flows;

4) agriculture – due to the restricted areas there are no possibilities for significant development of agriculture;

5) tourism – the region offers good conditions for the development of tourism.

The following comments could be made: During the period of the crisis and the transition to market economy in the last decades, many production enterprises were reduced and/or stopped due to a number of reasons. Bulgaria is now gradually coming out of the transition. This implies industrial development, higher life standard of the population and development of tourism and agriculture in the Mesta River catchment. If certain steps are not made in ecological respect, then aggravation of some of the water quality parameters may be expected again. Only one waste water treatment plant (WWTP) was built till the present moment near the town of Razlog.

For this reason the problem with the sustainable water quality solution is very important – [6].

FORMULATING OF ALTERNATIVES AND OBJECTIVES

The following alternatives for sustainable and long-term improvement of water quality and water use in the region of the Mesta River may be suggested following the idea to control the water quality in the main cities along the river.

As a first alternative, the construction of four waste water treatment plants is proposed for the main settlements along the Mesta River course – the towns of Yakoruda, Bansko, Gotse Delchev and Hadjidimovo. This means altogether five WWTPs with the newly built plant in the town of Razlog.

As a second alternative, the construction of four waste water treatment plants is proposed for the main settlements along the Mesta River course – the towns of Yakoruda, Bansko, Gotse Delchev and Hadjidimovo, in combination with a mini-dam (volume of 2-4 million cubic meters) for improving the river water quality in the region of Hadjidimovo.

As a third alternative, the construction of three waste water treatment plants is proposed for the main settlements along the Mesta River course – the towns of Yakoruda, Bansko and Gotse Delchev, and of a medium-sized dam at the Eleshnitsa River, Mesta-2.

As a fourth alternative, the construction of two waste water treatment plants is proposed for the towns of Bansko and Gotse Delchev, and of a medium-sized dam at the Eleshnitsa River, Mesta-2 with envisaged volume of 20-25 million cubic meters.

For comparison we have included as a fifth alterative the option of not undertaking anything, i.e. the present situation with only one waste water treatment plant in the town of Razlog.

The following assumptions are made:

1) with respect to the measuring point. We suppose that the point of measurement will be after Hadjidimovo and close to the border with Greece. In this way the problem with ensuring the necessary quality of the water flowing to Greece is solved. At the same time we also want to achieve good water quality in the possibly longest section of the water course in Bulgaria. Measuring points may be introduced to other four places (after the WWTPs) or more control points may be organized. However, when working with more

points it is convenient to use the model (see the analysis matrix further on) with averaged data for the parameters.

In our case we work with one control point in Hadjidimovo. We set the task of achieving parameters for II category pure water and III category satisfactory pure water – see [1].

2) with respect to the waste water treatment plants. We suppose that their capacity is sufficient to meet the requirements for reaching the above formulated water quality parameters within a time horizon including for example tens of years in future, corresponding to the WWTP operational lifetime. It is expected that the growth of population, development of tourism, industry and agriculture at least to the level of the 80-ies of the last century, should be taken under consideration. This applies also to the characteristics of dams. It is also supposed that an appropriate hydropower plant will be constructed at the medium size dam.

We have selected the following criteria, which could be classified in two groups: economic and ecological criteria.

Economic criteria

1 – costs for the project (alternative) realization (Bulgarian leva)

2 – time for the project realization (years)

3 – period of operation of the realized project (years)

4 – operation costs of the given project (Bulgarian leva)

Ecological criteria

5 – level of ammonium nitrogen (mg/l)

6 – level of nitrate nitrogen (mg/l)

7 – level of nitrite nitrogen (mg/l)

8 – level of phosphates (mg/l)

9 – biochemical oxygen demand - BOD_5 (mg/l)

10 – level of dissolved oxygen (%)

11 – level of permanganate oxidizability (mg/l)

The following considerations were taken into account when selecting the above criteria. The mentioned economic criteria provide sufficiently full description of the "cost" of each alternative. The ecological criteria include the most important (but not all) parameters for the water category determination. We have included the parameters, for which observations have been made.

Some more words about defining the criteria.

