DECISION SUPPORT SYSTEM FOR MANAGEMENT OF WATER SOURCES

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ABSTRACT

Meeting the quality criteria for drinking water is one of the areas which require constant monitoring. The monitoring in Slovenia is currently done by experts. Due to large amounts of data collected while monitoring water adequacy, an expert carries a large burden and also his decisions are prone to errors. In this paper we present a decision support system for controlling the adequacy of drinking water. The approach is based on the qualitative multi-criteria modeling method DEX. We developed two different models – one for general monitoring and another for a specific location and specific pollutant, when a major pollution is discovered. The models and the developed software is presented and evaluated with a case study of Ljubljansko polje aquifer.

1 INTRODUCTION

Drinking water must meet many chemical and microbiological criteria to be appropriate for drinking. All these criteria need to be regularly controlled and monitored.

Presently in Slovenia, the monitoring is done by water experts in a manual way. The expert compares measured concentrations of pollutants in the water with the reference maximal concentrations. If the measured concentrations are larger than maximal reference concentrations, the expert must suggest a measure to make water adequate. Since large amounts of data are collected, the expert is prone to making errors in their decisions. Therefore, some kind of decision support would be a large help to the expert.

The goal of this work was to develop a decision support system (DSS) that would monitor water quality and suggest measures that need to be taken in case of pollution. The measures suggested should be as similar as possible to the ones of the decision maker. In the DSS, the assessment of measures is carried out by a qualitative multi-criteria model, developed using the method DEX.

This paper is structured as follows. The second section gives introductory facts about water sources. DEX methodology is described in section 3, and the DSS in section 4. Evaluation of the DSS is presented in section 5.

2 WATER SOURCES

Drinking water is monitored with a purpose of securing the health of people from harmful effects of water pollutants. Drinking water is, by definition [4], water in its prime state or after preparation, meant for drinking, cooking, and production, preparation and transport of food, regardless of it being supplied from water supply networks, water tanks or as bottled water.

Drinking water is wholesome by chemical and microbiological criteria when following criteria are met [4]:

- Water does not contain microorganisms, parasites and their developmental forms in numbers, which can be harmful to health of people.
- Water does not contain substances in concentrations, which alone or in combination with other substances can present danger to people's health.
- Water measurements are in line with the regulatory maximal pollutant concentrations tables in [4].

The main source of drinking water in Slovenia is groundwater; 97 % of the country's population depends on groundwater for its water supply. This work is concerned only with the most important Slovenian drinking water source, *Ljubljansko polje* aquifer. Monitoring network, used in this study consists of 20 abstraction and observation wells – locations where water is monitored.

Regulation policy [4, 6] for monitoring drinking water requires that at each monitoring location, water needs to be monitored at least three to five times a year, evenly distributed through the year. In case of increased concentrations of the pollutants, additional monitoring is needed. In Slovenia, data monitored within the framework of the national monitoring of groundwater for the past six years is available online [5, 11].

3 DEX METHODOLOGY

DEX is a qualitative multi-criteria decision making methodology [1, 2, 3, 10]. DEX facilitates development of qualitative multi-attribute models, with which decision alternatives are evaluated and analyzed. Evaluation criteria are represented by a hierarchy of qualitative attributes. The evaluation of alternatives is carried out using decision rules. More specifically, a DEX model consists of:

- Attributes: variables that represent basic features and assessed values of decision alternatives.
- Hierarchy of attributes: represents the decomposition of the decision problem and relations between attributes; higher-level aggregated attributes depend on lower-level ones. The lowest-level attributes are basic attributes, which represent basic measurable properties of alternatives. One or more top attributes are called roots.
- Scales of attributes: these are qualitative and consist of a set of words, such as: 'excellent', 'acceptable', 'inappropriate', etc. Usually, scales are ordered preferentially, i.e., from bad to good values.
- Decision rules: tabular representation of a mapping from lower-level attributes to higher-level ones. In principle, a table should specify a value of the higher-level attribute for all combinations of values of its lower-level attributes (as in Table 1).

Evaluation of alternatives is done in a bottom-up manner. Alternative's values are first assigned to basic attributes, then aggregation functions are progressively computed until all attributes obtain their corresponding values. The final evaluation of alternative is the value in the root attribute.

Because of its nature, DEX is an ideal methodology for developing decision support systems. After a model has been developed, it can be used numerous times for evaluating different alternatives, without additional expert's input. Many decision making methodologies, particularly outranking multi-criteria methods, do not have this property and require additional preference information, e. g. pair-wise comparison of alternatives [10].

