A Spatial Decision Support System for Land-use Structure Optimization

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Abstract: - This article describes a decision support system for land-use structure optimization and land-use allocation. This system was established for the rural land managers to explore their land use options. It integrated database technology, expert system technology and spatial decision support system technology. The DSS consist of four components: a geographic information system (GIS), land use modules, a graphical user interface and land use planning tools. The linear programming, fuzzy clustering, and other land-use structure optimization algorithms are implemented on the ArcEngine software platform. The system has been applied in Beijing Pinggu area. The results suggest that this system can be a useful tool to support management decisions.

Key-Words: - Land-use Structure Optimization; Land use allocation; ComGIS; DSS

1 Introduction

The land-use structure optimization refers to the reasonable arrangement of the different land-use areas and spatial layout to achieve optimal ecological and economic objectives. It is based on the characteristics of the land resource and the results of land suitability evaluation. It aims to improve the efficiency and effectiveness of land-use, maintain the relative balance of the ecosystem and achieve sustainable use of land resources. The process of land-use optimization requires dealing with many correlation factors, it is a complex systemic project. In this context, there is an increasing demand for land use planning tools that are flexible enough to contribute usefully to the task of allocating land use in a way that reconciles, as much as possible, such frequently conflicting objectives as economic viability, maintenance of social structure, and environmental conservation [1] . While GIS has an advantage in the management and organization of the spatial data, It has a widely applications in land management, especially in data acquisition, storage, updates, query, computing and graphics tabulation. As it not enough powerful at modeling, the decision support role of a geographic information system is particularly notable [2] .

The process of rural land-use planning involves different stages that require different kinds of studies [3] . Many studies have aimed to optimize the management of natural resource by applying mathematical models. The term multiple criteria decision analysis (MCDA) was introduced by Espen Løken to aid decision makers in the complex process of energy planning [4] . Brett A. Bryan develop and apply a systematic regional planning approach to identify geographic priorities for on-ground natural resource management actions that most cost-effectively meet multiple natural resource management objectives[5] , simulated annealing was used for the allocation of land units[6] . Ralf Seppelt developed a framework of procedures for numerical optimization in spatially explicit dynamic ecosystem simulation models to optimize the land use [7] . Several studies have developed techniques for integrated planning for addressing multiple natural resource management objectives. Notably, LUPIS (Land Use Planning and Information System), a generic tool for optimizing land-use patterns and landscape structures has been applied in

The first IT applications designed for land-use planning only evaluated land suitability. In addition, many systems have been designed to analyze the area assigned to each land use. The only commercial GIS that include tools for land evaluation and for the spatial allocation of land uses is IDRISI [8] . There are currently many methods and IT applications that deal with one or several land-use planning studies; however, only a few systems, such as What-If [9] and SIRTPLAN, incorporate all of the aforementioned stages. Most land-planning IT applications focus on urban planning; Other systems are specifically designed for agro forestry uses, including LADSS[10] , LUPAS [11] , LADSS includes stages of land evaluation, spatial allocation of land uses, and evaluation of environmental impact. LUPAS include stages of land evaluation and area optimization, while NELUP includes area optimization, environmental evaluation, and a hydrological analysis [6] .

Some of the above systems are commonly used in land use plans. However, it is difficult to apply these systems to China .Some are not yet available (e.g., LADSS), and most of the commercial systems are adapted to the characteristics of North American land-use plans and focus on urban land uses. In addition, few of the remaining applications deal with the all stages mentioned above. For these reasons, we tried to develop a new system that can be easily used in China.

Building on the work in this field, we developed a decision support system for land-use structure optimization. The system described in the present paper includes two main stages in this process: (1) the optimization of the different land-use areas; (2) the spatial allocation of land uses. In order to meet the requirements of land-use optimization, this paper developed a new planning support system for rural land-use allocation. It is base on the powerful ArcEngine components. The two stages correspond to two system modules: (1) area optimization, and (2) spatial allocation. The results of one module become the input for the others. This feedback between the modules enables the final result to be refined and improved. The land-use structure optimization decision support system can be used for land-use data management, spatial analysis, cartography, and it also integrated the decision support function.

