Spatial Decision Support System for Reclamation in Opencast Coal Mine Dump

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Abstract: - This paper describes the development and applications of a decision support system that uses spatial information techniques and field survey data. The SDSS can enable the various levels of the target groups to easily identify the best available solutions of reclamation problems. To make reasonable decisions, the overall purpose of the SDSS is to provide a support tool for site evaluation and selection of the most appropriate reclamation schemes. The system consists of three models: (1) an evaluation model for reclamation potentiality based on the physical, chemical, and biological growth-limiting factors in the target area. (2) Fuzzy similarity models to determine the native plant species and metal-tolerant plants. (3) A case-based and rule-based model to select the most appropriate reclamation schemes based on the similarity in the physical, chemical, and biological growth conditions. The models are developed in the C# language and integrated with GIS. All these models are integrated in the SDSS which is able to provide information concerning the recommended reclamation technologies for each case. Finally, the uses of the SDSS in two cases which are Haizhou (China) and Mao Moh Mine (Thailand) are described.

Key-Words: - Coal mine waste land, Reclamation, Spatial decision support system, Remote sensing, Geographical information system

1 Introduction

In opencast coal mining, the entire protective and productive soil cover has been removed or destroyed; therefore the loss to production is permanent. Further, due to haphazard piling of overburden materials, a series of dumps results during surface mining. The soils of overburden dumps are physically, nutritionally and biologically poor. The natural succession on the soil is also a very slow process [1, 2]. Coal mine waste material, which usually consists of a mixture of coarse-grained particles to rock fragments grading to fine-grained particles, causes geotechnical and environmental problems on disposal [3]. The mining industry in China produces a large amount of derelict land, and causes pollution of water and soil erosion as well as other environmental damage. Large areas of degraded mining land remains barren prevent agricultural, social and economically sustainable development in affected areas. As land is under short supply in China, exacerbated by the rapidly expanding population, the policy is to restore or reclaim land degraded by mining [4]. Based on the data from the National Bureau of Land Administration, it is estimated that more than 400

000 ha area was destroyed at present; the rate of land reclamation in mining area is 15%. However, compared with reclamation rates as high as 70%-80% in developed countries, China still has a long way to go. To have an environmentally sustainable development of coal mining activities, reclamation and re-vegetation of depleted and/or abandoned coal mines is essential [5]. Reclamation planning for surface coal-mine disturbances is a form of environmental problem-solving and decision-making in which professionals must consider the concerns of government regulators and corporate executives [6].The plant species attaining good growth and producing sufficient biomass will able to speed up the site occupancy by surface stabilization and soil fertility restoration and accelerate the natural regeneration of mine spoils [7].

A range of reclamations techniques available to coal mine reclamation are examined. First of all, it is necessary to find ecological reclamation principles and approaches for developing sustainable and healthy arable-land ecosystems [4], because performance standards and requirements are used as the regulatory instruments to indicate reclamation success or failure and to ensure that

long term environmental degradation is minimized or eliminated [6]. A study of the geotechnical aspects of the problem is also important in rational planning for the disposal, reclamation, treatment and use of such material [3]. Physical, chemical and biological condition often limit restoration at surface mine reclamation sites [8]. Hydrologic, chemical, and geo-morphic conditions were selected as the revegetation monitoring parameters before and after treatment by a method referred as direct revegetation [9]. Organic accumulation and microbial action such as Carbon (C), nitrogen (N) and phosphorus (P) were the main indicator for soil, their vertical distribution in the soil profile had relationship with site age [10,11,12].

In 1987, a variety of computer applications were used in surface mining operations, which include using computer to develop reclamation plans, establish technical and economic feasibility of various mining alternatives, evaluate hydrologic impacts of mining [13] Among all the information technologies, a GIS has been an important tool for land restoration and is often used as the integrating framework for spatial data analysis and modeling, such as to assess and analyze the soil quality change [14], to evaluate the benefits of farmland restoration [15], to predict the suitability for wetland restoration [16], to predict the spatial distribution of emission source activities based on widely available data [17], to produce a map of the landscape surrounding with 13 component land classes, to estimate the composition and configuration of the landscape [18], to analyze changes and their environmental impacts of coast [19, 20], to analyze the potential use of plant and soil properties in revegetation projects [21].

In this paper, in order to help decision makers in the potentiality evaluation and plant species and land consolidation schemes selection, a spatial decision support system is implemented through a SQL server database to ArcIMS, ArcSDE and Matlab. The SDSS uses the data from the on-the-spot investigation, comparison of the similarity of soil and climate situations between different coal mine waste lands, the fuzzy integrated evaluation, gray relating superiority analysis algorithm, distance-based similarity models and rule-based reasoning. The SDSS visualization capability is improved by its mapping extensions, summary report and tables, statistical reports and other forms of reclamation diagrams such as polygons, meters and flowcharts. Finally, two applications cases in Fuxin (China) and Mao Moh Mine (Thailand) are presented.

