A GIS-based support system for Environmental Impact Assessment of rehabilitation of coal mine dump

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Abstract: - Environmental Impact Assessment (EIA) of rehabilitation of coal mine dump is a complicated progress, it requires a synthesis of appropriate algorithms and a Geographical Information System (GIS) based computer system which identified as being necessary for effective information support. This paper looks at why a GIS-based is needed and what the advantages and difficulties in developing and using such a system. And this paper also presents the architectural design of a system for EIA of rehabilitation of coal mine dump and the main functions of spatial and temporal simulation, assessment and management of vegetation, soil and biodiversity in coal mine dump. The prototype system was implemented and pilot used in FuXin, the experience and feedback from testing and evaluating the system with potential users are discussed. Some valuable insights into the use of the Internet as a decision tool in mining resource management are highlighted.

Key-Words: - EIA, rehabilitation, GIS

1 Introduction

In order to improve environment of coal mine dump, one of the significant tasks in ecological management in coal mine dump is to restore and rehabilitate vegetation on waste dump. And a key problem that government cared is what influence will happen after revegetation. As a man-made terrace hill, the dump is a unattached ecosystem comparatively, which will influence soil nutrient and community. Public decisions recording rehabilitation of coal mine dump, which produce a major soil and biodiversity impact, can be facilitated by EIA. In order to provide support information for a wide range of regional land-use planning, the EIA procedure was introduced to overcome the limitations of classical benefit analysis that uses the criterion of the maximum total net benefit to choose the optimum solution [1, 2].

In the presence of solutions, technical search for the optimum project is assumed to be meaningless. The philosophy adopted is that of the Support System. EIA is not a single technique but a decision procedure that may exploit a range of different techniques. The underlying logic is to give all the necessary information to the decision maker, and to eliminate successively all the alternatives that are inferior because they are Pareto-dominated or too conflicting. This gradually narrows the problem and better defines the significant characteristics of the remaining alternatives, making the actual entity of the existing conflicts clear. And the underlying procedure can be made rational and transparent. The significance of environmental impacts is largely dependent on the spatial distribution of the effects of the proposed action and of the affected receptors. The choice of the level of analysis to adopt for the assessment can also have a decisive influence on the results. However, in current EIA practice, this spatial dimension of impacts is often ignored or hidden in the overall decision-making process. This paper presents a new methodology for impact assessment which aims to improve the assessment of impact significance by considering explicitly the spatial dimension of the impacts. Therefore, it relies on the assessment of the spatial significance of impacts, using information generated within the EIA process, with the support of GIS [3].

GIS are tools for collecting, storing, retrieving at will, transforming, and displaying spatial data for a particular set of purposes [4]. Given the spatial nature of many environmental impacts, GIS can have a wide application in all EIA stages, acting as an integrative framework for the entire process, from the generation, storage, and display of the thematic information relative to the vulnerability/sensitivity of the affected resources, to impact prediction and finally their evaluation for decision support. Given the local and regional nature of many environmental impacts, we combine the spatial analysis capabilities of GIS and the analytical properties of succession models into an efficient decision tool [5-7]. The introduction of computerized methods of analyzing spatial information has made it possible to evaluate map data while accounting for the spatial distribution of components. We were interested in combining the spatial analysis capabilities of GIS and the analytical properties of forecast models into an efficient decision tool.

The aim of this paper is to develop a support system for Environmental Impact Assessment of rehabilitation of coal mine dump, enabling the manager to use quantitative and qualitative criteria in order to visualize the predict future states of the soil and communities. The paper begins with a brief overview of Characteristics of the study area. This is followed by the presentation of the System architecture and proposed methodology. An interface dealing with the soil nutrient assessment of environmental impacts of FuXin coal mine dump is presented to illustrate in detail the practical application.

2 Characteristics of the study area

The coal mine dump in FuXin extends over 170 km from West to East and over 84 km from North to South, covering an area of 13 km^2. (Fig.1) The dump is located in the north temperature zone and characterized by the mountainous topography. This natural barrier has a strong influence in the meteorological conditions determining the air pollution situation [8].