2 System functionality and architecture

This land-use structure optimization decision support system supports the following functions: (1) support the basic map operations, including the conversion between different viewer, show the map in different ways, allow the user to editor the map, thematic mapping, printout, and other related functions;(2) Allow users to choose different models for the land-use optimization; automatically formulating land-use models to give the program of land-use optimization;(3) Access the database, retrieve and display required data graphically;(4) According to the land-use optimization program, made spatial allocation;(5) Provide helpful information about the modeling process, system's functionality and use;(6) Generate cartographic displays and tabular reports.

Given that land-use planning is closely linked to the spatial component of data, the basis of RULES is a GIS; this facilitates data management and analysis. Other tools have been integrated into the GIS by programming to solve linear programming models, fuzzy cluster model and genetic algorithm that optimize the spatial allocation of land uses. The GIS and the other decision support tools are fully connected, as specific commands have been created for the application using Visual C# and have been included in the existing GIS commands. The GIS is used as a means of visualizing data and as a framework for analysis and modeling operations. Three new menus have been added to the GIS interface: one for each of the system's modules. These menus can be used to access the commands that execute the different methods of land regionalization, area optimization, and spatial allocation. Some of these commands establish links with other software components; however, the results of all operations are visualized in the GIS, thereby enabling total integration to be attained.

The architecture of the system is composed of a user interface, a database system、a model base system as well as a knowledge library system (Fig. 1). The entire system uses the popular three layers service model: users interface layer, business service layer, data service layer. The corresponding configuration software is database management system and components, middleware components and applications. The users interface layer is responsible for the expression of the interface and the interaction whit users, this system developed an application by using C#.net to serve as users interface layer. Multi-view structure of the window is to make full use of resources and maximum reduces the data-processing work of data service layer. The data service layer is to deal with the core business logic, mainly relying on the dynamic link library provided by ArcGIS platform. Data services layer is responsible for the management of spatial data and attribute data.

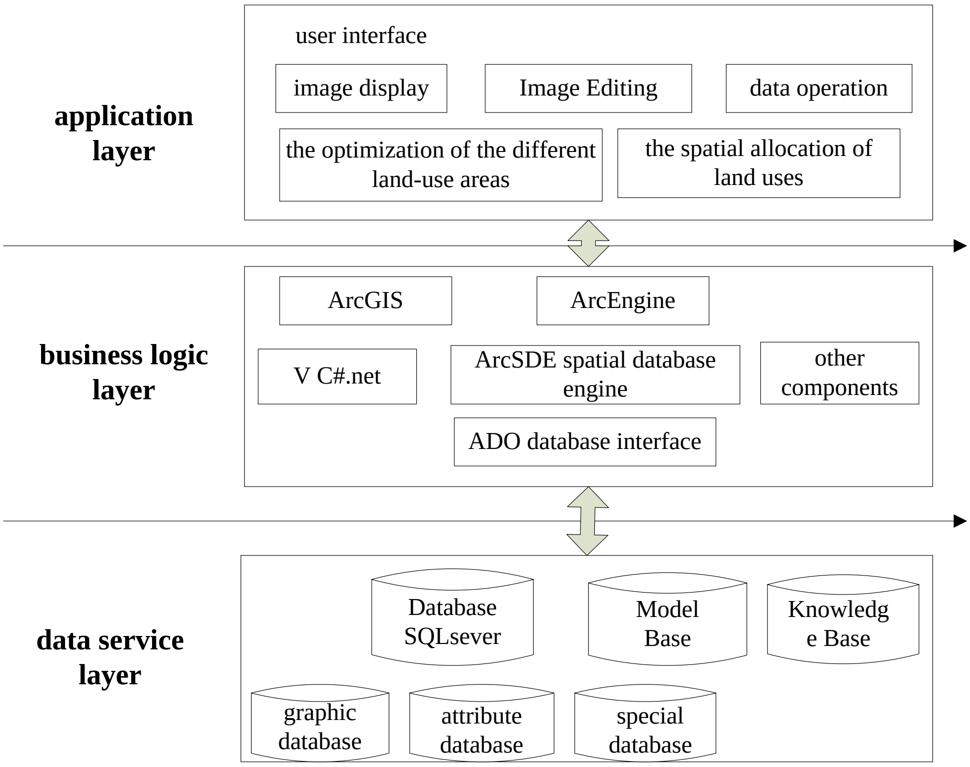

Fig.1. architecture of the system

3 Data and methods

3.1 The study area

For the development of an appropriate methodology for optimization procedures for spatial landscape models, we focus on the problem of optimum land use patterns and optimum fertilization in a mainly agricultural region in eastern Beijing, China. We have focused our studies on the Pinggu which is located at east of the city of Beijing(40° 02′ - 40° 22′ N,116° 55′ 21″ -117° 24′ 07″ E,). The annual rainfall is about 615.5mm. Main land use of this area are farmland and construction land. Rapid population growth, development and change in land use and land cover have become obvious features of the landscape.

