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DESIGN AND APPLICATION OF DYNAMIC MONITORING AND VISUALIZATION MANAGEMENT INFORMATION SYSTEM OF KARST LAND ROCKY DESERTIFICATION

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ABSTRACT: In order to study the spatial-temporal change and environmental management of regional karst LUCC (land use and land cover change) and its causative environmental effect—rocky desertification by integrating qualitative analysis and quantitative analysis, and relying on RS, GIS and GPS (3S) techniques, karst land rocky derification dynamic monitoring and visualization management information system (KLRD.DMVM.IS) is framed, which includes design aim and structure model, function design, database design and model system design. The model system design gives priority to dynamic monitoring, drive force diagnosis, comprehensive evaluation and decision support of karst rocky desertification. From the viewpoint of model type, mathematic expression and its meaning, the dynamic monitoring models are concretely devised to reflect the spatial and temporal changing features and the trend of karst LUCC and rocky desertification. Taking Du'an Yao Autonomic County of Guangxi as an example, the KLRD. DMVM.IS is systematically analyzed in the application of the process and trend of karst LUCC and rocky desertification in Du'an County, and it provides the technical support for the study on karst land rocky desertification.

KEY WORDS: karst rocky desertification; GIS secondary development; dynamic monitoring; visualization management

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1 INTRODUCTION

Many nations in the world all have quite attached importance to studying karst environment in recent 30 years. LEGRAD firstly expounded karst regional eco-environmental problems in 1979(WANG, 2002); USA Scientific Promotion Committee formally classed karst area and desert fringe area equally into frail environment on the 149th annual meeting in 1983 (LU, 2002), and international society has thoroughly confirmed that water erosion activity takes an important part in desertification process. Since its development possesses evident regionalism, geo-eco-environmental calamity—the rocky desertification in karst area of Southwest China has never been given rise to wide attention in international society all along, and also has not been definitely arranged into the International Convention to Combat Desertification. In recent years, from various viewpoints, some specialists and scholars have conducted preliminary research on rocky desertification problem in Southwest karst area, mostly including preliminary studies on characteristics, distribution, formation mechanism and ecological rehabilitation of karst rocky desertification under the conditions of frail karst eco-environment. The efficiency and objectivity of these studies have been increased by RS & GIS means, and then some gratifying study results have been acquired (ZHOU, 2001; WU and LI, 2002; YANG *et al.*, 2002). But it has not yet been reported to develop GIS software for the study on karst land rocky desertification system by now. Taking Du'an County of Guangxi as an example, and relying on 3S techniques, this paper designed karst land rocky derification dynamic monitoring and visualization management information system (KLRD.DMVM.IS). The system took the dynamic monitor, driving mechanism, synthetic evalua-

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tion of karst LUCC and rocky desertification as the principal things to provide strong technique support for the study on karst land rocky desertification.

2 SYSTEM DESIGN

2.1 Design Aim and Structure Model

The general target of establishing KLRD.DMVM.IS is to provide satisfactory information support for spatial-temporal change and synthetic prevention and control of land rocky desertification on the basic platform of spatial database. Its specific target includes collection, display, search, statistics and analysis of land rocky desertification data. And under the integrated environment, the system can process and analyze image data and vector data, at the same time, combining with analysis model and spatial statistic model, it can conduct LUCC and rocky desertification spatial-temporal dynamic analysis, driving mechanism diagnosis, rocky desertification precautionary analysis and calamity risk evaluation, which can provide technical support for further study on karst land rocky desertification, karst environmental management, and measures to shake off poverty.

According to the system analysis, the structure models are confirmed as the following parts: 1) spatial analysis model, 2) graphic processing model, 3) image processing model, and 4) data regulation model. In addition, there are "system use illustration" and "escape" push buttons on the main interface of the system.