2. Methods

This section presents the methodology used for reclamation. Three models were developed and separately used to evaluate reclamation potentiality, select trees/plants for pilot and choose reclamation scheme.

2.1 Reclamation potentiality evaluation model (RPEM)

The objective of this work is to establish a model based on different soil physical, chemical and biochemical properties, in different vegetation zones from coal mine dumping area. For soil quality assessment, the development of relationships between all the soil quality indicators and the soil functions may be a monumental task. Therefore, land evaluation analysis may serve as a first step towards developing a soil physical/chemical quality assessment procedure [22]. The model has potential for the use of selected physical, chemical and biological indicators for an integrated assessment of soil quality in the laboratory and in the field [23]. Soils with different characteristics mainly related to differences in soil organic matter content [24]. Using the soil attributes that comprised them, all of the components identified using factor analysis contributes to one or more soil functions proposed by Larson and Pierce. Varimax-rotated factors – (calcium, magnesium, soil pH), (available nitrogen, organic carbon, total nitrogen), (extractable phosphorus, available nitrogen (0.457) and (macro aggregates, micro aggregates, silt, clay) – were designated as contrasts that described soil quality status yield and performance, and soil physical descriptive indicators [25].

However, in this project, reclamation potentiality refers to not only soil, but also plant. So thirteen factors were selected as the main factors to evaluate the potentiality of reclamation of lands contaminated from mining activities; they are in four aspects, such as soil quality, topoclimate, and vegetation situation. Eight experts from China Agricultural University and National technical University of Athens, Ten engineers from Fuxin General Mine Group, China and Mao Moh Mine, Thailand were involved in the discussion of factors and their weights. The degree of difficulty for reclamation of land contaminated from mining activities, from 0 to 1, is given after input the value of all required factors. The weighing of each factor was identified by analytical hierarchy process. The factors and their weigh were shown in Table 1.

Table 1 Factors impact on reclamation and their weighing

Type	Weight	Factors	Weight
		Texture	0.443
		Permeability	0.1728
Derelict land quality	0.4091	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 reclamation, a mix of imprecise numeric information upon which linguistic variables are defined and purely linguistic variables for which there is no formal measurement scale. As a result, fuzzy models were required to identify the potentiality of the reclamation. 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 ranges of different classes

	V_1	V_2	V_3	V_4	V_5
Slope (°)	0-3	3-7	7-15	15-25	>25
Organic matter (%)	>1.7	1.7-1.4	1.4-1.1	1.1-0.8	<0.8
N content (g/cm3)	>1	0.6-1	0.2-0.6	0.1-0.2	<0.075
Daily temperature (℃)	30-32	26-30, 32-35	2-26, 35-38	18-22, 38-40	<18, >40
Precipitation (mm)	>1000	600-1000	400-600	200-400	0-200
Texture (g/cm3)	1.3-1.4	1.2-1.3,1.	1.1-1.2,1.1,	1-1.1,	<1,>1.7
pH	6-7	5-6,7-8	4-5.5, 8-8.5	3.5-5, 8.5-9	<3,>9
Abandonment time (years)	>10	5-10	3-5	1-3	<1

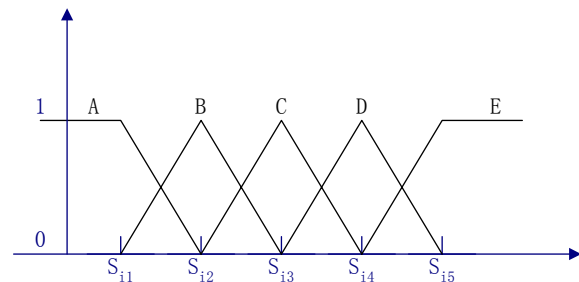An example fuzzy model was shown in Fig.1.

Fig. 1 An example fuzzy model

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

$$\mu_5(x_i) = \begin{cases} 0 & X_i \le S_{i4} \\ \dfrac{x_i-S_{i4}}{S_{i5}-S_{i4}} & S_{i4} < X_i < S_{i5} \\ 1 & X_i > S_{i5} \end{cases} \quad (2)$$

$$\mu_h(x_i) = \begin{cases} 0 & X_i \le S_{i4} \\ \dfrac{x_i-S_{ih}}{S_{ih}-S_{ih-1}} & S_{ih-1} < X_i < S_{ih} \\ \dfrac{S_{ih-1}-x_i}{S_{ih+1}-S_{ih}} & S_{ih} < X_i < S_{ih+1} \\ 1 & X_i > S_{ih+1} \end{cases} \quad (3)$$

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

Let factor set $U = \{u_1, u_2, ... u_n\}$, evaluation set $V = \{v_1, v_2, ... v_m\}$, weight set $\tilde{A} = \{a_1, a_2, ... a_n\}$, single factor evaluation matrix $\tilde{R} = (r_{ij})_{n \times m}$, fuzzy

set $\tilde{B}$, $\tilde{B} = \tilde{A} \circ \tilde{R}$, $\tilde{B} = \dfrac{\dfrac{b_1}{v_1} + \dfrac{b_2}{v_2} + ... + \dfrac{b_m}{v_m}}{}$. Where

$$b_j = \sum_{i=1}^{n} a_i \cdot r_{ij}.$$

The set V is the result of the reclamation potentiality.

