An Environmental Diagnosis Expert System

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Abstract. The paper presents an expert system, SBC-MEDIU, developed` for environmental diagnosis. Two modules of the system are discussed in detail: the module for air pollution analysis and dispersion assessments, SBC-AIR, and the module for soil erosion risk assessments, SBC-SOIL. Both modules provide at the end of the analysis the environmental diagnosis result and the associated allert code. Some experimental results obtained so far are also described.

1 Introduction

An efficient environmental management system has to include software tools for air, water and soil pollution diagnosis. In the recent years, several artificial intelligence (AI) tehniques were applied to environmental diagnosis (such as knowledge-based systems, expert systems, case-based reasoning, artificial neural networks, data mining). Some systems recently reported in the literature, that are based on AI techniques, could be found in [1], [8] and [12]. Usually, these systems are specialized either to air, or water or soil analysis. Most of the systems are dedicated to air and water analysis, and few of them to soil analysis. Our research work involved the integration of all three main components of the environment analysis (air, water and soil) into an environmental diagnosis expert system. The reason of developing an integrated system is the dependency that can appear between air, water and soil pollution. Due to the high complexity of such a system we have concentrated our efforts to the inclusion of the expert knowledge for some types of environmental diagnosis. We have developed an expert system, SBC-MEDIU, that has three modules, SBC-AIR, SBC-SOIL, and SBC-WATER, for air, soil and water pollution analysis. In this paper we shall focus on two modules of the system, SBC-AIR, for air pollution analysis and dispersion assessments, and SBC-SOIL, for soil erosion risk assessments. The module SBC-WATER makes a surface water pollution analysis and is described in [9]. The expert system can be used as an educational tool for students, and also, as a decision support tool for the local Environmental Agencies.

2 The architecture of the expert system

The expert system SBC-MEDIU has a modular architecture, presented in Figure 1. The three modules of the system are SBC-AIR, SBC-WATER and SBC-SOIL, each having a knowledge base with specific expert knowledge represented under the form of production rules. All modules are using the inference engine of VP-Expert, an expert system generator [2]. The purpose of module SBC-AIR is to make a diagnosis of the air pollution, taking into account different parameters such as the air pollutants concentrations, and some meteorological data. Also, this module is doing air pollution dispersion assessments. The module SBC-WATER makes surface water pollution diagnosis, while the module SBC-SOIL is doing soil erosion risk assessments.

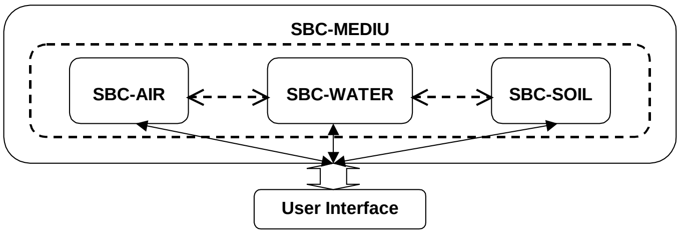


Fig. 1. The modular architecture of the expert system SBC-MEDIU.

Figure 2 shows the basic components of each module of the system SBC-MEDIU: a knowledge base, the inference engine, and the databases with standards (for a clean air, water and soil), and timeseries of specific measurements (meteorological, concentrations of air pollutants, water pollutants, and soil pollutants etc).

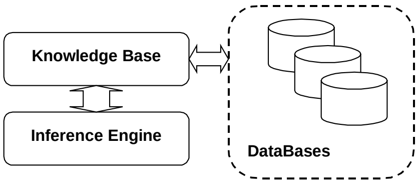


Fig. 2. The basic components of each module of SBC-MEDIU.

3 The module SBC-AIR

The analysis made by the module SBC-AIR has the following parts: (1) the air quality index assessment, (2) the air pollution analysis, and (3) the air pollution dispersion assessment. The knowledge base used in the air pollution analysis includes rules from the knowledge base of the expert system DIAGNOZA_MEDIU [7]. In this section we describe parts (1) and (3) of the analysis.

