APPLICATION OF GIS IN LAND MANAGEMENT－BUILDING A MODEL FOR SLOPE-LAND CAPABILITY CLASSIFICATION

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ABSTRACT

The safety of slope is strongly affected by the current usage of slope-land. This research of slope-land capability classification in Taiwan began in 1953. Fifty years of valuable experience have now been collected. The work, however, has not been administered in the city of Taipei. This study combined geographic information system (GIS) and global positioning system (GPS) to improve the field surveys efficiency, built a model to exhibit the slope-land capability classification, and verify the accuracy of input data for GIS. This process includes four factors, which include average gradient, soil erosion estimate, parent material, and soil depth. A demonstration slope-land site in the vicinity of Taipei has been closely evaluated the suitability of the GIS classification procedure. The evaluation will be the basis of further enhancement of the slope safey management. In this study, as an example, the model for slope-land capability classification will be carried out by the Taipei city government.

KEY WORDS: GIS, slope-land capability classification

1.INTRODUCTION

The work of land capability classification (LCC) in Taiwan began in 1953. In early stage of this project, the main goal of LCC was mainly used to the efficiency of agriculture propose. In recent years, classification involves the sustainable usage and development of slope-land resources. The LCC system used in Taiwan has been modified over the years to respond the social and economic changes. The scheme used to classify and manage slope-land in Taiwan can be applied to other countries as well. However, some adaptation is required, to correct for differences in social, economic, and environmental needs. A classification sheme should also be integrated and extended on a regional basis, so that it is both effective and easy to implement.

2.METHODS AND MATERIALS

2.1 Study Area

Taipei is basin surrounded by mountains with 55% of slope-land. The work of land capability classification in Taiwan began in 1953. The digital geologic, topographic, and soil maps are available for the geographical conditions of Taipei. This study combined geographic information system (GIS) and global positioning system (GPS) to advance the field surveys efficiency and built a model for slope-land capability classification.

2.2 Data

The study collected a large much of digital maps, including for definition of study areas, creating cadastral maps, four classification parameters, and based maps for querying, all of them were integrated into the 1: 000- scale cadastral units for land capability extent inventory. The following table provides descriptions of the layers.

Table 1. Data description

Input Layer	Data Format	Data Type	Scale	Output Layer
Slope-land zoning map	Shapefiles	Polygon	1:1,000	Study area
Prevention forest zoning map	Coverage	Polygon	1:1,000	Study area
Land-use zoning map	Shapefiles	Polygon	1:500	Study area
The text-file of cadastre	TEXT	Point	—	Cadastral map
The attribute of cadastre	TEXT	—	—	Cadastral attribute database
Digital terrain models	TEXT	Raster	4m by 4m	Average gradient map
Geologic map	Shapefiles	Polygon	1:5,000	Parent material map
Geologic hazard map	Shapefiles	Polyline	1:1,000	Landslide map
Soil map	Coverage	Polygon	1:25,000	Soil depth map
Topographic map	DGN	Polyline	1:1,000	Based map
Air photo	MrSID	Raster	12.5cm by 12.5cm	Based map