2.2 Function Design

The two main routes of developing resources and environment information system (REIS) are data organization and model application. As one of the REIS systems, KLRD.DMVM.IS processes and analyzes various data in its basic work in researching course. The components of the system and their connections are programmed and corroborated in the light of system design object, and the system function design must satisfy practical requirements, and ensure the achievement of general target of the system. Generally speaking, the functions of GIS include data input, data management, graph displaying and processing, image displaying and processing, model bank and spatial analysis facilities, and data output (Fig. 1). Consequently, the main functions of the system are listed as the following: 1) Data input: importing various kinds of image data, vector data, DEM data and statistical data into system database. Image data, vector data and DEM data can be led into automatic building data collection, and the relative attribute and store route of the data are automatically received by database. 2) Data regulation: data addition and deletion, editing, search and statistic analysis. The above-mentioned functions are integrated in one interface. User can operate in database through selecting different data tables. 3) Graph displaying and analysis: the model displays and analyzes vector graph, including map showing operation, such as graph amplification, reduction, roam, all-view, multi-window displaying, and map layer processing (layer displaying, implying, reordering, overlaying of various factors and the addition of image background map). 4) The system read in original RS image to show and simply process the image by binary.

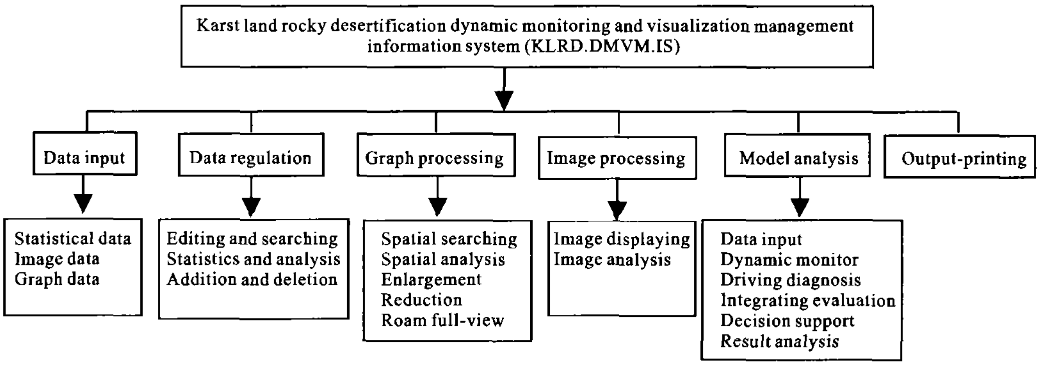

Fig. 1 System functions in KLRD.DMVM.IS

2.3 Database Design

Data is the core component of GIS, and a complete database is the key to achieve various functions of GIS system. Database management includes not only usual attribute data, but also abundant RS image data and partial vector data. In so far as present GIS software and RS image processing software, it is not easy to unitedly manage and analyse RS image data, vector data and attribute data (LI *et al.*, 1999; YANG *et al.*, 2000; QIAN, 2002). In KLRD.DMVM.IS, attribute data is managed by common relative database,vector data is managed by spatial database in GIS software, and RS image data is employed in enlarged relative database, i.e., the route of image file stored in the database; whereas real image files are deposited to disk files in an index manner organization. The framework of system data flux is ascertained by resting on various data disposal and analysis flow chart (Fig. 2), and prepared for further system designation, encoding editing and system achievment.

3 MODEL SYSTEMS

GIS and specialty model are all used to process and analyze spatial data. GIS can input, store, operate, and manage spatial data and export the result in the expression of graph, but the system itself is lack of mighty spatial analysis capacity. Spatial model can accurately calculate spatial data, but the result often needs to be expressed by GIS.