Air Quality Index

A comprehensive environmental assessment system can facilitate tracking and benchmarking of the air quality performance, providing a tool for measuring any continuous improvement [6]. Legislation, through regulations and norms, establishes the ambient concentrations of pollutant to which the receptor is limited. Air quality criteria delineate the effects of air pollution.Standards for air pollution (e.g. Romanian O.M. 592/2002) are concentrations over a given time period that are considered to be acceptable in the light of what is known about the effects of each pollutant on health and on the environment. They can also be used as a benchmark to see if air pollution is getting better or worse. An exceedence of a standard is a period of time where the concentration is higher than that set down by the standard. In order to make useful comparisons between pollutants, for which the standards may be expressed in terms of different averaging times, the number of days on which an exceedence has been recorded must be reported by the expert system. After making specific inferences, the expert system provides reliable answers (solutions /results /decisions) to solve air pollution aspects based on the information identified in the knowledge base. SBC-AIR established the air quality indicator using recorded imissions pollutant concentrations (15 minutes - sulfur dioxide, hourly - ozone, nitrogen dioxide and 24 hours values - PM10 fraction), introduced by the user, providing warning capabilities related to the potential impact of air pollution on sensible individuals: (1) *Green Code* – levels 1, 2 and 3 - Effects are not noticed by individuals sensitive to air pollutants; (2) *Yellow Code* - levels 4, 5 and 6 - Medium effects, may be noticed amongst sensitive individuals, do not require intervention; (3) *Red Code* - levels 7, 8 and 9 - Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed; (4) *Maximum Code* - level 10 - The effects on sensitive individuals described for 'High' levels of pollution are worsening - Maximum Alert threshold. Figure 3 shows a screenshot of the SBC-AIR module run.

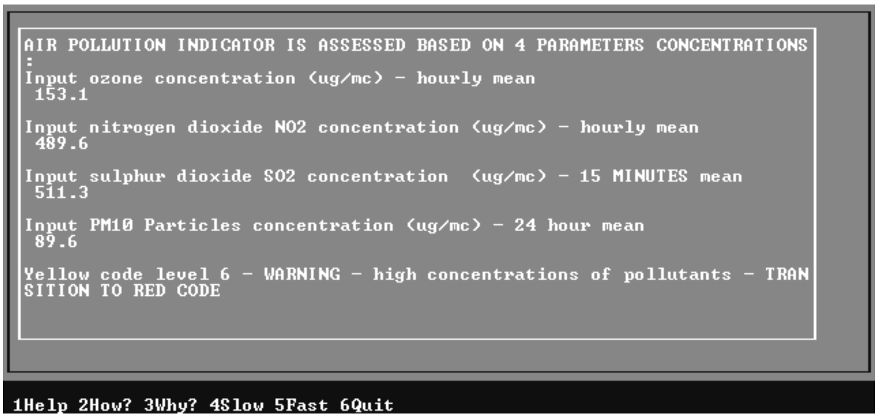


Fig. 3. SBC-AIR quality index result: Yellow code level 6.

Air pollution dispersion

SBC-AIR required the integration of a simple tool assessing what happens to pollutants in the atmosphere after they are discharged from stationary emission sources. For the present, the stochastically based Gaussian type model is the most useful in modeling for regulatory control of pollutants [13]. The Gaussian plume model provided rough estimates of pollutant ground level concentrations (imissions) in the absence of monitored data, allowing Air quality index calculations. Therefore, the final objective of the calculations using SBC-AIR capabilities was to determine if an emission will result in ground ambient concentrations which exceed air quality standards that have been set by reference to air quality criteria.

Local meteorological processes and topography control the amount of pollution as it spreads and reaches ground level. Inversions are the principal meteorological factor present when air pollution situations occur, such as: Surface or Radiation Inversions, Evaporation Inversion, Advection Inversion and Subsidence Inversion [13]. Pollutants are transported by wind and turbulence, and they may undergo chemical transformations before being deposited on the earth's surface [10]. The way in which atmospheric characteristics affect the concentration of air pollutants after they leave the source can be viewed in three stages: effective emission height, bulk transport of the pollutants and dispersion of the pollutants. Several factors affect the plume, including the effective height (*H*) of emission, which is a measure of how high the pollutants are emitted into the atmosphere directly above the source. The height is dependent upon source characteristics and atmospheric conditions. The turbulence caused by the air flow over the surface and by possible instability governs the diffusion of the plume contents. Visible plumes are indicators of stability conditions. Five special models have been observed and classified by the following names: looping (unstable), coning (stable), fanning (slight stable), fumigation (moderately stable) and lofting (dispersal upward). Recognition of these conditions is helpful to the modeler and in gaining an additional understanding of dispersion of pollutants [14]. The major factors that characterize the emission source are: composition, concentration, and density, velocity of emission, temperature of emission, pressure of emission, the diameter of emitting stack or pipe, and the effective height of emission.