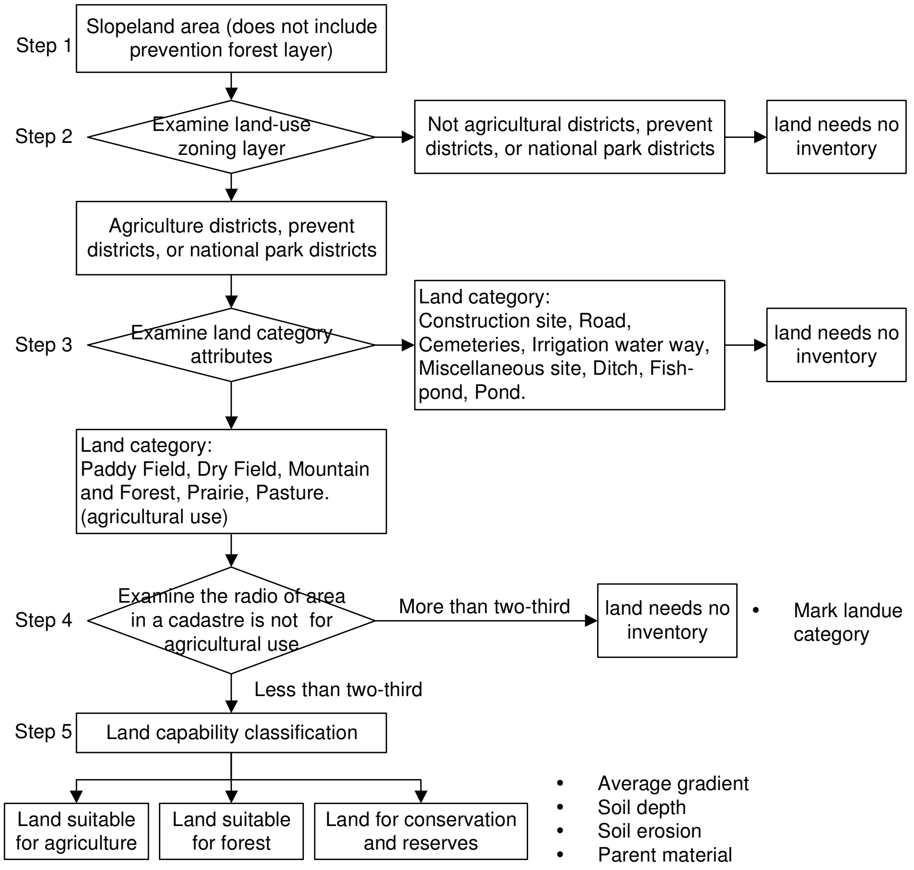


Figure 1. Flowchart of definition of lands that need inventory

2.3 Inventory Area

Slope-land is defined as land with at least an elevation of 100 m, or with a 5% gradient. This definition does not include national forest, prevention forest or other kinds of protected reservation. Figure 1 shows, the definition of lands that need inventory. There is no national forest, but prevention forest in Taipei. Step 1, the prevention forest must be excepted. Step 2, land capability extent inventory area is suitable for agricultural use, so land-use zoning and land category layers should be examined. When the land-use zoning is agriculture, prevent, or national park district. Step 3, referring to the land category is paddy field, dry field, mountain and forest, prairie, or pasture, the cadastre layers should be examined the radio of area in a cadastre is for agricultural use.

Step 4, when more than two-third area in a cadastre is not assigned to agricultural use, the land needs no inventory to be marked the land-use category. Otherwise, Step 5, it would be evaluated from four factors, including average gradient, soil depth, soil erosion, and parent material, to classify land suitable for agriculture, forest, or conservation and reservation, which is land capability extent inventory area.

2.4 System Building

In this study, two systems are defined to build a model for the slope-land capability classification. The process of computing field-inventory system, inventory data management information system and web-based query information system is shown in Figure 2.

2.5 Slope-Land Capability Classification

In 1976, the government passed the regulation of "Stature and Regulations on Conservation and Use of Slope-land in Taiwan" to develop a standard for slope-land capability classification. A field survey has been carried out since 1977, on slope-land areas. Six classes of average gradient, four of soil depth, four of soil erosion, and two of parent material were used to classify land into three categories, including arable, livestock production, and forest. The classification and field survey parameters are summarized in Table 2, showing the standards used with this classification.

After examining the four classification parameters, each land unit was classified according to the LCC scheme described in Table 3.

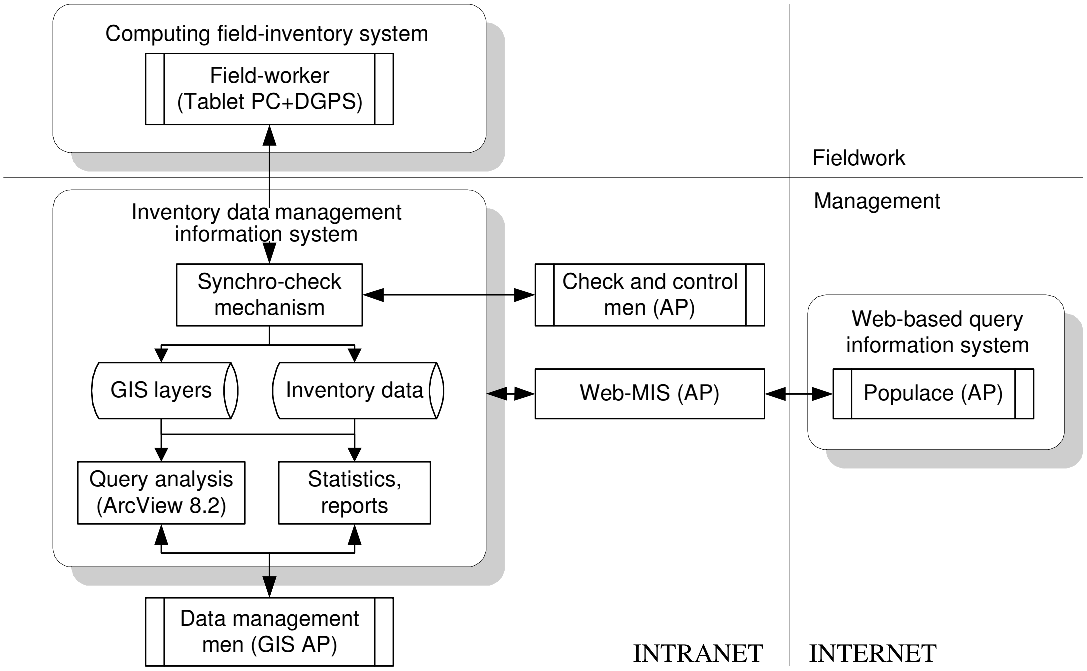


Figure 2. Framework of systems (Liao et al., 2003)

Table 2. Classification parameters (Chan, 2000)

Average gradient as %

Class	1	2	3	4	5	6
Gradient	<5	5-15	15-30	30-40	40-55	>55

Soil depth (ground surface to the root-limiting depth in cm)

Class	Very deep	Deep	Shallow	Very shallow
Depth	>90	50-90	20-50	<20

Soil erosion estimate (determined by surface erosion symptoms and rate of soil loss)