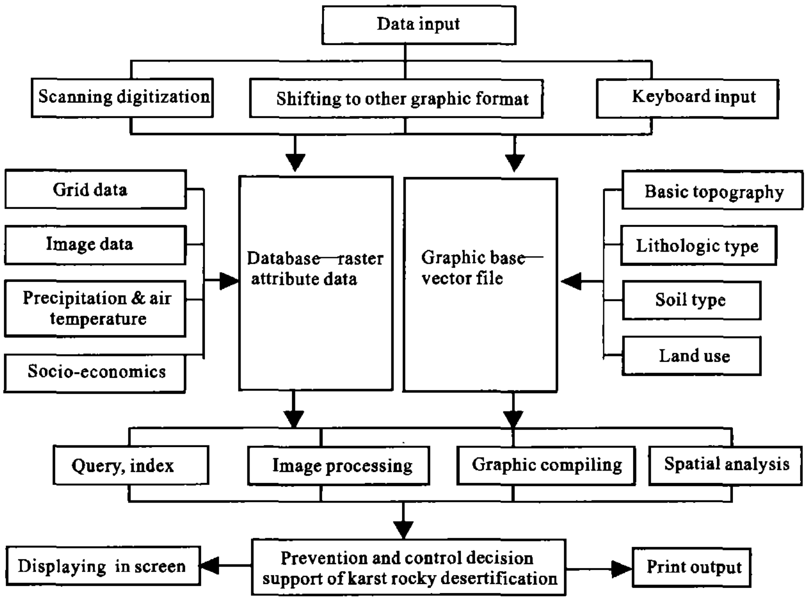

Fig. 2 Flow chart of data in KLRD.DMVM.IS

In addition, the mutual complement of GIS and specialty model in functions are main driving force of integrating GIS and specialty model. According to the system target and deeply analysis of typical frail karst eco-economic system, some models are established, such as spatial-temporal dynamic analysis model, driving force diagnosing model, evaluation model and decision support model of karst LUCC and rocky desertification.

Herein, the paper mainly introduces the dynamic analysis and forecast model of karst LUCC and rocky desertification. A sequence of rocky desertification type maps in karst woodland, bare rock and their interlaced zone are acquired by using RS image. Taking multi-temporal RS digital image as data source, referring various kinds of thematic maps and socio-economic statistic data, the paper quantitatively analyzes the spatial-temporal change of LUCC and rocky desertification in Du′an County of Guangxi Zhuang Autonomous Region using RS image processing software ERDAS.

3.1 Spatial-temporal Change Model

Process and tendency of karst LUCC and rocky desertification can be expressed by their change extent, area change velocity, change tendency index and regional change difference (LOU, 2003; ZHANG *et al.*, 2002). The types, expression and connotation of the specific models reflecting spatial-temporal change of karst land use/cover and rocky desertification are listed in Table 1.

3.2 Forecasting Model

Markov process is a kind of especial random process, of which the biggest characteristic is that the state at $t+1$ moment is only related to the state at occasion t, but not to the former state. This characteristic justly fits for the forecast of karst LUCC and rocky desertification. The mathematical expression of its transfer probability matrix is: ① $0 \leqslant P_{ij} \leqslant 1$, which means that every element is non-negative value; ② $\sum_{j=1}^{n} P_{ij} = 1$, which means that the

Table 1 Spatial-temporal change models of karst land use/cover and rocky desertification

Model type	Expression	Connotation
Change extent	$R_d=(U_b-U_a)/U_a\times100\%$	Area change of various types
Change speed and tendency	$R_s=(U_b-U_a)/U_a/T\times100\%$ $=(\Delta U_{in}-\Delta U_{out})/U_a/T\times100\%$	Dynamic degree of single type is used to express the change rate of a certain LUCC type or rocky desertification grade in certain region within certain time
	$R_{ss}=(\Delta U_{out}+\Delta U_{in})/U_a/T\times100\%$	Dynamic degree of spatial change of single type
	$P_s=R_s/R_{ss}=(\Delta U_{in}-\Delta U_{out})/(\Delta U_{in}+\Delta U_{out})$ $\lvert R_s/R_{ss}\rvert\leqslant1$, i.e., $-1\leqslant P_s\leqslant1$	Tendency and state of LUCC type change when $0\leqslant P_s\leqslant0.5$,"arising"; when $0.5\leqslant P_s\leqslant1$, "falling"
	$R_t=\sum_{i=1}^{n}\lvert U_{bi}-U_{ai}\rvert\Big/2\sum_{i=1}^{n}U_{ai}$ $=\sum_{i=1}^{n}\lvert\Delta U_{in-i}-\Delta U_{out-i}\rvert\Big/2\sum_{i=1}^{n}U_{ai}/T\times100\%$	Dynamic degree of synthetic LUCC (rocky desertification) is referred to comprehensive change ratio of area of all types (or grades) in the studied area within the studied time
	$R_{ts}=\sum_{i=1}^{n}(\Delta U_{out-i}+\Delta U_{in-i})\Big/2\sum_{i=1}^{n}U_{ai}/T\times100\%$ $=\sum_{i=1}^{n}\Delta U_{out-i}\Big/\sum_{i=1}^{n}U_{ai}/T\times100\%$ $=\sum_{i=1}^{n}\Delta U_{in-i}\Big/\sum_{i=1}^{n}U_{ai}/T\times100\%$	Synthetic dynamic degree of spatial change of all types or grades in the studied area
	$P_t=R_t/R_{ts}=\sum_{i=1}^{n}\lvert\Delta U_{out-i}-\Delta U_{in-i}\rvert\Big/\sum_{i=1}^{n}\Delta\lvert U_{out-i}+\Delta U_{in-i}\rvert$ $0\leqslant R_t\leqslant R_{ts}\leqslant1$, i.e., $0\leqslant P_t\leqslant1$	Total tendency and state of regional LUCC and rocky desertification change $0\leqslant P_t\leqslant1/4$, balance $1/4\leqslant P_t\leqslant1/2$, para-balance $1/2\leqslant P_t\leqslant3/4$, unbalance $3/4\leqslant P_t\leqslant1$, extreme unbalance