2.2 Plant species selection model (PSSM)

The goal of plant species selection model is to provide a method to identify the suitable tree/plant species for reclamation of land contaminated from mining activities. A better understanding of the tree properties on restored opencast coal mine spoils can lead to beneficial changes in reclamation practice and renewed the prospect of commercial forestry on these restored land. These plantations can provide fuel, timber, and non-wood forest products to local people [7].When selecting plants for the reclamation, indigenous species are most preferred over exotic species because they are likely to fit into a fully functional ecosystem and to be climatically adopted but most of the native species in the region are slow growing species. Exotic fast-growing species were therefore tried in view of their large scale use in afforestation schemes in the country [26]. Exotic species may be especially recommended for primary rehabilitation on bare coal mine spoil due to their fast growth and establishment as observed in the present study. Care is, however, needed so that introduced exotic species may not become a problematic weed to local flora [7]. A plant species can be selected if it has the similar growth environment with the successful rehabilitation species. During selecting plant species process, the factors of site conditions representing landform, climate, parent rock, soil were surveyed by field investigation, and vegetation types, vegetation composition, coverage and growth should be considered [27].

The plant species include the local plant which can be grown well in the local area, but also the imported plants or new species. The plant species collection can be identified by the similarity in topoclimate, soil quality, and vegetation cover factors. Generally, topoclimate, soil quality, and vegetation cover factors can be represented in a set of ranges, and values, so the similarity cannot 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.

Similarity algorithm is described as follows.

Here, A, B and C are intervals, if:

(1) $0 \le C(A,B) \le 1, C(A,A) = 1$;

(2) $C(A,B) > C(B,A)$, $B \subset A$;

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

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, $0 \le \lambda \le 1$, $S(A)$ 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 $A \cap B = \Phi$, $C(A,B) = (1-\lambda) \dfrac{S(B)}{S(A \cup B)}$,

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）

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

2. If $A \cap B \ne \Phi$ and $A \cap B \ne A$ and $A \cap B \ne B$, 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）

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

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

b1< a1< a2≤b2, $C(A,B) = \lambda \dfrac{a_2 - a_1}{b_2 - b_1} + (1-\lambda)$

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

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

2.3 Reclamation scheme selection model (RSSM)

The reclamation scheme selection model is to identify the engineering reclamation and amendment schemes on the abandoned wastes. Fig.4 shows the framework of the model. Based on the successful restoration cases, a rule-based reasoning program were developed, which is used as the inference engine to identify the proper approaches. If-then rules were also used to identify the suitable quantitative approaches. Some production rules are listed in the Table 3.

Table 3 The Rule bases

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}
6	If	mantle rock >10cm	Then	Not cover soil
7	If	5< mantle rock regolish <10cm And 5mm	Then	Cover with thin soils
….				

Based on the values of parameters and the characteristics of the rehabilitation technologies developed worldwide, the system, using IF-THEN rules, defines a list of appropriate techniques for the rehabilitation of the examined waste. Then, the model involves the application of multi-criteria analysis (MCA), i.e. a structured system for ranking alternatives and making selections and decisions. Each technique shall be evaluated based on its behavior in four fields, i.e. financial, social, technical and environmental criteria.

3. Software development

The three models were developed using C# programming language with Matlab function library. All the models were integrated with ArcIMS 9.0 and ASP.NET, using a tight-coupling approach (achieved with the Avenue programming language and dynamic link libraries (DLLs). All the collected data and the developed models and tools were integrated in one website with a user friendly interface, through which the evaluation and decision support can be performed at all the necessary decision levels.

The software development work was divided into 5 distinct tasks which are described below. The first step gather sand compiles information from a range of experts, and builds a picture of how the decision process progresses from initial thoughts to a final solution. The next step structures this process into a sequence of decision tables so that a non-expert is guided through the appropriate decision points. At this stage the software system is designed and coded, and rigorously tested against a test plan. Finally, the prototype decision support system is launched with installation procedure and user manual/help.

