Influence of land-use changes on soil erosion based on geo-information Tupu theory in Zhujiang Delta

Donghai Li*, Bin Ai, Xia Li, Qiusheng Wu, Xiaoguang Xie
Geography and planning School, Sun Yat-sen University, 135 West Xin'gang RD, Guangzhou, 510275, Guangdong, P.R.China

ABSTRACT

This paper improved the traditional method of researching soil loss changes based on land-use dynamic changes, geo-information Tupu theory was introduced in to study the heterogeneity of soil erosion caused by land-use changes. With the example of Zhujiang Delta, we investigated the land-use changes and soil erosion changes over the period from 1998 to 2006. The results showed: the soil erosion intension aggravated in recent years, the average amount of soil erosion in 2006 was as much as 1.5 times of that in 1998; the change of land-use was the main reason for the change of soil erosion, and the diversity of soil erosion varied obviously with the transformation of land-use patterns; especially, soil erosion changed sharply with the mutual transformation between developing area or sand land and other land-use types correspondingly.

Keywords: soil erosion, land-use change, Tupu, Zhujiang Delta

1. INTRODUCTIONS

Soil loss is a serious environmental problem in the world, and China is one of those countries which suffer such situation most.[1-3].As the important factor of regional ecological security, soil erosion causes many problems such as degradation of land resource and ecological systems, this phenomenon becomes more distinct as the land-use change increases because it influences the impetus and resistance of soil erosion[4]. Land-use change will transform the types of the earth's surface, therefore, the impetus and resistance of soil erosion will be influenced, and it comes out to be the element of initiation and strengthening of soil erosion. Unsuitable patterns of land-use would aggravate soil loss, and the patterns would be restricted in return, causing the deterioration of the land productivity and a more intense human-land contradiction [5].

The economy in Zhujiang Delta develops fast in recent 20 years, the urban region expands rapidly and the pattern of land-use changes sharply as well [6,7]. With the severe human activity and large amount of rainfall, man-made soil loss together with that caused by water is quite serious in this area[8]. Accordingly, studying the relationship between land-use changes and soil loss changes is very meaningful for human.

In the studies of the relationship between soil erosion and land-use changes, early research paid attention to revealing characteristics of soil loss and figuring out suitable value of soil loss factors of different land-use types[4]. After the appearance and development of Remote Sensing and Geographical Information Systems(GIS), scholars now lay more stress on dynamical、muti-scale and quantity between soil loss and land-use changes[4,9,10]. Based on the method of transferable matrix, the condition of soil loss would be revealed according to the analysis of different characteristics of soil loss in a certain period and the comparison of the area and proportion of soil loss. However, this method is incapable to reveal the details of soil erosion changes caused by land-use changes, for example, when a big forest plot is converted to small plots such as urban area, developing area and water field, we could not know the different changes of soil loss on the land-use types: forest-urban area, forest-developing area and forest-water field. Geographical information Tupu has been used to study the relationship between land-use changes and temperature, precipitation and so on. It is precedent to introduce geographical information Tupu theory into the study of land-use changes and soil erosion changes.

On the basis of the cognizance theory of geo-spatial information, geo-information Tupu is a spatio-temporal compound analytic procedure supported by remote sensing, GIS, virtual reality, internet communication, computer graphic science

* lee_mao@126.com, (+86) 15913163074

Geoinformatics 2008 and Joint Conference on GIS and Built Environment: Monitoring and Assessment of Natural Resources and Environments, edited by Lin Liu, Xia Li, Kai Liu, Xinchang Zhang, Yong Lao
Proc. of SPIE Vol. 7145, 71451E · © 2008 SPIE · CCC code: 0277-786X/08/$18 · doi: 10.1117/12.813029

etc.. It integrates the spatial units and the jumping-off point and process of time and is a really temporal-spatial complex. Each Tupu unit depicts the time-attribute-process, in this respect, regional diversity could be distinguished simultaneously. So in this paper, we use the Tupu to study the influence of land-use changes on soil erosion, doing this could reveal different grade of soil erosion when one land-use type changed into any other types. In order to illuminate this theory, we can see the sketch map (Fig.1), (a) and (b) respectively represents land-use of period ⅰand periodⅱ, plot A is converted to plot A,B,C and so on, using layer (b) subtracts layer (a) would get the land-use changed process plots of A-A,A-B,A-C and so on, then we could use the process plots as the zonal statistics layer to calculate soil loss to reveal the soil loss changes. When some land-use types are converted to one type ((c) and (d)), the principal is the same as above.