Notes: U_a and U_b are type (or grade) area at starting time and ending time of study, respectively; T is study period; U_{in} and U_{out} are the area sums of other types changing into certain type (or grade) and certain type changing into other types (or grades), respectively; ΔU_{out-i} is the area sum of type i (or grade i) changing into other types (or grades) within study time T; ΔU_{in-i} is the area sum of other types (or grades) changing into type i (or grade i)

sum of all elements in a row is 1. In the formula P_{ij} is the transfer probability from land use type i (or rocky desertification grade) to land use type j (or rocky desertification grade).

4 APPLICATION OF KLRD.DMVM.IS

The subsystem information of KLRD.DMVM.IS includes RS image processing, rocky desertification thematic information and database. With the data flow, together with spatial-temporal dynamic analysis, driving force diagnosis, evaluation model, and decision support model, KLRD.DMVM.IS can be applied in the synthetic analysis of karst LUCC and spatial-temporal change of rocky desertification intensity, driving force index, eco-degradation and rocky desertification evaluation, and the ecological rehabilitation and comprehensive management of rocky desertification, thus providing strong supporting technology for comprehensive management of environment and the strategic decision of sustainable development in rocky mountainous areas.

4.1 Course and Trend of Karst LUCC

In the light of the LUCC spatial-temporal change models (Table 1), the paper calculates and analyzes the classified area, structure, change extent, and annual change rate (single dynamic degree, synthetic dynamic degree, and tendency and state index) of LUCC in Du'an County in 1977 and 1988 (Table 2). Among them, U_0 represents no changing area of various land types. Accordingly, the process and trend of karst LUCC are inscribed. The result manifests that: 1) forestland, slope cropland, building land, and bare rock increased, of which the increasing extent of forestland was the largest, and the increasing area of bare rock is the largest; scrub, open forest, grassland, ravine cropland and water area lessened gradually, of which scrub had the largest lessening extent and area. 2) As for the change tendency and state of various LUCC types from 1977 to 1988, building land and slope cropland show steadily rising trend; bare rock assumes quite fast increase and its type of transform assumes two-way situation; ravine cropland shows gradually decreasing posture; scrub, open forest, grassland and water area assume slow de-

Table 2 Change rates of various land-use types in Du'an calculated by different models during 1977–1988

Type	U_a (ha)	U_b (ha)	U_0 (ha)	ΔU_{in}		ΔU_{out}		R_d (%)	R_s (%)	R_{ss} (%)	P_s
				Area (ha)	Ratio (%)	Area (ha)	Ratio (%)				
Forestland	7271.66	11834.73	7060.76	4773.97	65.65	210.9	36.14	62.75	5.70	6.23	0.91
Scrub	144484.88	115533.48	97666.73	17866.72	12.37	46818.12	43.15	–20.04	–1.82	4.07	–0.45
Open forest	10430.88	8105.43	5057.25	3048.18	29.22	5373.63	53.24	–22.29	–2.03	7.34	–0.28
Grassland	44150.11	34106.57	24412.30	10694.27	24.22	19737.81	43.01	–20.48	–1.86	6.27	–0.30
Ravine cropland	37631.64	33446.45	32710.51	735.94	1.96	4921.13	6.93	–11.12	–1.01	1.37	–0.74
Slope cropland	15932.80	25369.24	11980.27	13388.97	84.04	3852.53	2.45	59.23	5.38	9.89	0.54
Building land	5219.03	7219.80	4866.82	2352.98	45.08	352.21	8.79	38.34	3.49	4.71	0.74
Water area	4705.68	4669.39	4404.17	265.22	5.64	301.51	19.34	–0.77	–0.07	1.09	–0.06
Bare rock	139363.02	167904.61	121063.26	46841.35	33.61	18299.76	12.95	20.48	1.86	4.25	0.44
Synthetic change	R_t=0.99 R_{ts}=2.22 P_t=0.45										

creasing state. The state and tendency index of whole Du'an County is 0.45, type of transfer assumes two-way situation, and it lies in the para-balance state.

