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Present land use and cover patterns and their development potential in North Ningxia

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With the objectives to acquire the fundamental data of the territorial resource, understand the impacts of human activities on the land use and cover patterns and evaluate the potential of the future exploitation, an intensive land cover classification with an accuracy of 93% has been completed for North Ningxia by remote sensing technique based on the adoption of a combination method composed of texture training, maximum likelihood classification and post-processing such as re-allocation and aggregation. This classification result was incorporated with the contemporaneous socio-economic and meteorological data for cross-sectional regression modelling to reveal the spatial determinants of the land cover patterns and understand the human-environmental relationships. A tentative evaluation on the potential of soil exploitation in the near future was carried out in combination with our land use and cover change detection results aiming at supplying some useful references for the central and local governments in their sustainable land use planning.

Present land use and cover patterns and their development potential in North Ningxia WU Weicheng1, ZHANG Wenfeng2 (1. Dept. of Geography, University of Louvain, Place L. Pasteur, 3B1348 Louvain-la-Neuve, Belgium; 2. Remote Sensing Center of Ningxia, Yinchuan 750021, China) Abstract: Key words: CLC number: 1 Introduction North Ningxia, administratively including seven counties and cities and surrounded by Inner Mongolia, geographically composed of 50% of the Helan Mountains and 80% of the Yinchuan Plain and adjacent areas with the Mu Us Sandy Land on the east, Ulan Buh Desert to the north and Tengger Desert to the west, is an arid and semi-arid region in Northwest China. The annual precipitation ranges from 78 to 295 mm (the maximum, 430 mm, appears in the Helan Mts.), annual evaporation from 1,473 to 2,318 mm and average temperature from 8.2oC to 9.6oC in recent decades (Ningxia Statistical Yearbook, 1988, 1990, 1992, 1997 and 2000). The analysis on the meteorological data in the past half century indicates that the annual temperature has been increasing and precipitation decreasing in Yinchuan region. It is probably a local indication of the global warming (Wu et al., 2002). The natural conditions have been getting more and more difficult. According to the Economic Atlas of Ningxia (1990, 1997) and Geng et al. (1992), land use has a long history in the Yinchuan Plain. Since the Qin Dynasty (221-207 BC), the first irrigation canal came into existence; in the successive Han (206 BC-220 AD) and Tang (618-907 AD) dynasties, the agricultural irrigation and drainage system was further developed and improved. But due to the frequent wars and several large scale emigrations in the history, land use did not have a stable development until recent decades. With the execution of the reform and opening up policy at the beginning of the 1980s in China, land use and cover changes have taken place rapidly owing to the agricultural, industrial developments and population growth in the study area. Recently, some important development policies of the Chinese government have been focused on Northwest China. Yinchuan region has become one of the ´hotspots´. It is therefore necessary to carry out an intensive territorial resource investigation, a synthetic human-environmental linkage analysis and a development potential evaluation aiming at producing the fundamental data and useful references for the local governments in their sustainable land use planning and decision making. This is the objective of our research and also one of the tasks scheduled in the Sino-Belgian co-operation project on Northwest China. 2 Methodology Investigation of present territorial resources is usually carried out by a land cover classification on the remote sensing images. This is one of the widest and most traditional applications of the remote sensing techniques. This procedure is, however, often confronted with some difficulty, especially, when applied to the component complex and land cover type continual areas. The ap proaches still remain to be improved both in algorithms and separability of clusters. In fact, hundreds of researchers have been engaged in this kind of practice and made efforts to ameliorate the classification result by using various methods and algorithms in their land cover information extraction, mapping and change detection (Haralick et al., 1973; Weismiller et al., 1977; Gordon, 1980; Toll, 1984; Thomas et al., 1987; Franklin et al., 1990; Gong et al., 1992, 1996; Atkinson et al., 1997; Chen et al., 1999, etc.). The conventional classification on the remotely sensed data has adopted pattern recognition techniques including both supervised and unsupervised approaches, assuming that the