Mulino DSS realizes the scheme for decision analysis suggested by S. French in 60-s and adapted by European Environmental Agency (EEA) – [2]. It is based on the so called DPSIR conceptual framework (Driving forces, Pressures, State, Impact and Response). According to this approach the factors of main importance are divided into three groups:

1) Driving forces and
2) the resulting environmental Pressures, on
3) the State of the Environment

and all are measurable.

Then the set of criteria is formed as a subset from the set of Driving forces-, Pressures- and States-factors. For this purpose the so-called DPS-chains/relations (driving force -> pressure -> state) are constructed in a definite manner. The respective Driving forces, Pressures and States are taken from preliminarily developed to this end catalogues – [3]. The user can also develop additionally such catalogues, as we have proceeded in the case with the Mesta River. At the later stages this set can be changed according to DM's wishes.

It is important to point out that one DPS chain may contain only one or two (and not three) elements. The indicators that will be used as criteria in our model are selected from the list of already created DPS chains. It is not obligatory for all indicators to be criteria. An example of DPS chain is: urban-populatuion -> urban-net-emission-of-BOD5 -> BOD5-level-in-river.

FILLING THE CELLS OF THE ANALYSIS MATRIX (AM) AND TRANSFORMING TO THE EVALUATION MATRIX (EM)

Following the scheme from the beginning we enter values in the cells of AM (analysis/decision matrix) as follows:

For the economic criteria

1 – time for the project realization

2 – period of operation of the realized project.

We have expert data on our disposal in real units (years), which we write there.

However we have no concrete data for the next two criteria:

3 – costs for the project (alternative) realization (leva)

4 – operation costs of the given project (leva).

This may happen and direct comparison of the alternatives with each other is envisaged in MULINO DSS – [3]. For this purpose a 9-degree scale is applied. A similar scale was used for the first time by Th. Saaty in the method Analytic Hierarchy Process – [8].

1 – the alternatives are equal with respect to the corresponding criterion

3 (1/3) – the alternative is moderately (better/worse) than the other alternative

5 (1/5) – the alternative is strongly (better/worse) than the other alternative

7 (1/7) – the alternative is very strongly (better/worse) than the other alternative

9 (1/9) – the alternative is extremely (better/worse) than the other alternative

The levels 2 (1/2), 4 (1/4), 6 (1/6) and 8 (1/8) are intermediate ones.

We set thresholds for the ecological criteria #5 – #11 that would be met by the alternatives (projects). These are the conditions for water of the second (II) and third (III) category. They are proposed by experts from the Central Laboratory of General Ecology of the Bulgarian Academy of Sciences – [1].

In this way we have already filled in all the cells of our AM matrix – see Fig. 1.

SOLVING OF THE PROBLEM

After the completing the matrix AM it is transformed into normalized matrix EM (evaluation matrix) by performing “Value Function transformation”. Three types are provided – cost, benefit and user defined transformations. In our case we use cost and benefit types of transformations.

This is the stage where the DM chose the method for selecting the alternatives. Three alternative methods are realized in mDSS Mulino – SWA (simple additive weighting), OWA (order weighted averaging) and TOPSYS (Technique for Order TOPSYS (Technique for Order Preferences by Similarity to Ideal Solution).

Here we present the solution computed by method OWA – see fig. 2.

In advance the DM gives ranging weights for every objective. In our case the ranging weights are equal – 0.1.

CONCLUSION

As it can be seen, the selected alternative is the second one – 5 treatment stations plus mini-dam. Intuitively, it seems to be one of the promising alternatives with the third alternative also. This is due to the fact that we pursue the goal to have a good water quality along as long as possible section of the river. Indeed, the method produces this alternative. But when solving the problem with more detailed data and when the DM gives different weights to different objectives the result can be very different.