4.2 Forecasting Analysis of Land-use Structure

4.2.1 Land-use change trend

For calculating the transfer probability matrix, the land-use change of the studied area is divided into various stages by historical periods, and the transfer matrix of land-use area in various times is figured out. By the basic time unit of year, average annul transfer probability of some land-use types is counted out within various time limits, for example, woodland in certain plot on land-use map in 1977 changes partially into scrub, slope cropland and grassland etc. in 1988, its annual average transfer probability is obtained by dividing the average percentage of the latter ones accounting for woodland area by year number (n=11). The transfer probability of cropland changing into other land-use types is taken as the first line, that of scrub changing into other land-use types as the second line, the rest may be deduced by analogy. By so doing, an annual average transfer probability matrix can be formed. Probability transfer matrix of land-use type from 1977 to 1999 is used to obtain average multi-year weighted transfer probability matrix of land-use type during 1977–1988 and 1988–1999. The matrix is probability vector($P^{(0)}$) at initial time t, and its calculating formula is as follows:

$$P^{(0)}=(n_1 \times P_1+n_2 \times P_2)/(n_1+n_2)$$

where, P_1 and P_2 are average transfer probability matrixes from 1977 to 1988 and from 1988 to 1999, respectively, n_1 is 11 years, and n_2 is 11years. Calculating result is listed in Table 3.

Table 3 Conversion probability matrix of various land-use types at initial time (n=0)

	Forestland	Open forest	Scrub	Grassland	Ravine cropland	Slope cropland	Building land	Water area	Bare rock
Forestland	0.7650	0.0028	0.1201	0.0316	0.0042	0.0655	0.0005	0.0000	0.0104
Open forest	0.0034	0.6280	0.0000	0.0324	0.0001	0.0266	0.0075	0.0001	0.3020
Scrub	0.1457	0.0019	0.4774	0.1481	0.0427	0.0427	0.0073	0.0049	0.1292
Grassland	0.0495	0.0249	0.0359	0.5591	0.0170	0.1240	0.0020	0.0006	0.1869
Ravine cropland	0.0000	0.0028	0.0109	0.0065	0.8984	0.0091	0.0058	0.0108	0.0557
Slope cropland	0.0033	0.0159	0.0039	0.0094	0.0015	0.8895	0.0033	0.0020	0.0713
Building land	0.0000	0.0007	0.0000	0.0080	0.0630	0.0058	0.9211	0.0000	0.0014
Water area	0.0000	0.0000	0.0059	0.0117	0.0284	0.0176	0.0117	0.8875	0.0372
Bare rock	0.0006	0.0829	0.0059	0.0184	0.0054	0.0134	0.0037	0.0000	0.8697

4.2.2 Land-use transfer process

By the help of MATLAB software, the transfer probability matrix ($P^{(n)}$) and various land-use percentages (A_n) of various years since 1977 are counted out, and change percentage of various land-use types also can be simulated. For example, from 1977 (Table 3) to 1999 by n=22, the transfer probability matrix of various land-use types are shown in Table 4.

On the basis of the initial state matrix in 1977 and their initial state transfer probability, it is shown comparatively that forestland, bare rock, ravine cropland and water area are different in simulating result and actual survey situation is not salient, so the two tally preferably. It is feasible to adopt transfer probability of area corroborated by transfer matrix among land-use types to forecast the change of land-use structure by Markov process model (Table 5).

