A Decision Support System for Evaluation and Remediation of Contaminated Sites

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Abstract

A computer aided system is presented which should be an effective support for the government offices which are responsible for the evaluation of contaminated sites and the decision with regard to the kind of remediation. This system consists of two main parts. These are the knowledge based program XUMA and a decision support system.

XUMA includes a knowledge base with the principal methods for handling contaminated sites. The main features belonging to XUMA are:

- Evaluation of contaminated sites
- Creation of analysis plans
- Assessment of contaminated sites
- Knowledge acquisition tool
- Explanation Facility

The decision support system which bases on the decision analysis theory of vonNeumann-Morgenstern with multiple value extensions from Keeny-Raiffa is to support the responsible authorities in order to find out the best kind of remediation from a given set of alternatives.

Introduction

In the last years contaminated sites have become a relevant problem in the Federal Republic of Germany because there exist a large number of these sites. About 10% of these sites have to be remediated. That's why in Germany more intensive efforts are undertaken in order to start necessary remediations. Basic initial conditions for an effective execution of these works are on the on side a systematically registration of these sites and on the other side the creation of an uniform possibility of evaluation in connection with the assessment of environmental hazards.

Beside the 18.000 communal and the 27.000 private sites may be contaminated the responsible governmental offices of the State of Saxony have additional problems during remediation of sites because radioactive components are in the sites of the former Soviet-German Corporation WISMUT which has been an uranium mining corporation.

The Structure of the Environmental IT-System in Saxony

In order to solve the problems regarding the background described above the responsible institutions of the State of Saxony are going to build up a registration and evaluation system for sites may be contaminated.

Figure 1 shows the structure of this registration and evaluation system. The lines between the objects only represent the data flow. On-line data connections don't exist. Therefore the direction of data transfer is defined in the following manner.

The data acquisition takes place at the engineering offices. In order to ensure data consistency and data completeness the engineering offices use an interface program which can be generated automatically from the knowledge base of the expert system XUMA. This interface program was developed by the Research Centre Rossendorf Inc. (FZR - Forschungszentrum Rossendorf) together with the Technical University of Dresden.

After that the data have to be transferred to the office which is responsible for the rural district (LRA - Landratsamt). Each LRA of a governmental district on the one side stores the data and of the other side transfers the data to the responsible governmental office (StUFA - Staatliches Umweltfachamt). Beside storing their own data all StUFAs transfer the data to the Institute of Environmental Protection of the State of Saxony (LfUG - Landesamt für Umweltgestaltung und Geologie). At LfUG the complete data of the State of Saxony are stored. In order to handle these data different programs will be connected with this central data base. Some of the main functions these programs have to realise are shown in figure 2. The upper part of this figure represents the site-evaluation system which is partly implemented in XUMA and the lower one describes the decision support for remedial actions.

The Evaluation Method

The evaluation method used for contaminated sites in the state of Saxony bases on the method which was developed at the State Institute for Environmental Protection of Baden-Württemberg (Landesanstalt für Umweltschutz Baden-Württemberg). The goal of this method is to determine priorities with respect to the environmental hazard and to the further investigations or a possible remediation of the site. In order to evaluate, the site has to be separated into four different media to be protected (ground water, surface water, soil and air). For each of these media the following five steps have to be carried out. Each of these steps contains the calculation of hazard-increasing or -decreasing factors relative to a defined comparative site.

- r0 - risk value of the site (hazard of substances)
- m1 - transport of substances out of the site
- m2 - transport of substances into the media to be protected
- m3 - transport and effects of substances in the media to be protected
- m4 - the significance of the media to be protected concerning the human

These five steps result into a numerical risk value describing the environmental hazard of the site. In dependence on the level of evidence this risk value allows to derive priorities with respect to further investigations and the environmental hazard of the site. The levels of evidence are defined through the kind of investigation. There exist four levels of evidence:

- BN1 - historical investigation is finished (limited informations with assumptions concerning the substances and the geological situation but without any chemical and physical analyses)
- BN2 - oriented investigation is finished (more detailed informations with a limited set of samples and chemical or/and physical analyses)
- BN3 - detailed investigation is finished (detailed informations concerning the substances, the transport of substances etc.)