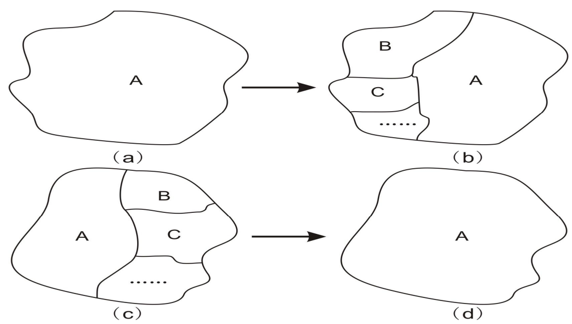

Fig.1. sketch map for Tupu of land-use change

2. TEST AREA

The test area chosen for this project is located in the southeast of Guangdong Province, Southeast China. It includes Guangzhou、Shenzhen and other seven cities. Three branches of Zhujiang river and many small rivers run through this area. Surrounded by hills, a plain locates in the middle of this area, and 30 percent of this area are mountains, and islands, the hypsography is obvious. The climate here is semitropical climate with average temperature from 21 to 23 centigrade, the average precipitation is more than 1500mm, it is coldest in January and hottest in July, the air is very soppy through all year. In this small region, the area of Zhujiang delta is only 14 percent of Guangdong Province but the population occupies 61 percent with 4.2 million.

3. METHODS AND MATERIALS

3.1 Data preparation

The data sets in this research are as follows: DEM with 100*100m resolution, vector data of soil types which has fifty-nine types, land-use types both in 1998 and 2006, rainfall data and some other ancillary data. Taking consideration of the area Zhujiang Delta and the amount of calculation, we transformed all data to raster format in 100m*100m resolution, the image was rectified to WGS 1984 coordinate system, the subset of this area is 4262*3345(Fig.3). Two Land-use layers were interpreted from TM images(Fig A and B), the final classification scheme and definitions were based on the limitation of sensors and the land cover of Zhujiang Delta, the precisions of 1998 and 2006 land-use classification had been assessed and were suitable for this research. Nine raw land use/cover types are included, namely Water, Dry Land, Paddy Field, Forest, Wasteland, Grass land, Urban, Developing area and Sand Land.

3.2 Analysis of land-use changes

Land-use changes is the main factor of the global environmental change [12,13], and is also the crucial input element of the geo-process to combine atmosphere with biosphere. In order to investigate the speed and pattern of land-use changes, we utilized the matrix of transform and the velocity of land-use changes to explore the land-use changes from 1998 to 2006[4,11]. Transition matrix can describe the structure attribute of land-use changes, it is depicted as follows:

$$P_{ij} = \begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{vmatrix} \tag{1}$$

P_{ij} indicates the area difference form land-use i in period of k to land-use j in period k+1. Transition matrix can not only reflect structure of all land-use types in different periods, but also disclose condition of land-use changes. From the Matrix, we can easily see the area of one land-use type changed to/from any other land-use types. It makes the research accessible, which concerns about the primary outlets and the origins and constitution of ultimate forms of varieties of soil erosion

3.3 Soil erosion model

Erosion models are empirical, conceptual or physically based [14]. The application of process-based numerical models is often problematic because of the often low quality of available input data [15]. Empirical models have generally a much simpler structure, require less input parameters and show often similar performance in terms of prediction accuracy than deterministic models when considering yearly averages. Reducing model complexity will generally lead to a minimization of the error propagation of erosion models [16]. Comparisons between empirical and process-based models showed that the average error and model efficiency in soil loss prediction was similar [17].

