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# GIS-Based Assessment of Land Suitability for Optimal Allocation in the Qinling Mountains, China*[1]

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## ABSTRACT

A GIS-based method was used to assess land suitability in the Qinling Mountains, Shaanxi Province of China through simultaneous consideration of physical features and current land use. Through interpretation of Landsat TM images and extensive field visits the area was modeled into 40 land types in five altitudinal zones (valleys and gullies, hillsides and terraces, foothills, mid-mountain, and sub-alpine mountain). Then, a suitability score was assigned to five physical factors (climate, hydrology, topography, soil, and vegetation). Next, their integrated overall suitability value scores were compared with the observed land cover to determine whether it should be reallocated a new use. Results showed that the five suitability classes of agriculture, forest, grassland, farmland-woodland, and scrub-pasture had altitudinal stratification and a total of 1151 km$^2$ (8.89%) of lands on the northern slopes of the Qinling Mountains had to be reallocated. To achieve this reallocation, 657 km$^2$ of arable land should be reduced, and forest, grassland and scrub-pasture increased by 615 km$^2$, 131 km$^2$ and 405 km$^2$, respectively. Implementation of these recommended land reallocations should help achieve suitable use of land resources and prevent land degradation.

*Key Words*: GIS, landforms, optimal allocation, Qinling Mountains, suitability evaluation

Land cover is a product of human activities altering the terrestrial surface. In turn, it also governs the kind of activities that can take place over a given piece of land. Because it may not represent the true potential of the land, land cover, as an important element in a complex ecological and economic system, needs to be evaluated periodically. By comparing this potential with the current use, it is possible to know whether land resources have been utilized optimally, and if not, how the current allocation can be modified to achieve optimal or the best use, defined as generating maximum return from the land with minimum detrimental effect on it. Optimal allocation, defined as the assignment of the optimal use to a piece of land, of land resources is especially important in mountain ecosystems that have played an important role in human existence and development (Fu *et al.*, 2004). However, if the land is not used properly, potentially unstable slopes in mountainous regions may be highly vulnerable to land degradation and landslides. In fact, because of unsustainable exploitation, these regions face a more severe challenge of degradation than ever before (Becker and Bugmann, 2001; Xia *et al.*, 2005; Zuo *et al.*, 2005).

Several studies have been undertaken to assess land suitability. Steiner *et al.* (2000) presented a framework for land suitability analysis based on a thorough ecological inventory of the watershed, so that constraints of and opportunities for land conservation and development could be identified. Land use suitability has been studied from topography, soil, land cover, and the interrelationships among landform, soil, and vegetation (Allen *et al.*, 1995). However, integration of multiple variables in one assessment cannot produce accurate, efficient results unless a geographic information system (GIS) is

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used. Thus, GIS has found wide applications in land suitability evaluation. With the assistance of a GIS, Liu and Deng (2001) developed a land resources management system to evaluate land suitability. Furthermore, using GIS, Wandahwa and van Ranst (1996) implemented land suitability evaluation and mapped climate, altitude, soil type, and ecotype. GIS, in combination with the average of individual ratings from a group of experts, was also used to implement a land suitability evaluation model (Kalogiroua, 2002; Liu *et al.*, 2003). In addition, GIS functions helped to manage spatial data and to visualize evaluation results (Chen *et al.*, 2003; Wu *et al.*, 2004; Liu *et al.*, 2005).

These studies were limited in that the assessment was carried out to identify whether the land was suitable for a particular application. So there were a limited number of physical variables considered. Nevertheless, assessing land potential for all kinds of use has been done very little. Moreover, evaluation concerning land potential has not incorporated current land use practices. Therefore, whether the current land use is optimal remains unknown. In this study a GIS-based method of comprehensive assessment, in which landform was integrated with current land cover to quantify land suitability, was devised to overcome these limitations. Through introduction of the "land type" concept, information on area, quality, pattern, and present and evolving use of either or both land use and landform, is fully incorporated into the evaluation, thereby denoting a combination of land covers found in different landforms. The evaluation results were then used to optimize the allocation of land uses across different landforms in the Qinling Mountains of China.