BN4 - investigation for remediation is finished

In dependence on the described evaluation level and the risk value the following activities are derived:

A - elimination (registration of site with no further investigations or inspections)
B - deposit with the demand for an inspection after a certain time
C - deposit with the demand for continuous technical control measures
D - the demand for checking possibilities in order to reduce the hazard of the site (containment or/and remedial actions)
E - further investigations (not enough informations for decision)

The background for this step by step investigation method is that the costs for investigations increase rapidly from one level of evidence to the next one. With the help of this method many costs can be saved if actions A...C are derived at a lower level of evidence. The flow chart of the described evaluation method is shown in figure 3.

<u>The Knowledge Based System XUMA</u>

Regarding this background the FZR together with the Society for Nuclear Technique and Analysis Rossendorf (VKTA - Verein für Kernverfahrenstechnik und Analytik Rossendorf) apply the computer program system XUMA as one component of the central program pool.

XUMA (German synonym for expert system on environmental hazards of contaminated sites) is a joint project of the Institute for Applied Information Science (Institut für Angewandte Informatik) of the Karlsruhe Nuclear Research Centre (Kernforschungszentrum Karlsruhe) and the State Institute for Environmental Protection of Baden-Württemberg (Landesanstalt für Umweltschutz Baden-Württemberg).

XUMA is a knowledge based computer system, which shell support the staff of the responsible government offices at the uniform evaluation of the hazard potential, the preparation of analysis plan and the assessment of contaminated sites and mines. The system is to relieve the staff in their routine work, makes available the specialists knowledge for them and allows to take into account the most new findings with the help of a knowledge acquisition component.

XUMA runs under the operating system UNIX® on a SPARC workstation. It communicates with a relational database (oracle®) in which the site-specific and the knowledge base data (substances, branches, etc.) are stored. XUMA is designed to the client-server principle. The server is written in Lisp and ART®, a hybrid expert system development environment. The user communicates with XUMA through the client - a Graphical User Interface (GUI), managed by an the User Interface Management System Open-UI®.

The functions of XUMA principally consists of the following five components.

1. Evaluation

The evaluation method used in XUMA corresponds with the method described above.

Functions:
- systematically registration of waste suspected sites and their technical data
- objectivity during site evaluation with the help of a determined comparative risk value
- derivation of a need of action
- estimation of efficiency with respect to activities in order to decrease environmental hazard

Method:
- comparative evaluation of sites may be contaminated
- separate observation of the media to be protected (ground water, surface water, soil, air)
- step by step evaluation of substantial hazard, transport and effects of pollutants and significance of the media to be protected
- evaluation process in the four levels of evidence

The next two components have a great significance at the higher levels of evidence. They evaluate the input data for the evaluation component at these levels.

2. Preparation of analysis plan and analyses acquisition

Functions:
- systematically registration of site-specific samples and analyses data
- derivation of an analysis plan for chemical and physical investigation of the specific site or a typical industrial branch

Method:
- supporting the selection of relevant analytical parameters by substantial or/and branch-specific hints
- three different possibilities of access for the derivation of an analysis plan
  - branch access (use of a branch tree which is implemented in the knowledge base)
  - substantial access (use of knowledge about site-specific waste)
  - standard access (waste with an unknown hazard potential)
- possibility of different detailed substantial investigations corresponding to the level of evidence
- possibility of different detailed analyses of samples corresponding to a eligible investigation level

3. Assessment

Functions:
- assessment of a specific site or a part of the site concerning to its samples, analysis quality and analyses results

Method:
- possibility to choose between three alternatives
  - assessment of an analysis
  - assessment of a complete sample
  - assessment of whole site or a part of it
- kinds of assessment results:
  - quality of samples and/or analyses and their safety (comparison between analysis plan and analyses really carried out)
  - quality classes (classification of the measured values with the help of reference value tables)
  - statements about substances occurred in the site
  - derived assessment statements
  - statistics

In order to use this expert system effectively and to get an acceptance from the governmental offices, the two additional components are implemented. These are the explanation facility and the knowledge acquisition facility.