3.1 System components

The SDSS consists of different tools available in an ArcIMS and ASP.NET environment depending on whether the user is interested in analyzing data using RPEM, PSSM and RSSM modules (see Fig. 2). The user can select RPEM, PSSM and RSSM subsystem for decision support using the multi-source spatial data. When the user selects the subsystem, model specification and model run components are enabled. Other tools provided in the interface include the Area Selection Tool and the Output Display Tool. The following paragraphs describe the important system component within SDSS.
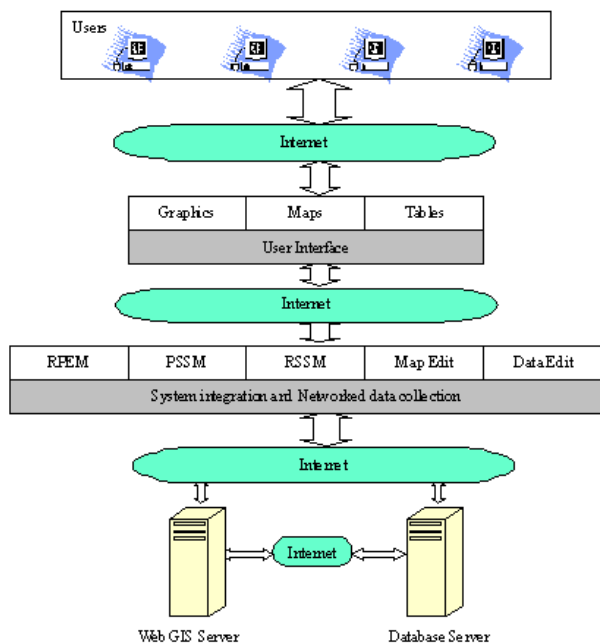
Fig. 2 Integrated system components of the SDSS system

3.2 System framework

Fig.3 shows the schematic representation of the basic architecture of the integrated SDSS modeling system. As it can be seen, the system tightly couples the RPEM, PSSM and RSSM modules within an ArcIMS and IIS environment. The entire system is based on the ArcIMS (Version 9.0) platform which consists of the ArcIMS Application Server, the ArcIMS Service (image service) and the HTML Viewer. The three main components (RPEM, PSSM and RSSM) in the SDSS include criteria scores (i.e. how great an effect is), criteria weights (how important it is) and evaluation. Each criterion could be weighted by all involved parties, such as experts, environmental managers, policy makers and local community representatives, to determine its relative importance in the overall balance.

This system has three main sections. At the user end, our aim is to provide a user- friendly interface for map viewing, inputting user specifications and allowing the user to remotely access and interact with ArcIMS and ASP.NET. At the application server, the aim is to provide seamless integration of ArcIMS, RPEM, PSSM, RSSM and GIS data stores. The application server includes a data retrieval system developed using Java servlets. The servlets are supported using an IIS. The servlets communicate using a HTTP network protocol with the client web browser (see Fig. 3). The servlets provide the vital link between the user interface and the other modules with the integrated system.

A web server handles requests and responses from the user end. The web server first receives the request from the web browser. Depending upon the request, either the ArcIMS server is directly invoked or RPEM/ PSSM/RSSM is activated which then calls the ArcIMS server. When the request is directly sent to the ArcIMS server, the ArcIMS server generates a map for the request and the web server sends back the map as images to the browser. RPEM, PSSM and RSSM are invoked remotely and executed online to process the region-of-interest selected by the user. Then the outputs of RPEM, PSSM and RSSM are stored locally for further use. The local storage allows the user to document the results or to generate faster displays and data visualization. Compared to pure on-line processing, this approach substantially improved performance of user access.

The databases residing in different servers in the networked environment at physically different locations were developed using MS SQL Server 2000, and the data were stored in a Geodatabase which is an efficient format for both raster and vector GIS data types. ArcSDE was used to manage the distributed database across the internet and ArcCatalog for data preparation. ArcSDE is used as the middle tier to coordinate between ArcIMS and the SQL server. The purpose of the multi-server system is to improve performance by creating multiple databases to store large raster and vector data. Furthermore, the failure to access the data from one database will not cause a system failure as the system can still function using the data from other databases.
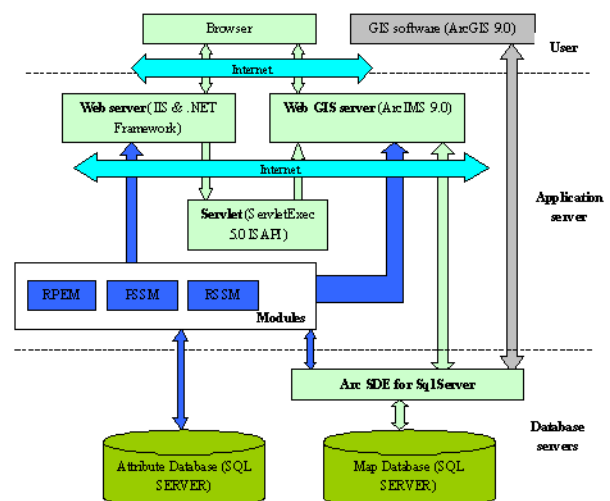

Fig.3 Basic architecture of the SDSS

3.3 Database Development

A review of satellite sources in relation to the objectives of SDSS was initially carried out. Based on the results and taking into account the existing geographical information at the mine sites, selected satellite data including historical Landsat images and past and current medium and high resolution data (SPOT5-China, Orthophoto-Thailand) were collected. The images were geometrically processed and analyzed and a number of vector and raster information layers including land cover maps, road and river maps, vegetation coverage, landscape diversity and dominance index were extracted. The satellite data and information layers are handled by the GIS system.

Database design for the study area, based on layout restrictions and applications, are as follows:

(1) Boundary of coastal research: extending inland and based on town administrative limits. It is convenient to acquire statistical/economic data.