## MATERIALS AND METHODS

### *Study area*

The study area is on the northern slope of the Qinling Mountains, which encompasses an area of 12 950 km$^2$ including Baoji, Xianyang, Xi'an, and some counties south of Weinan in Shaanxi Province. The Qinling Mountains, one of the highest mountain ranges in China, extend from central to western China. Climatically, the study area spreads into two zones: from subtropical in the south to warm temperate in the north. Vertically, it has a large range of elevation with the highest point, Taibai Mountain, being 3 767 m above sea level (ASL). Within this range at the micro-scale several climate regimes exist. Groups of various landforms, differing individually in their formation and attributes but associated with each other across altitudinal zones, can be found across a range of altitudes. Such a wide range of physical features creates an excellent opportunity to assess land suitability for optimal allocation.

Historically, plantation forest dominated the land cover over these mountain ranges. However, in modern times the forest has been cleared for farming. In addition, due to over population in the region, remnant trees have been felled for fuel. Thus, a conversion of land cover from woodland to farmland and reckless exploitation of natural resources have led to land degradation.

### *Assessment variables and criteria*

A comprehensive analysis of the physical settings for the Qinling Mountains revealed five major environmental variables (climate, hydrology, topography, soil, and vegetation) for land suitability assessment at the primary level. There were a different number of sub-variables under each category totaling 13 at the secondary level (Table I, column 2). Climate was important because it affected the growth of vegetation and crops, whereas hydrology determined the amount of water available for plant growth. Terrain was important for maintaining slope stability and was critical to the distribution of other variables at a local scale (*e.g.*, a steep terrain should not be tilled to prevent soil erosion). Soil governed the type of vegetation that could grow most productively in that area, and vegetation (*e.g.*, its presence and health conditions) showed whether the land could be used productively. The role of these factors in the environment varied with land cover. Therefore, due to its changing dominance in different areas, the same environmental factor could have dissimilar influences.

TABLE I

Evaluation of five variables and thirteen sub-variables with evaluation scores for land suitability in the Qinling Mountains

| Variable (weight) | Sub-variable (weight) | Assessment classes and their scores (weight) | | | | |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | V |
| Climate (0.30) | January temperature (°C) (0.15) | > 2.0 (100) | 0.1–2.0 (90) | −2.0–0 (75) | −4.0–−2.1 (50) | −6–−4.1 (45) |
| | ≥ 10 °C annual temperature (°C) (0.45) | > 4 400 (100) | 4 001–4 400 (85) | 3 601–4 000 (70) | 3 201–3 600 (50) | 2 801–3 200 (40) |
| | Annual rainfall (mm) (0.30) | > 1 200 (100) | 1 001–1 200 (95) | 901–1 000 (90) | 801–900 (80) | 701–800 (70) |
| | Annual dryness (0.10) | < 0.75 (100) | 1.0–0.75 (95) | 1.3–1.1 (80) | 1.5–1.4 (60) | 1.8–1.6 (40) |
| Hydrology (0.10) | Underground water depth (m) (0.40) | > 1 000 (100) | 501–1 000 (80) | 101–500 (60) | 11–100 (35) | ≤ 10 (20) |
| | Surface runoff (mm) (0.60) | > 1 000 (100) | 901–1 000 (85) | 801–900 (70) | 701–800 (60) | 601–700 (40) |
| Topography (0.25) | Slope gradient (°) (0.60) | ≤ 5.0 (100) | 5.1–15.0 (85) | 15.1–25.0 (75) | 25.1–35.0 (50) | > 35.0 (20) |
| | Elevation (m) (0.40) | 600–1 000 (80) | 1 001–1 600 (65) | 1 601–2 750 (40) | 2 751–3 250 (30) | > 3 250 (20) |
| Soil (0.15) | Thickness (cm) (0.50) | > 80 (90) | 51–80 (70) | 31–50 (50) | 16–30 (35) | ≤ 15 (20) |
| | Texture (0.30) | Loam (100) | Sandy loam (80) | Sandy clay (50) | Sandy gravel (25) | Gravel (5) |
| | Surface erosion (0.20) | Absent (100) | Sheet (80) | Rill (50) | Gully (25) | Deep gully (10) |
| Vegetation (0.20) | Cover density (%) (0.35) | > 70 (100) | 51–70 (80) | 31–50 (50) | 11–30 (25) | ≤ 10 (10) |
| | Potential of vegetation resources (0.65) | Deciduous forest (100) | Mixed forest (95) | Coniferous forest (85) | Cropland (70) | Grass-scrub (65) |