Knowing the location of the source relative to the receptor and its characteristics would allow calculating the concentration at a particular downwind receptor using a dispersion model. A Gaussian mathematical model was used, which incorporates source-related factors and meteorological factors to estimate pollutant concentration from the stationary sources. The model is applicable to continuous sources of gases and particulates less than 10 μm in diameter estimating the plume concentrations over horizontal distances of 10^2 to 10^4 m [6].

$$C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z U}\cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\cdot\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad \mathbf{(1)}$$

where: *C(x, y ,z, H)* - pollutant concentration at any point in the plume ($\mu g\ m^{-3}$);

Q – emission rate of pollution from the source ($\mu g\ s^{-1}$) ;

H - the effective height of the pollution source, function of the chimney height, its diameter, speed and temperature of gas exhaustion, and air layering;

σ_y, σ_z – horizontal and vertical standard deviations of the pollutant concentration distributions in the y and z directions;

U - the wind speed measured at the height of the source ($m\ s^{-1}$).

The Gaussian model (equation 1) and related additional algorithms, were used to allow SBC-AIR to compute ground level concentrations at any receptor point (X_o,Y_o) in a polluted region resulting from each of the isolated sources in the emission inventory. Despite its limitations in building a complex image of the bulk transport of pollutants and their chemical transformations before being deposited on the earth's surface, and the building downwash and surrounding topographical features effects, the system provided preliminary information of main air pollution dispersion factors status and trends based on real data from different emission sources in the Dâmboviţa County. We have selected as exemplification the emission source of Doiceşti power plant stack (1074.6 and 392.5 $m^3 s^{-1}$) from the 17 stationary sources with mass flows greater than 4 $m^3 s^{-1}$.

The first step of the program is to compute lateral and vertical dispersion coefficients for each atmospheric stability category: Very Unstable, Moderately Unstable, Slight unstable, Neutral, Somewhat stable, and Stable. The user is asked to input the distance from the stationary source (km) of the point required to assess the pollutant concentration. Plume shapes are comprehensive indicators to estimate and select the atmospheric stability class. A screenshot of this step run is shown in Fig. 4.

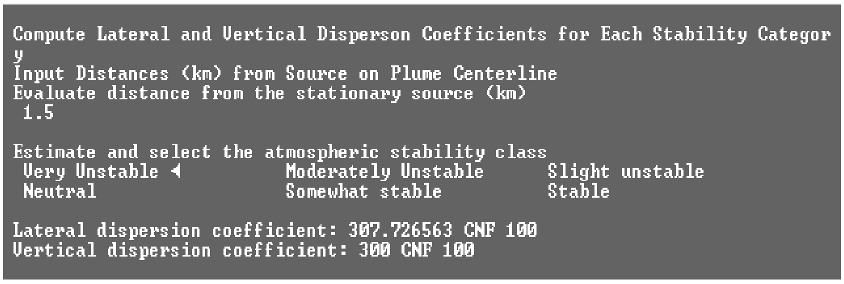


Fig. 4. SBC-AIR screenshot of the first step run.

The second step involves the introduction of the emission source characteristics such as: gas exit velocity (m/s), stack diameter (m), gas exit temperature and ambient temperature in Kelvin degrees. A screenshot of this step run is shown in Figure 5.

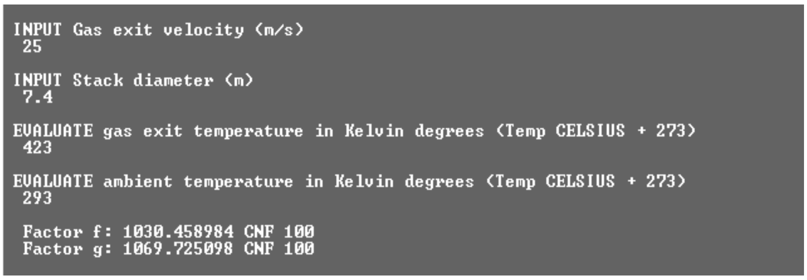


Fig. 5. SBC-AIR screenshot of the second step run.