4. Explanation

The explanation facility enables the reconstruction and verification of the results. It shall help the user to check the plausibility of solution and to reconstruct the derivation path. Furthermore, it shall enable the expert to trace back the results to the basic knowledge and to prove the correctness of the solution.

Functions:
- explanation of derived assessment statements in natural language

Method:
- mouse-sensitive explanation of statements concerning the assessment in two justification levels
- the local justification describes:
  - the fact to be explained
  - the name of the rule, which has derived this fact
  - the rule content in natural language
  - the facts which have fulfilled the conditions of the rule
- the global justification describes:
  - the complete derivation tree of a statement
  - the possibility of rule-editing

5. Knowledge Acquisition

With the help of the direct knowledge acquisition facility the expert user is able to modify and complete the knowledge base. That means, the facility allows the manipulation (addition, modification, deletion) of objects and rules without any experience in programming.

Functions:
- changing or completing the knowledge base with respect to the following components:
  - substantial data
  - analysis parameter
  - branches of industry
  - reference value tables
  - rules with regard to reference value tables
  - rules with regard to analysis parameters
  - evaluation features

Method:
- menu-controlled choice of the part of the knowledge base to be edited
- support of rule editing by a rule editor which represents the eligible rule components in a natural language manner

Beside the Saxony-specific modification of the evaluation knowledge base FZR and VKTA are going to implement components, in order to get a suitable knowledge based system also for radioactive contaminated sites. The implementation of this "radioactive tree" requires the insertion of complex computer simulated calculation modules, because the distribution of radioactive substances in the environment, the radioactive decay and the transfer to human plays an exponent rule. This includes

- distribution in the air, in the surface water and in the ground water
- bio-transfer chain earth - plant - animal - human
- the radioactive decay during distribution and bio-transfer
- the different hazard of radioactive substances for the human

The relational data base ORACLE is to use as the connection between the expert system and the calculation modules. With these implementations the knowledge based system has the in picture 4 showed structure.

Decision Support for Remedial Actions

When the need for remedial actions at the contaminated site has been determined, the responsible authorities are faced with the problem of designing and comparing feasible remedial alternatives. As the investigation process at the site gives in general a good overview of the type of contamination and the surrounding environment, several plausible remedial scenarios can be constructed easily. Comparing these alternatives and taking a decision for one of them in a rational and defensible way is hard to achieve. This task is furthermore complicated by conflicting arguments for the alternatives and uncertainty about the actual outcomes.

This is a typical situation for the use of decision analysis. To assist the responsible authorities in taking their decision, we apply methods based on the theory of vonNeumann-Morgenstern [vonNeumann-47] with multiple value extensions from Keeney-Raiffa [Keeney-76]. If the decision maker is willing to act according to the axioms defined in this theory, the existence of a real-valued utility function u is assured, that accurately reflects the preferences of the decision maker over the state of possible outcomes $\boldsymbol{X}$. This function can be used to evaluate the different alternatives i taking the uncertainty (represented by a probability function p_i over $\boldsymbol{X}$) and the multiple objectives explicitly into account. This is done by calculating the subjective expected utility SEU_i for every alternative.

$$SEU_i = \int_{x} dx\, u(x)\, p_i(x)$$

Additionally further investigation of the decision situation can be performed via sensitivity analysis and by calculating the value of additional information.

The application of the theory described above consists of the following three succeeding steps.

1. Definition of the utility function u

The definition of the utility function starts with the construction of an appropriate outcome space. The restrictions the outcome space has to comply with can be found in [von-Winterfeldt-86, pp. 36]. The application of the theory currently under way was complicated by the existence of several, decision relevant agents with different opinions about the important values in the outcome space. As an agreement about the outcome space to use was nevertheless achieved, step 2. has already started. For the codification of the preference structure into a unifying utility function computational aids are required (see step 3.).

