Assessment of Ecological Risk to Land Use in Liaoning Province Based on Climate Change

SUN Yun-peng[1,2]*

1. College of City and Environment, Liaoning Normal University, Dalian 116029, China; 2. Tangshan Teachers College, Tangshan 063000, China

Abstract Based on the climatic data and other statistics of climatic data of 54 meteorological stations from 1956 to 2005 in Liangning Province, the annual and seasonal light, heat and water and the like major elements of climatic resources are diagnosed and analyzed by using the method of linear climate trend rate. The results show that warming trend is 0.25 ℃/10 a, the precipitation decrease gradually by 2.2 mm/a and the decreasing trend of solar radiation and hours of sunshine is not dramatic. The overall climate change trend is warming and drying, featuring " significantly increased temperature, the decreased precipitation and sunshine" . These features are significant in autumn, thus leading to the trend of moving west and retreating east of the phenology boundaries. The results of scenario analysis on ecological security show that the ecological risk is spreading rapidly from the northwest to the east and to the south and form the southeastern and southern coastal line to the inland; different ecological land-use system have different ecological fragility. Specifically, the bare land and low coverage grassland have highest ecological vulnerability, while the forest and paddy filed have lowest ecological vulnerability. Therefore, suggestions on the ecological land use are put forward in terms of maintaining the overall ecological land use balance, saving water and adapting to climate change.

Key words Global climate change, Land use, Scenario analysis, Ecological security assessment, China

According to the fourth assessment report from 1906 to 2005, issued by the Intergovernmental Panel on Climate Change (IPCC), the global average temperature has increased by 0.74 ℃. In the past 50 years, the average temperature growth in china has increased to 1.1 ℃, the growth speed is faster than global temperature growth and than that of the northern hemisphere at the same period of time. Climate warming will cause increase of extreme weather and climate events, glacial recession, deterioration of the ecological environment and sea level rise. The climate change, which has occurred or will occur in the impending future, will have grave impact on agriculture and food security, water security, energy security, ecological security, and even public health and the like. The increase of temperature has many adverse effects, for example, the frequently happened warm winters make the winter wheat and trees sprout and blossom ahead of usual time, but if frost, late spring or some other climate disasters occur in spring, the crops and plants will be seriously damaged. Global warming will further increase the frequency and intensity of climate disasters such as high temperature, drought, and heavy precipitation (flood). These disasters will increase the volatility of agricultural production. To meet the increase of temperature and the change of precipitation, agricultural layout and structure need adjusting correspondently.

The research on eco-environment quality[1-4] shows that temperature, precipitation, average daily quantity of radiation and some other climate elements are the central factors, which have an impact on the quantity of ecological environment, of which the temperature and precipitation have the gravest impact on ecological environment while the impact of average daily quantity of radiation is relatively small. At present, through researching the features of climate, the climate elements which have impact on ecological security will be summed up. There are many methods and models for assessing ecological security and many scholars both at home and abroad have made the research in terms of theories[1-15] and practice[16-34].

Received: March 24, 2010 Accepted: April 17, 2010

* Corresponding author. E-mail: sunyunpeng007@yahoo.com.cn

1 Overview of the survey region

1.1 Natural conditions Liaoning Province is located in the south of the Northeastern China. It covers from 118°50′E to 125°46′E and from 38°43′N to 43°26′N. Liaoning Province is in the central part of southeastern Asia and the significant junction of Chinese northeastern economic zone and the Bohai economic zone, so its geographical position is superior. The land area of Liaoning Province includes medium-sized mountains, low mountains, hills, terraces, plains, wetlands, beaches and islands. The landscape differentiation of land area of Liaoning Province is evident, from west to east, the western low mountains region, the central plain region and the eastern hilly region are distributed regularly. The areas of the western low mountains region, the central plain region and the eastern hilly region account for one third of the total areas respectively, among them mountains and hills account for 58% and plains account for 33%[35]. Liaoning Province is also noted energy base and agricultural and industrial production base in China, for its rich natural resources, convenient transportation and favorable climate.

