A GIS-based decision support system for revegetation and reclamation of Opencast Coal Mine spoils

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Abstract: Abandoned coal mine spoils can result in severe pollution and have aesthetic on the local environment. A range of reclamation techniques is available for substrate but only through the use of vegetation to stabilize coal mine spoils can complete long-term rehabilitation be achieved. Experimentation has been undertaken at coal mine sites to attempt to elucidate and overcome limitations to vegetation establishment, allowing large-scale revegetation schemes to be formulated. Although such schemes have often been successful at specific sites, their widespread application is limited owing to the great variation in physical, chemical and biological factors which exist between mine spoils. This paper presents a research attempt to develop and evaluate a GIS-based Decision Support System (DSS) for revegetation of land contaminated from mining activates. As a means of Expert System (ES) and Decision Support System (DSS) approach, the system was developed assisted with Multi-Layer fuzzy synthetic Judgment and gray relating priority analysis. The system is being developed and tested by China Agricultural University, which is funded by Asia IT&C program. This paper looks at why a spatial DSS is needed and what are the advantages and difficulties in the developing and using such a system. And the system's architecture and components are described. Some valuable insights into the use of GIS as a tool for decision support in decision plan for revegetation of land contaminated from mining activities are highlighted.

Key-Words: Remote sensing; GIS; Intelligent reasoning; land contaminated from mining activities.

1 Introduction

Mining activities have been in existence for thousands of years. Mining activities are known to ravage large areas leaving them uncultivable resulting in permanent, non-restorable land surface. The disturbances are most evident and protracted in arid areas subjected to moisture deficiency, salt accumulation and erosional hazards with the result that satisfactory vegetation establishment is difficult on these sites.

Once mining has ceased, it is desirable to establish quickly a permanent vegetation cover that will reduce soil erosion, provide wildlife habitat and support other land use. It is only in this century that serious consideration has been given to the rehabilitation of areas before the actual mining takes place. Bradshaw and Chadwick (1980) reviewed the state of restoration of land and did much to formulate ideas and concepts on rehabilitation. They, and in later papers, Bradshaw (1983, 1984, 1990) identified the major problems of derelict land as being high concentrations of toxic metals and salts, acidic conditions, coarse particles and lack of moisture and essential nutrients. These factors combined to create a hostile environment, which is not conducive to the establishment of plants. Fortunately, in dune mining, only mobile sand and lack of nutrients and moisture are important. Early work on rehabilitation of derelict land concentrated more on the removal of the nuisance value of pollution and unsightly mine dumps (e.g. Thatcher, 1979). More recently, the emphasis has been on the reclamation of land in a way that allows it to be re-used. Thus, Bradshaw (1984), like Harris et al. (1996), prefers the general term of reclamation to relate to the return of the land to a functional use.

Many research projects were reported. Catherine Neel, et al. (2003) identified the factors affecting natural development of soil on 35-year-old sulphide-rich mine tailings at the gold mine of La Petite Faye in France, Rao & Tak (2002) investigated the growth of different tree species and their nutrient uptake in limestone mine spoil as influenced by arbuscular mycorrhizal fungi in Indian arid zone. Leteinturier, et al. (2001) reported the reclamation of lead/zinc processing waste at Kabwe Zambia. Ye, et al. (2002) evaluated the major constraints to the revegetation of lead/zinc tailings use bioassay techniques in China. Bleeker, et al. (2002) described revegetation of the acidic as contaminated Jales mine spoil tips using a combination of spoil amendments and tolerant grasses in Portugal. Bech et al. (1997) presented arsenic and heavy metal contamination of soil and vegetation around a copper mine in Northern Peru.

From above, many pilot studies and field trails of revegetatation or rehabilitation are carried out on settlement ponds or tailing dumps to determine the effectiveness of replacing topsoil, the desirability of using a brushwood mulch and on evaluation of the rate of establishment of various species from seeds, and landscape development all over the world. The success of these studies provides much valuable data, knowledge and technologies, which can be used to determine what techniques shall be applied.

Although such schemes have been successful at specific sites, their widespread application is limited owing to the great variation in physical, chemical, and biological factors which exist between mine spoils. Rehabilitation of lands contaminated from mining activities are a very complicated process and requires requires high level of domain knowledge, only the experts and researchers involved these projects absolutely can't meet the demand of rehabilitation of land contaminited from mining activities, the knowledge and techniques transfer were awfully limited only buy journal papers and research project. A decision support system for rehabilitation of land around mining city and landscape development are essential required to support this area.China is one of the world's most important raw material producers, possessing extended quantities of mineral fuel, metallic and non-metallic resources; currently, there are 330 mining cities, over 8000 national and 230 000 private mining companies presently operating, 12,000 active mine sites producing annually producing 60 million ton mining spoils annually (Ye, et al, 2002).