One of the still most widely used empirical models is the Revised Universal Soil Loss Equation (RUSLE), it has been verified the feasibility on assessing soil erosion. Therefore, we used the RUSLE model to calculate the soil erosion in Zhujiang Delta. The RUSLE model is expressed as follow:

$$A = 224 \cdot R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{2}$$

Where A is the soil loss in one year ($t/km^2 \cdot a$), R is the precipitation erosionl factor (N/hm^2), K is the soil erodibility factor ($Kg \cdot hm^2/Nm^2$), LS is the slope length and steepness factor, C is the crop management factor and P is the erosion-control factor. $N=10^{-1} t \cdot m \cdot cm/h$. All factors were calculated as outlined bellow:

3.3.1 Precipitation erosivity factor, R

$$R = \sum_{i=1}^{12} 1.735 \times 10^{(1.5 \lg \frac{P_i^2}{P} - 0.8188)} \tag{3}$$

Where P_i (mm)is amount of rainfall of the i month, P(mm) is the amount of rainfall of one year, both the P_i and P is come from 27 local weather stations.

3.3.2 Soil erodibility factor, K

Factor K is calculated by EPIC model[18] described as follows:

$$K = \left[0.2 + 0.3e^{-0.0256SAN(1-SIL/100)}\right] \cdot \left(\frac{SIL}{CLA+SIL}\right)^{0.3} \cdot \left(1 - \frac{0.25C}{C + e^{3.72-2.95C}}\right) \cdot \left(1 - \frac{0.7SN_1}{SN_1 + e^{-5.51+22.9(1-SAN/100)}}\right) \tag{4}$$

Where SAN is sand percent of soil, SIL is little sand percent of soil, CLA is the most little sand percent of soil and C is the organic carbon percent of soil. There are 59 soil types in Zhujiang Delta; the parameters are from Soil Categories in Gugangdong Province [19].

3.3.3 Topographic factor, LS

The topographic factor includes slop length factor (L) and steepness factor (S). L and S were calculated by following equations [20]:

$$L = \left(\frac{x}{22.13}\right)^m \tag{5}$$

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613} \tag{6}$$

Where x is the slope length, m is an index, **s** is steepness.

3.3.4 Crop Management Factor, C

According to the Prediction and Control of Soil Loss edited by US soil reservation group and taking into account character of Zhujiang Delta, we set C as follows:

Table 1 Factor C of different land-use type

Field	Dry Land	Forest	Waste land	Grass land	Urban	Developing Area	Water	Sand Land
0.18	0.31	0.006	0.1	0.12	0.001	1	0.001	1

3.3.5 Erosion control factor, P

The erosion control factor, P, was set as follows:

Table 2 Factor P of different steepness

Steepness (%)	0 ~ 2	3 ~ 8	9 ~ 12	13 ~ 16	17 ~ 20	21 ~ 25	25 ~
P	0.45	0.38	0.45	0.53	0.6	0.67	0.75

3.4 Tupu of land-use changes

We made out the Tupu of land-use changes image from 1998 to 2006 (Fig. 3(E)) referring to the spatial land-use data of the year 1998 and 2006 of the sample araea. The Tupu code were fixed by the following equation: Tupu code='1998'*10 + '2006', where '1998'and '2006' represents codes of land-use types both in 1998 and 2006 which could been seen in the table 3. The Tupu code were described in the table 4, for example, the code '12' represents paddy field in 1998 converted to dry land in 2006 . With ARCGIS9.2, the soil erosion modulus of 2006 subtracted that of 1998 comes to the change value of soil erosion modulus. The affect which the land-use change patterns made on soil erosion could be analyzed by building up masks with land-use change Tupe and counting the change values of land-use changes.