The total land area of Liaoning Province is 148 100 km^2, of which the land area is 147 500 km^2, the area of beaches and island is 600 km^2. The soil types are mainly hilly dark brown soil and brown forest soil in the hilly and mountainous region of eastern Liaoning Province and the thickness of soil layer is usu-

ally 0.5 – 1.0 m. In the peninsula hilly region or the northern part of the eastern costal region, the dominant soil type is sandstone soil. In the eastern mountainous region, the valleys are narrow with alluvial soil and hilly sandstone soil. The soil in the southern part of the coastal area is mainly black soil. As for the central part of Liaoning Province, it is in the belt of alluvial soil and brownish yellow soil. Taking the Liao River Plain as the center, the soil is alluvial soil, black soil, brownish yellow soil and coastal saline soil successively ranging from the coastal area of western Liao River to the low valley belt of the right side of Changchun-Dalian Railway. The surface of land in the Liao River Plain is low, smooth and vulnerable to flood. Most part of the plain has been used and the plain is the major grain production region of the Province for its fertile soil. The western part of Liaoning Province stays in the brown forestry soil belt and the yellow and white soil belt of low hills and mountains region. The major soil of it is yellow and white soil of sandy loam soil and sand soil, in the hilly region, the major soil is brown forestry soil. The fine sandy loam is mainly distributed in the northern part of Kangping and Zhangwu; the hilly brown forestry land is mainly distributed in the forests and Yiwulv mountain area of Chaoyang and Jinzhou; black soil is distributed in the rest region. The major vegetation in Liaoning Province is herbaceous plants and shrubs. Besides, the soil in Liaoning experiences intense water erosion and serious soil erosion. The soil structure in the northern part is poor with desert plants, except the water erosion, wind erosion and soil erosion are also very serious in the area. The coastal beaches are important land resources, for there are 53 pieces of coastal beaches with each have more than 600 hm^2 arable lands in the coastal area. In the coastal beaches, 193 300 hm^2 of them have been explored and exploited and there are still 197 300 hm^2 have not been exploited[35-36].

1.2 The status quo of economy and land use By the end of 2007, the total population of Liaoning Province is 42 317 000 and the population density 285.8/km^2, among which the agricultural population is 21 558 000, accounting for 50.9% of the total amount of population. By the end of 2007, the CDP achieved 1 102.35 billion yuan, 14.5% more than last year. The proportion of the primary industry, secondary industry and tertiary industry is 113.34 billion yuan, 585.31 billion yuan and 403.7 billion yuan, which account for 10.3%, 53.1% and 36.6% of GDP respectively. Besides, the per capita GDP is 25 725 yuan and the per capita net income of rural residents is 4 773 yuan[35].

During the process of urbanization, the land use structure has changed with the continuously increased level of economy and urbanization, the land use structure in Liaoning Province has no exception. From 2000 to 2006, the non-agricultural area has increased from 1 558.6 km^2 to 1 859.6 km^2, the growth rate has come to 20%. During the seven years, the total area of the expropriated land reached 279.4 km^2. In 2006, the area of agricultural land use, including farmland, woodland, gardens, pasture and other agricultural land use, achieved 116 000 km^2, among which the major land use is woodland and farmland and their area is 59 800 km^2 and 40 900 km^2 respectively. The construction land, including settlements, mining, transportation, water facilities is 13 800 km^2.

2 Information, evaluation processes and research methods

2.1 Information Information in the paper is collected from the climate materials during the 50 years from 1955 to 2005 of 54 weather stations in Liaoning Province, *Communique of Climate Change in Liaoning Province* and *Communique of Environment of Liaoning Province*. In addition, it includes human activities or natural disasters recorded in the *Comprehensive Report on Remote Sensing of Territorial Resources of Liaoning Province*, *The* 2004 *Quality Report on Environment of Liaoning Province* and Statistical Yearbook of Liaoning Province[35-37].

2.2 Evaluation processes By mirroring the reference of the former experience[32, 35-37], the ecological security assessment procedure of land use is established (Fig.1).