Several more parameters are required to be introduced: wind velocity measured at 10 meter height (m/s), the stack height of the emission stationary source (m), and the source emission rate (g/s). Consequently, SBC-AIR computes the ground level concentrations (e.g. 208.5 μg m^{-3}) at any receptor point from the emission source on plume centerline in the selected region resulting from each of the isolated sources in the emission inventory. These steps are shown in Figure 6.

If the main composition of the emission from the analyzed stack is known, by comparing the result of the estimated concentration of ground-level pollution on plume centerline at selected distance from source with the standard limit values, SBC-AIR provides the estimation of the pollutant exceeding. Aggregation of the results obtained for different distances permits the graphical visualization of the pollutant dispersion (see Figure 7).

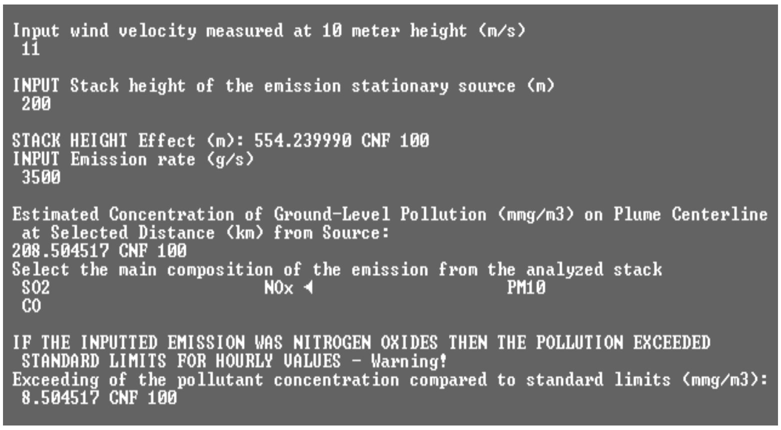


Fig. 6. SBC_AIR screenshot of the last step run.

Smoke plume from stack is often trapped in the radiation inversion layer at night and then brought to the ground in fumigation during morning hours. This converts into high ground-level concentration. With moderately unstable condition, pollution is transported downward toward ground level. In the looping pattern situation, the sinusoidal path may bring the plume content to ground level close to the emitting source. Figure 7 highlights this situation showing a maximum ground concentration at 1.5 km far from the power plant stack. This is a dangerous situation for the inner-locality residents suffering from asthma or other respiratory illnesses. In this case, the wind speed regime does not have a significant influence on the ground concentration.

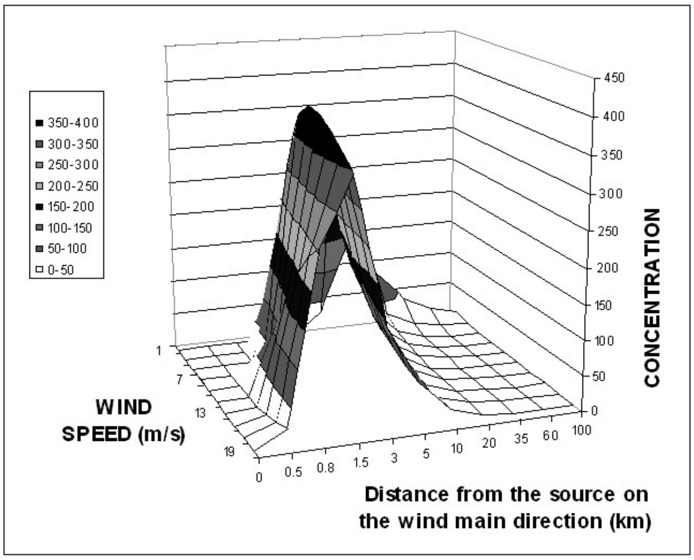


Fig. 7. Pollutant ground concentration (μg m^{-3}) in unstable atmospheric conditions for Doiceşti power plant stack using SBC-AIR dispersion assessment.