Table 3 Codes of different land use

Land-use types	Paddy Field	Dry Land	Forest	Waste Land	Grass Land	Urban	Development Area	Water	Sand Land
code	1	2	3	4	5	6	7	8	9

Table 4 Tupu codes of land-use changes

code	Tupu types	…	…	code	Tupu types
11	PF—PF	…	…	91	SL—PF
12	PF—DL	…	…	92	SL—DL
13	PF—F	…	…	93	SL—F
14	PF—WL	…	…	94	SL—WL
15	PF—GL	…	…	95	SL—GL
16	PF—U	…	…	96	SL—U
17	PF—DA	…	…	97	SL—DA
18	PF—W	…	…	98	SL—W
19	PF—SL	…	…	99	SL—SL

PF=Paddy Field, DF=Dry Land, F=Forest, WL=Wasteland, GL=Grassland,

U=Urban, DA=Development Area, W=Water, SL=Sand Land

4. RESULTS AND DISCUSSION

4.1 Land-use changes in Zhujiang Delta

Based on the interpretation of the TM image, distinction of land-use pattern and structure is shown in the table 5 and fig 3(A,B) from 1998 to 2006 in Zhujiang Delta. Taking consideration of area changes, paddy field, dry land and forest decreased sharply, the decreased area was 1006 km^2,1403km^2 and 2132k km^2 ; however, undergoing rapid economy development, intense urbanization extension in this area, wasteland, urban and development area increased acutely, the increased area was 1274 km^2 ,1158 km^2 and 1491 km^2. Regarding the speed of land-use changes, developing area increased by 270%, urban increased by 29.42%,wasteland increased by 27.35%, dry land decreased by 30.63%, san land decreased by 41.66%.

From the table 6, we know that the conditions of each type of land-use change over the period from 1998 to 2006. Much paddy field was converted to urban, water, forest, developing area; dry land was converted to paddy field, forest, urban and so on.

Table 5 Land-use changes during 1998 to 2006 in Zhujiang Delta

Land-use Type	1998		2006		1998 ~ 2006	
	Area(km^2)	(%)	Area(km^2)	(%)	Area(km^2)	(%)
Paddy field	9411.48	17.51	8405	15.63	-1006.48	-10.69
Dry land	4583.24	8.53	3179.35	5.91	-1403.89	-30.63
Forest	25221.85	46.92	23089.39	42.94	-2132.46	-8.45
Wasteland	4659.52	8.67	5933.91	11.03	1274.39	27.35
Grassland	1189.58	2.21	1271.06	2.36	81.48	6.85
Urban	3939.35	7.33	5098.32	9.48	1158.97	29.42
Developing area	551.47	1.03	2042.48	3.80	1491.01	270.37
Water	4128.75	7.68	4715.64	8.77	586.89	14.21
Sand land	71.34	0.13	41.62	0.08	-29.72	-41.66

Table 6 Matrix of land-use changes during 1998 to 2006 in Zhujiang Delta

Land-use in 1998	Land-use in 2006								
	Paddy field	Dry land	Forest	Waste land	Grass Land	Urban	Develop-ing area	Water	Sand Land
Paddy field	5441.83	394.51	623.89	459.25	130.63	968.13	475.92	908.79	4.35
Dry land	753.8	1657.89	612.06	366.21	119.57	474.19	271.2	321.67	3.57
Forest	797.58	681.05	20313	2368.63	321.05	190.14	235.21	267.24	19.1
Wasteland	435.75	210.07	951.35	2308.05	107.24	220.91	240.17	178.61	2.24
Grassland	89.57	54.32	237.07	126.83	533.49	41.79	51	51.96	0.94
Urban	385.77	96.1	123.57	147.1	19.23	2753.26	254.47	156.03	0.75
Developing area	41.94	16.7	31.86	24.58	3.59	127.54	250.8	50.31	0.33
Water	439.33	68.12	161.29	129.63	32.12	312.12	256.07	2714.52	2.24
San land	19.76	0.66	1.41	1.09	0.52	6	6.17	26.73	7.76

4.2 Soil erosion in Zhujiang Delta

The mean soil loss in 1998 was 281.21t/a·km^2 and the number was 424.65 t/a·km^2 in 2006, the soil erosion aggravated sharply over the period from 1998 to 2006(Fig 3(C,D)).