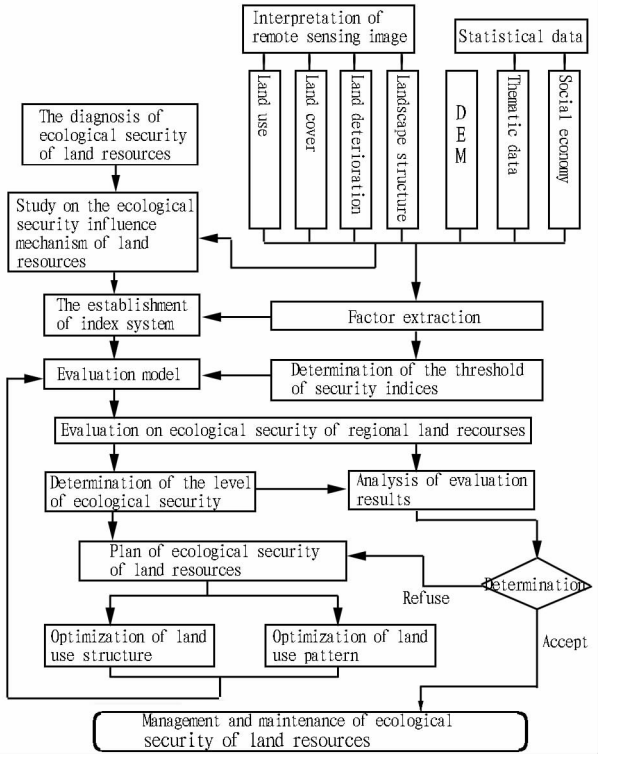

Fig.1 Evaluation process of land ecological security

2.3 Research methods

2.3.1 Method of linear climate trend rate. In the climate analysis, there are *n* elements in n years. In two lines of data, the first line is *y*, it indicates that the variable in the first year is y_1, in the second year is y_2, and then to the nth year is y_n. The second line is integer *x*, *x* means 1, 2, 3, …, *n*. The linear equations used for calculating the two lines is $y = ax + t$. The regression coefficient *a* shows the trend of climate change of climate variable *y*. If *a* is greater than 0, it shows that the *y* is increasing over time, or vice verse. By applying the method of linear climate trend rate, that is to say by building linear equa-

tion, the climate resources elements, which cover annual and seasonal light, heat and water, are analyzed and diagnosed.

2.3.2 Scenario analysis. The scenario analysis[32] is an important method used for futurology research, it can deal with the uncertainty of environmental influence effectively. The method should indentify the drivers of the future development in the initial stage. And then based on the assumptions of future events, the causality between each elements and the developmental process in the future will be analyzed. After the analysis, various kinds of situations in the future will be predicted by close reasoning.

2.3.3 Methods of evaluating ecological security. The steps of evaluating ecological security are as follows:

(1) Index selection. Based on the exiting research results[7-9, 14-16], 16 meaningful indices of ecological security are selected from the three aspects concerning resource and environment pressure, resource and environment status, human environment. The resource and environment pressure covers density of population x_1, the natural population growth rate x_2, housing space per capita x_3, arable land per capita x_4, water consumption per capita x_5, index of land degradation x_6 and disaster index x_7; the resource and environment status includes the green coverage in built-up area x_8, the treatment rate of "three wastes" x_9, comprehensive index of air quality x_{10}, humid index x_{11}, vegetation cover index x_{12}, water density index x_{13}; the human environment covers population quality index x_{14}, the proportion of investment in environmental protection in GDP x_{15}, the proportion of science and technology investment x_{16}.

(2) Data standardization. Before conducting calculation and evaluation on data, the impact of different dimension and parameters of different orders on the evaluation results needs ruling out. Therefore, the standardization of index data is needed[15-16]. The standardization applies the standardized approach, the formulas are as follows:

$$x'_{ij} = \frac{x_{ij} - x_{j(\min)}}{x_{j(\max)} - x_{j(\min)}} \quad (1)$$

$$x'_{ij} = \frac{x_{ij(\max)} - x_{ij}}{x_{j(\max)} - x_{j(\min)}} \quad (2)$$

In the formula, $i = 1, 2, \cdots\cdots, n$; $j = 1, 2, \cdots\cdots, m$; x_{ij} is the original data of the jth index of the ith city; $x_{j(\max)}$, $x_{j(\min)}$ indicate the maximum and minimum of the jth index of all the cities respectively; n show the number of cities; m is the number of indices. The formula (1) shows positive indices; formula (2) shows negative indices.