2. Assessment of the probability distributions p

The assessment of the probability distributions for the alternatives is a complex problem. The input data consist primarily of measurements, statistical data and subjective estimations. These data are connected by functional dependencies, complex simulation programs and approximations to the decision relevant outcome space. Additionally possible events during the remediation process must be taken into account and the consequences of them estimated. Especially these events lead to probabilistic dependencies between different values of the outcome space.

To represent the various data and relationships graphically an editor for functional networks was programmed. Because the same editor can also be used to define the utility function, a unifying environment is available.

3. Calculation of SEU_i and advanced investigations

At this point, a functional network representation of the p-distributions and the utility function has been constructed. To calculate the SEU for the alternatives it is necessary to compute the p-distribution of the utility function u. Unfortunately it is not computationally feasible to calculate the distribution directly because of the various probabilistic dependencies mentioned above. Therefore we had to use Monte-Carlo techniques [Morgan-90]. A big advantage of these techniques is the easy implementation of a sensitivity analysis. If the program package is finished, a unifying environment for the definition of utility functions, for calculating p-distributions, for evaluating alternatives with the SEU and for advanced investigation of the decision situation will be available.

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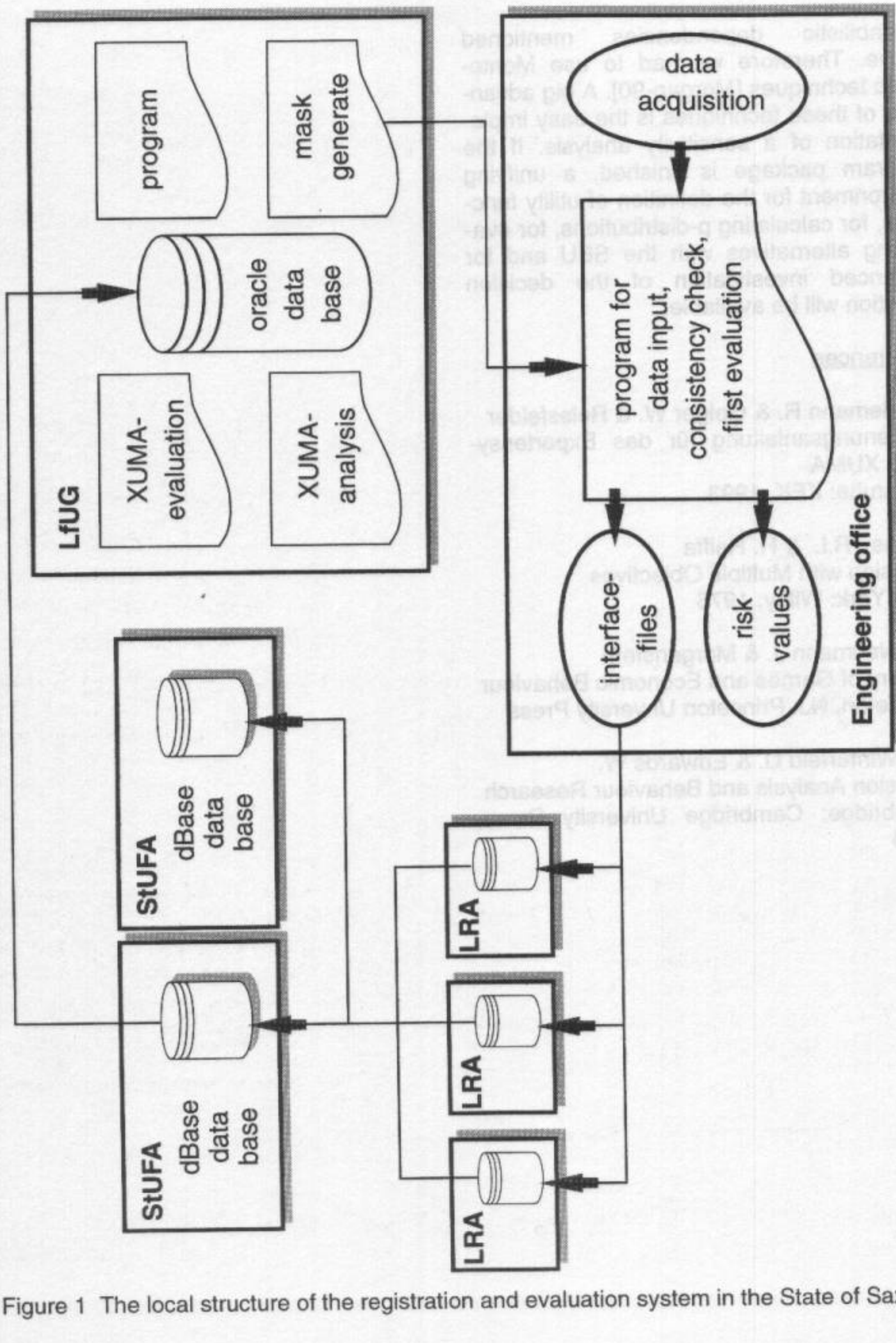