We used the land-use layer as mask to calculate the soil loss of each land-use type, the results were presented in the table7. In 1998, the most grievous soil loss were developing area and sand land, which were 4016 and 3300 t/a·km^2, soil loss on dry land was 1015 t/a·km^2, on paddy field and grassland hold closely which were 526 and 522 t/a·km^2, there were little soil loss on the water and urban. In 2006, the tread of soil loss on each land-use type was the same as in 1998, but the soil loss increased by different proportion.

Table 7 soil loss on different land-use types during 1998 to 2006 in Zhujiang Delta

Land-use Type	1998			2006		
	Area (km^2)	Soil erosion ($t/a{\cdot}km^2$)	Erosion amount /t	Area (km^2)	Soil erosion ($t/a{\cdot}km^2$)	Erosion amount /t
Paddy field	9411.48	526.18	4952104.31	8405	575.15	4834093.73
Dry land	4583.24	1015.21	4652951.08	3179.35	1081.12	3437258.87
Forest	25221.85	28.33	714623.29	23089.39	38.59	890968.76
Wasteland	4659.52	377.68	1759821.49	5933.91	516.53	3065012.86
Grassland	1189.58	522.29	621309.31	1271.06	719.29	914260.75
Urban	3939.35	0.63	2464.79	5098.32	2.90	14763.41
Developing area	551.47	4016.84	2215166.75	2042.48	4617.27	9430681.63
Water	4128.75	0.65	2691.04	4715.64	2.68	12623.77
Sand land	71.34	3300.06	235426.28	41.62	5648.34	235083.91
All	53756.58		15156558.35	53776.77		22834747.69

4.3 Analysis of soil erosion based on Tupu theory

We used the two layers of classification in 1998 and 2006 to make the Tupu of land-use change (Fig3 (E)). There were 81 kinds of Tupu according to the classification system which had 9 land-use types. We used the soil erosion layer of 2006 subtract the layer of 1998 to get the change of soil loss, and then calculated the soil loss change on the mask of each Tupu unit (Fig 3(F)).

Table 8 and fig 2 illustrated the distribution of the soil erosion on each type of Tupu of land-use changes, when developing area and sand land were converted form/to any other land-use types, the soil erosion increased or decreased sharply, for example, when paddy field was converted to developing area, the soil loss increased by 3428.69 t/($km^2{\cdot}a$) which could be found out by the code ‘17’ in the table 8, the soil loss of the change type of sand land converted to forest was 4108.63 t/($km^2{\cdot}a$) through finding the code ‘93’.

Table 8 soil loss change based on Tupu of land-use changes

code	area (km^2)	Soil loss t/($km^2{\cdot}a$)	code	area (km^2)	Soil loss t/($km^2{\cdot}a$)	code	area (km^2)	Soil loss t/($km^2{\cdot}a$)
11	5741.83	82.20	41	435.75	318.54	71	41.94	-1803.40
12	394.51	530.44	42	210.07	638.09	72	16.7	-1686.84
13	623.89	-518.74	43	951.35	-284.89	73	31.86	-4860.89
14	459.25	-143.23	44	2308.05	161.34	74	24.58	-3590.66
15	130.63	-65.09	45	107.24	308.27	75	3.59	-2917.57
16	668.13	-492.36	46	220.91	-219.00	76	127.54	-3928.11
17	475.92	3428.69	47	240.17	3956.19	77	250.8	574.49
18	908.79	-544.17	48	178.61	-288.28	78	50.31	-3787.37
19	4.35	3336.07	49	2.24	3285.37	79	0.33	-2642.18
21	753.8	-231.26	51	89.57	253.62	81	439.33	444.26
22	1657.89	45.63	52	54.32	625.60	82	68.12	880.76
23	612.06	-1131.08	53	237.07	-441.38	83	161.29	57.12
24	366.21	-507.48	54	126.83	31.67	84	129.63	406.36
25	119.57	-395.27	55	533.49	173.20	85	32.12	524.06
26	474.19	-914.89	56	41.79	-288.65	86	312.12	65.78
27	271.2	3075.76	57	51	3930.73	87	256.07	3719.48
28	321.67	-1173.74	58	51.96	-414.43	88	2714.52	45.09
29	3.57	2217.21	59	0.94	4927.92	89	2.24	3405.64