study area is composed of a number of unique internally homogenous classes that are mutually exclusive (Townshend, 1984). However, such assumption is not applicable to the areas where the land cover types exist as continua rather than as a mosaic of discrete classes. As a result, the classes intergrade and cannot be separated by sharp boundaries (Kent et al., 1997). Our study area, North Ningxia, is such a site, which is complex in geomorphology and various and continual in land cover types. For example, the coal residue, marsh and some wetland could never be automatically discriminated. In view of the reasons mentioned above, some pre-and-post-classification processing was added to the traditional method to increase the separability and reasonability of classes in our practice. Hence, texture features (Haralick et al., 1973; Franklin et al., 1990; Gong et al. 1992; Sali et al., 1992) were firstly identified and incorporated in pre-classification training area selection since they are fundamental characteristics of image data and often crucial to target discrimination (Woodcook et al., 1987). Its features of different classes are produced by the inhomogeneity of the land cover elements (Shaban et al., 2001). In our study area, bare rock, pluvial fans, fishing ponds, rice field, sandy grassland etc., are of their own particular spectral and textural features. These characteristics were combined into the training areas as clustering criteria. Post-classification processing was followed to the maximum likelihood clustering for re-allocating the spectrally mis-classified and spatially mis-distributing classes by a reference of spatial land cover zoning. An aggregation was then carried on for merging the similar or proximate classes. This processing yields a spatially and categorically reasonable classification result with a high accuracy. Besides the present land cover pattern data, two other kinds of knowledge are necessary to evaluate their future situation and development potential. One is the land cover change rate in the past, which has fortunately been measured in our change detection (Wu et al., 2002). The other is the understanding about the impacts of human activities on the environment. It is common knowledge that land use and cover patterns cannot take place independently but are more or less influenced and reformed by human activities. Understanding the dynamics of land use and cover has increasingly been recognised as one of the key research imperatives in global environmental research (Lambin et al., 1999; Geist et al., 2001). To reveal such relationships is thus of importance to the local environment planning. Numerous authors have focused their researches on the land cover change driving forces or proximate causes by multivariate statistical analysis using linear and/or logistic regression models (Lambin, 1994, 1997, 2000; Mertens et al., 1997; Serneels et al., 2001; Wu et al., 2001, 2002). Lambin suggested (1994) that such model could also be applied to understand and establish the linkages between land cover patterns and human activities by cross-sectional analysis. The latter was followed in this research in revealing the human-environmental relationship. 3 Classification and accuracy assessment 3.1 Pre-classification processing 3.1.1 Rectification The remotely sensed data, Landsat ETM dated August 15, 1999, were rectified by the topographic maps on a scale of 1/200,000 to 1/300,000 in the datum WGS84 and projection UTM (48) with 92 GCP (including 28 field GPS). The RMS error was controlled at 0.65 pixel (a pixel covers 30×30 m2). 3.1.2 Selection of texture training areas All training areas were carefully selected upon the following points: Data in-situ A field survey was carried out in the research area in August 2000. Most cover types were observed and photos with GPS were taken. The field data, as interpretation key, were as many as possible used in selecting training areas, which ensure a high reliability of the classification results. Texture features It is well distinguished that most of the land cover types in the site have their own texture features. Pluvial fans, composed of the pluvial sediments from the Helan Mountains when flooding, have clearly light drainage lines in a form of a ´fan´, open to southeast and east. These fans constitute a southwest-northeast continuous dark pink belt between the Helan Mountains and Yinchuan Plain in the ETM 741 composite. Fish farming ponds are shown in grids. Bare rock, natural forest, rice field, sandy grassland, etc., all own their typical textures in the composite image caused by different mineral compositions, altitudes and plant species. More than one training area per class was therefore defined for covering those textures and features. Classification system For the sake of applying the research results in local environment planning, one present land cover classification system from China (EFS Expert Group, 2000) was introduced to this Sino-Belgian co-operation project. This system was particularly designed for land cover investigation by remote sensing data on a scale range of 1/500,000 to 1/1,000,000. Although being not officially proved yet by the Chinese professional department, it has been widely used in the China national research programs on the ecological environment investigation. 