Figure 1 The local structure of the registration and evaluation system in the State of Saxony

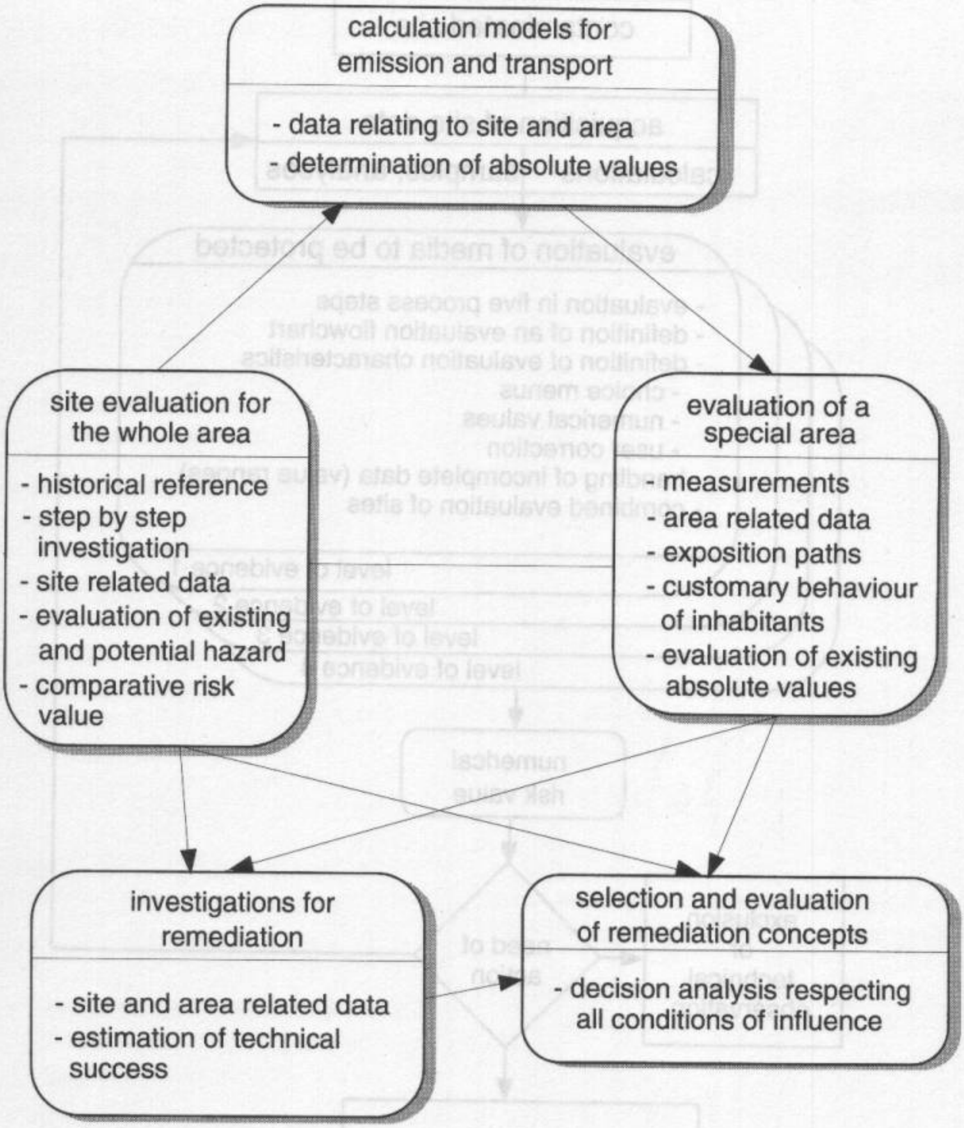