There are several problems exiting in the process of land-use in Pinggu area. The rapid growth of urban population and reduction of arable lands, results in increasing of land supporting capacity. In addition the land-use is not adequate, the structure of land use and spatial distribution are unreasonable.

Fig2. Location of the study area

The available data were stored in the vector-based GIS system implemented in the system consisting of the following maps: land utilization map; land suitability evaluation; Roads and trails map; Rivers, streams, lakes and wetlands map.

3.2 The optimization of the different land-use areas

Most applications of mathematical programming to rural land use allocation have employed linear models. Examples of the use of single-objective linear programming models include that of Chuvieco (1993), designed to minimize rural unemployment by maximizing the area devoted to labor-intensive uses; and that of Campbell et al. (1992), designed to balance local production and imports in Antigua in such a way as to minimize overall cost while satisfying demand. The increasing complexity involved in agricultural land planning makes multi objective models increasingly necessary. When multiple objectives must be taken into account (total production, gross value, net profit, cost minimization, prevention of erosion, self-sufficiency, etc), single-objective models are of limited help to the land use planner. Multi objective linear programming and related techniques provide a methodology for analyzing the relationships and conflicts among these objectives [6] .

This system implemented the linear programming, multi-objective planning for the optimization of different land-use areas. This paper will describe the process of linear programming.

Linear programming method is based on the basic data provided by land-use survey .Pick up the single benefit from the region's comprehensive benefit that can represent the characteristics of the study area and the requirements of social development as the objective function, in addition, take the other benefits as constraint condition, then solve the linear programming equation by using computer technology to obtain a set of optimal land-use structure. The basic ideas and steps is: ① According to the characteristics of land resource and society development demand, combined with the current situation of the region, take a single benefit from the economic, social and ecological benefits of the study area as the leading goal of the planning.② Make the land use of the study area as the variables of the system.③The construction of the objective function: $f(x) = \Sigma C_jX_j = \max$, where Cj is the efficiency coefficient of land-use, Xj for the type of land-use; f (x) is the gross domestic product (GDP); ④ Pick up the requirements from the demand of the total area of land, ecological balance and economic balance, as well as the requirements of manpower, material and financial resources, and other constraints on the planning year as the constraint, and then construct a sets of line equations as the constraint condition of the system.⑤ Establish the equations and inequalities, solve the linear programming equation by means of computer technology to obtain a set of optimal land-use structure, which is the region's best land-use structure.

First, the user should execute the command “Model definition” to adjust the model’s parameters. In this command, the user selects the objectives and land uses, and introduces the technical coefficients and the right-hand side of demand constraints for each land use (Fig. 3). In the command for executing the constraint method, the user should select the objective that is to be the objective function. The remaining objectives are transformed into constraints by introducing the value r: the number of different values of the constrained objectives. Call MATLAB mathematical function to solve the linear programming equation. The process ends when the user considers that the achievement rate for all of the objectives is appropriate and the program of land-use optimization is appropriate.

3.3 Land-use spatial distribution

Land-use planning maybe defined as the process of allocating different uses to specific units of area within a region [4]. Once the optimization of the different land-use areas is determined, it should be implementation on spatial distribution. The spatial distribution of land-use structure is called as Land Use Planning Model, which generally has two formats: land-use regionalization and land-use spatial allocation. Land-use spatial allocation is unique and unrepeatable while several land-use types exiting in one region is allowed for Land-use regionalization. This paper will describe these two land-use planning models in detail.

3.3.1 Land-use regionalization

Land-use regionalization is very complex work with strong technical sense. The contents involve the distribution of regional natural factors, the regional feature of the resource, land use status and the difference of economic development level, but also to combine development plan for social economy and land use planning and then reveal the regional characteristics, indicate the land utilization guide、structure and spatial layout. The process of land-use regionalization should follow the principle of combined comprehensive analysis and leading factor, the quality difference of land, land suitability degree and maintain the integrity of the administrative line. Based on the comprehensive analysis of the Comprehensive Physical Regionalization, agriculture Regionalization, land suitability and the land’s natural productive force, outburst the Similarity of dominant factors, divide the regional unite with similar conditions into the same region. The difference and similarity between regions can be reflected by a set of indexes.