(2) Statistical data published by Government or data from special departments or field experts.

(3) Land-use classification referring to national criteria and local regulations. All raster and vector maps are referred to 1:10 000 scales of relief maps.

(4) Remote sensing images are used to update the databases.

Ninety-two topsoil samples were collected, concurrently with the spot imagery, and analyzed for ion types and contents, electrical conductivity and soil reaction. GPS was used to determine the spatial location of the field samples. Other biophysical properties such as soil texture, soil colour, topographic position, drainage conditions, and dominant vegetation types were also recorded and stored in a soil geographic database.

The three models of SDSS (RPEM, PSSM and RSSM) extract the necessary information from the corresponding databases of each theme in order to run the simulations. The outputs of each model are returned back to the geo-database where the corresponding output themes are generated.

Sets of grid and vector maps are implemented, containing spatially distributed information for most of the input parameters required for model runs. All of these basic maps as well as the result maps conform to the map (see Table 4).

Table 4 Maps of the SDSS

Data	Parameters
Spots 5	Resolution 2.5m and 10m, 2005,
Orthoimage	Natural color, 0.5-meter resolution, 2003 vintage
Soils	Soil thickness, PH, soil texture, soil permeability, PH, soil toxicity, nutrient content,

	organic matter content, N, Totally N, P, totally P, K, Total K,
Vegetation	Vegetation cover
Climate	Daily temperature precipitation
landform	Gradient, slope direction
Abandoned situation	abandoned time, abandoned type, Irrigation situations
Roads	
Boundary	Boundary for research area and terrace in the research area

3.4 Map service development

Publishing GIS content over the Internet or intranet should publish it through a service. The content provided by the primary service types ArcIMS are Image, ArcMap Image, and Feature services. These services may appear similar in a Web browser; however, an Image and ArcMap Image Service sends a "snapshot", or image file, of a map to the client, while a Feature Service streams map features. Other ArcIMS service types are Metadata and Route Services.

In order to accelerate the access speed to the website, an Image Service was selected as the system service, supported by all viewers, that delivers map content to users as Joint Photographic Experts Group (JPEG), Portable Network Graphics (PNG), and Graphics Interchange Format (GIF). A new map image is generated each time client requests new information. Image Services have internal access to query, geocode, and extract functions. This internal access is possible through the Query, Geocode, and Extract Private Virtual Servers. This service type can satisfy most of Web site needs.

In the SDSS system, six image services should be new in ArcIMS. The AXL files build by arc Author image server are shown in Table 5.

Table 5 Map service of the SDSS

Map service name	Description
plant_china	System application for Fuxin, China
plant_thai	System application for Mao Moh Mine, Thailand
Potential_china	System application for Fuxin, China
potential_thai	System application for Mao Moh Mine, Thailand
soil_china	System application for Fuxin, China

soil_thailand	System application for Mao Moh Mine, Thailand

3.5 Modules development

The GIS software package was programmed in C# using ArcObjects and ArcIMS. Three independent software modules were designed with graphical user interfaces (GUIs) to perform each of the tasks in the model. Each module allows the user to select the input data, and the locations for the output files. The individual modules are described in the Models part of this paper.

3.6 System evaluation

A model was developed for monitoring and control of mining activities and can be used as a powerful tool for designing of related activities. The model requires the input of characteristics, e.g. climate, topography, geology, land use, hydrology, geochemistry, ecology, wastes and/or soils, including physical-grain size distribution, hydraulic conductivity, mineral composition, etc. of the study area. Then, a fuzzy classification of similarity based on EO/RS information and cases based selection will be compared. Finally, suggested selections of vegetation covers, type of trees, plant species, rehabilitation approach, as well as economic analysis scheme, etc. will be compared.

The system will help users to monitor the environmental information of extractive operation, identify best available practices for rehabilitation on different type of waste soils under various conditions (wet/dry climate, topography, etc.).

The objective of this activity is the evaluation of SDSS in order to ensure that it will be a valuable tool for the relevant target groups (extractive industries, environmental organizations, research institutions) that will enable them to easily make the best decisions regarding a specific environmental management problem in the extractive industry activities. SDSS testing by representatives of the target groups in Asia and Europe is ongoing.

An efficient strategy has been defined for an extensive dissemination of results and achievements. A number of actions have been carried out to date including the publication of the project web site, presentation of an overview of SDSS in the Partnership Match-making Event on Information Society Technology for EU-Asia held in September 2005, China, organization of an open meeting in Thailand for informing and discussing with the target groups on project activities, and publication of project results on scientific journals and conference proceedings.

4. Application of the SDSS

The SDSS was applied to Fuxin coal mine dump area (China) and Mao Moh Mine (Thailand). The system was used to classify and describe the reclamation potential, select trees/plant and find suitable land consolidation approaches. Fig.7 shows the location of the two study areas. Red point in China on the map is Fuxin, black one in Thailand is MMM. The study area was selected due to the two areas are the typical open-bit coal mine activities and part of the waste land have been successful reclaimed. This section discusses the definition of the study area, the estimation of the models, and the information that can be derived from the models. The DSS visualization capability is improved by its mapping extensions, text and table summaries, statistical reports and other forms of reclamation diagrams such as polygons, meters and flowcharts.