4 The module SBC-SOIL

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture [4]. During the last 40 years, nearly one-third of the world's arable land has been lost by erosion and continues to be lost at a rate of more than 10 million hectares per year [11]. Average rates for soil loss have been estimated at 17 tones/ha per year in the United States and Europe, and 30-40 tones/ha per year in Asia, Africa and South America, mainly due to inadequate agricultural land use [11]. A recent review on erosion models and the quality of spatial predictions [3], states the great difficulties associated with calibrating and validating spatially distributed soil erosion models. It is mentioned that this is due to the large spatial and temporal variability of soil erosion phenomena and the uncertainty associated with the input parameter values used in models to predict these processes. Jetten et al. conclude that the construction of more complete and therefore more complex models will not overcome this problem; rather the situation may be improved by using more spatial information for model calibration and validation, and by using models that describe the dominant processes operating in a given landscape.

SBC-SOIL is a simplified assessment tool for soil erosion risk that assists novice application users in evaluating environmental problems for various local weather and geo-morphological conditions. It was developed by using the elements of universal erosion formula: pluvial intensity (aggression), soil erosion capacity, vegetation and cropping system influence, versants characteristics and adding surface runoff effect (soil permeability and surface slope). Validation and verification steps were done according a special attention to the input and control variables definition, interface conditions definition, rule base structure, inference rules design and their transformation to actions – consequently, the expert decision elaboration.

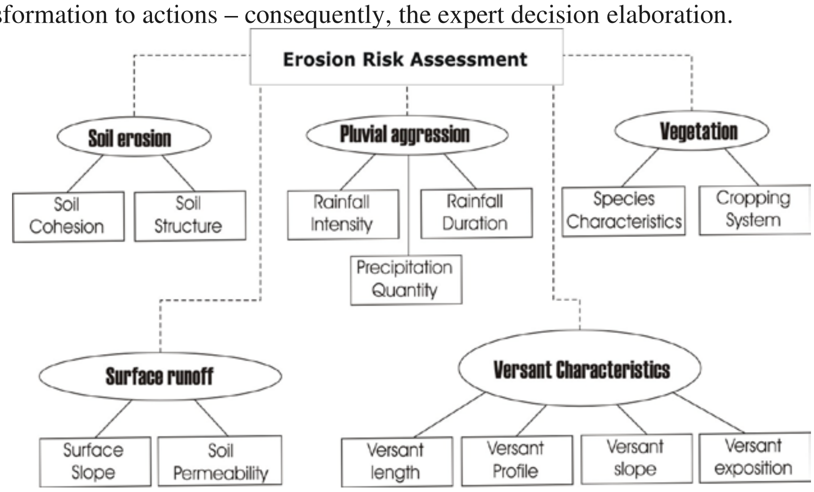


Fig. 8. The decision tree for heuristic assessment of global erosion risk of a specific site.

Figure 8 highlights the SBC-SOIL inner structure, consequently the decision tree that provides the evaluation of global erosion risk from a specific location based on the risk analysis of the individual components. The development of SBC-SOIL has relied on the elements that constitute the erosion universal formula, adding surface runoff effects on erosion. Production rules were conceived for the following components: soil erosion capacity (9 rules), pluvial aggression (10 rules), vegetation and cropping system influence (13 rules) and versant characteristics (10 rules), adding surface runoff risk estimation (9 rules). The final rule set that evaluates the global erosion risk contains 5 rules. We show the run of SBC-SOIL step by step.

1) *Soil erosion* capacity is influenced by factors such as the structural soil aggregates dimension and water stability, granular structure, soil volume weight etc. Two factors were considered to empirically estimate this parameter: particles cohesion and soil structure. Figure 9 shows the screenshot of the system run for soil erosion analysis.

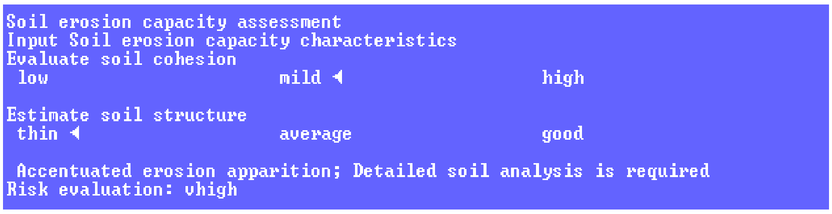


Fig. 9. Soil erosion analysis – screenshot of system run.