Cluster analysis, a tool for data analysis, is a branch in statistical multivariate analysis and also is an unsupervised learning technique in pattern recognition. As the process of land-use regionalization is affected by a variety of factors which are incorporated with notable ambiguity and uncertainty, it is generally can't be estimated by traditional two-valued logic. So fuzzy clustering was introduced to this problem. Since Bellman et al. [7] first initiated the research on clustering based on fuzzy sets; fuzzy clustering has been widely studied and applied in a variety of different areas. Take the process of land-use planning regionalization as a sample, the first step is choosing the cluster indexes.

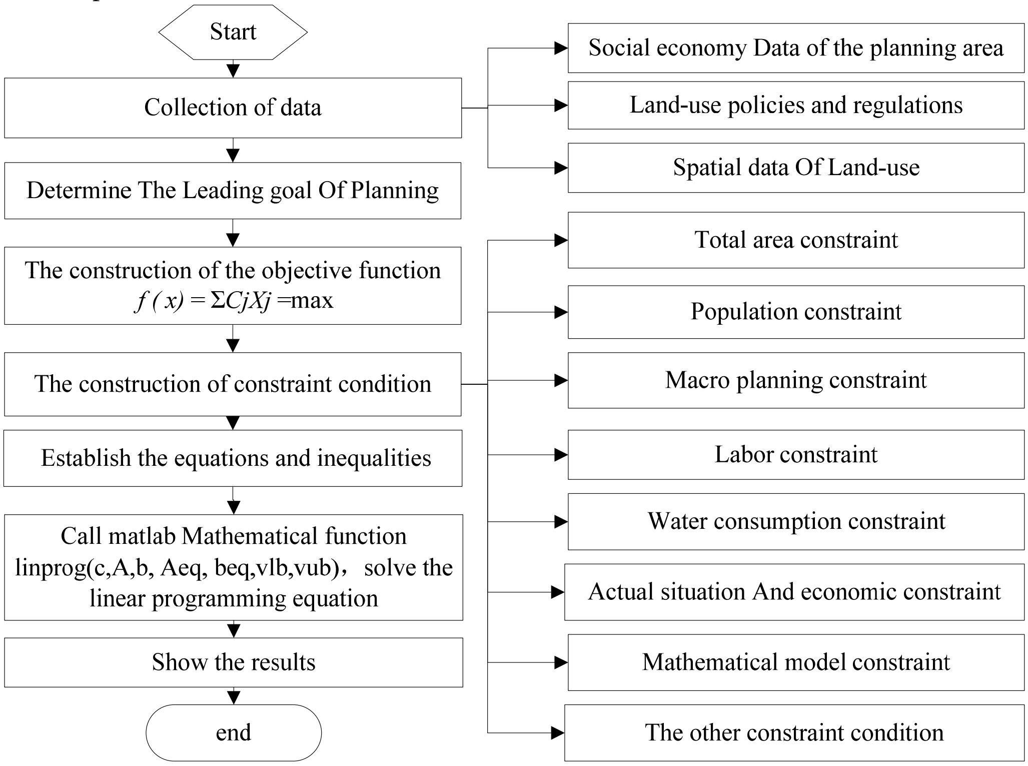

Fig.3. the optimization of the different land-use areas

The indexes system of land-use planning regionalization include 15 cluster factors involving land-use effect, the extension of land exploitation and the level of land intensive management. Then assign the value for each cluster factor. The assignment can be realized through acquiring values form the database and the user interface. Call MATLAB mathematical function to built fuzzy matrix and return the solutions. The result of classification is related to the size of threshold. Generally, the whole area is divided into more categories when threshold gets bigger; when the threshold is little enough, all the categories combined into one class. According to the feedbacks, the users are allowed to change the threshold to get the reasonable regionalization program. By using GIS, the solution can be show as each class having one corresponding color to distinct from the other units.