The actual implementation of SDSS was carried on 5-8 September 2006 at MMM. A second trial was conducted in Beijing, China, during 16-21 October 2006. Both trials were based on Fuxin and MMM existing geology, climate, topographic, or hydrology data, as well plants species.

Fig.4 The location of the study areas for SDSS

4.1 The study area

Fuxin with about 1.9 inhabitants is a prefecture-level city in the Liaoning province of northeastern China (see Fig.4), where is in the north temperature zone and is characterized by mountainous topography. The research area is Haizhou opencast coal mine with longitude between $121°\ 36'$ E and $121°\ 42'$ E, and latitude between $41°\ 56'$ N and $42°\ 00'$ N. This site has been studied for

approximately 5 years by researchers at China Agricultural University. According to the meteorological data supplied by Fuxin Environmental Protection Department, the annual rainfall is 420~540mm but the annual average evaporation reaches 1 644.9mm. The annual mean wind speed is 3.8 m/s while the predominant wind direction is SSW. The annual frost-free period lasts 150 days. Annual hours of sunshine is 2 850~2 950. Fig.5 shows the RS image of the study area which had been preprocessed.
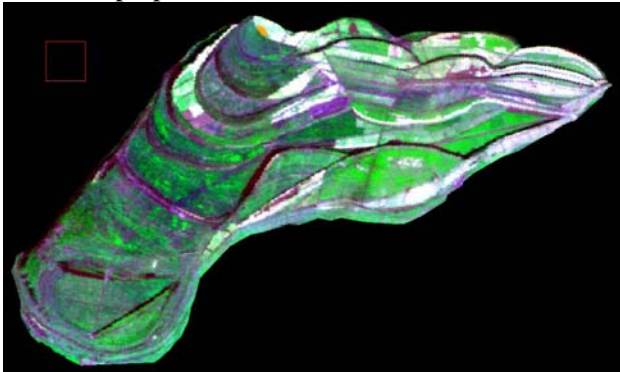

Fig.5 RS image of the study areas-Fuxin

4.2 Test of Models

The three models of the SDSS extract the necessary information from the corresponding databases of each theme in order to run the simulations. The outputs of each model are returned back to the geo-database where the corresponding output themes are generated. Fig.6 shows the homepage of the SDSS. Input attributes may be changed in the attribute window (see Fig.12), which is bound to the attribute database. The previous results are then deleted and the new input data can be transferred into the calculation program input file. After the input data has been changed the calculation program has to be started again by a menu command. New results are stored in the system's database immediately and the results can be displayed in a graphic form. The described program does not support further geographic analyses, but the data can be saved as a geographic theme in a standard GIS format by ArcGIS, and can then be used for further processing in another specialized program or in a common GIS.
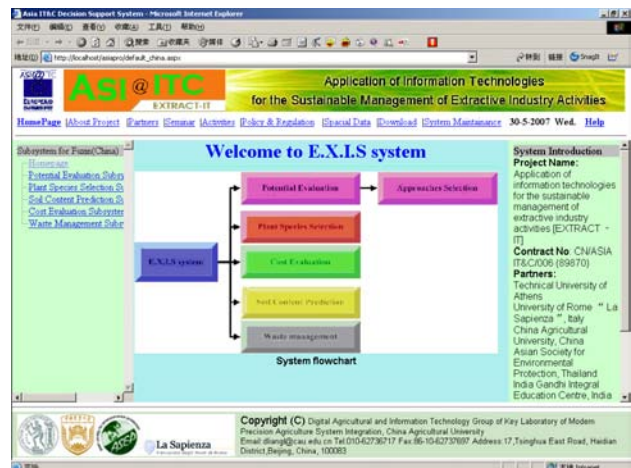

Fig.6 Homepage of the SDSS

(1)RPEM and RSSM simulation

In order to validate the RPEM's veracity, 10 typical sites were selected by the RS image (SPOT5) from Fuxin coal mine. 90% results match with fact of typical site that the data obtained by locale experimentation. RSSM was integrated with RPEM because the result is difficult to show on the map.