(3) The calculation of ecological security. The calculation formula is:

$$S_{es} = \sum_{i=1}^{n} x'_{ij} \times w_i \quad (3)$$

In the formula, S_{es} is the comprehensive security value of the evaluation area; x'_{ij} is the security index of each index; w_i is the weight of each index; n is the total entries of index; $i = 1, 2, 3, \cdots, n$.

(4) The determination of safe threshold value. $S_{es} < 0.1$ shows grave warning; 0.1 – 0.3 indicates medium warning; 0.3 – 0.5 indicates early warning; 0.5 – 0.7 means relatively safe; $S_{es} > 0.7$ indicates ecological security.

3 Results and analysis

3.1 The evaluation result of the method of linear climate trend The diagnosis result of annual and seasonal climate in Liaoning Province is: the climate warming trend (Fig. 2a) is 0.25 ℃/10a. It can be seen from the time series of precipitation during the 50 years, the precipitation in the 50 year is "stable and declining", the decrease rate is 2.2 mm/a. Among the 50 years the precipitation in spring increases slightly, and that in summer, autumn and winter decrease to some degree (Fig. 2a), but the growth trend is not so obvious, but the seasonal trend is significant. The solar radiation and the hour of sunshine show the trend of decrease (Fig. 2d). The overall agricultural climate change in Liaoning is "the temperature has increased greatly; the precipitation and hours of sunshine have declined". This kind of trend is significant in autumn. The time series shows that the growth rate of temperature in spring is large and the growth of accumulated temperature in growing season is significant, but the performance in each region is different (Fig. 2c). Through the analysis of climate[32, 35-38] in the growing season (from April to September) of the 50 years of Liaoning Province, the hours of sunshine and the percentage of sunshine show the significant trend of decline. The hours of sunshine decrease 30 hours every 10 years and the percentage of sunshine decreases 1.2% every 10 years. The decline of sunshine is harmful to the photosynthesis. The data of surpassing the limitation of accumulative temperature of 10 ℃ in Liaoning Province has advanced obviously, for example, most areas have 6 days in advance in the 50 years. In the recent 10 years, the limitation 3 350 ℃ accumulative temperature (above the limitation temperarure of 10 ℃) has the obvious trend of expansion, the trend of northward and westward in particular. Thus, boundary of the crops increasingly extending northward in Liaoning Province.

3.2 The evaluation result of ecological security and the prediction of scenario analysis Due to the long-term characteristic of climate change and many other uncertain factors, research of the climate change impact is characterized by formulating climate change scenario, which can signify the climate change condition, in the future[32,34]. I assume the climate change scenario in the future and analyze the changes of future climate so as to investigate the sensitive response of climate change affected by ecological security.

Under the stable situation of the exsisting ecological security of land use, the distribution of ecojlogical security of Liaoning Province will change in 2015 (Fig. 3 – 4). The scenario analysis is carried out through the following steps. In the first step, conducting trend analysis in ArcGis9.3 software, then overlapping the weight of climate influence F_c, and at last outputting the thematic map (Fig. 5). In Fig. 5, the linear equations of the three essential indices of climate are: temperature: $y = 0.245\,7x + 8.54$, precipitation: $y = -22.369x + 757.14$, hours of sunshine $y = -0.785\,7x + 58.267$ and S_e is the value of ecological security. However, the three elements of F_c all accelerate the decrease of ecological security coefficient and the performances of F_c space is different, which lead to the significant expansion of limit

of penology, especially the trend of northward and westward and the ecological security also have relative change.