The importance of each sub-factor was assessed in five assessment classes numbered I to V (Table I). A method known as the Delphi approach was used to determine the selection of these variables, their weights, and the thresholds for each class. In this method 12 experts, independently of one another, were asked to place a value on each factor. The average was used as the final weight. Determination of class thresholds was based on the actual land use combined with expert opinions. These thresholds were tested in a few experimental areas and found to accurately reflect the local agricultural operation and land use.

### *Landform zoning*

Spatially, mountains are comprised of zones of landforms. In a given zone, differences in slope gradient and orientation, soil type, and vegetation all contribute to differentiation in land type. Their zoning requires an analysis of the characteristics and criteria of altitudinal differentiation and separation of altitudinal ranges according to large- and medium-scale geomorphologic units. For the purpose of this study, the Qinling Mountains were partitioned into five altitudinal zones derived from a combination of altitude and physical features (Liu and Deng, 2001), namely valley and gully (Zone A); hillside and terrace (Zone B); foothills (Zone C); mid-mountain (Zone D); and sub-alpine mountain (Zone E).

### *Mapping of land types*

Land types were mapped from a variety of data sources, including topographic, vegetation, and soil maps. The topographic map had a scale of 1:50 000, whereas both the vegetation and soil maps, which were published by the China Surveying and Mapping Publishing House in 1989, had a scale of 1:250 000. Other collected data were eight Landsat TM images recorded on October 30, 1998 with Bands 4 (red), 7 (green), and 3 (blue) used to produce a color composite of 1:10 000. Land cover was mapped into six categories (arable agro-plantation, forest, grassland, farmland-woodland, scrub and pasture, and barren land). Arable land referred to land used for growing crops, even if it was not cultivated every year. Forest referred to any vegetated land that trees or shrubs dominated. Grassland was defined as any land used to grow grasses for the purpose of grazing. Farmland-woodland referred to tilled mountain slopes at a gradient > 25° that were pure farmland, but had evolved and at present was distributed with mature trees or shrubs. Its soil was less than 15 cm thick with fertility lower than that of arable land. Scrub-pasture land referred to former woodland that had been degraded to sparsely populated scrub. Barren land referred to any land that was not used productively. These land covers were combined with their local physiographical characteristics (*e.g.*, terrace, hillside, foothill, valley, and gully) and land use type to represent 40 land types, within altitudinal zones derived from TM imagery, over the entire northern slopes of the Qinling Mountains. Additional information on geomorphology, terrain, and climate of the northern slopes of the Qinling Mountains was used to distinguish modern and historical geomorphic units.

Prior to image interpretation the study area was extensively inspected over a three-year period. In the field, elevation above sea level for all landform types was measured. Soil for each type was also determined; afterward, a landform type map was produced from land use and land cover maps using indoor visual interpretation of Landsat TM color composites. This land type map was then digitized using Arc/Info 7.1 with the area of each land type polygon being calculated and input into Foxpro® 2.5 for statistical analysis.