Fig.7 illustrates the reclamation potential map generated from the system for classifying reclamation level and the RPEM attributes such as derelict land quality, climate, topography, situations. The figure also indicates reclamation potential classes. On the map potentiality is classified into five grades by their values, shown in different colors: the larger the potentiality values, the darker red the color. Thus, cells with darker red colors indicate areas with higher level of source activity, possible areas of easier to reclamation. By the way, in Mao Moh Mine map, some place that colored in gray means the data is null or potentiality is low. You can differentiate them by the clew from the table that is located under the map in browser.
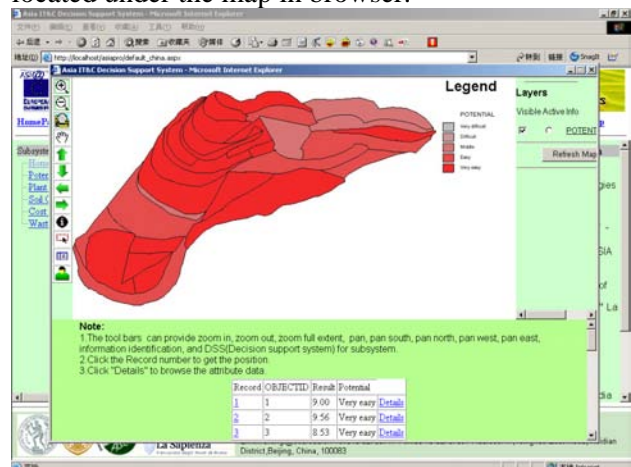

Fig.7 The REPM results in Fuxin

Fig.8 shows the tool bars of the SDSS. Besides zoom in, zoom out, pan, move south, move north, move west, move easy and show all layers are in

common use; the decision support is for the model run. Fig.9 illustrates decision support application. The attribute data is shown on the form and it can be edited by users. Users can get the potential result. Here you can get the RSSM results by clicking the button "Reclamation Approach". The entire knowledge base and case base was stored in database.
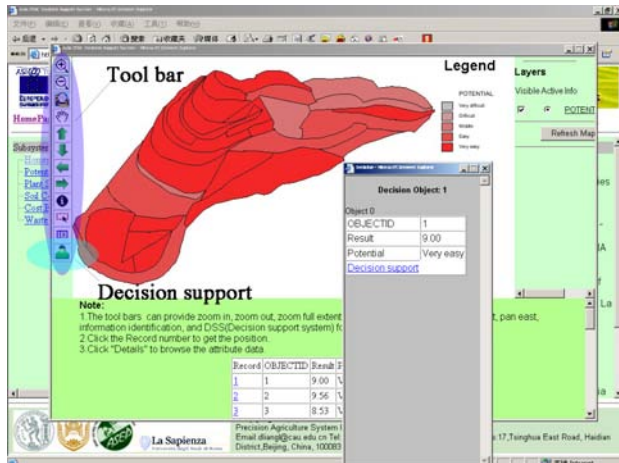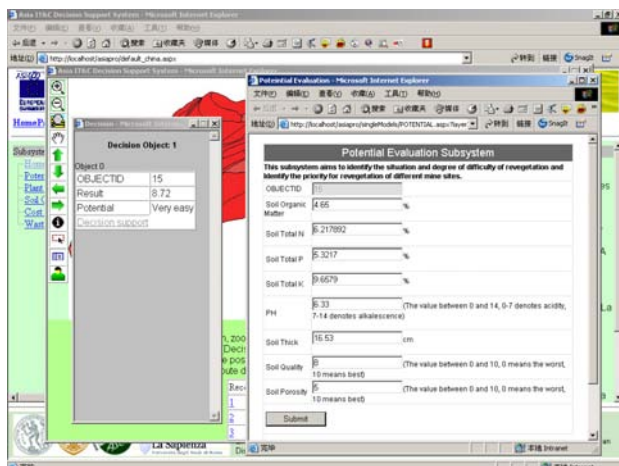

Fig.8 Interface of SDSS

Fig.9 The REPM run for the research area.

(2)PSSM simulation

PSSM is also applied in Fuxin. The plant database can be edit by the system management. Fig.14 shows the results of PSSM running in Fuxin. The place that can be planted with more species colored in dark red. The same problem with RPEM running, some places that colored in gray means the data is null. You can differentiate them by the clew from the table that is located under the map in browser. When you click the "decision support" button, the dialog box will point out it (see Fig.10) similar with RPEM simulation (see Fig.9). Most of the plant/trees that the models select are local plant.

When you click the tree/plant, you can get the details of it from plant knowledge database.
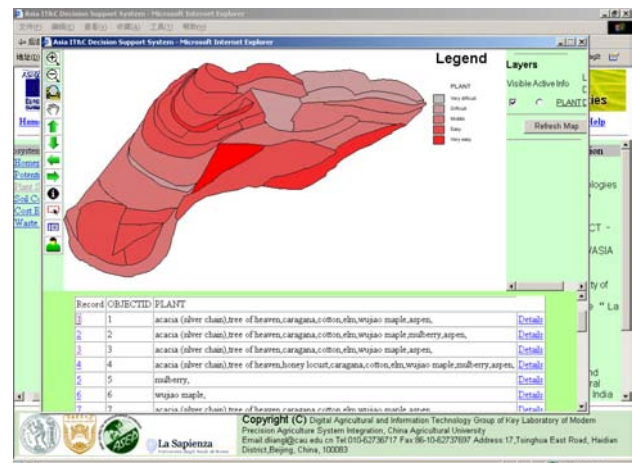