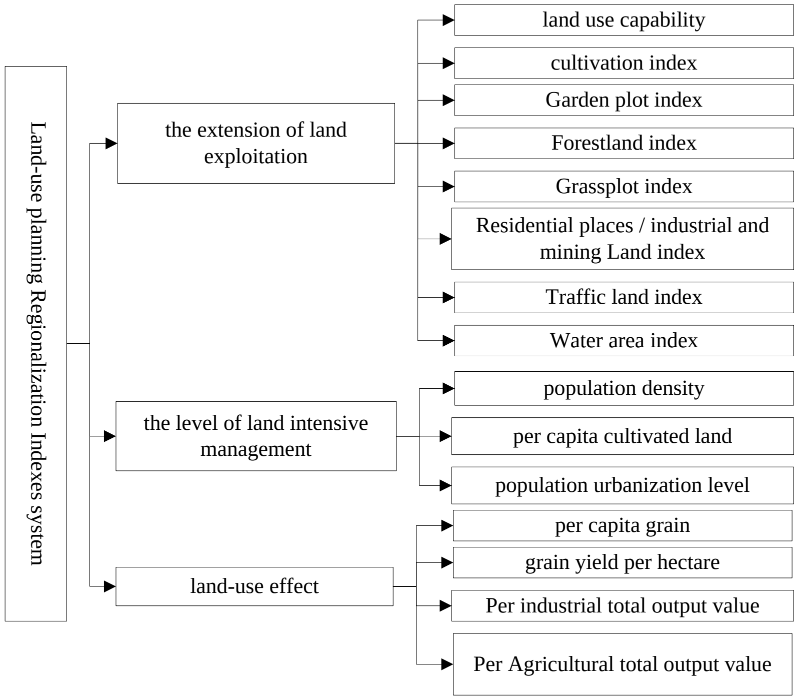

Fig.4. land-use planning regionalization index system

3.3.2 The spatial allocation of land uses

At the beginning of the procedure a configuration is generated that satisfies the constraint on the total area of land allotted to each land use. In order to ensure satisfaction of this constraint by successive trial configurations, these latter are generated by simply exchanging the land-use allocations of a randomly selected pair of land units. This procedure furthermore facilitates calculation of the value of the objective function for the trial configuration, which will differ from the value for the current configuration by a quantity that can be determined by consideration of only the land units affected by the proposed change in configuration.

Land-use allocation problems are complex planning problems. Two objectives were considered in this paper: comprehensive index and the compactness of maximum distribution scheme. The compactness refers to the guarantee of compact of the same land-use type assure that each type of land is not fragmentary in the space. At the same time, the allocation problems still have to meet the following constraints:

Demand constraint. All the land-use area will be arrangement among the planning region, and have to satisfy the configuration of land-use area optimization.

(1) Suitability constraint. The area of each type has to be less than the total area of the planning region.
(2) Uniqueness constraint. Each planning unit can only be arranged one type of land-use.

The function for this problem is give by the following expression:

$$MaximizeZ = \sum_{K=1}^{K} \sum_{i=1}^{n} z_{ik} x_{ik} \quad (1)$$

$$MaximizeR_k = \sum_{i=1}^{n} r_{ik} x_{ik} \quad (2)$$

Subject to:

$$\begin{cases} B_{1k} \le \sum_{i=1}^{n} b_j x_{ik} \le B_{2k} \\ \sum_{K} x_{ik} = 1 \\ x_{ik} \in \{0,1\} \end{cases} \quad (3)$$

Where Z is comprehensive index of the distribution scheme, Rk is the compactness index, n is the number of planning unit of the region, z_{ik} is comprehensive index when planning unit i is arranged for land-use type k, a_i is the area of planning unit I, B_{1k}, B_{2k} respectively represent the maximize and the minimize area of land-use type k, x_{ik} is a bivariate, x_{ik} =1when planning unit i is arranged to land-use type k, or x_{ik} =0.

Many optimization techniques have been proposed to select optimal sites for a single land use. However, this problem is more complex when multiple conflicting objectives are considered. Only a few techniques have been developed to deal with this multi objective problem, which are based fundamentally on multi criteria evaluation methodologies or on heuristic algorithms. We selected an optimization algorithm based on Genetic algorithms, as it has a demonstrated suitability for multi objective land-use allocation problems.

Genetic algorithms (GA) offer a solution to the optimization problem based on the global performance criteria. The first step of GA is to define a representation of the control variables of the optimization problem to a genome. Based on the idea of 'survival of the fittest' a stochastically generated first population of a distinct number of individuals runs through an evolutionary process. GA determines which individuals of a population should survive, which should reproduce and which should die. New individuals are created based on the operations of cross over, mutation and gene migration.