### *Implementation of assessment*

An overall score $S_k$ was derived for the $k$th environmental variable ($k = 1$ to 5) from its sub-variables in five grading classes using the following proposed evaluation model:

$$S_k = \sum_{i=1}^{r} a_i^k \sum_{j=1}^{5} A_{ij}^k F_{ij}^k \tag{1}$$

where $r$ refers to the number of sub-variables under a given environmental variable ranging from 2 for hydrology, topography, and vegetation to 4 for climate (Table I, column 2); $a$ stands for the ecological effect of the $i$th environmental sub-variable quantified for climatic sub-variables from 0.10 for annual dryness to 0.45 for $\geq 10$ °C accumulated temperature (Table I, column 2) with all $a$ values totaling 1 for a given environmental variable; $A_{ij}$ represents the areal proportion of the $i$th environmental sub-variable in the $j$th grading class to the whole study area; and $F_{ij}$ is the corresponding grading score of $A_{ij}$ for a range between 0 and 100. $S_k$ was calculated separately $k$ times (5 times) or once for each of the five environmental variables of climate, hydrology, topography, soil, and vegetation, then expressed on a scale of 1 (totally unsuitable) to 100 (perfectly suitable).

The five environmental variables had different potential resource values and effects on the local environment and were combined to derive an overall suitability value (SV) using the following formula:

$$\mathrm{SV}_h = \sum_{k=1}^{5} \beta_k^h S_k^h \tag{2}$$

where $\beta_k^h$ stands for the weight of the $k$th variable in the $h$th ($h = 1, 2, 3, \cdots, 40$) land type varying from 0.10 for hydrology to 0.30 for climate (Table I, column 1); and $S_k^h$ refers to the overall score of the $k$th environmental variable derived from Eq. 1. Eq. 2 was repeated 40 times, each time for one of the 40 land types, with derivation of SV being implemented in Foxpro® and the attribute database created in Arc/Info being linked to the spatial database built from the land type map.

Then, all 40 SVs were arranged in order from the largest to the smallest and divided into five classes of suitability using a roughly equal SV interval (Table II) with intervals (score ranges) from the highest to the lowest delineated as: most suitable—for agriculture, moderately suitable—for forest, suitable—for grassland, less suitable—for farmland and woodland, and least suitable—for scrub and pasture. To determine the suitability class of each land type, the calculated SV was compared to the upper and lower limits of each suitability class. During comparison, the pre-set limits of a particular suitability class might be slightly adjusted to avoid partitioning a cluster of land types into two suitability classes.

For each of the 40 land types its suitable use was compared with its current use. If the two were in agreement, then no reallocation was necessary. Otherwise, the land type under study was reallocated to the new use type.

TABLE II

Suitability value (SV) scores of 40 land use types for five landform zones derived from comprehensive consideration of five factors of climate, hydrology, topography, soil and vegetation

| Item | Landform zone[a)] | | | | |
|---|---|---|---|---|---|
| | Zone A | Zone B | Zone C | Zone D | Zone E |
| Score range | $\geq 78.5$ | 65.5–78.5 | 59.3–65.4 | 52.0–59.2 | $\leq 52.0$ |
| Area (km$^2$) | 1917 | 2795 | 5291 | 2470 | 477.74 |
| Percent (%) | 14.80 | 21.58 | 40.86 | 19.07 | 3.69 |
| Best use | Arable | Forest | Grassland | Farmland and woodland | Scrub and pasture |

[a)] Zone A=valley and gully; Zone B=hillside and terrace; Zone C=foothills; Zone D=mid-mountain; and Zone E=sub-alpine mountain.

## RESULTS

### *Landform zones*

The northern slope of the Qinling Mountains was partitioned into five landform zones (Fig. 1). The valley and gully (Zone A) had the largest suitability score (78.5 or higher, Table II), but for area it was the fourth most dominant zone (Table II). The hillside and terrace (Zone B) was the second most common inside the study area with a marginally higher area than the mid-mountain zone (D). The foothills (Zone C) had a moderate suitability score and was the most dominant landform, being larger than the combined area of Zones A and B. The mid-mountain region (Zone D) was the third most dominant landform, and the sub-alpine mountain region (Zone E) was the tiniest.