4.2.3 Land-use change trend after 2010

In order to forecast the trend of land-use change in Du'an Yao Autonomous County, the area percentages

Table 4 Conversion probability matrix of various land-use types during 1977–1999

1977	1999								
	Forestland	Open forest	Scrub	Grassland	Ravine cropland	Slope cropland	Building land	Water area	Bare rock
Forestland	0.0344	0.1142	0.0204	0.0441	0.0683	0.2006	0.0393	0.0110	0.4678
Open forest	0.0251	0.1254	0.0171	0.0436	0.0638	0.1648	0.0448	0.0078	0.5074
Scrub	0.0295	0.1170	0.0188	0.0434	0.0752	0.1828	0.0433	0.0120	0.4782
Grassland	0.0271	0.1207	0.0178	0.0433	0.0661	0.1828	0.0420	0.0098	0.4904
Ravine cropland	0.0235	0.1051	0.0178	0.0402	0.1503	0.1443	0.0503	0.0277	0.4408
Slope cropland	0.0250	0.1190	0.0169	0.0424	0.0582	0.2042	0.0417	0.0097	0.4829
Building land	0.0180	0.0727	0.0154	0.0334	0.2206	0.1135	0.1840	0.0241	0.3182
Water area	0.0224	0.0971	0.0170	0.0393	0.1206	0.1510	0.0634	0.0784	0.4109
Bare rock	0.0250	0.1261	0.0171	0.0437	0.0639	0.1625	0.0436	0.0079	0.5100

Table 5 Verification of various land-use types simulation by Markov process

Item	Forestland	Scrub	Open forest	Grassland	Ravine cropland	Slope cropland	Building land	Water area	Bare rock
Initial value	1.7771	35.3100	2.5492	10.7896	9.1966	3.8937	1.2755	1.1500	34.0583
Simulated value	2.5036	12.1597	1.7343	4.3094	7.4852	16.5909	4.6347	1.1146	49.4405
Observed value	2.5981	18.6315	2.1287	6.7961	8.6008	8.5723	2.0191	1.1440	49.5093
Difference	0.0945	6.4718	0.3944	2.4867	1.1156	-8.0186	-2.6156	0.0294	0.0688
Error (%)	3.77	53.22	22.74	57.70	14.90	48.33	56.44	2.64	0.14

of various land use are calculated in this county in 2010 and 2021 further (Table 6). During 1999–2021, the cropland area in the county is going to reduce unceasingly. According to the character of Markov process, the probability distribution of many limit states of Markov process has nothing to do with initial state. With regard to land-use change, when undergoing a long-term use, tends to infinity, transfer probability comes up to relative stable state. At this moment the area percentages of various land-use types are not connected with their initial states. Markov process equation group in stable state is as follows:

$$\begin{cases} \sum_{j=1}^{n} a_j = 1 \\ a_j = \sum_{i=1}^{n} a_i P_{ij} \end{cases}$$

where a_i and a_j represent area percentage of various land-use type; P_{ij} transfer probability; n number of land-use type; i , j represent amount from 1 to n, in the LUCC of Du'an, n=9. The above-mentioned equation group can be spread out:

$$\text{for:} \begin{cases} a_2=a_1P_{12}+a_2P_{22}+a_3P_{32}+a_4P_{42}+a_5P_{52}+a_6P_{62}+a_7P_{72}+a_8P_{82}+a_9P_{92} \\ a_3=a_1P_{13}+a_2P_{23}+a_3P_{33}+a_4P_{43}+a_5P_{53}+a_6P_{63}+a_7P_{73}+a_8P_{83}+a_9P_{93} \\ a_4=a_1P_{14}+a_2P_{24}+a_3P_{34}+a_4P_{44}+a_5P_{54}+a_6P_{64}+a_7P_{74}+a_8P_{84}+a_9P_{94} \\ a_5=a_1P_{15}+a_2P_{25}+a_3P_{35}+a_4P_{45}+a_5P_{55}+a_6P_{65}+a_7P_{75}+a_8P_{85}+a_9P_{95} \\ a_6=a_1P_{16}+a_2P_{26}+a_3P_{36}+a_4P_{46}+a_5P_{56}+a_6P_{66}+a_7P_{76}+a_8P_{86}+a_9P_{96} \\ a_7=a_1P_{17}+a_2P_{27}+a_3P_{37}+a_4P_{47}+a_5P_{57}+a_6P_{67}+a_7P_{77}+a_8P_{87}+a_9P_{97} \\ a_8=a_1P_{18}+a_2P_{28}+a_3P_{38}+a_4P_{48}+a_5P_{58}+a_6P_{68}+a_7P_{78}+a_8P_{88}+a_9P_{98} \\ a_9=a_1P_{19}+a_2P_{29}+a_3P_{39}+a_4P_{49}+a_5P_{59}+a_6P_{69}+a_7P_{79}+a_8P_{89}+a_9P_{99} \\ 1=a_1+a_2+a_3+a_4+a_5+a_6+a_7+a_8+a_9 \end{cases}$$

Transfer probability of various land-use types at the initial state in 1977 in Du'an County is substituted into above-mentioned equation group, and then the change tendency of land use can be obtained. When cropland area lessens to 7.88% of total land area, the system come to stable state, and the area percentages of land-use types in stable state can be figured out by solving this equation group (Table 6).