2) *Pluvial aggression* is assessed using three variables according to end-user estimation, as follows: rainfall intensity, rainfall duration and precipitation quantity. Figure 10 shows a screenshot of pluvial aggression analysis.

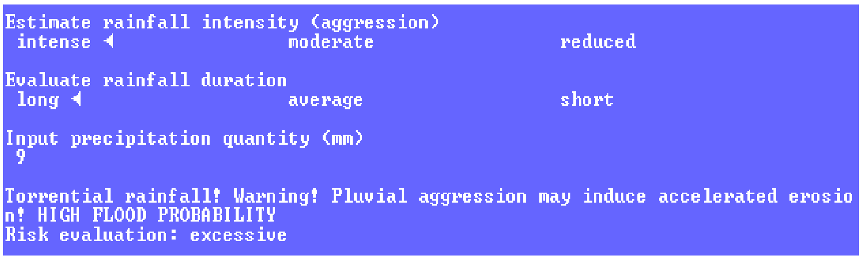


Fig. 10. Pluvial aggression analysis – screenshot of system run.

3) *The vegetation and cropping system* or vegetation arrangements influence considered the grouping of species by erosion sensibility, and cropping system by erosion protection degree. Figure 11 shows a screenshot of vegetation analysis.

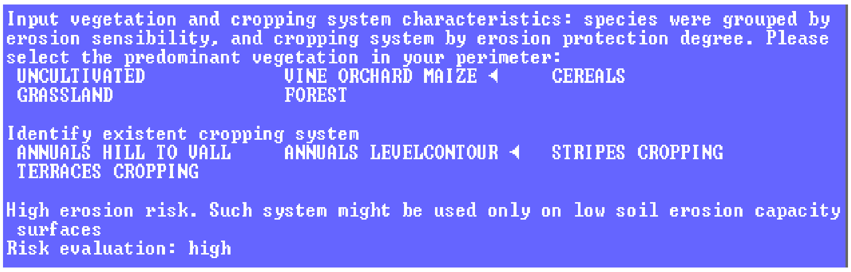
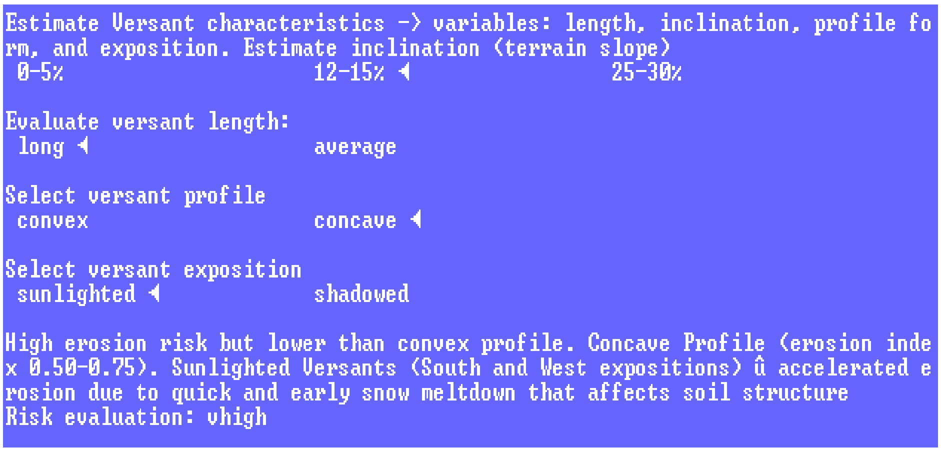


Fig. 11. Vegetation analysis – screenshot of system run.

4) *Versant characteristics effect* on erosion risk was estimated based on versant length, slope, profile form and exposition. Figure 12 shows a screenshot of versant characteristics analysis.


Estimate Versant characteristics -> variables: length, inclination, profile fo
rm, and exposition. Estimate inclination (terrain slope)
0-5% 12-15% ◄ 25-30%

Evaluate versant length:
long ◄ average

Select versant profile
convex concave ◄

Select versant exposition
sunlighted ◄ shadowed

High erosion risk but lower than convex profile. Concave Profile (erosion inde
x 0.50-0.75). Sunlighted Versants (South and West expositions) û accelerated e
rosion due to quick and early snow meltdown that affects soil structure
Risk evaluation: vhigh

Fig. 12. Versant characteristics analysis – screenshot of system run.