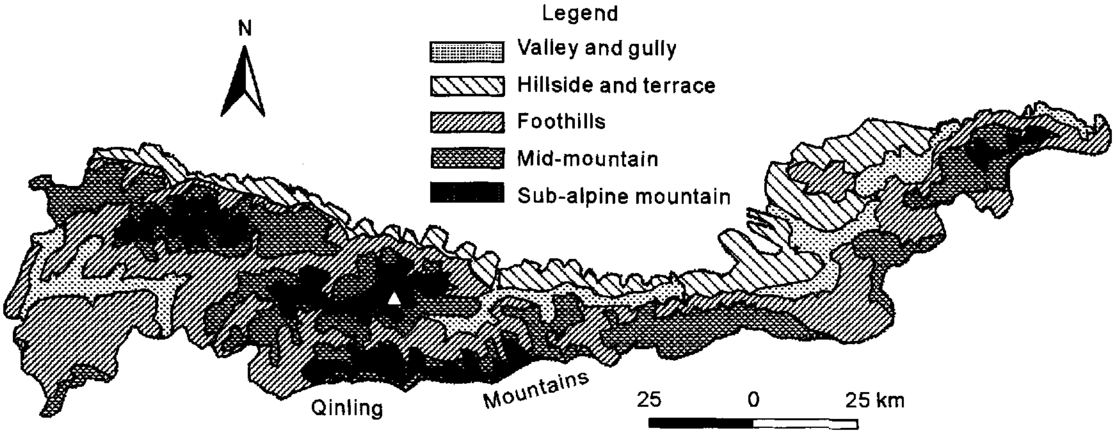

Fig. 1 Five landform zones derived from interpretation of TM images and field trips for the northern slope of the Qinling Mountains.

There was an obvious altitudinal stratification of landforms over the wide range of elevation. Associated with this distribution were distinct patterns in soil and vegetative cover. Zone B (warm-temperate foothills) lay at an elevation of 600–1 000 m in which mixed coniferous and deciduous forests were distributed on brown cinnamon soils. At higher elevations, this was succeeded by three zones: Zone C of deciduous forests and steppe on cinnamon soils; Zone D of mixed coniferous and broadleaf forests on mountain podzolic soils; and Zone E of shrubs, meadows, and stone ledge vegetation on sub-alpine meadow soil. As altitude increased, human activities also decreased, and less adverse impact on the ecosystem was noted.

### *Optimal land use through reallocation*

A practical solution for the optimal allocation of mountain land use for the northern slope of the Qinling Mountains was proposed (Table III). Because the area was over-cultivated, to maintain a sound ecosystem, agro-plantations (arable land) required reallocation with the recommended reduction coming from three land use types (Tables III and IV). In contrast, forestland needed an increase with 311 km$^2$ representing under-utilization of land potential (grassland) and 215 km$^2$ as over-utilization (arable).

TABLE III

Cover areas of different land use types before and after reallocation

| Land use type allocation | Current reallocation | After | Change | Land reallocation[a)] | |
|---|---|---|---|---|---|
| | | | | From (decrease) | To (increase) |
| | km$^2$ | | | | |
| Arable land | 3174 | 2517 | −657 | $A_5$ (215); $B_9$ (55); $B_{11}$ (387) | |
| Forest | 7561 | 8176 | +615 | | $A_5$ (215); $B_3$ (311); $B_6$ (89) |
| Grassland | 638 | 769 | +131 | $B_3$ (311) | $B_9$ (55); $B_{11}$ (387) |
| Farmland-woodland | 907 | 664 | −243 | $A_2$ (243) | |
| Scrub-pasture | 372 | 777 | +405 | $B_6$ (89) | $A_2$ (243); $B_5$ (251) |
| Barren | 298 | 47 | −251 | $B_5$ (251) | |
| Sum | 12950 | 12950 | 0 | 1151 | 1151 |

a) For an explanation of the symbols used to denote the land reallocation referring to Table IV below.