Table 6 Change trend of the land-use structure in Du'an in the future (%)

Time domain	Forestland	Open forest	Scrub	Grassland	Ravine cropland	Slope cropland	Building land	Water area	Bare rock
1977	1.7771	35.3100	2.5492	10.7896	9.1966	3.8937	1.2755	1.1500	34.0583
1988	2.8922	28.2349	1.9808	8.5795	8.1738	6.1999	1.7644	1.1411	41.0333
1999	2.5981	18.6315	2.1287	6.7961	8.6008	8.5723	2.0191	1.1440	49.5093
2010	2.5059	12.0308	1.7236	4.2806	7.6462	16.8014	4.9290	1.1282	48.9543
2021	2.4982	11.9793	1.7211	4.2701	7.7652	16.8160	5.0440	1.1423	48.7664
$t \to \infty$	2.4931	11.9404	1.7202	4.2627	7.8819	16.7887	5.1216	1.1627	48.6288

4.3 Dynamic Monitoring

The spatial distribution and transformation law of karst land desertification can be monitored through the positioning, qualitative and quantitative analyses by adopting GIS technique, including transfer matrix and mathematical model, of various interpreted rocky desertification classification maps in different times and database.

4.3.1 Transfer matrix analysis

Spatial overlay operation about rocky desertification intensity in 1988 and 1999 is carried out from the rocky desertification distribution maps of Du'an Yao Autonomous County in the two times, the transfer probability matrix of rocky desertification process in the recent 11 years is counted out (Table 7), and then the process of karst rocky desertification in Du'an is analyzed.

4.3.2 Transfer velocity and trend

By overlaying the spatial distribution maps of Du'an rocky desertification in 1988 and 1999, the distribution map of spatial-temporal change of Du'an rocky desertification in the late 10 years can be obtained. Then the multi-side attribute table search is pursued in changing graph-layer, thus can reach the change situation of intensity grades of land rocky desertification in Du'an within corresponding times statistically (Table 8).

The changing zone of intense rocky desertification is mainly distributed in the middle, west and north of Du'an Yao Autonomous County. During 1988–1999, though the rocky desertification intensity of 61.33% of the area in the county remained unchanged, karst rocky desertification has worsened very obviously.

Table 7 Conversion probability matrix of rocky desertification in Du'an between 1988 and 1999 (%)

1988	1999				Sum ratio
	No rocky desertification	Light rocky desertification	Moderate rocky desertification	Intense rocky desertification	
No rocky desertification	68.97	11.14	5.19	1.24	86.54
Light rocky desertification	1.55	5.65	1.58	0.15	8.93
Moderate rocky desertification	0.29	0.61	1.50	0.79	3.19
Intense rocky desertification	0.00	0.00	0.23	1.11	1.34
Sum ratio	70.81	17.40	8.50	3.29	100.00
Change	-18.17	+94.81	+167.21	+144.40	
(Change rate)	(1.65)	(8.62)	(15.20)	(13.13)	

Table 8 Change of rocky desertification intensity in Du'an in 1988–1999

Intensity change	Change degree		Intensity change	Expansion-type		Intensity change	Reversion-type	
	Area (ha)	Ratio (%)		Area (ha)	Ratio (%)		Area (ha)	Ratio (%)
No grade change	315996.61	61.33	Enhance 3 grades	5061.81	1.43	Reduce 1 grade	9797.53	15.83
Change to desertification	64350.41	1.83	Enhance 2 grades	21847.94	7.68	Reduce 2 grades	1190.74	9.09
Change to non-desertification	7552.31	13.72	Enhance 1 grade	55295.07	55.32	Reduce 3 grades	0.00	0.00

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