A GIS based decision support system for rehabilitation of lands contaminated from mining activities (REHALAND) was designed and developed by China Agricultural University, which is funded by Asia IT&C program (CN/ASIA - IT&C/006 (89870).

2 Description of REHALAND

Although mining can bring much economic prosperity, large areas of industrial dereliction often result once mining has ceased. This dereliction includes a legacy of abandoned tips and tailings, which are often a major source of heavy metal pollution in local environment. It is now a requirement in most countries that reclamation schemes are incorporated at the planning stage of mining proposals.

A range of reclamation techniques is available for metalliferous substrates but only through the use of vegetation to stabilize mine spoils can complete long-term rehabilitation be achieved. Successful revegetation can be a permanent and visually attractive solution and at the same time be relatively inexpensive (Tordoff, et al. 2000). A vegetation cover also goes a long way towards reducing the visual scars in the landscape caused by large-scale mining operations. Successful revegetation way allows recreational use of the land, and even agriculture or forestry if conditions are favorable. A well-planed scheme should overcome the problems on a permanent basis. This requires a thorough site evaluation and selection of the most appropriate revegetation technique with regard to local conditions. To make reasonable decisions, the overall purpose of RELAND is to provide a support tool to for site evaluation and selection of the most appropriate revegetation schemes. More detailed objectives are: (1) Design a general site evaluation model for revegetation potentiality based on the physical, chemical, and biological growth-limiting factors in the target area. (2) Use fuzzy similarity models to determine the native plant species and metal-tolerant plants.(3)Design case-based and rule-based model to select the most appropriate revegetation schemes based on the similarity in the physical, chemical, and biological growth conditions.(4)Integrate all these models in a GIS based DSS able to provide information concerning the recommended rehabilitation/revegetation technologies for each case.

The architecture of REHALAND is shown in Fig. 1. Databases, model bases, control programs, and interface were the main components of the GIS-based system. The database includes all attribute data for models and vector data and the information obtained when each one is executed. The user interface serves to define and store scenarios and also to select the analysis tools of the system to be used. 4 subsystems, such as revegetation potentiality evaluation subsystem, plant species selection subsystem, and revegetation schemes selection subsystem, were included in REHALAND.

2.1 Revegetation potentiality evaluation subsystem

The goal of revegetation potentiality evaluation subsystem is to provide a reasonable evaluation on the revegetation potentiality, in another word, to identify the degree of difficulty for revegetation based on the situations of the target mine site. The degree of difficulty for revegetation of land contaminated from mining activities, from 0 to 1, will be given after input the value of all required factors. This is the first step which will support the actions to revegetate or not.