31	797.58	586.42	61	85.77	496.73	91	19.76	-2039.59
32	681.05	1095.08	62	96.1	879.67	92	0.66	-1379.38
33	20313	30.38	63	123.57	87.39	93	1.41	-4108.63
34	2368.63	482.96	64	147.1	466.24	94	1.09	-2529.62
35	321.05	691.55	65	19.23	553.42	95	0.52	-3531.86
36	190.14	62.97	66	3053.26	50.20	96	6	-3916.67
37	235.21	4454.08	67	254.47	3914.08	97	6.17	288.13
38	267.24	29.18	68	156.03	102.25	98	26.73	-3603.76
39	19.1	4702.77	69	0.75	4620.82	99	7.76	124.39

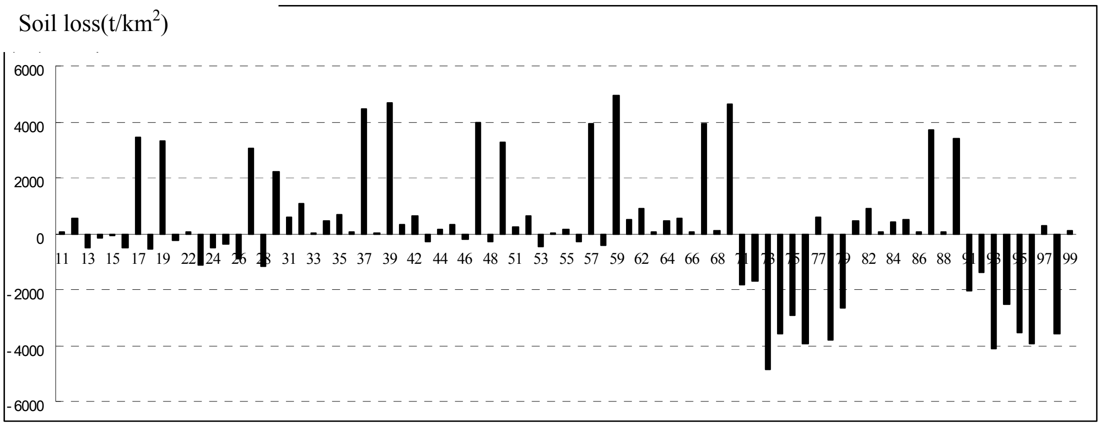

Fig 2 Soil loss change based on Tupu of land-use changes

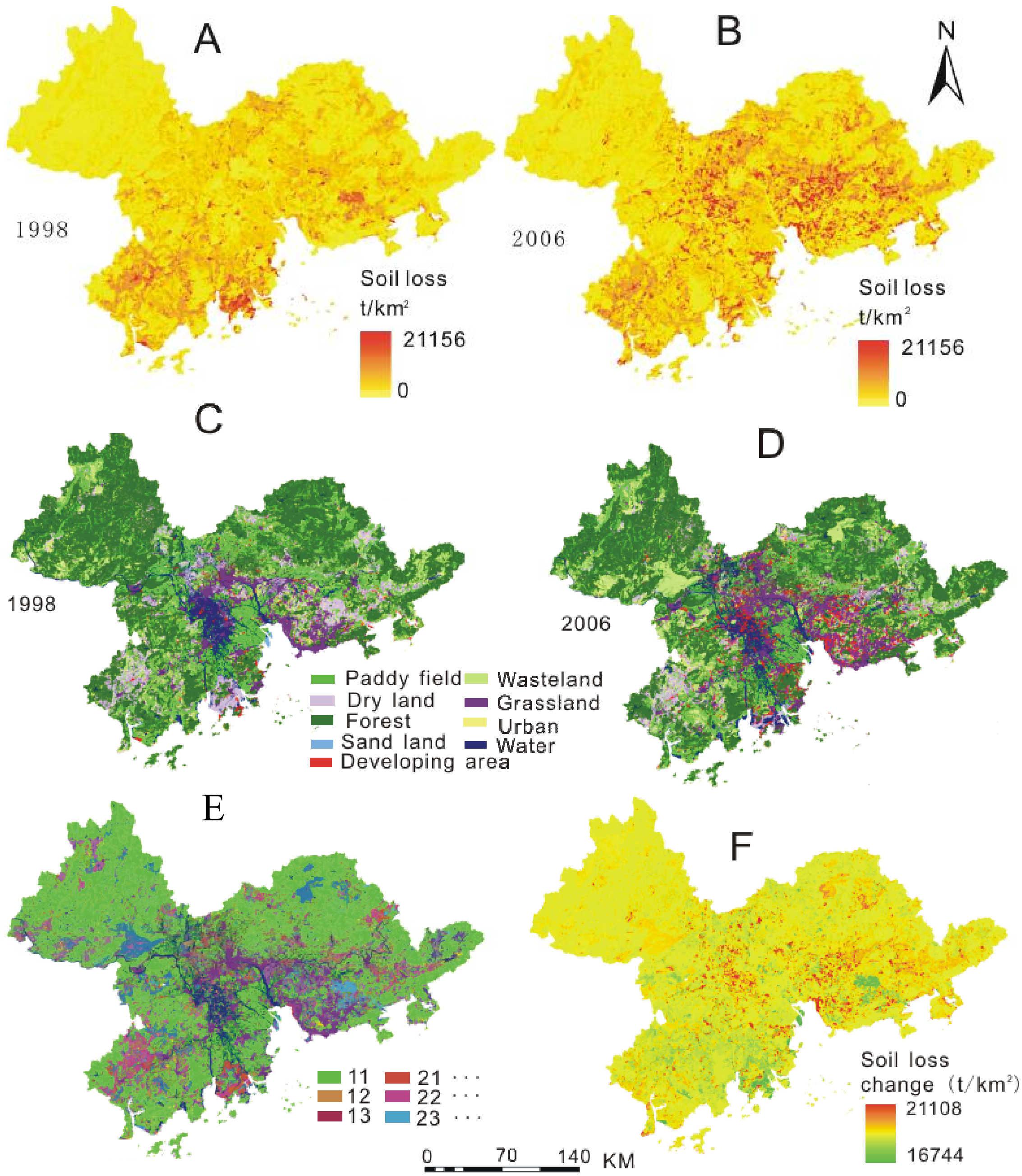

Fig3 A: pattern of land-use in 1998 B: pattern of land-use in 2006

C: Soil loss in 1998 D: Soil loss in 2006

E: Tupu of land-use change from 1998 to 2006. F: change of soil loss based on Tupu

5. CONCLUSIONS

(1) This research is a some precedent which introduced Tupu of land-use changes into study the rule of soil loss changes. This method could depict detailed soil loss changes caused by land-use changes, as well as show the represent the principle of differentiation of soil erosion modulus changes. It will be useful for government or conductor to make soil reservation rules.

(2) Stimulated by rapid economy development, Zhujiang Delta land-use changes sharply. On the whole, the area of forests, grassland, urban, water and developing area enlarged more or less, while the area of water field, dry land, wasteland , sand land decreased sharply. From 1998 to 2006, large area of water field, dry land, forest and water were converted to urban and developing area.

(3) The soil loss aggravated fiercely from 1998 to 2006, the mean soil loss in 2006 was as much as 1.5 times of 1998.