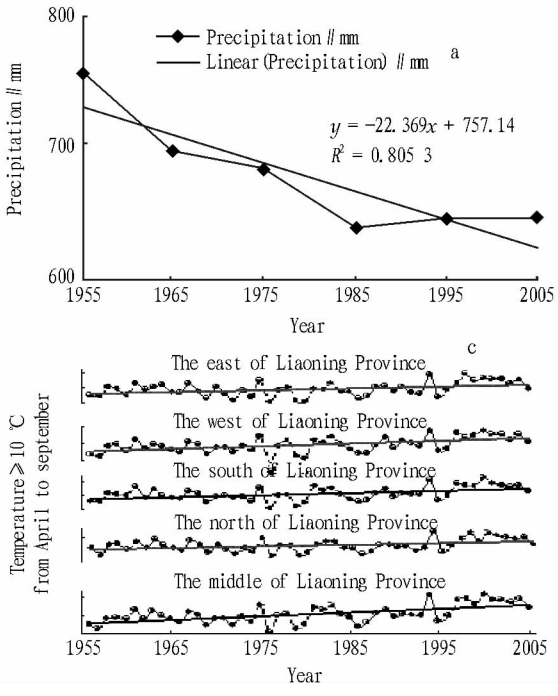

Fig. 2 Climate trend of Liaoning Province from 1956 to 2005

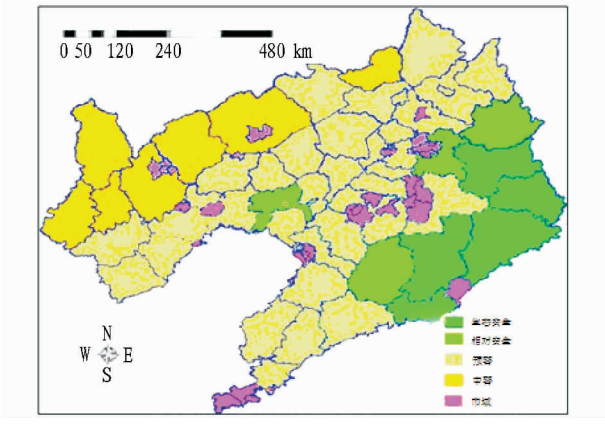

Fig. 3 Ecological security evaluation of 2005

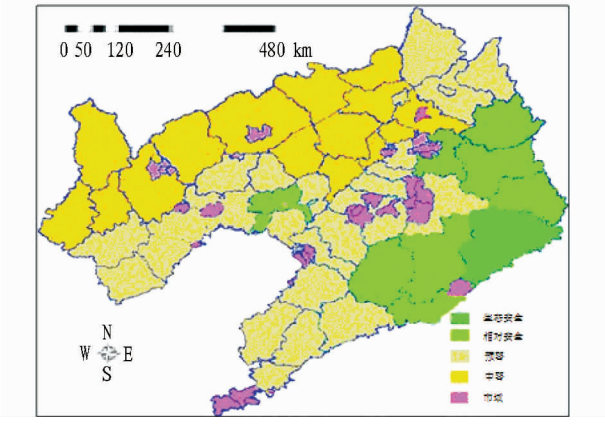

Fig. 4 Ecological security evaluation of 2015

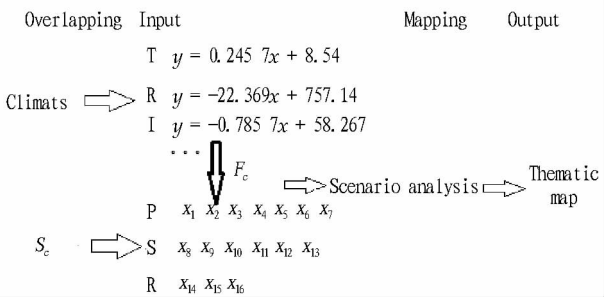

Fig. 5 Scenario analysis process of ecological security

4 Conclusions and suggestions

4.1 Conclusions

(1) The overall trend of climate change in Liaoning Province is " the obvious increase of temperature, the decrease of precipitation and hours of sunshine" and the trend of northward and westward is significant, the result leads to the increasingly northward of crops in Liaoning Province. Under such circumstances, the ecological risks have the trend of spreading from the northwest to the east and to the south.

(2) Under the circumstance of global warming, the climate abnormity and the frequency of extreme climate have became the main factors of aggravating the regional vulnerability. Affected by the climate warming, the climate disasters of sea have been aggravated, for example, sea level rise, storm surge, sea water intrusion, wind changes and the like, which result in the expansion of ecological risks from southeast and south sea to the inland.

(3) The vulnerability of ecological security are different in various kinds of land use as well as the ecological capacities, which have something to do the internal structure of ecological

system. The bare land and low coverage grassland have the highest rate of vulnerability, while the forest and paddy filed have the lowest rate of ecological vulnerability.