3.2 Class ification and reclassification After the selection of the texture-based training areas, a maximum likelihood classification was launched upon. Each cluster was coloured as natural one on the first classification image and its distribution was checked upon the firsthand and other data. Single clusters were kept and some training areas added to the confused ones. Then a new classification was commenced once again. This ´check and reclassification´ process was repeated tens of times for pursuing the best result. 3.3 Post-classification processing and final results 3.3.1 Filtering When the ´best´ result reached us, a filtering in mode 3×3 was applied to the classified image to attribute the separate or solitary pixels into their surrounding classes. This processing was aimed to exclude the small clusters that were considered as ´noise´ and increase the clarity of the map. We used 3×3 filter rather than other filtering dimension based on the fact that the minimum length and area (e.g., 100 m and 10,000 m2) could be shown in the map on a scale of 1/100,000 derived from the TM data with a spatial resolution of 30 m. 3.3.2 Re-allocation, aggregation and final classification results After the filtering, it was found that a spatial mis-distribution of some clusters still existed in the ´best´ classification map. Then a re-allocation of these mis-distributing clusters was followed among different zones according to their occurrence reasonability in space. For example, some parts of the ´lake´ and ´fish farming pond´ clusters falling in the mountains should be excluded and re-allocated to the ´bare rock´ cluster. A large part of the ´urban´ class occurring in the mountains and pluvial fans should also be cut off and returned to their possible clusters such as ´bare rock´ and ´pluvial fan´, etc. Thus spectrally similar and intergraded classes were separated according to their spatial distribution possibility. There are at least four different soil belts recognised in the study area: Zone 1: bare rock in the mountains; Zone 2: pluvial fan between the mountains and Yinchuan Plain; Zone 3: Yinchuan Plain; and Zone 4: sandy pastoral land in the west Mu Us Sandy Land. Thus the re-allocation was a time-consuming job in this classification practice which needs a delicate comparison between the confused classes and ETM composite among the four zones according to their spectral and visual attributes. An aggregation was followed by incorporating the classes with similar characters after the re-allocation, e.g., three classes previously named ´waterlogged depression´, ´lake´ and ´fish farming pond´ were combined into one class ´lake & pond´ ´desert´ and ´sand dune´ were put together in one cluster ´desert´ ´wet land´ and ´marsh´ into ´marsh´. This merging produced a final 19-cluster land use and cover map from the previous 31-group classification result. In this way, a complete classification with 19 classes was achieved (Figure 1). In order to facilitate the class description and statistical analysis, these 19 classes were further simplified in light with their similarity. For example, ´desert´, ´gobi´, ´pluvial fan´, ´bare rock´ and ´sand land´ were merged into one new group ´bare & sandland´ ´rice field´ and ´irrigated land´ into ´farmland´, etc. In this way, 12 land cover types were derived (Table 1). 3.4 Accuracy assessment The average accuracy of the ´best´ supervised classification results is 87.00% and the overall accuracy is 84.41%. As mentioned before, this so-called ´best´ result demonstrates its principal correctness and includes still much class confusion, intergrading and mis-distribution. Such a result could not meet the requirements of the fundamental territorial investigation for the critical areas where the land cover map would be shown on medium to large scale (1/100,000 to 1/200,000). That is why we need a further post-processing (e.g., re-allocation) for improving the classification result. However, the accuracy of the post-processed classes cannot be given by the program PCI we used in this practice. The assessment has to be done manually. To complete this task, three lines cutting through the whole classified area were drawn on the final classification map and a random verification upon each line between the classified cover type and ETM 741 composite carried out (Figure 1). Line 1: NW-SE, 127.53 km, 102 points verified, 7 points in error; Line 2: NW-SE, 126.31 km, 84 points checked, 7 points in error; and Line 3: NE-SW, 175.66 km, 133 points confirmed, 10 points in error. The accuracy of the classification was evaluated by the following formula (1): $A = [1- [\Sigma(\Sigma Ei / \Sigma Pi)\ Li / \Sigma Li]] \times 100\%$ (1) where A represents the accuracy, Ei error points counted in the random check on the line i, Pi total points checked on the line i and Li length of the line i. A = 93.02%. After re-allocation and aggregation, the accuracy of the classification has been largely increased from 84.41% to 93%. The final classification map represents better the reality of the present land use and cover patterns. With the increase of the check lines and points, more exact accuracy could be reached. 