5) *The Surface Runoff Class* site characteristic determined from the relationship of the soil permeability class and field slope was adapted from the Soil Survey Manual (1993) and was included in SBC-SOIL in order to increase the system complexity. The erosion risk is established based on runoff classification from soil permeability category that characterize the infiltration process and surface slope. Table 1 shows the erosion risk assessment, while the decision table for the surface runoff effect on erosion risk is given in Table 2.

Table 1. Erosion Risk assessment in SBC-SOIL based on runoff classification from soil permeability category and surface slope, and the decision table of extracted specific rules.

SLOPE	Very rapid	Moderately Rapid and Rapid	Moderately Slow and Moderate	Slow	Very Slow
Concave	N	N	N	N	N
<1	N	N	N	L	M
1-5	N	VL	L	M	H
5-10	VL	L	M	H	VH
10-20	VL	L	M	H	VH
>20	L	M	H	VH	VH

Soil permeability Classes (mm/h):
Very slow < 0.15 mm/h
Slow 0.15-0.5 mm/h
Moderately slow 0.5-1.5 mm/h
Moderate 1.5 – 5 mm/h
Moderately rapid 5-15 mm/h

RISK: *N-negligible*
M-medium
VL – very low
L - low
H- high
VH-very high

Table 2. Decision table for the surface runoff effect on erosion risk.

RULE	SURFACE SLOPE	SOIL PERMEABILITY	RISK
A1	REDUCED	SLOW	**NEGLIGIBLE**
A2	AVERAGE	SLOW	**MODERATE – RELATIVELY HIGH**
A3	ACCENTUATED	SLOW	**HIGH-VERY HIGH**
A4	REDUCED	MODERATE	**NEGLIGIBLE**
A5	AVERAGE	MODERATE	**MODERATE**
A6	ACCENTUATED	MODERATE	**RELATIVELY HIGH**
A4	REDUCED	RAPID	**NEGLIGIBLE**
A5	AVERAGE	RAPID	**REDUCED**
A6	ACCENTUATED	RAPID	**MODERATE**

Figure 13 shows a screenshot of the system run for surface runoff analysis.

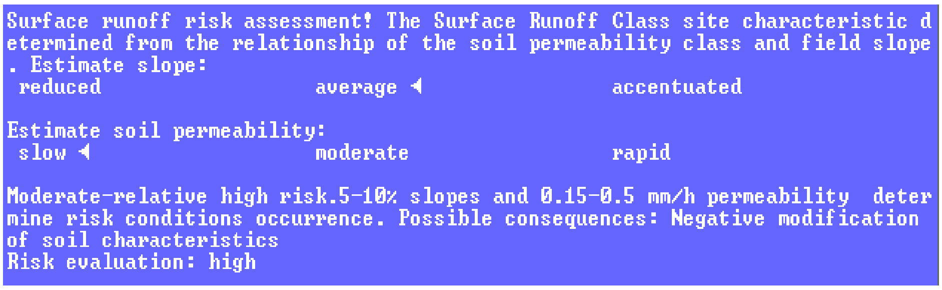


Fig. 13. Surface runoff analysis – screenshot of system run.

6) SBC-SOIL provides the final analysis giving comprehensive answers concerning the global erosion risk and brief descriptions of the negative consequences which might occur. Several color codes were considered to facilitate the understanding of final results: (1) *RED CODE* – Maximum Risk; (2) *ORANGE CODE* – Critical Risk; (3) *YELLOW CODE* - High Risk (with two levels, 1 and 2); (4) *GREEN CODE* – Moderate or reduced Risk; (5) *IDEAL CONDITIONS* – Absence of Risk or minimal Risk.