The region is mostly classified with the semi-arid and semi-wetness continental monsoon climate, which is characterized by four distinct seasons and sufficient sunshine. The winter in the region is long and cold, and the snowfall is less than the other areas. Spring and autumn are transition seasons, and the temperature rises and falls rapidly within the periods. According to the metrological data(Environmental Protection Bureau of Fuxin), the annual average temperature is between 6.5°C and 7.5°C, with the lowest average minimum temperatures occurring in January(-37.9°C) and the highest average maximum temperatures in July(40.9°C). The annual rainfall reaches 448.8 mm, but the annual average amount of evaporation reaches 1644.9mm. Furthermore, the precipitation shows asymmetrical distribution in spatial and temporal extension, descending from south to north and focus on June to September. The annual mean wind speed is 2.84 m/s while the predominant wind direction is SSW. And the annual frost-free period covers 150 days.

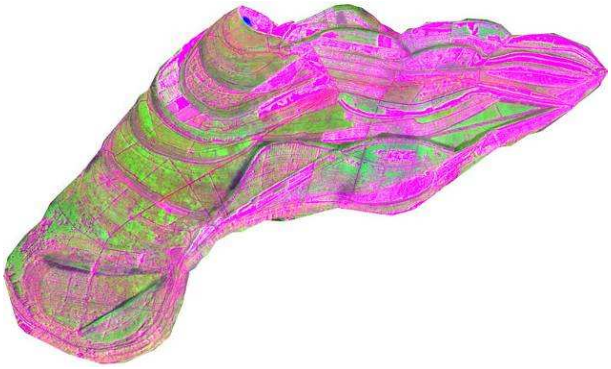

Fig.1 The study area

From 1982, the revegetation of the FuXin dump has been actualized by FuXin Land Consolidation and rehabilitation Centre, China Agricultural University and Beijing Forestry University. According to the situation of investigation, the community and soil nutrient has changed remarkably.

3 System architecture

The diagram in Fig. 2 represents the principal content of the system developed, which is composed of interface, modules and database.

The interface provides the user visible tools, which can process and analysis data, analyze the spacial attribute and provide necessary information for EIA. In this software, a particular display of the different shapes (industries, houses and roads) are called themes and can be selected in any order, e.g. localization of plant, soil plot, etc. These themes can be selected or sorted according to the modeler criteria, highlighting the most relevant features on individual digital maps. GIS is used as the main component of the system for capturing, storing, checking and manipulating data that are spatially referenced. It is important to note, that GIS is not only used as a map viewer in the system, but more as an integrated tool to handle data from many sources [9]. The next content consists of GIS tools, programming language and forecast models. This software is also well suited for developing dynamic environmental models. Depending on these, the system function can come true. The last part is database which is the groundwork of the system.

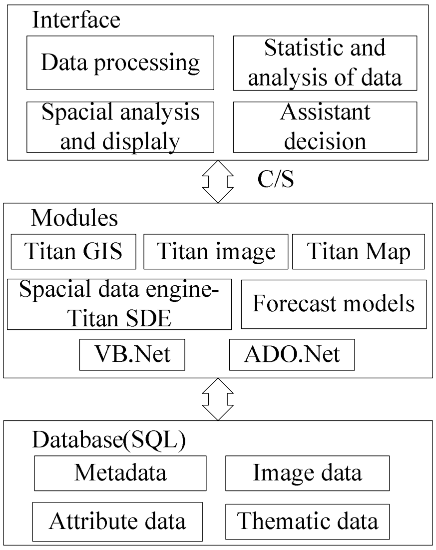

Fig.2 Structure of the system

In order to integrate GIS and models for the EIA of coal mine dump, the following software tools have been used. Titan tools are powerful and easy-to-use software in china. They give user the power to visualize, analyze, explore, query and progressing data spatially. Titan Map ActiveX (Tmapx) is a set of tools and mapping objects which allow the user to add maps in his application and to manage the map with the linked data base. Map Object applications can be greatly expanded when advanced programming is involved, such as Visual Basic, Delfi and C#. Visual Basic is powerful programming language, especially when it is used under Windows, Tmapx customized with Visual Basic, allows user to construct various scenarios or proposals which can then be collected, combined, discussed and prioritized.

For the development of this case study, a geo-referenced database was built including elevation data, land use, areas of ecological interest, soil nutrient and plan. The GIS software of Titan was used, considering cells of $2.5m^2$ (the resolution associated with SPOT satellite image Data and metadata), which was imported to the spacial database as thematic data. The impact indices computations were performed in Excel. The environmental components presented in this case study are soil nutrient, community, and landform of the study area.