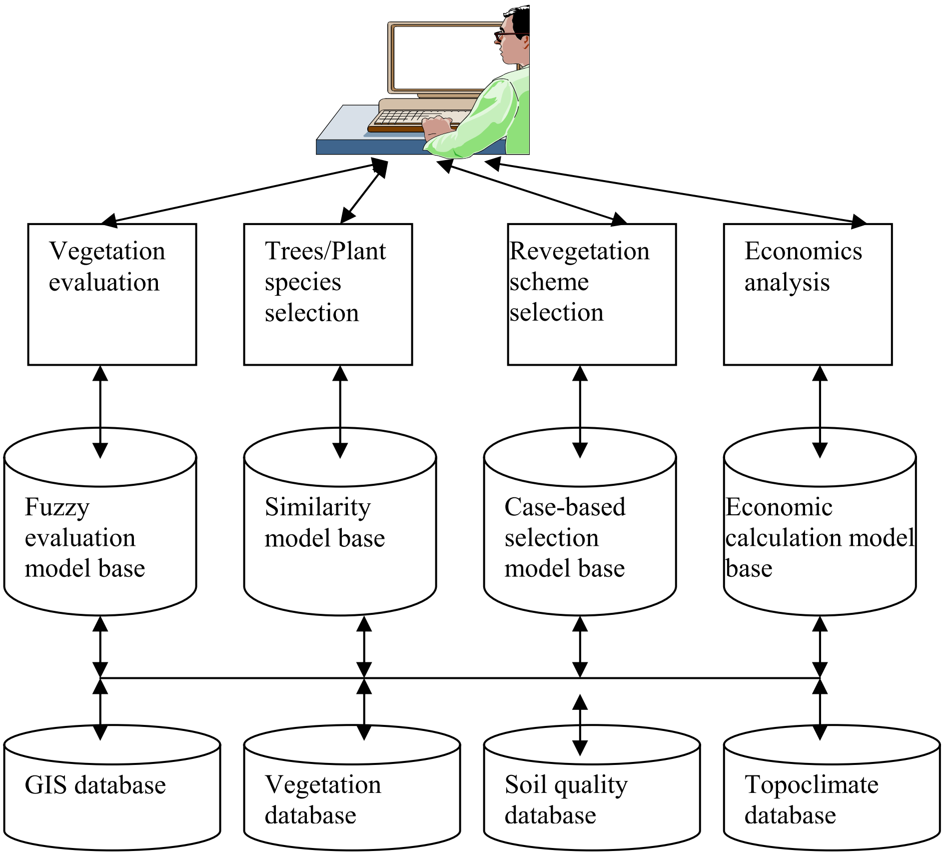

Fig. 1. The architecture of REHALAND

Owing to the great variation in physical, chemical and biological factors which greatly impact on the direct vegetation, factors selection and their weights determination are the two most import work in the subsystem.

8 experts from China Agricultural University and National technical University of Athens, 5 engineers from Fuxin General Mine Group involved the weights. Finally, 13 factors were selected as the main factors to evaluate the potentiality of revegetation of lands contaminated from mining activities, they are in 4 aspects, such as soil quality factors, topoclimate factors, and vegetation situation factors. The weight of each factor was identified by analytical hierarchy process. The factors and their weights were shown in table 1.

Table 1 Factors impact on revegetation and their weights

Type	Weight	Factors	Weight
Derelict land quality	0.4091	Texture	0.443
		Permeability	0.1728
		pH	0.2365
		Toxicity	0.0492
		Nutrient content	0.0492
		Organic matter	0.0492
Climate	0.4090	Precipitation	0.5
		Daily temperature	0.5
Topography	0.0455	Gradient	0.9
		Slope direction	0.1

		Abandonment time	0.0989
Situations	0.1364	Vegetation cover	0.011
		Irrigation situations	0.8901

In the area of revegetation, a mix of imprecise numeric information upon which linguistic variables are defined and purely linguistic variables for which there are no formal measurement scale often co-exist. As a result, fuzzy models were required to identify the potentiality of the revegetation.

The potentiality level of each factor was divided into 5 classes, such as very easy, easy, middle, difficult and very difficult, denoted as $\{V_1, V_2, V_3, V_4, V_5\}$, the interval of each factor is shown in table 2.

Table 2 the range of different class

	V_1	V_2	V_3	V_4	V_5
Slope direction	0□3°	3□7°	7□15°	15°□25°	≥25°
Organic matter content	≥1.7	1.7□1.4	1.4□1.1	1.1□0.8	≤0.8
N content (g/cm^3)	≥1	0.6□1	0.2□0.6	0.1□0.2	≤0.075
Daily temperature	30□32	26□30□32□35	22□26□35□38	18□22□38□40	≤18□≥40
Precipitation	≥1000	600□1000	400□600	200□400	0□200
Texture (g/cm^3)	1.3□1.4	1.2□1.3□1.4□1.5	1.1□1.2□1.5□1.6	1□1.1□1.6□1.7	≤1□≥1.7
PH	6□7	5□6□7□8	3.5□5□8□8.5	3□3.5□8.5□9	≤3□≥9
Abandonment time (years)	≥10	5□10	3□5	1□3	≤1