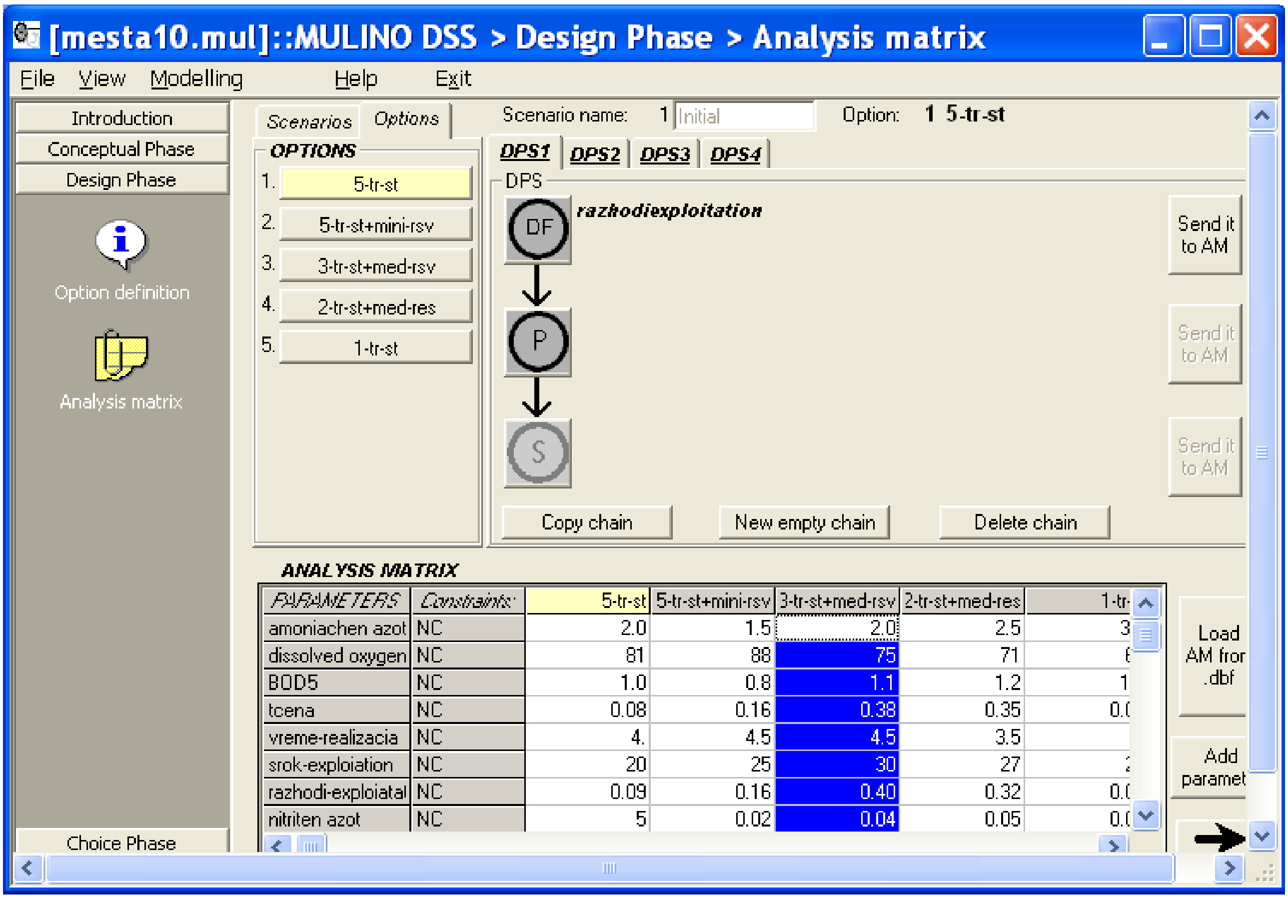

Fig. 1. AM matrix

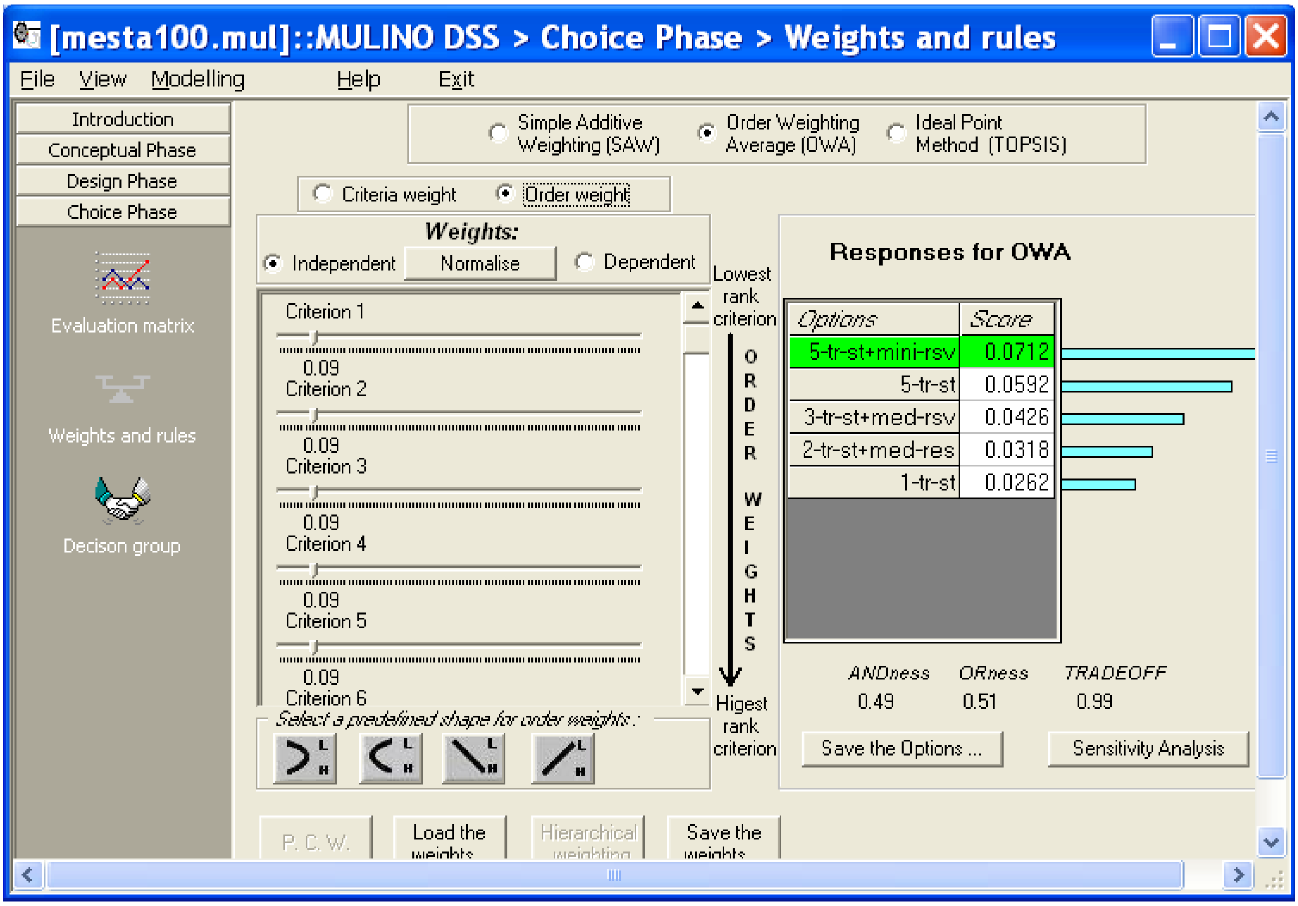

Fig. 2. Solution by OWA method

For example, the objective "price-of-the-project" and/or "time-for-exploitation" could have significant influence to the final solution. Therefore it is recommended the problem to be solved several times at different stages of design and by different DMs.

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ABOUT THE AUTHORS

Assoc. Prof. Emil G. Bournaski, PhD, Department of hydraulics, Institute of Water Problems – Bulgarian Academy of Sciences, Sofia, Bulgaria, Phone: +359 2 979 2413, E-mail: bournaski@netscape.net

Assoc. Prof. Leoneed M. Kirilov, PhD, Department of Decision Support Systems, Inst. of Information Technologies – Bulgarian Academy of Sciences, Sofia, Bulgaria, Phone: +359 2 870 0391, E-mail: lkirilov@iinf.bas.bg

Eng. Rossen St. Iliev, PhD, Defence Advanced Research Institute – MA, Sofia, Phone: +359-2-9226854, E-mail: r.iliev@abv.bg

Assoc. Prof. Ivan Diadovski, PhD, Central Laboratory of General Ecology - Bulgarian Academy of Sciences, Sofia, Bulgaria, Phone: +359 2 871 7195, E-mail: diadovski@hotmail.com