4 Results

A land-use structure optimization system was developed by integrating ArcEngine component and decision support system technology. The GIS is used as a means of visualizing data and as a framework for analysis and modeling operations. Three new menus have been added to the GIS interface. These menus can be used to access the commands that execute the different methods of area optimization, and spatial allocation. Some of these commands establish links with other software components; however, the results of all operations are visualized in the GIS, thereby enabling total integration to be attained. This system was used in the land-use planning as a attempt.

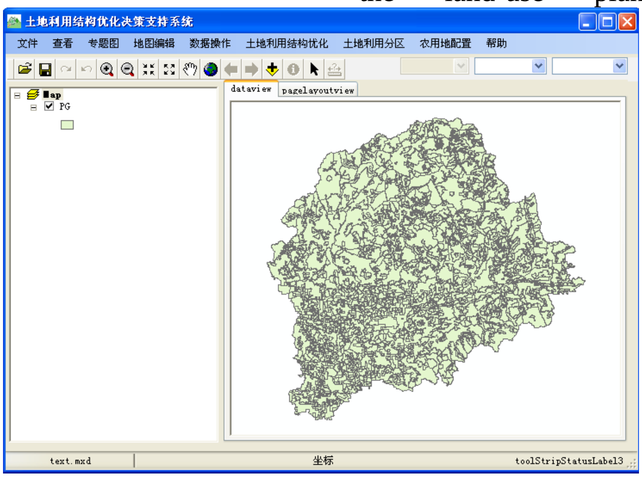

Fig.5.the graphical user interface

A graphical user interface for the decision support system for land-use structure optimization has been designed and built on top of the windows XP system. Fig. 5 is a screenshot of this DSS, which shows four basic windows in a typical land-use structure optimization decision support system session. Going clockwise, the top-left window is the main menu, through which a user can access all functions of this system. Beneath this is a toolbar to support the basic map operations.To the right is the map display window for map display and query. To the left is a image layer management window. It can be used to created, added or deleted an image layer. In addition there are pop-up windows which are used to display relevant information at different stages of a session. For example, it can be used to inform the user of the current or next operations, ask the user questions and receive the user's responses. In the following, we will outline the implementation of the main ILUDSS functions: query, the optimization of the different land-use areas and land-use regionalization.

4.1 Query

The decision support system for land-use structure optimization allows the user to query data. For queries on data, the user may go to the Data menu on the menu bar in the main window. Selecting the data operations and query menu item, the user gets a list of data, from which one data set can be selected for query and display. The selected data set or map data layer will be displayed in the map display window. By choosing the delete data menu item, the user can delete any data layer in the database. At the same time, its associated meta-data is deleted from the meta-data knowledge module. The meta-data can be retrieved by selecting the show metadata menu item.

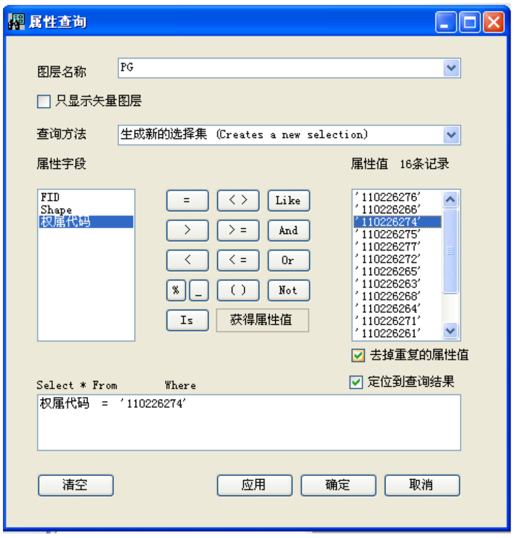

Fig.6.the query interface

4.2 The optimization of the different land-use areas

To get the result of different land-use areas optimization, Firstly, the user should execute the command "Model definition" to adjust the model's parameters. In this command, the user selects the objectives include economic, social, and environmental aspects to be the objective function. The remaining objectives are transformed into constraints by introducing the value r: the number of different values of right-hand sides of the constrained objectives. And then introduces the technical coefficients and the right-hand side of land availability and demand constraints for each land use.

Fig.7. Form for introducing the parameters (land uses, objective functions, technical coefficients, land constraints) of the area optimization model.