4 Cross-sectional analysis This is a multivariate statistical analysis revealing transversally the relationship between the dependent and independent variables at one point in time and across a large number of localities (Lambin, 1994). This can be conducted by multivariate regression modelling using a mathematical expression as follows (Kleinbaum et al., 1976, 1998; Lambin 1994; Wu et al., 2002): Y = ?苗0 + ?苗1X1 + ?苗2X2+ ?苗3X3 + ?苗4X4 + ... + ?苗nXn + E (2) where Y is the dependent variable, i.e., land cover types, Xn are independent variables, i.e., the socio-economic factors, or rather, spatial determinants, ?苗0 is a constant and ?苗n is the regression coefficients and E a random error component. The final county-level classification result (dependent variables, Table 1) and the corresponding socio-economic and meteorological data of 1999 (independent variables, Table 2) were incorporate d and inputted into the SYSTAT for computing. Within a confidence level α = 0.05, the modelling results are listed in Table 3. 5 Discussion and conclusions Based on the above soil resource investigation by remote sensing and spatial determinant analysis by cross-sectional regression modelling, an evaluation of the land use potential in the near future in North Ningxia was discussed as follows in combination with our land cover change detection results (Wu et al., 2002): (1) The predominant land cover type in North Ningxia is the farmland (including rice field and irrigated land), with an area of 2,835 km2, 36% of the total land. This land cover type is strongly associated with the rural population, where R2 = 0.9563 (eqn. 3). However, its related socio-economic production takes up only 13.4% of the annual GDP (Table 2). [Farmland] = 1.472 + 3.9016 [Rural population], (R2 = 0.9563) (3) As revealed in our other change detection study, the farmland has extended by 471 km2 (47,100 ha) since 1987 at an annual increase rate of 39.3 km2/yr or 1.53%. At such a development rate, it will increase by another 432 km2 till 2010. In fact, to compensate the lost in urbanisation and village extension (respectively 41 and 101 km2, see the following paragraphs), the farmland should have a net increase of about 574 km2 in 2010 to meet the population growth demand. This means that 10.1% of the present non-agricultural land will have to be converted into farmland. However, where to find such a reclaimable territory? The Yinchuan Plain has a long history in its development in agriculture. The usable land has been almost fully exploited. Even the most infertile sand land in the counties of Yongning (e.g., vineyard and plantation of ephedra), Yinchuan (e.g., Nanliang Farm), Helan and Pingluo has been transformed into farmland in the past 12 years. The land resource investigation shows that there is little arable or reclaimable land left for further extension. The candidates will be probably the marsh along the river and around the irrigation system, some unreclaimed sand land and sandy grassland along the west margin of the Yinchuan Plain. But the soil quality improvement would be a hard engineering and more water provision and financial investment requested. (2) Urban in an area of 158.69 km2 (66.11 km2 for Yinchuan City and 51.54 km2 for Shizuishan City), occupies only 2% of the total territory, but concentrated with 86.6% of the GDP production (Table 2). This means that the urban area is the prevailing economic producer. This land cover type is closely linked with the total industrial output (R2 = 0.9634, eqn. 4). [Urban] = 2.233 + 0.0101 [Total industrial output] (4) It has been measured that the urban area has extended by 35.84 km2 (19.13 km2 in Yinchuan and 9.39 km2 in Shizuishan) at an increase rate of 2.99 km2/yr or 2.16% in the period 1987-1999. If there is not significant fluctuation in this process in the near future, the urban area will be extended to 200.6 km2 (90.9 km2 for Yinchuan and 61.9 km2 for Shizuishan) in 2010. This extension will take place at a cost of farmland loss of around 41 km2 till 2010. (3) Village, in an area of 174.5 km2, taking up a feeble percentage in the land use and cover pattern (2%), is also related to the rural population (R2 = 0.7189, eqn. 5). [Village] = 3.361 + 0.216 [Rural population] (5) This kind of land use had augmented by 68.33 km2 in the past 12 years since 1987 with an annual extension rate of 5.69 km2/yr or 4.23%. With