(4) Different types of land-use changes caused different degree of soil loss. Generally, when sand land and developing area were explored to/from other land-use types, the changes of soil loss changed most sharply.

(5) As the test data is very hard to collect, we did not verify the accuracy of soil loss amount, and therefore, the uncertainty is inevitable. But all parameters in the RUSLE model were referenced to authentically mature results from former scholars, the results of soil loss would not warp largely [4].

REFERENCES

1 Wei JB, Xiao DN et al. Relationship between landscape pattern and soil erosion of an agricultural watershed in the Mollisols region of northeastern China. [J] Acta Ecology Sinica , 2006 , 8 (Vol. 26, No.8)

2 Jonathan D P. Predicting minimum achievable soil loss in developing countries. Applied Geography ,1989 , 9(4) :219～236.

3 Zhang KL , Cai YM, Liu B Y. Evaluation of Soil Erodibility on the Loess Plateau. Acta Ecologica Sinica , 2001 , 21 (10) :1687～1695.

4 Yu F, Li XB et al . Land Use Change and Soft Erosion Evaluation in Huangfuchuan Watershed. [J] Acta Ecology Sinica . 2006 , 6 (Vol. 26, No. 6)

5 Fu BJ et al . Effect Simulations of Land Use Change on the Runoff and Erosion for a Gully Catchment of the Loess Plateau, China . [J] Acta Ecologica Sinica , 2002 , 11 (Vol. 57, No. 6)

6 Yan XP et al . Research on the Human Dimensions of Land Use Changes in the Mega-Urban Region: A Case Study of the Pearl River Delta. [J] Acta Geographica Sinica, 2006 , 6

7 Zhang WZ et al . Coupling Relationship Between Land Use Change and Industrialization & Urbanization in the Pearl River Delta. [J] Acta Geographica Sinica, 2003 , 5

8 Zhu LA et al . Initial Probe into the Man-made Soil Erosion & Monitoring Activities in Pearl River Delta. [J] Subtropical Soil And Water Conservation, 2005 , 4

9 Zhao XL , Zhang ZX et al . Method of Monitoring Soil Erosion Dynamic Based on Remote Sensing and GIS. [J] Bulletin of Soil and Water Conservation, 2006, 8

10 Zhao WW, Fu BJ et al . Land Use and Soil Erosion at Multiscale. [J] Progress in Geography, 2006, 1 (Vol. 25, No. 1)

11 Zhao J , Ge CP et al . Spatial and Temporal Variability of Landuse and Soil Erosion at Hailun County. [J] Bulletin of Soil and Water Conservation, 2007, 4 (Vol.25, No.1)

12 Feng HX . Land Use Dynamics of Luquan City Based on 3S Integrative Technologies. [J] Geography and Geo-Information Science, 2007, 4

13 Zhu Y , Li JX et al . Land Use Change in the Eastern Part of Chongming Island in Shanghai in Recent Two Decades. [J] Chinese Journal of Applied Ecology, 2007,9

14 Aksoy. A review of hill slope and watershed scale erosion and sediment transport models. Catena 64, 247-271.

15 Jordan,G. Historical land use changes and their impact on sediment fluxes in the Balaton basin. Agriculture, Ecosystems & Environment 108, 119-133.

16 Comeils, W., Gabriels,D. 25 years of assessment of erosion. Catena 64, 139-141.

17 Schiettecatte, W., et al., Influence of landuse on soil erosion risk in the Cuyaguateje watershed (Cuba), Catena (2008), doi:10.1016/j.catena.2007

18 Sharply A N, Williams J R. EPIC—Erosion/Productivity Impact Caculator:1. Model Documentation. U.S. Department of Agriculture Technical Bulletin, Nc.1768.1990

19 General detailed soil survey office in Guangdong. Eucalypt plantations[M] Science Press-Scientific Publishing Center,Beijing, 1996

20 Smith. Soil erosion[M] Water Conservancy and Electricity Construction Publishing, 1985:43