4 The forecast models

4.1 soil prediction model

Markov-chain theory is a stochastic process theory. It describes how likely one state (e.g. soil nutrient) is to change to another state. Its major descriptive tool is its transition probability matrix (TPM).Soil nutrient can be modeled as a Markov-chain with continuous space and dispersed states. The continuous space of states with the same property follows an exponential distribution, which is an intrinsic characteristic of the Markov-chain [10, 11].

A Markov TPM determines the probability principle of the state transition process of the Markov-chain. So together with its initial probability distribution (IPD), it can entirely describe the statistical characteristics of the Markov-chain. The initial probability distribution should be theoretically the ratio of areas of different types of surface nutrient of FuXin dump.

The IPD and the TPM may be expressed, respectively, by

$$P[E(t_n)=j/E(t_{n-1})=i]=Pi_j \tag{1}$$

$$P=\begin{matrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \cdots & \cdots & Pi_j & \cdots \\ P_{m1} & \cdots & \cdots & P_{mn} \end{matrix} \tag{2}$$

The formula defines different state of soil nutrient as E1□E2□E3…, and variable time as t1□t2□t3…. When the system time is t_{n-1}, the state is defined as Pi_j, and

$$Pi_j=\frac{N_{ij}}{\sum_j Ni_j} \tag{3}$$

According to the Monte Carlo method, the probability distributions need to be changed into accumulative probability distributions in simulating. And the probability can be given by

$$Pi_j^{(n)}=\sum_K P_{ik}^{(n-1)}\bullet P_{ki} \tag{4}$$

4.2 community succession model

The Multi-Dimensional Sphere Model (MDSM) was used to analyze multivariate instantaneous trend in a vector form to express the magnitude, direction and rate of instantaneous change in vegetation composition at a given time. In addition to trend analysis, the MDSM is used for correlation analysis, vegetation classification, and system monitoring [12].

The model was designed for multivariate time series, three subscript data z(i, j, k), or three way data. When used for vegetation analysis, i, j, k represent species, quadrat and time, respectively. MDSM fixes i as the dimension of multivariate space; groups and combines j to eliminate it from the analysis; and performs trend analysis over time.

Application of the Multi-dimensional sphere model to vegetation analysis involves four phases: quadrat data are divided by the vector length; determination of quadrat similarities; clustering of quadrats based on similarities (centralization); trend analysis and prediction.

4.2.1 Standardization of data by quadrat

Standardization of quadrat data projects the quadrat points from an n-space to the unit hypersphere by dividing each element of a vector by the vector's length.

$$Q'_{(i)} = \frac{Q_{(i)}}{L_{(q)}} \quad (5)$$

The length of a vector is the square root of the sum of the squares of the elements of a quadrat.

$$L_{(q)} = \sqrt{\sum Q_{(i)}^2} = || Q || \quad (6)$$

Therefore,

$$Q'_{(i)} = \frac{Q_{(i)}}{|| Q ||} \quad (7)$$

where Q is the quadrat, Q (i) is the ith species of the quadrat, L(q) is the vector length of the quadrat represented as ||Q||, Q' is the standardized quadrat, and Q'(i) is the ith species of the standardized quadrat. In this paper Q'(i) is referred to as the Importance Value (IV) of the ith species, and is the cosine value of the variable in the vector. This process standardizes the different vector lengths to unity, while retaining their composition ratio.

The MDSM can be described simply as an extension of division and percentage calculations from a scalar to a vector. The mufti-dimensional space, n-space, built from these sample data is a two-dimensional surface defined by the orthogonal axes of X and Y with the points of quadrat.

4.2.2 Similarity coefficient

When dimensions are more than two, or the quadrats are numerous, it is impossible to visualize the entire data structure. Consequently, a similarity coefficient is needed to determine the relative position of the quadrats. The similarity coefficient between two vectors (quadrats) is defined by MDSM as the cosine of the angle between the two vectors.

$$SC_{(a,b)} = COS\angle AOB = COS\angle BOA = \sum \frac{A_{(i)} B_{(i)}}{\|A\| \cdot \|B\|} = \sum A'_{(i)} * B'_{(i)} \quad (8)$$

SC is the Similarity Coefficient, and □AOB is the angle between vectors a and b. Because the lengths of the standardized vectors are one, vector lengths are omitted in the calculation: If the cosine values calculated by MSDM are closer, the two quadrates are similar in species composition.