Fig.10 PSSM results in Fuxin coal mine

(3) System management

There are four subsystems in the system management; they are page layer management, models management in China, models management in Thailand. Page layer management subsystem is used to manage the page content composition (see Fig.11). In the modes management all the attribute data, knowledge base and case base that were stored in the data base can be edit, all the coefficient of the models' can be edit by administrator (see Fig.12).
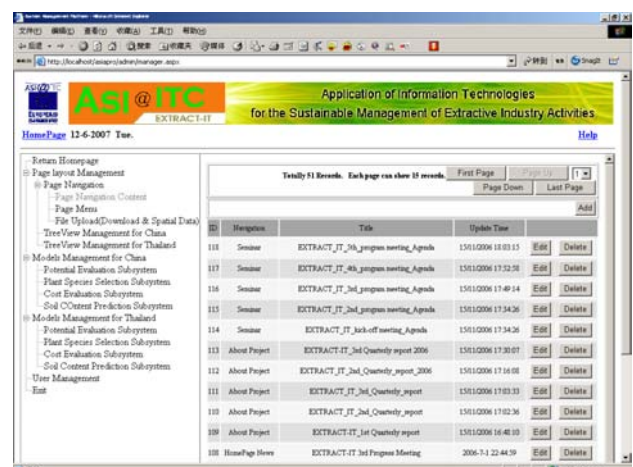
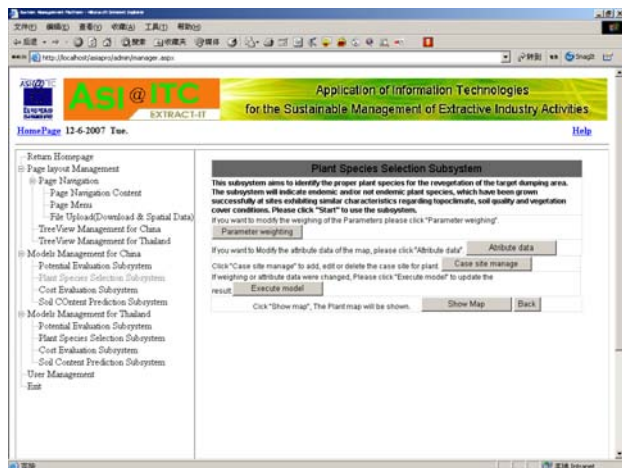

Fig.11 Page layer management subsystem

Fig.12 Models management subsystem

5. Conclusions

The SDSS is regarded as an effective tool to help users in their rehabilitation activities. The usefulness and flexibility of the proposed approach have been illustrated in the application. In addition to its powerful capabilities in processing, analyzing and modeling spatial data, GIS provides excellent visualization tools that can be used effectively to present reclamation situation and give solutions to reclamation problems. Therefore, the use of GIS can improve not only the analytical capabilities for reclamation management but also our ability to communicate work results and research findings to the decision makers and the public in general. The system is able to support and facilitate restoration of reclamation on lands contaminated from coal mine waste. The attempt was resulted from a pilot use of a SDSS for reclamation of lands contaminated from mine waste developed by China Agricultural University. The SDSS for reclamation 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.

The RPEM, PSSM and RSSM used in the SDSS has been developed and integrated in the SDSS. The systems have been applied in the two case studies. It can be concluded that: (1) Based on the analysis of the fuzzy integrated evaluation & gray relating priority analysis algorithms, a reclamation potentiality model was integrated and used to evaluate the reclamation potentiality of abandoned land and identify the reclamation priority in different regions. (2) Based on the analysis of climate-substrate similarity theory, the distance-based similarity algorithm was modified, and the pioneer plant species selection model was integrated

in the SDSS. This model could select the suitable plant species for reclamation, by considering the similarity of the climate and substrate between the target site and successful reclamation cases. (3)The production rule was selected to represent the knowledge on reclamation of abandoned wastes, and the rule-based reasoning was used to build the readjustment schemes for abandoned land selection model. This model was used to identify the engineering reclamation and amendment schemes on the abandoned wastes based on the analysis of waste type, mining mode, and ground status and so on.

Generally, SDSS needs to be enhanced with more data, more cases and data of plant and soil to make it workable in different coal mine waste lands. 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. The corresponding planting methods should also be provided in detail, this help users' rehabilitation practice. Most of the plants that stored in the database for Thailand can be plant in MMM because of rainfall. Thus we will consider the ecological benefit and social benefit for the place that is easy to reclamation in the future.

Additionally, SDSS generated data from the system should be able to provide enough information for day-to-day operation, such as, assess the re-vegetation status, or monitor the physical changes of the plantation. It should also be able to generate enough information for rehabilitation project monitoring and control. So, it is expected that the developed software tool will provide useful information for decision-making on their re-vegetation or rehabilitation activities, as well as become a useful rehabilitation program monitoring and control tool.

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The development of the tool is based on the working conferences and the experience of EU partners regarding the performance of alternative technologies for the rehabilitation of different types of mining cities under various environmental conditions (wet/dry climate, topography, etc.) and the experience of both EU and Asian partners.

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