4.2 Suggestions of ecological land plan (1) In the overall balance of ecological land use in Liaoning Province, the number of conservation area can be limited, but the existing ecological conservation area must be strictly preserved. The buffer area, 5 km around the conservation area should be protected as well and the area of ecological land should be remained at 30 340 km^2 (according to the National Construction Plan of Ecological Security). Ecological land in the new construction land should be planned rationally and it can be measured according to the proportion that the ecological land is no less than 19% of the occupied land.

(2) In terms of the decease of precipitation, 3 km around the 171 drinking water sources (excluding other water sources and reservoirs with the functions of water supply) should be strictly preserved. The government should develop the water-saving agriculture; strengthen the management and adjustment; save water; explore and exploit the rainfall and desalinated sea water. Besides, the ecological corridor should be built 2 km around the edge of ecological vulnerability area and the city plan area.

(3) In terms of adapting to the climate change, the unified strategies on alleviating and defending serious meteorological disasters should be formulated[32-33, 38]. The government should enhance the construction of infrastructure, improve the comprehensive response capacity and mobilize various kinds of forces in order to alleviate the losses caused by climate change and meteorological disasters scientifically, effectively, forcefully and orderly. In relation to agricultural production, the government should try to change and improve crop varieties and adjust agricultural structure and layout. In order to cope with the impact on human health caused by climate change, the public infrastructure should be improved and the warning system of possible diseases aroused by climate change should be set up. In connection with the challenges caused by sea level rise, the monitoring system of sea level rise and the construction of dike should be strengthened.

References

[1] OLE NIELSEN N. Management for agroecosystem health: the new paradigm for agriculture[R]. Proceedings of the Annual Meeting of the Canadian Society of Animal Science, Vancouver, British Columbia, Canada, 1998: 5-8.

[2] CHEN X, ZHOU CH. Review of the studies on ecological security [J]. Progress in Geography, 2005, 24(6):8-20. (in Chinese).

[3] SMIT B, WALTNER TOEWS D, RAPPORT D, *et al*. Agroecosystem health:analysis and assessment[R]. Guelph, Ontario, Canada: University of Guelph, 1998: 1-14.

[4] RAPPORT DJ, BOHM G, BUCKINGHAM D, *et al*. Ecosystem health:the concept, the ISEH, and the important tasks ahead[J]. Ecosys Health, 1999, 5:82-90.

[5] WANG XY, SHEN ZR. Progress of assessment methods of agroecosystem health[J]. Journal of China Agricultural University, 2001, 6(1):84-90. (in Chinese).

[6] FU BJ. Characteristics of land ecosystems and main aspects of their research[J]. Chinese Journal of Ecology, 1985, 4(1):35-38. (in Chinese).

[7] ZHANG JX, XING XD, LIU XE. Evaluation on ecological security of sustainable utilizaton of land resource[J]. Hunan Geology, 2002, 21(2):119-121. (in Chinese).

[8] YANG JP, LU JB. The systems analysis of ecological security[M]. Beijing: Chemical Industry Press, 2002. (in Chinese).

[9] QU GP. The problems of ecological environmental have become a popular subject of country safety[J]. Environmental Protection, 2002(5):3-5. (in Chinese).

[10] YANG JP. Ecosystem management and technology[M]. Beijing: Chemical Industry Press, 2004. (in Chinese).

[11] CAO XX, GUO ZR. Study on ecological security of regionally sustainability utilization of land resources[J]. Journal of Soil and Water Conservation, 2004, 18(2):192-195. (in Chinese).

[12] HERRMANN S, OSINSKI E. Planning sustainable land use in rural areas at different spatial using GIS and modeling tools[J]. Landscape and Urban Planning, 1999, 46:93-101.

[13] OJIMA D, LAVOREL S, GRAUMICH L, *et al*. Terrestrial human-environment systems: the future of land research in IGBP[J]. Global Change Newsletter Issue, 2002, 50:31-34.

[14] MORAN EF. News on the land project for the new combined IGBP and IHDP activities[J]. Global Change Newsletter Issue, 2003, 54: 18-20.