such a tendency, the village will reach 275.3 km2 in 2010 due to the contribution of the rural population. In this way, another 101 km2 of the green land will be lost at that time. (4) Lake & pond, in an area of 436.3 km2 and constituting 5% of the total land, is related to the total sown area (R2 = 0.7332), i.e., [Lake & pond] = 2.318 + 2.159 [Total sown area], R2 = 0.7332 (6) According to Wu et al. (2002), the surface of water-body enlarged by 49 km2 in the Yinchuan Plain at an increment rate of 4.07 km2/yr or 0.998% in the period 1987-1999. With the farmland extension, another 45 km2 of lake & pond will probably occur till 2010. As the precipitation has been gradually decreasing, the Yellow River is surely the principal water source of these water-depressions. Then what will be the destiny of the river? (5) The Yellow River, presently possessing a course surface of 81.3 km2 and a percentage of 1% of the land in the scope of North Ningxia, has been narrowing at a rate of 6.99 km2/yr or 6.10% since 1987. If the farmland keeps in extension, rural people continue to overuse the river water in agriculture under the background of global warming, the river course would completely convert into land and the Yellow River would not exist any more in 2010. This is not a sensation! It is well worthy of attention of the world. (6) Sandy grassland, with a proportion of 9% among the total land, has somewhat relation with the annual mean temperature (R = -0.625). This suggests that climate is a factor influencing this vulnerable land cover type. Field investigation uncovered another impact: human activity. It was noticed that grazing on the fragile sandy grassland in the pluvial fans could easily lead to a degradation of the ecosystem due to the fact that sheep and goats pull out even the grass roots when eating. Another phenomenon observed is that local people dig some herb roots, e.g., licorice, a Chinese traditional medicine herb growing in the sandy land in Mu Us. If these activities happened at large scale, the fragile vegetation cover would be destroyed rapidly. Therefore, whether this kind of sandy grassland can be kept or degraded or partially turned into farmland in the near future relies on the natural conditions but principally on human activities including cattle grazing. (7) Saline-land might be to some extent related to the chemical fertiliser usage (R2 = 0.6813). It is a little difficult to understand this relationship. As a matter of fact, fertilizer itself is chemically a kind of salt. Overuse and long time us age in agriculture could lead to degradation of the land fertility and quality, in worse case, cause a consolidation of the soil and make it infertile. Therefore, chemical fertilizer should be sometimes carefully used. The following equation illustrates this relationship: [Saline-land] = 3.799 + 4.015 [Chemical fertilizer used] (7) (8) Fallow-land is in fact a kind of cultivated land in rest. Regression modelling shows that it is related to both the total sown area and food crop area (R2 = 0.8937, eqn. 8). Its existence is spatially linked with the cultivated land. Their relation equation can be expressed as: [Fallow-land] = -3.995 + 2.234 [Total sown area] - 2.035 [Food crop area] (8) (9) From the regression modelling results (Table 2), the marsh (occupying 3% of the soil resources) is likely to have certain relationship with the total sown area (R2 = 0.6760). This is probably owing to the fact that a part of the marsh is formed by water leaking from the irrigation system, e.g., the canals, and occurs around the farmland. The forest in the Helan Mountains (5% of the total land) seems associated with the total agricultural output (R2 = 0.6076). But this needs a further insight for understanding. In conclusion, this is a synthetic research from space to land, from human activities to environment. If more detailed socio-economic data, for example, commune-level ones, average water quantity demanded for cultivating a hectare of crop, etc., were available, the cross-sectional regression modelling results would be more relevant and the potential evaluation more valuable. The future is not optimistic. No much arable land is left for the future farmland extension, no much water resource is available for the future development, and the Yellow River might dry up in ten years. These are worthy of thinking in the sustainable land use planning and development policy making. Acknowledgements The authors want to thank first the Federal Office for the Scientific, Technical and Cultural Affairs (OSTC) of the Belgium Government for funding our research of the Sino-Belgian co-operation project on Northwest China. We are very grateful to Prof. Eric F Lambin for his strong support throughout this study. 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关键词： land use and cover patterns; human-environment relationship; development potential; North Ningxia; cross-sectional analysis; spatial determinant