TABLE IV

Land type units that were reallocated a new use after the assessment

| Symbol | Landform | Altitude | Soil | Vegetation | Present use type |
|---|---|---|---|---|---|
| | | m | | | |
| $A_2$ | Valley and gully | 600–650 | Colluvial | Crops | Farmland |
| $A_5$ | Valley and gully | 600–650 | Colluvial | Crops | Arable land |
| $B_3$ | Hillside | 800–1000 | Cinnamon | Pasture | Grassland |
| $B_5$ | Hillside | 900–1000 | Limestone | Barren | Barren |
| $B_6$ | Hillside | 900–1000 | Podzolic | Scrub | Scrub |
| $B_9$ | Terrace | 700–850 | Loessial | Crops | Arable land |
| $B_{11}$ | Terrace | 900–1000 | Residual loess | Crops | Arable land |

To achieve the true potential of the land, current grassland area should increase overall, but with a reduction in the grassland type ($B_3$, Table IV) and increases in loessial terrace ($B_9$) and residual loess terrace ($B_{11}$) types, both presently used for farming. Similar to agro-plantations, farmland-woodland needed to be reduced. This would come from valley and gully farmland ($A_2$) and would help remedy over-cultivation. Scrub-pasture areas should expand overall with a reduction in scrub ($B_6$) and additions from farmland ($A_2$) and Barren land ($B_5$).

Overall, a total of 1151 km$^2$ (8.89%) of lands on the northern slopes of the Qinling Mountains had to be reallocated. Thus, 657 km$^2$ (5.07%) of arable land required reallocation to other less intensive use, and forest, grassland and scrub-pasture increased by 615 km$^2$ (4.74%), 131 km$^2$ (1.01%), and 405 km$^2$ (3.13%), respectively.

## DISCUSSION

### *Accuracy of the modeled reallocation*

It was proposed that the land unsuitable for agriculture should be reallocated to forestry and animal husbandry (Table III). All of these reallocations took place between land types in Zones A (valley and gully) and B (hillside and terrace). At lower altitudes (1 000 to 1 300 m ASL), a mixture of agriculture and forestry should be implemented. However, to meet the needs of the local population that would grow substantially in the next 5–10 years, a portion of the land must be used for grain production. Nevertheless, some of this land could be reused for forestry at some time in the future.

The recommended reallocations were tested in a few experimental sites and more or less reflected the land use practice in reality. As in any assessment, though, accuracy of the final results was subject to the accuracy of the input data layers. Some data (*e.g.*, land cover) had a definite boundary, whereas other variables (*e.g.*, climate and soil) had a vague boundary. Therefore, the final map boundaries in Fig. 1 involved some uncertainty and should be treated with caution.

### *Implications of allocation*

The irrational way of land use such as conversion from woodland to farmland has led to land degradation. However, through reallocation of land that has been excessively exploited to a new use commensurate with its potential, this problem could be remedied. The recommended optimal allocation emphasized the ecological suitability for exploitation of natural resources and encouraged mixed farming with forestry and stockbreeding (Zhao and Ye, 2004). Naturally, switching from farming to forests would reduce grain output. However, improving farmland productivity through construction of irrigation facilities as well as converting the existing sloped farmland into terraced land to conserve soil and water could compensate these decreases.

Nevertheless, successful implementation of these recommendations relies on other related measures (Bao *et al.*, 2005). Those farmers disadvantaged by the reallocation should be compensated for their economic loss in the form of a government-sponsored grant. In this way farmers' livelihoods would not be negatively affected. Another means of achieving the reallocation was through cultivation of medicinal herbs. As a perennial vegetative cover these plants could prevent soil erosion. Finally, to reduce overpopulation, realocation of some of the rural population should be encouraged. With these measures the recommended reallocation could ensure sustainable exploitation of land resources in the study area.