[15] ZANG SY, NI HW, LI YH. Response of land utilization in resource-rich cities to wetland ecology safety:a case study of Daqing in Heilongjiang Province[J]. Progress in Geography, 2004, 23(5):33-42. (in Chinese).

[16] YANG FT, LIU JY, ZHUANG DF, *et al*. The preliminarily study on the ecological environment effects of land-use change in red earth hilly area in Southeast China[J]. Progress in Geography, 2004, 23(5):43-55. (in Chinese).

[17] TRIMBLE SW, CROSSON PUS. Soil erosion rates——myth and reality[J]. Science, 2000, 289:248-250.

[18] SOLOMON D, LEHMANN J, ZECH W. Land use effects on soil organic matter properties of chromic luvisols in semi-arid northern Tanzania:carbon, nitrogen, ligning and carbohydrates[J]. Agriculture, Ecosystems and Environment, 2000, 78:203-213.

[19] RUSMUSSEN PE, GOULDING KW, BROWN JR, *et al*. Long-term agroecosystem experiments: assessing agricultural sustainability and global change[J]. Science, 1998, 282:893-896.

[20] RICHEY JE, NOBRE C, DESER C. Amazon River discharge and climate variability:1903-1985[J]. Science, 1989, 246:101-103.

[21] MURRAY KS, ROGERS DT. Groundwater vulnerability, brownfield redevelopment and land use planning[J]. Journal of Environmental Planning & Management, 1999, 42(6):801-806.

[22] WANG GX, CHENG GD, QIAN J. Several problems in ecological security assessment research[J]. Chinese Journal of Applied Ecology, 2003, 14(9):1551-1556. (in Chinese).

[23] ZHAO WW, FU BJ, CHEN LD, *et al*. Effects of land-use pattern change on soil and water loss at the catchment scale in the hilly and gully area of the loess plateau of China[J]. Acta Ecologica Sinica, 2004, 24(7):1358-1364. (in Chinese).

[24] SHI PJ. Strengthening the study of land use/cover change and its impact on eco-environmental security——the trend of the study of the dynamics of human-nature system based on "Global Change Open Science Conference 2001" in Amsterdam, Netherlands[J]. Advance in Earth Sciences, 2002, 17(2):161-168. (in Chinese).

[25] FAO. FESLM:an international framework for evaluating sustainable land management[R]. FAO, Rome, Italy: World Soil Resources Report, 1993.

[26] World Bank, Land Quality Indicators. World bank discussion papers 315[R]. Washington DC:The World Bank, 1995.

[27] SEPPELT R, VOINOV A. Optimization methodology for land use patterns using spatially explicit landscape models[J]. Ecological Modelling, 2002, 151:125-142.

(To page 56)

ing and leisure, cultural transmission and so on. For another thing, the development of tourism in the Three Reservoir area can drive the construction of social culture and ecology, explore and exploit the profound culture connotation of the Three Reservoir area and strengthen the culture highlight of ecological environment and ecological decoration of cultural landscape.

3.2 Strengthening infrastructure construction and improving investment environment Infrastructure is an essential external condition as well as an important prerequisite for investment and industrial development. During the process of speeding up the assumption of infrastructure, the new infrastructure system, which includes the construction of road, waterways and airlines, should be built in order to improve the transportation conditions of waterways and ports in Yangtze River area. The road and railways with high standard, high density and high grade will be built as well. Moreover, new communication facilities should be available so as to realizing industrial information. At the same time, the facilities of post service, power supply, water supply and the like should be refined in order to create good living conditions. Besides, more efforts should be made to create favorable investment environment. The government should make full use of the existing human resources, introduce competent people, improve political environment, reduce the admittance limitation, provide favorable policies, attract foreign investment and solve the problems of inadequate self-accumulation and some other limitations.

3.3 Optimizing human resources and providing intellectual support for industrial development in the reservoir area The Three Gorges Reservoir area is rich in natural resources, but its human resources are in the position of weakness. The comparative disadvantages make the advantageous resources in the reservoir area hard to effectively integrated and transformed to industrial advantages. Based on this, the government should pay attention to the education of ordinary personnel and cultivating of senior talents with creativity. Besides, the government should enhance the culture quality of workers and introduce talents by the way of multi-channel, multi-level and wide-ranging. The key personnel and urgently needed personnel for the industrial development should be introduced and the diversified mechanisms of personnel training and introducing should be launched.