4 DSS FOR WATER SOURCE MANAGEMENT

Construction of the DSS builds on results of the INCOME project [7]. The starting point is a flow of events on which the monitoring of water must look upon [7, 8, 9]. The flow of events is constructed for a general case of water monitoring, but it can also be specified for a specific pollutant and location of monitoring. The scheme requires four binary input data items for the analysis:

- Is regulatory margin of pollutant exceeded?
- Is there an unfavorable trend of past concentrations?
- Location type: abstraction or observation well.
- Is additional monitoring currently performed?

The event flow is applied on every measured pollutant and for every location. Measures are applicable only for that particular pollutant and location.

4.1 Requirements

As input data the DSS should get the five input values: location, pollutant, date, concentration and if additional monitoring is performed. This data were collected in the INCOME project [7]. From input data, the DSS should produce a set of measures which need to be taken, so that the water would be adequate in the future.

The DSS should facilitate an easy addition of actions for specific pollutants and locations, since not all actions are known at development time. The DSS must be able to store previous measurements in its data structures, and it must be able to add new measurements to the data structures.

A wrapper program which forms a bridge between DEX models and stored data is needed. Also, it should support command line options and a suitable GUI for plotting time series of measurements, trend lines and regulatory margins.

4.2 DEX models

We firstly developed one model for a general case of pollution; it can be applied for any location or pollutant. The model is completely based on the event flow [7, 8, 9]. However, the measures after pollution may differ between pollutants and locations, therefore more specific models must be created. In principle, one model should be developed for each location/pollutant pair. In this work so far, we constructed one specific model for pollutant *tricloroethene* and location *AMP Hrastje*.

Action
- Exceeded regulatory margin
- Unfavorable trend line
- Location type
- Additional monitoring

Figure 1: Hierarchy of the general model.

4.2.1 General Model

This model contains four input attributes and one root attribute (Figure 1). The input attributes are logically constructed from attributes in section 4 and have two values: *yes* or *no* – except the *Location type*, which can be *abstraction* or *observation well*.

The root parameter of the model is named Action and has the following values, sorted by the severity of the action: Regular monitoring; Activate the well into network; Repeat measurement; Increase measurement frequency; Finding reasons for bad state and remedial measures; Implementation of measures to achieve good state; Deactivation of well. The decision rules for Action are presented in Table 1.

4.2.2 Model for Hrastje and tricloroethene as pollutant

When a major pollution is discovered it is possible to suggest specified measures for a specific pollutant and location. This model suggests measures for *Hrastje* wells and pollutant *trichloroethene*. In comparison with the general model, the specified model has the same structure (Figure 1), but decision rules (Table 1) differ so that some general actions from the general model are replaced by more specific actions in the specific model. *Remedial measures* in the general rules were changed to:

- Ventilation.
- Combination of ventilation with carbon absorption.
- Ventilation of soil.
- Ventilation in the borehole.
- Biological removal.
- Heating of soil or borehole.
- Removal with hydrogen.

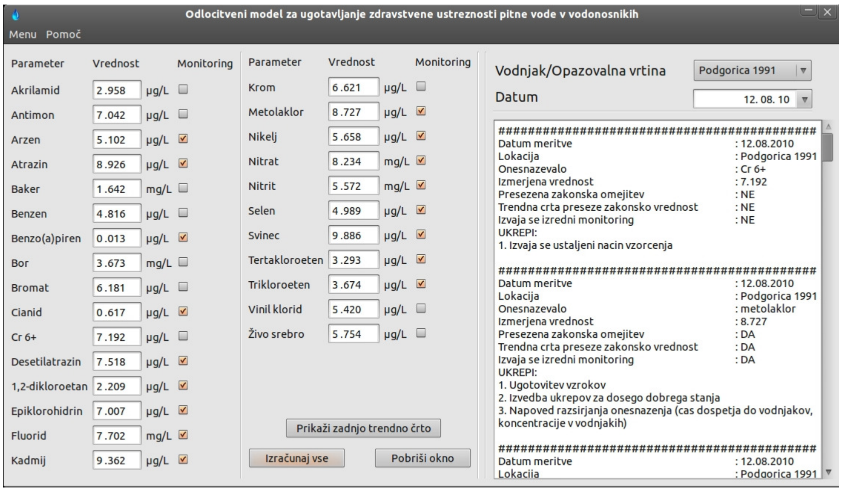

Figure 2: The main graphical user interface of the DSS. Data are input on the left, the results are shown on the right.