Figure 2 The main components of a site evaluation and remediation system

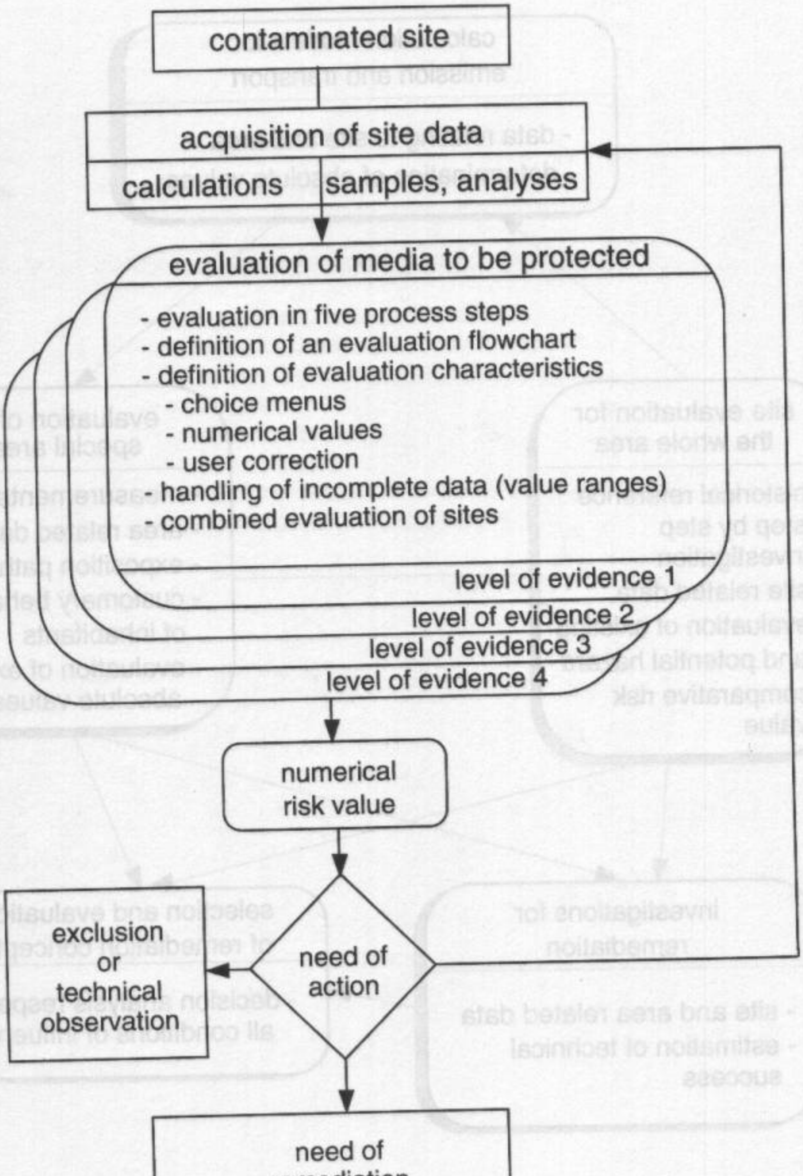