An example fuzzy model was shown in fig.2

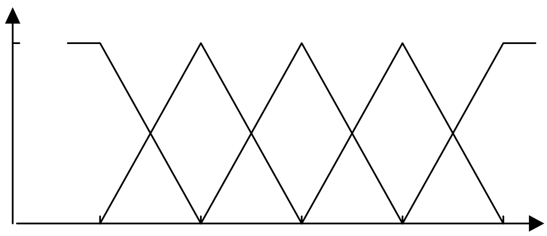

Fig. 2 fuzzy model

$$\mu_1(x_i)=\begin{cases}1, & X_i \le S_{i1}\\ \dfrac{S_{i2}-x_i}{S_{i2}-S_{i1}}, & S_{i1}<X_i\le S_{i2}\\ 0, & X_i > S_{i2}\end{cases}$$

$$\mu_5(x_i)=\begin{cases}0, & X_i \le S_{i4}\\ \dfrac{x_i-S_{i4}}{S_{i5}-S_{i4}}, & S_{i4}<X_i\le S_{i5}\\ 1, & X_i > S_{i5}\end{cases}$$

$$\mu_h(x_i)=\begin{cases}0, & X_i \le S_{ih-1}\\ \dfrac{x_i-S_{ih-1}}{S_{ih}-S_{ih-1}}, & S_{ih-1}<X_i\le S_{ih}\\ \dfrac{S_{ih=1}-x_i}{S_{ih+1}-S_{ih}}, & S_{ih}<X_i\le S_{ih+1}\\ 0, & X_i > S_{ih+1}\end{cases}$$

Where $\mu_h(x_i)$ is the number *h* factor's fuzzy model, S_{ih} is the standard value of the *i*th factor in *h*th class. X_i is the real value of the *i*th factor.

Let factor set $U=\{u_1,u_2,...u_n\}$ □evaluation set $V=\{v_1,v_2,...v_m\}$, weight set $\widetilde{A}=\{a_1,a_2,...a_n\}$ □ single factor evaluation matrix $\widetilde{R}=(r_{ij})_{n\times m}$ □fuzzy set $\widetilde{B}$, $\widetilde{B}=\widetilde{A}\circ\widetilde{R}$ □ $\widetilde{B}=\frac{b_1}{v_1}+\frac{b_2}{v_2}+...+\frac{b_m}{v_m}$. Where $b_j=\sum_{i=1}^{n} a_i\cdot r_{ij}$.

2.2 Plant species selection subsystem

The goal of plant species selection subsystem is to provide a tool to identify the proper plant species for rehabilitation of land contaminated from mining activities, it is the key subsystem of REHALAND, the plant species not only include the local plant, which is grown well in the local area but also the introduction plant or pioneer plant, which is never planted in the location

A plant species can be selected if it has the similar growth environment with the successful rehabilitation species. The Plant species collection can be identified by the similarity in topoclimate, soil quality, and vegetation cover factors. As a result, how to identify the similarity between 2 sites becomes the most important part in this subsystem. Generally, topoclimate, soil quality, and vegetation cover factors can be represented in a set of ranges, and values, so the similarity can not be determined by the distance between the value of successful rehabilitation site and the target abandoned land. Here a cover degree model is used to identify the similarity of environmental factors between the successful rehabilitation site and the target abandoned land.

Here let A, B, C are 3 intervals, if:

□1□0≤C(A,B)≤1□C(A,A)=1□

□2□C(A,B)>C(B,A), if $B \subset A$□

□3□C(A,C)<C(A,B), if $C \subset B \subset A$.

then C(A,B) is the cover degree of A with respective to B

so let

$$C(A,B)=\lambda \frac{S(A \cap B)}{S(B)} + (1-\lambda)\frac{S(B)}{S(A \cup B)}$$ □

Where□0≤ λ ≤1□ S (A) is the area of rectangle, which width is the distance of interval A, height is 1.

Let A=[a_1, a_2]□B=[b_1, b_2]□

1. if $A \cap B = \Phi$ □ $C(A,B)=(1-\lambda)\frac{S(B)}{S(A \cup B)}$, then□

□1□ $a_1<a_2 \le b_1<b_2$ □ $C(A,B)=(1-\lambda)\frac{b_2-b_1}{b_2-a_1}$

□2□ $b1< b_2<a_1<a_2$ □ $C(A,B)=(1-\lambda)\frac{b_2-b_1}{a_2-b_1}$

2. if $A \cap B \neq \Phi$ and $A \cap B \neq A$ and $A \cap B \neq B$ □

then $C(A,B)=\lambda \frac{S(A \cap B)}{S(B)} + (1-\lambda)\frac{S(B)}{S(A \cup B)}$ □