Because of the lack of data in Beijing Pinggu area, we select the Nanjing area to test the function of land-use optimization in this decision support system. According to the characteristic of the land resource of Nanjing, the optimization model is composed of 16 variables and 33 constraint conditions. The optimization result was show in fig8.

The blue bars represent the current land use classification, and the red ones are for the optimization results. The results show that the farm land will reduce by 3.97%, while the cities will increase by 3.37%. It is consistent with the practical situation, as the development of economic need more land for construction. Transport land is a guarantee for economic development. It is reasonable for the increase of transport land. Forest and garden plot play an important role in the protection of ecological balance. To keep a sustainable development, the area of forest and garden should be sizeable.

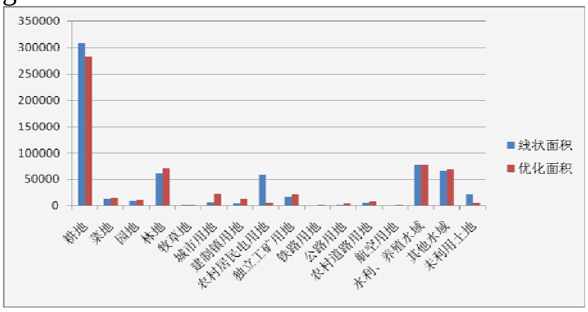

Fig.7.the current land use and optimization

4.3 Land-use regionalization

According to the land use planning in pinggu area and the data provided by the department of land use management, the indexes system of land-use planning regionalization was assigned a value. By adjusting the threshold, the whole area was divided into three zones: the western zone of industrial and high-speed development along the expressway, the Central area of Comprehensive Development, north area of tourism development and fruit industry.

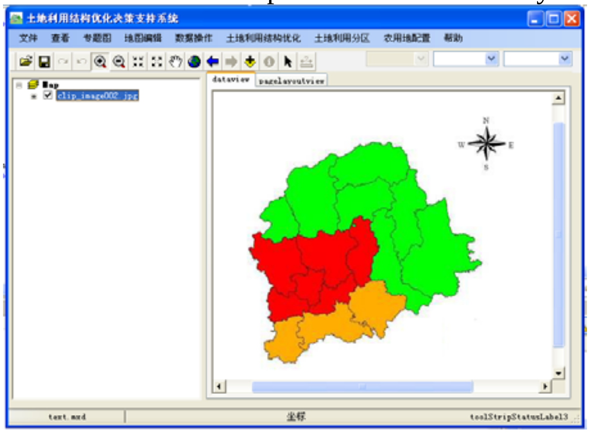

Fig.8. Land-use regionalization

5 Discussion and conclusions

This paper presents the application of SDSS tools integrated in a GIS system to help decision makers in the development of strategies for land-use planning in china. Linear programming is the most commonly used method of optimal allocation of land resources. It can be used to solve many problems, including the linear problem and the nonlinear. As the procedure of land-use structure optimization is very complex and simultaneously affect multiple factors. The objectives include economic, social, and environmental aspects. So multi-objective programming is more suitable.

This land-use structure optimization decision support system is fully operational. However, its current stage of development is that of a prototype rather than a production system. It is mainly for demonstration of the flexibility of DSS technology for rural land-use planning. The current implementation of this has the following limitations: ILUDSS can only deal with three types of land-use. The land-use regionalization model is limited to three classes of evaluation factors, some other important attributes influencing land-use potential on Islay, such as potential impacts on wildlife, have not been included; this system can only handle spatial data conversion between ARC/INFO coverages and ARC/INFO grids. No other spatial data transformation facilities, such as scale change and map projection conversion, are available; this paper designed a method based on genetic algorithms to give several schemes for land-use spatial allocation. This method is not affected by the subjective views of decision makers, and the results are impersonal and quantifiable. However, it is a attempt by simplifying the constraint condition. When it comes to the practical application, more constraint condition and objectives should be taken into consideration to meet the requirements.

There are a number of constraints to overcome for the successful application of such DSS systems in land use decisions. Lack of data and poor data quality remain serious drawbacks to the application of computer-based systems of land resources management. In addition, although this system is an interactive tool that promotes debate between the different interest groups, one of its main limitations is that it lacks a mathematical model that enables different users' opinion to be considered simultaneously. There is also a lack of a scenario evaluation module, which would speed up feedback in the process.

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