Figure 3 The flowchart of site evaluation

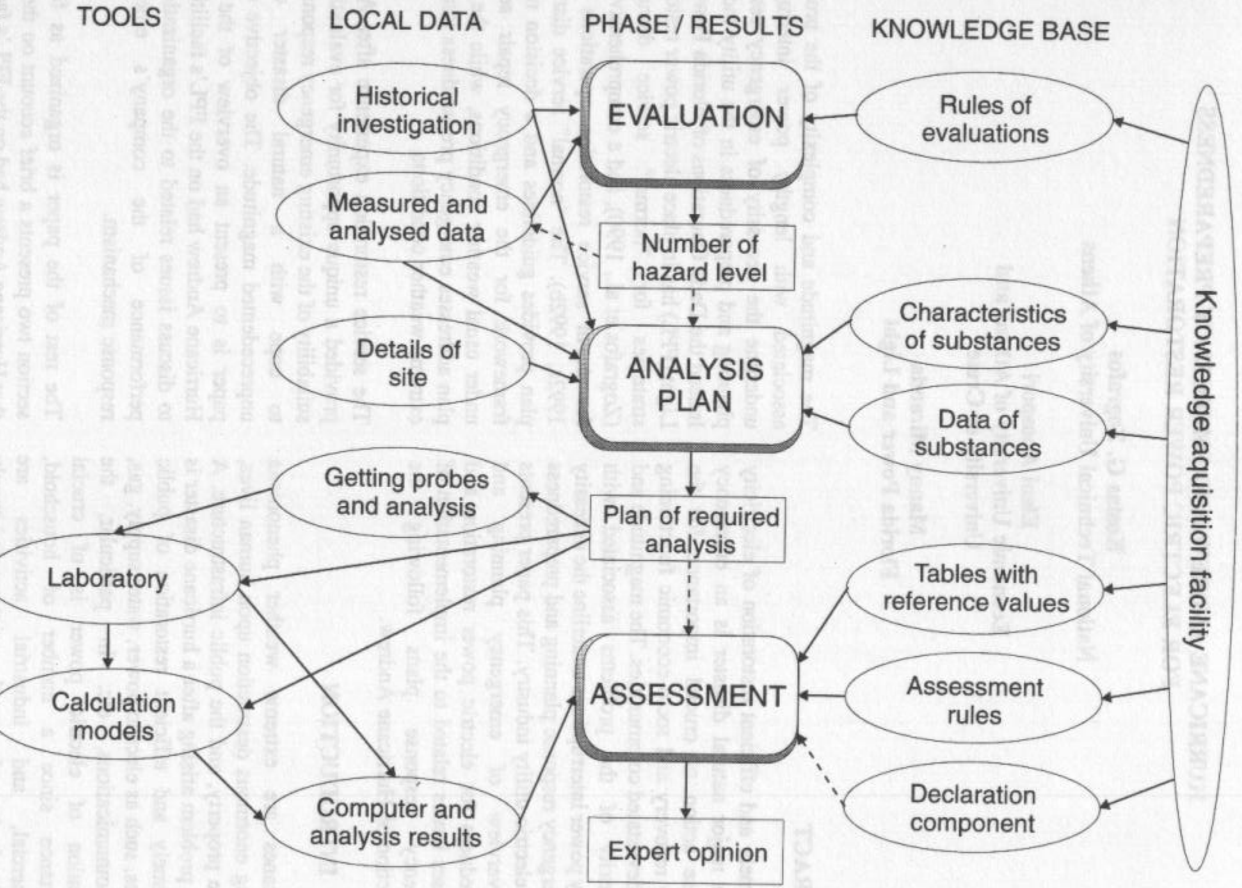

Figure 4 Structure of XUMA