□1□ $a_1 \le b_1 < a_2 \le b_2$ □

$$C(A,B)=\lambda \frac{a_2-b_1}{b_2-b_1} + (1-\lambda)\frac{b_2-b_1}{b_2-a_1}$$

□2□ $b1< a_1 \le b_2 < a_2$ □

$$C(A,B)=\lambda \frac{b_2-a_1}{b_2-b_1} + (1-\lambda)\frac{b_2-b_1}{a_2-b_1}$$

3. if $A \subset B$ □then $C(A,B)=\lambda \frac{S(A)}{S(B)} + (1-\lambda)$

$b1< a_1< a_2 \le b_2$ □ $C(A,B)=\lambda \frac{a_2-a_1}{b_2-b_1} + (1-\lambda)$

4. If $B \subset A$ □then $C(A,B)=\lambda + (1-\lambda)\frac{S(B)}{S(A)}$

$a1<b_1<b_2 \le a_2$ □ $C(A,B)=\lambda + (1-\lambda)\frac{b_2-b_1}{a_2-a_1}$

2.3 Rehabilitation approaches selection subsystem

Based on the plant species section model, the rehabilitation approaches selection subsystem is to identify the proper approaches (techniques) for the identified available plants, such as direct seeding, additives, nutrients, and combined approaches, heavy metals, organic mater, fertilizer, climate, toxicity of the waste, longitude, latitude etc. should be considered in the decision making. The framework of this model can be seen in fig. 3.

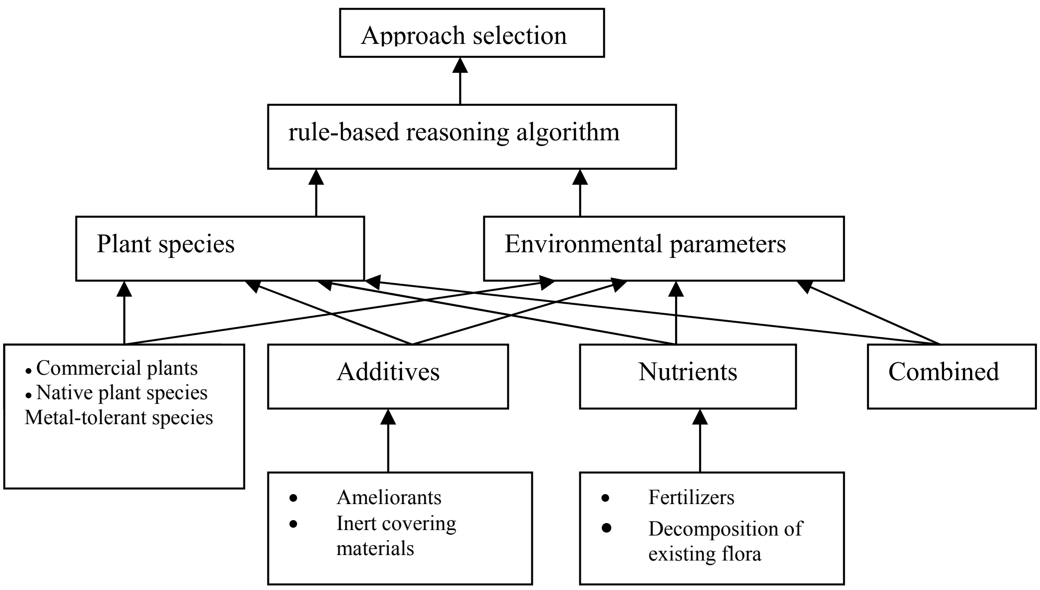

Fig. 3. The structure of revegetation approaches selection model

Based on the successful restoration cases, a rule-based reasoning programme were developed, which used as the inference engine to identify the proper approaches. If-then rules were also used to identify the proper approaches, which can be described quantitative, some rules were listed in the table 2.

The Rule bases are shown in table 2.

Engineering reclamation techniques				
1	If	Sink-in area Or stope dig	Then	Fill in
2	If	Coal mine waste cover	Then	Soil cover
3	If	Sink-in area	Then	Input□depth=death of sink-in area
Fill in				
4	If	Fill in	Then	select□with coal mine waste/|with powder
5	If	with coal mine waste	Then	{ with coal mine waste□input□ situation of mantlerock regolish}
6	If	mantlerock regolish >10cm	Then	Not cover soil
7	If	5< mantlerock regolish <10cm And 5mm	Then	Cover with thin soils
….				

3 methodology

The work will be split into 5 distinct tasks which are described below. The first step will be to gather and compile information from a range of experts, and to build a picture of how the decision process progresses from initial thoughts to a final solution (Task 3.1). The next step will be to structure this process into a sequence of decision tables so that a non-expert is guided through the appropriate decision points (Task 3.2). At this stage the software system can be designed and coded, (Task 3.3) and rigorously tested against a test plan (Task 3.4). Finally, the prototype decision support system can be launched complete with installation procedure and user manual/help.