## CONCLUSIONS

The study area was modeled into five altitudinal zones. Then, after taking into consideration of vegetation, soils, and land use, the northern slope of the Qinling Mountains was divided further into forty land type units. In composition, the zones showed altitudinal stratification. On the northern slopes of the Qinling Mountains, 1 151 km$^2$ (8.89%) of the lands required reallocation to forestry, grassland, and scrub-pasture so that a sound ecosystem could be restored. This could be achieved with a reduction of arable land 657 km$^2$ and a reallocation of forest 615 km$^2$ and grassland 131 km$^2$. Also, scrub-pasture land should expand by 405 km$^2$, mostly from farmland and barren land. These recommendations were based on consideration for sustainable development of ecosystems within the landform and allowed a steady improvement in biological productivity of mountain land.

## REFERENCES

Allen, R. B., Hewitt, A. E. and Partridge, T. R. 1995. Predicting land use suitability from vegetation and landform in depleted semiarid grassland, New Zealand. *Landscape and Urban Planning.* **32**: 31–42.

Bao, H. J., Wu, Y. Z., Wu, C. F. and Xu, B. G. 2005. Planning and design for eco-sustainable farmland consolidation. *Pedosphere.* **15**(3): 327–333.

Becker, A. and Bugmann, H. (eds.). 2001. Global Change and Mountain Regions: The Mountain Research Initiative. IGBP Report No. 49. Stockholm, Sweden. 86pp.

Chen, J. Z., Chen, J., Xie, X. J. and Zhang, X. L. 2003. Soil pollution and its environmental impact. *Soils* (in Chinese). **35**(4): 298–303.

Fu, B. J., Liu, G. H., Wang, X. K. and Ouyang, Z. Y. 2004. Ecological issues and risk assessment in China. *International Journal of Sustainable Development and World Ecology.* **11**: 143–149.

Kalogirou, S. 2002. Expert systems and GIS: An application of land suitability evaluation computers. *Environment and Urban Systems*. **26**: 89–112.

Liu, Y. S. and Deng, X. Z. 2001. Structural patterns of land types and optimal allocation of land use in Qinling Mountainous. *Journal of Geographical Sciences*. **11**(1): 99–109.

Liu, Y. S., Gao, J. and Yang, Y. F. 2003. A holistic approach towards assessment of severity of land degradation along the Great Wall in Northern Shaanxi Province, China. *Environmental Monitoring and Assessment*. **82**(2): 187–202.

Liu, Y. S., Hu, Y. C. and Peng, L. Y. 2005. Accurate quantification of grassland cover density in an alpine meadow soil based on remote sensing and GPS. *Pedosphere*. **15**(6): 778–783.

Steiner, F., McSherry, L. and Cohen, J. 2000. Land suitability analysis for the upper Gila River watershed. *Landscape and Urban Planning*. **50**: 199–214.

Wandahwa, P. and van Ranst, E. 1996. Qualitative land suitability assessment for pyrethrum cultivation in west Kenya based upon computer-captured expert knowledge and GIS. *Agriculture, Ecosystems and Environment*. **56**: 187–202.

Wu, L. X., Sun, B., Zhou, S. L., Huang, S. E. and Zhao, Q. G. 2004. A new fusion technique of remote sensing images for land use/cover. *Pedosphere*. **14**: 187–194.

Xia, J, Wang G. S., Ye, A. Z. and Niu, C. W. 2005. A distributed monthly water balance model for analyzing impacts of land cover change on flow regimes. *Pedosphere*. **15**(6): 761–767.

Zhao, Q. G. and Ye, F. 2004. Information technology and agro-modernization. *Acta Pedologica Sinica* (in Chinese). **41**(3): 449–455.

Zuo, W., Zhou, H. Z., Zhu, X. H., Wang, Q., Wang, W. J. and Wu, X. Q. 2005. Integrated evaluation of ecological security at different scales using remote sensing: A case study of Zhongxian County, the Three Gorges area, China. *Pedosphere*. **15**(4): 456–464.