References

[1] MAO HY, GAO Q, FENG RG. The selection of pillar industries under the ecologically and environmentally friendly principles in Three Gorges Area [J]. Acta Geographica Sinica, 2002, 57(5):553 –560. (in Chinese).

[2] LI ZH. Strategic way of developing high efficiency agriculture in Three Gorge area[J]. Forward Position in Economics, 2005(6): 23 –27. (in Chinese).

[3] DONG GC, LUO YX, CHEN YP. On the hollow of industries in Three Gorges reservoir area[J]. Modern Economics, 2008(7): 48. (in Chinese).

[4] CHEN SY. Opening strategy of Three Gorges reservoir area[M]. Beijing:The Geological Publishing House, 2008: 28 –29. (in Chinese).

[5] ZHONG HL, GAO R, YANG X. Climate characteristics in Three Gorges reservoir area after water storage and its impact on the production potential[J]. Journal of Anhui Agricultural Sciences, 2010, 38 (12): 291 –293. (in Chinese).

[6] WANG SB. Research on the industry development and anaphase support of the resettles in the Three-gorges reservoir area[J]. Journal of Chongqing University: Social Science Edition, 2006, 12(3):5 –17. (in Chinese).

[7] ZHONG HL, GAO R, ZHANG Q. Evaluation of the climate production potential of agriculture in Three Gorges reservoir area[J]. Journal of Anhui Agricultural Sciences, 2009, 37(6): 492 –496. (in Chinese).

[8] ZHOU YJ. Research on industry development of reservoir region of the Three Gorges subject to environment protection[J]. Journal of Chongqing University: Social Science Edition, 2007, 13(4):111 –15. (in Chinese).

[9] ZHANG YL, LI XY, ZHANG WB, *et al*. Water quality research of Zhongxian in the Three Gorges reservoir before and after impoundment[J]. Journal of Anhui Agricultural Sciences, 2009, 37(12): 316 –317, 320. (in Chinese).

(From page 51)

[28] CAI YL, LI J. Measurement of land use sustainability: a comprehensive method representing processes [J]. Acta Geographica Sinica, 2003, 58(2):305 –313. (in Chinese).

[29] CHEN BM. Design and evaluation of indicator system of regional land for sustainable use[J]. Progress in Geography, 2002, 21(3): 204 –215. (in Chinese).

[30] MAKOWSKI D, ELIGIUS MT, HENDRIX C, *et al*. A framework to study nearly optimal solutions of linear programming models developed for agricultural land use exploration[J]. Ecological Modelling, 2000, 131:65 –77.

[31] ZHENG XF, ZHANG ZQ, HU YM. Coordinated development study on the about land utilization and ecological environment in Liaoning Province[J]. Research of Soil and Water Conservation, 2008(4): 212 –215, 219. (in Chinese).

[32] SUN XM, ZHAO XY. Assessment of ecological risk to climate change of the farming-pastoral zigzag zone in Northern China[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2009(1):83 –90. (in Chinese).

[33] GU XW, WANG Q, LIU JX, *et al*. Ecological footprint in sustainable use of resources in Liaoning Province [J]. Resources Science, 2005 (4):118 –124. (in Chinese).

[34] LI JG, HE CY, LI XB. Landscape ecological risk assessment of natural/semi-natural landscapes in fast urbanization regions——a case study in Beijing, China [J]. Journal of Natural Resources, 2008, 23(1):33 –48. (in Chinese).

[35] ZHANG HB, LIU LM. Main progress and prospects of land resource ecological security research [J]. Progress in Geography, 2006, (5):77 –85. (in Chinese).

[36] Liaoning Provincial Planning Commission, Institute of Applied Ecology, Chinese Academy of Sciences. Comprehensive report on remote sensing of territorial resources of Liaoning Province [R]. 2001. (in Chinese).

[37] Statistics Bureau of Liaoning Province. Statistical yearbook of Liaoning Province[M]. Beijing: China Statistics Press, 2008. (in Chinese).

[38] Department of Environmental Protection of Liaoning Province. The 2004 quality report on environment of Liaoning Province[R]. 2005. (in Chinese).