4.2.3 Clustering quadrate

In trend analysis, MDSM analyzes vegetation condition over time, as represented by state vectors. To determine a state vector of vegetation, the model groups quadrats based on their coefficients of similarity to generate a centroid vector representing the combined quadrats. We assume similar vegetation types will react similarly to environmental stressors and will have the same trend. A result of quadrat standardization, or projection onto the hypersphere, is the formation of clusters of quadrats.

4.2.4 Trend analysis and predication

For trend analysis, the MDSM is applied to quadrats sampled in different time periods but from the same location. When performing trend analysis, MDSM defines trend (t) as present over past:

$$t_{(i,k)} = z'_{(i,k)} / z'_{(i,k-1)} \quad (9)$$

and extends this trend to the next time interval to make a prediction (p) based on existing information):

$$t_{(i,k)} = z'_{(i,k)} / z'_{(i,k-1)} \quad (10)$$

The MSDM defines the quotient of elements of precious and current standardized state vectors as a successional trend, expressed as a trend vector, analyzing vegetation composition change over time. This successional trend can then be extended to predict future states of the vegetation.

4 Application

In order to demonstrate the functionality of the system developed in this study, the environmental data of coal FuXin coal mine dump were studied for the year of 2006. And the images, thematic data and attribute data were imported to the database, and converted into a raster format using the GIS. This was to ensure the system would work correctly before it was distributed to users.

The forecast models ware developed to integrate the capabilities of a GIS and incorporated into the system (soil nutrient and community succession). The function of spacial analysis activities commonly used to progress spacial data were also incorporated into the system. The models identify important cover types (soil and vegetation features) used, and this information was used to combine features for more efficient system operation.

Fig. 3 presents an example to predict the organic matter the system interface. After inputting the impact factors, the needed information can been acquired.

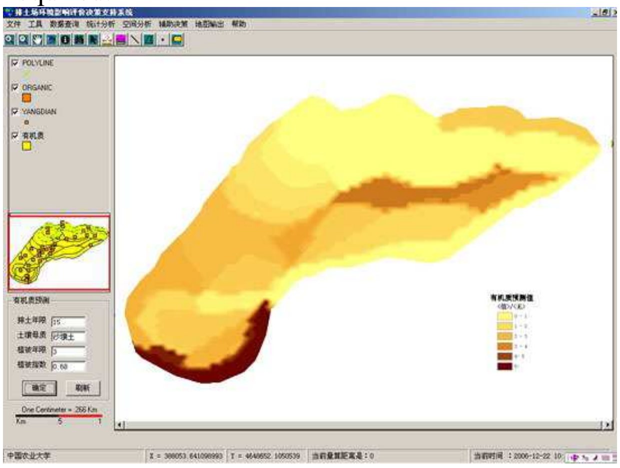

Fig.3 The system interface

In more detail, an analysis of system implementation results shows that: the system is practical and useful, and regarded as a useful tool. The system presented in this paper is preliminary outcomes of ongoing studies. The system will be further developed, e.g. expanding its database to validate the models and used in other coal mine dumps.

5 Conclusions and future

An integrated GIS-based prediction system has been briefly described. This system is intended to be an example for other coal mine dumps. Calculation of a species inventory, modeling and mapping by GIS are carried out as the components of this system. Forecast model is the main component of the system. The system in this study provides easy access for predicting environmental changes in the study area, and a complete picture of community dynamics can be obtained.

The system is a prototype spatial decision support tool to assist government receiving effective information of environment after revegetation that best assistant their decision and which provide the greatest likelihood of beneficial outcomes. The system also enables officer to manage, modify, add, delete and query the environmental information. The prototype application presented in this paper is a first step towards a fully integrated, professional-quality system that will provide comprehensive and rigorous information of the dump and will accelerate the ecosystem reasonably.

The models discussed here were developed to allow the user access to all relevant data in a convenient and cohesive format, as well as providing support in the form of rules for feasible actions. The system provides the user with a fast and convenient interface for testing 'what if' scenarios, thus saving valuable time. The system can provide important input into setting overall goals and objectives for the formulation of specific predicting data for soil and community. The models constitute a mechanism for integrating environmental resources with other land uses, and attribute data, and also provide guidance with respect to the types and quality of data required for effective revegetation.

However, a substantial amount of research and development is necessary in order for the system to be used on a forecast basis of data. Additional field research must provide insight into: categories of data that are of greatest importance will be imported to the database; specific measures for data elements that convey the greatest meaning to officer; an interface design that is consistent with the needs and expectations of users. The system, if redeveloped into a professional-quality application, will provide the assistant decision for revegetation of coal mine dump.

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