Exceeded regulatory margin	Unfavorable trend line	Location type	Additional monitoring	Action
YES	YES	Abstraction well	YES	Deactivation of well
YES	YES	Abstraction well	NO	Deactivation of well
YES	YES	Observation well	YES	Finding reasons; Remedial measures
YES	YES	Observation well	NO	Repeat measurement; Increase measurement frequency
YES	NO	Abstraction well	YES	Deactivation of well
YES	NO	Abstraction well	NO	Deactivation of well
YES	NO	Observation well	YES	Finding reasons; Remedial measures
YES	NO	Observation well	NO	Repeat measurement; Increase measurement frequency
NO	YES	Abstraction well	YES	Activate well
NO	YES	Abstraction well	NO	Measure implementation
NO	YES	Observation well	YES	Finding reasons; Remedial measures
NO	YES	Observation well	NO	Measure implementation
NO	NO	Abstraction well	YES	Activate well
NO	NO	Abstraction well	NO	Regular monitoring
NO	NO	Observation well	YES	Regular monitoring
NO	NO	Observation well	NO	Regular monitoring

Table 1: Decision rules of the general DSS model

4.3 User interface

The DSS was primarily developed for command line use. Thus, the core of the DSS is a command-line program that connects data and DEX model, and governs the processing.

On top of the command-line program, there is a graphical user interface (Figure 2). It supports entering of concentrations for all pollutants and declaring if the additional monitoring is being performed. It also supports selecting the date and the location from a drop down list. Plotting regression trend lines and loading and saving measurement data is also available. A sample plot is shown in Figure 3. Measurements are plotted with dots, the decreasing line represents the declining trend of the measurements and the horizontal line represents the regulatory margin for this particular pollutant.

4.4 Evaluation of one measurement

The DSS expects five arguments on its input: Monitoring location, pollutant, pollutant concentration, is additional monitoring performed and the date of measurement.

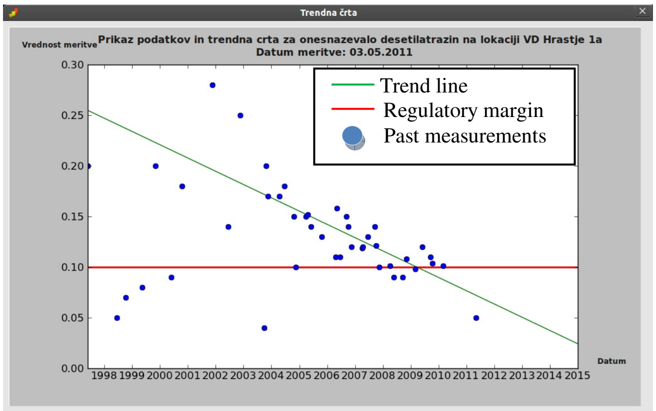

Figure 3: Window showing a decreasing trend line for deethylatrazine on VD Hrastje 1a location. Dots show past measurements; the horizontal line is the regulatory margin.

The input arguments are then transformed to qualitative values as follows:

- *Exceeded regulatory margin* is *yes* when the measured concentration is equal or higher than the regulation margin.
- *Unfavorable trend line* is set to *yes* if the linear trend line, extrapolated from past five-year measurements, is expected to reach the regulation margin in year 2015.
- *Location type* is set to *abstraction well* if ‘VD’ is in the name of the location; otherwise the location is *observation well* [9].
- *Additional monitoring* is supplied to the program with an explicit argument.

Actual evaluation is performed by an external DEXiEval utility [3], which evaluates the alternative on the specific model (if it exists), otherwise on the general model.

5 EVALUATION

In order to evaluate the DSS, we constructed two test cases. The first test case is evaluation of all locations with all pollutants. With it, we can assess chemical status of *Ljubljansko polje* aquifer. The second test case is an evaluation of *trichloroethene* pollution, discovered in *Hrastje* wells. After applying the DSS on both cases, we discussed the results with a water-management expert.

5.1 General model

For each of the 20 locations in *Ljubljansko polje* aquifer, we collected all last measurements for each of the most important pollutants [5]: *Cr6+*, *deethylatrazine*, *metolachlor*, *nitrates*, *tetrachloroethene* and *tricloroethene*. Because the data on performing additional monitoring was not available, we performed two assessments for each location-pollutant pair – one with additional monitoring assumed and one without. We applied the general model.