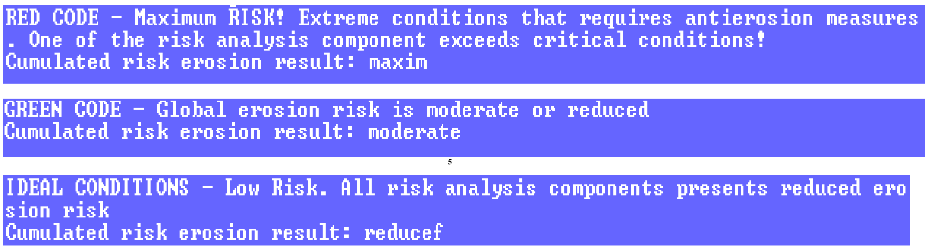


Fig. 14. Expert messages containing the final estimation of erosion risk using artificial reasoning.

Table 3 shows the decision table used by the module SBC-SOIL for the global evaluation of erosion risk.

Table 3. Decision table for the global evaluation of erosion risk.

<table>
<tr><th colspan="2"></th><th>6_1</th><th>6_2</th><th>6_3</th><th>6_4</th><th>6_5</th></tr>
<tr><td colspan="2">Operator</td><td>OR</td><td>OR</td><td>AND</td><td>AND</td><td>OR</td></tr>
<tr><td>Soil erosion capacity</td><td>erod</td><td>excessive</td><td>vhigh</td><td>high</td><td>reduced/vreduced</td><td>high</td></tr>
<tr><td>Pluvial aggression</td><td>stand</td><td>excessive</td><td>vhigh</td><td>high</td><td>reduced/vreduced</td><td>high</td></tr>
<tr><td>Vegetation</td><td>veg</td><td>excessive</td><td>vhigh</td><td>high</td><td>reduced/vreduced</td><td>high</td></tr>
<tr><td>Versant characteristics</td><td>versant</td><td>excessive</td><td>vhigh</td><td>high</td><td>reduced/vreduced</td><td>high</td></tr>
<tr><td>Surface runoff</td><td>risk</td><td>excessive</td><td>vhigh</td><td>high</td><td>reduced/vreduced</td><td>high</td></tr>
<tr><td rowspan="4">Global risk assessment</td><td>scop</td><td>maxim</td><td>excessive</td><td>high</td><td>reduced</td><td>high</td></tr>
<tr><td rowspan="3">code Display</td><td rowspan="3">Red</td><td rowspan="3">Orange</td><td rowspan="3">Yellow level 1</td><td rowspan="3">IDEAL CONDITIONS</td><td>Yellow level 2</td></tr>
<tr><td>/ELSE</td></tr>
<tr><td>moderate Green code</td></tr>
</table>

The rules from the knowledge base of module SBC-SOIL were generated from the decision tables 1, 2, 3, as well as from the existing speciality literature [3], [4] and [5].

The module SBC-SOIL facilitates the understanding of the complex relationships among the main factors that are responsible for the apparition, development and acceleration of various surfaces erosion process. It has proved to be a versatile diagnosis tool for the global erosion risk, providing the user with the ability to perform *a posteriori*, detailed analysis of the main erosion factors that presents high risks, using SBC-SOIL resources from its knowledge base.

5 Conclusion and future work

Environmental components (air-water-soil) are characterized by the high complexity of the involved processes, which are difficult to be translated into deterministic models. The expert system SBC_MEDIU provides an integrated decision support tool for environmental management, solving problems such as water quality, air pollution and soil erosion analysis. The system can be used as an educational tool for the students that study the environmental protection domain.

At the level of local Environmental Protection Agencies, SBC-MEDIU can be integrated in a Local Monitoring Plan to provide useful information for decisional support and reliable answers to:

- standards/regulations demands concerning qualitative and quantitative aspects;
- trends of environmental quality modification due to various factors;
- impact of deterioration on ecosystems;
- and the efficiency of strategies and management action for pollution control.

The preliminary use of this system might also facilitate the environmental monitoring-network design, control strategy evaluation or control-technology evaluation.

As a future work we shall verify the performance of the knowledge bases on more scenarios, with interdependencies between air, water and soil pollution. Also, we will consider the increasing of the system complexity to become an alert system serving to signal when potential pollution is high for water, air or soil, requiring interaction between control agencies and emitters. The system will serve to locate areas of expected high concentration for correlation with health effects, or to identify environmental pollution issues.

Acknowledgement. The research reported in this paper was partially funded by the Romanian Education and Research Ministry and the National Council of Academic Research (UEFISCSU-CNCSIS) under the postdoctoral research programme CEEX19-1533/2006.

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