Task 3.1: Knowledge elicitation

Assemble information on current planning and management practices.

Elicitation of key points in the decision making process, design and planning regulations, management procedures, legislative, social and economic constraints.

Identification of key design formulae, codes of practice, etc.

It is envisaged that the output of this activity will be flow diagrams of the decision making process, tables and formulae for design details, maps and charts, lists of criteria and decision making ‘rules’ or ‘knowledge’.

The method of work will be through literature search, peer review and workshops/questionnaires/interviews with experts, practitioners and academics.

The output of this activity will feed into Tasks 3.2 and 3.3.

Task 3.2: Knowledge base design

The design making process and key information will be mapped onto a logical framework. This will allow the links between different parts of the multi-disciplinary decision making process to be identified and codified into the knowledge base. The decision making process will be quantised into discrete sections for which the appropriate information and rules have been identified. The purpose of each section will be to determine (with appropriate input from the user) suitable courses of action that are compliant with external constraints as well as being technically feasible.

This task will be carried out through iterative discussion within the project team; specifically the software engineer (to be appointed), the technical experts at Plymouth and end user representatives.

The output of this activity will be a series of linked tableaux. Each tableau will prompt the user for input to describe a particular situation and will provide to the user a solution to a particular aspect of the coastal planning and management issue being addressed. The output of this task will feed into Task 3.3.

Task 3.3: System Coding

This activity will include an assessment of the most suitable platform on which to construct the decision support system, as well as the coding of the system. The system will use the output of Tasks 3.1 and 3.2 to create a series of linked tableaux which the user will have to complete in order to obtain a solution to a particular planning and management situation. The completion of any tableau may require evaluations, calculations or obtaining results from a numerical model. Any such computations will have been identified in Task 3.1 and the necessary tables/ formulae/model incorporated into the knowledge base, together with the rules for their use.

As software systems change rapidly we are not proposing a particular software solution at the moment but as a (very) possible option we envisage that the system could be constructed in Visual Basic running in Microsoft Windows on a desktop PC.

As part of this task a test plan will be prepared. The outputs of this task will be the prototype decision support software and the test plan, and will feed into Task 3.4.

Task 3.4: Prototype Decision Support System Testing

The initial version of REHALAND will be tested in the traditional manner. That is by a project team member, other than the code writer, working through the test plan with the initial version of REHALAND. Discrepancies and faults will be noted and the code writer informed. This process will be repeated until the tests are successfully completed. At this point further feedback from end users will be sought. Any final amendments to the system will be made at this stage to complete the output of this task, the prototype version of REHALAND.

Task 3.5: REHALAND finalization

Following successful development of the prototype version of RETA in Task 3.4, this task will complete the finalization of the decision support system. This includes the preparation of a user manual or help system, preparation of promotional materials (eg. Web site, technical papers), preparation of the installation package (including installation procedures, CD packaging and logo).

4 Implementation

The system can run on both the Internet and Intranet environments. The user can use a Web browser to access our Web server through HTML language and HTTP protocol. The kernel of the system is placed on the Web server. ASP.NET is used extensively and well integrated in the system. Moreover, with the use of integrated Web application development tool—VS 2003, network operation system—Windows XP, and database server—MS SQL Server 2000, and map server—ArcIMS 9.0, the system is well developed. The results of the system as follows:

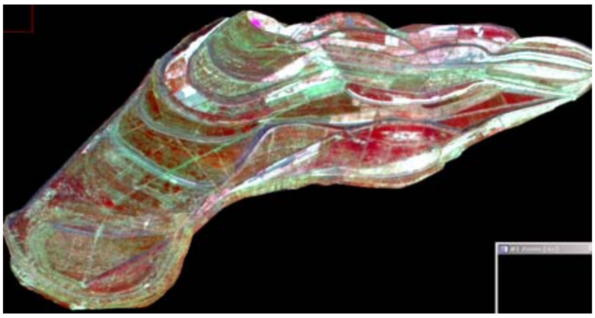

Fig.4 Supervised classification results of the spots data

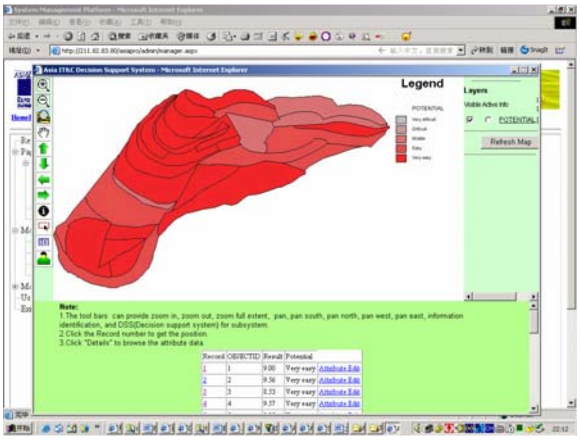

Fig. 5 Revegetation potentiality evaluation results

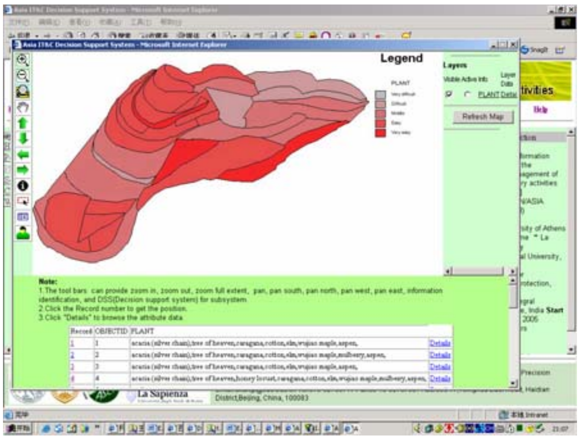

Fig. 6 Species selection results

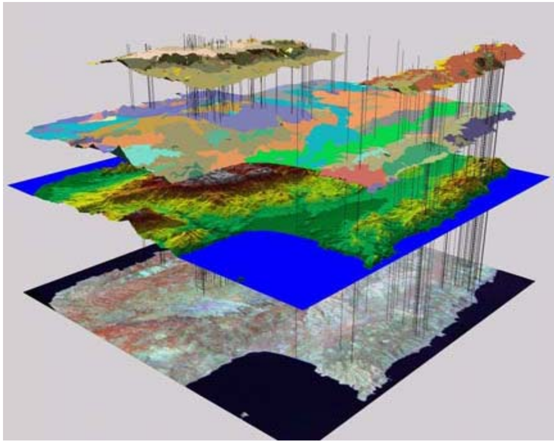

Fig.7 Soil, vegetation, landform Thematic Map

5 system evaluation

To test the usefulness, about 15 rehabilitation experts and technicians tested the prototype system; many useful suggestions have been received from the interview. Valuable comments and feedback were collected during the test and evaluation process as follows.

Generally, REHALAND is a prototype system at the present, many cases and data should be added to make it workable, even through some shortcomings exist, some strong points were found as follows:

- The GIS-based DSS is regarded as an effective tool to decision support in rehabilitation of land contaminated from mining activities, especially it can act as the knowledge base to collect the successful rehabilitation case.
- The plant species section subsystem is viewed as the most practical part in the system, as it contains 100 plant species all over the world. At the same time, a priority list of plant species is also given based on the similarity degree.
- Rehabilitation potentiality evaluation subsystem is also viewed as a useful tool, 10 sites were tested use this model, and the result proved that the model was reasonable.

Some shortcomings were also pointed out as follows:

- The properties of the plant species were not in details, the corresponding planting methods should also be provided in detail, this will help users' rehabilitation practice.
- SDSS for revegetation needs many experts cooperation as it need many fields expertise, such as soil, climate, vegetation, ecosystem, environment, GIS, computer, economics, management, for this reason, many continuous work needs to be finished.
- SDSS for revegetation of land contaminated from mining activities is a good and practical tool.

6. Conclusions

This paper reports a research attempt in developing and using GIS based Decision Support System for restoration or revegetation of land contaminated from coal mine waste. The system is able to support and facilitate restoration or revegetation of lands contaminated from coal mine waste. The attempt was resulted from a pilot use of a GIS-based DSS for revegetation of lands contaminated from mine waste developed by China Agricultural University. The research demonstrates that Spatial Decision Support System for ecosystem restoration is a good tool for revegetation decision support.

The research demonstrate the possibility and potential benefits of using the GIS, DSS to facilitate decision support in forest ecosystem, it needs cooperation of many experts in different research areas.

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