From the results we concluded that the state of the aquifer is almost perfect. On all 5 abstraction and 15 observation wells we got the measure of *Regular monitoring* for almost all pollutants, regardless of additional monitoring. However, there were a few exceptions: on location *AMP Mercator V2* with pollutant *deethylatrazine*, on *VD Hrastje 1a* with *deethylatrazine*, on *Hrastje V1* with *tetrachloroethene*, and on *OP-1* with *deethylatrazine*. In the case of *AMP Mercator V2, both* the regulatory margin and unfavorable trend line were breached. The second case *VD Hrastje 1a* indicated problems because of the regulatory margin. The remaining two cases, *Hrastje V1* and *OP-1*, both indicated problem because of the unfavorable trend lines.

5.2 Hrastje model

The evaluation set up was the same as with the previous case. We only collected data for four locations: *Hrastje V1*, *Hrastje V2*, *Hrastje V3* and *Hrastje V4*, and *tricloroethene* as pollutant. We selected it, as it is one of the most important pollutants in *Ljubljansko polje*.

In this case, all evaluations were non-problematic – the DSS suggested *Regular monitoring*. No regulatory margins were breached and no unfavorable trends were identified.

5.3 Expert opinion

We presented every aspect of the DSS to the expert and also all the experiments were discussed. He positively accepted the features and results of the DSS. About the evaluation of the aquifer, based on the DSS's recommendations, he said: "Results are logical and show relatively good chemical status of the aquifer, which in turn ensures the adequacy of the water source for pumping drinking water."

6 CONCLUSION

In this work we developed a decision support system for controlling adequacy of water sources in Slovenia, but with emphasis on the *Ljubljansko polje* aquifer. The work was based on the results of the INCOME [7] project. Two decision models were developed with DEX methodology, one general model and one specific model for *AMP Hrastje* location with pollutant *trichloroethene*. A wrapper program for querying available measurement data and interaction with the models was developed. For easier interaction, a graphical user interface was implemented. Finally, the system was assessed on two test cases: evaluation of the whole aquifer with the general model, and assessment of *AMP Hrastje* location with *trichloroethene* as pollutant. The results were consistent with the expert's expectations and indicated a relatively good state of the aquifer.

In the future work, more specific models need to be created for other locations and pollutants. Also a connection with a geographic information system would be a great advantage to the end-user.

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References:

[1] Bohanec, M.: Odločanje in modeli, DMFA – založništvo, 2006.

[2] Bohanec, M., Rajkovič, V., Bratko, I., Zupan, B., Žnidaršič, M.: DEX methodology: Three decades of qualitative multi-attribute modelling. *Informatica* 37, 49–54(2013).

[3] Bohanec, M.: A Program for Multi-Attribute Decision Making, User's Manual, Version 4.00. IJS Report DP-11340, Jožef Stefan Institute, Ljubljana, 2013.

[4] Pravilnik o pitni vodi, Ur. L. RS, št. 19/2004, Register predpisov Slovenije, 2004.

[5] Stanje voda, Agencija Republike Slovenije za okolje, accessible on http://www.arso.gov.si/vode/podatki/, August 2013.

[6] Gacin, M., Mihorko, P., Krajnc, M.: Poročilo o kakovosti pitne vode v Sloveniji v letih 2007 in 2008, Agencija Republike Slovenije za okolje, interno poročilo, Ljubljana, 2009.

[7] Project INCOME (LIFE07 ENV/SLO/000725, (January 2009 - June 2012), accessible on http://www.life-income.si/, august 2013.

[8] Janža, M., Prestor, J., Šram, D.: Sistem za podporo odločanja pri upravljanju vodonosnikov Ljubljanskega polja in Barja (poročilo za project INCOME), Geološki zavod Slovenije, Ljubljana, 2011.

[9] Trdin, N.: Decision support model for management of water sources, Diploma work, Faculty of Computer and Information Science and Faculty of Mathematics and Physics, Ljubljana, 2011.

[10] Figueira, J., Greco, S., Ehrgott, M.: Multiple Criteria Decision Analysis: State of the Art Surveys, Springer Verlag, 2005.

[11] ARSO: Program monitoringa stanja voda za obdobje 2010 - 2015. Slovenian Environment Agency, Ljubljana, 2011.

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