Soil erosion estimate	Class			
	Slight	Moderate	Severe	Extremely severe
Symptom	No rill	Rill formation	Sheet and rill erosion, bright soil color	Diffused gully erosion
(%) Gravel, or soil loss (%)	<25	<20 25-75	20-40 <50 subsoil	>40 >50 subsoil

Parent material (determined by ease of root proliferation and workability of machines)

Class	Soft	Hard
Characteristics	Friable or fragmented gravel, partial root growth and unrestricted machine operations	Consolidated, restricted root growth and machine operations

Table 3. Slope-land capability classification standard (Chan, 2000)

Effective soil depth (cm)	**Average gradient (%)**					
	<5	**5-15**	**15-30**	**30-40**	**40-55**	**>55**
Very deep >90	A1	A2	A2	A3	A4-1	F
Deep 50-90	A1	A2	A3	A4-1	A4-1	F
Shallow 20-50	A2	A3	A4-1	A4-1	A4-2/F1	F
Very shallow <20	A4-1	A4-1	A4-1	A4-2/F1	F	F
Unrestricted	P					

Note:

(1) Land suitable for agriculture and animal husbandry

A1: Class 1 land, unrestricted agricultural use.
A2: Class 2 land, needs moderate soil and water conservation treatments.
A3: Class 3 land, needs intensive soil and water conservation treatment.
A4-1: Class 4-1 land, needs intensive soil and water conservation treatment.
A4-2: Class 4-2 land, can produce crops but needs intensive soil and water conservation treatment.

(2) Land suitable for forest

F: Class 5 land, suitable for forestry but not for agriculture.
F1: Class 5 land, suitable for forest, but with either severe soil erosion problem or consolidated parent material.

(3) Land for conservation and reservation

P: Class 6 land, exposed parent material, severe soil erosion problem and subject to landslides. Intensive soil and water conservation treatments are needed.

(4) Land excluded from land classification but suitable for forest only

i: Forest used for disaster prevention, soil and water resources conservation and public safety, or an experimental forest, or forest where an important tree species is being conserved.
ii: Land with natural or cultural landscape, ecological environmental value, archeological sites, or used for public recreation.
iii: Reservoir watershed, or stream and river buffer zone.
iv: Forestland needed for multiple conservation purposes in regional planning.

2.6 Field Surveys for Land Capability Classification

In the study, 200 cadastral units were selected to verify the model for slope-land capability classification and the factors. The field- survey methods of four factors and their results of statistical analysis are listed as following:

2.6.1 Average Gradient Evaluation

Gradient is usually measured along the slope or the direction of natural drainage. When the slope is in irregular shape, the average gradient will be computed as:

$$S = \frac{A \cdot x + B \cdot y + C \cdot z + ...}{A + B + C + ...} \text{ .... Formula 1}$$

Where, S = average gradient (%),

A, B, C = area of each uniform slope surface,

x, y, z = gradient (%) of each uniform sloping surface.

Gradient is calculated with the square-land method in soil and water conservation field in Taiwan. This method includes:

(1) Create square grids at interval of 10 m or 25 m in contour maps.

(2) Count the intersection of each contour and each edge of grid.

(3) Compute the gradient as:

$$S = \frac{n\pi\Delta h}{8L} \times 100 \text{ .... Formula 2}$$

Where, S = gradient (%),

Δh = interval of contour,

L = spacing of the grid,

n = number of the intersection of each contour and each edge of grid,

π Ludolphian number (3.14).

2.6.2 Soil Depth Evaluation

Soil depth can be examined by using soil auger in the fieldwork. Usually, four to five sites should be sampled per hectare of land. Samples should be taken from the center, and at each compass point 50 m from the center. The average soil depth can then be computed.

2.6.3 Soil Erosion Evaluation

At least four or five sample sites are required for one hectare. Sites are needed when erosion-prone areas are considered. Several factors, such as the rill depth, the amount of coarse sand on the surfaces, and the estimated rate of soil loss, must be evaluated for an area of 1 to 4 m^2 at each site. The soil erosion status of each sample can then be used to calculate the average value.

2.6.4 Parent Material Determination

The parent material would be determined by observing the existing soil profile, or excavation of site.

2.6.5 Classification Determination

Land capability classification is then determined according to the four parameters mentioned in Sections 2.6.1 to 2.6.4.

2.7 Model Use

According to the LCC scheme (Table 3 and Figure 3), shows an automatic program flowchart. In the automatic program flowchart, the land is evaluated as the "exposed parent material, severe soil erosion problem and subject to landslides" with the landslide map (1:1,000-sclae geologic hazard map). If the cadastral unit any landslide polygon, it would be classified as the land suitable for conservation and reservation. Two hundred cadastral units selected to be verified in field surveys. Twenty-eight units of them have been examined and need no inventory.

3. RESULTS AND DISCUSSION

3.1 Classification Results

The classification results are the useful guide to select areas to develop and reduce soil losses. This study has classified more than 49,000 cadastral units into eight classifications by using LCC model (Figure 4 and Table 4).

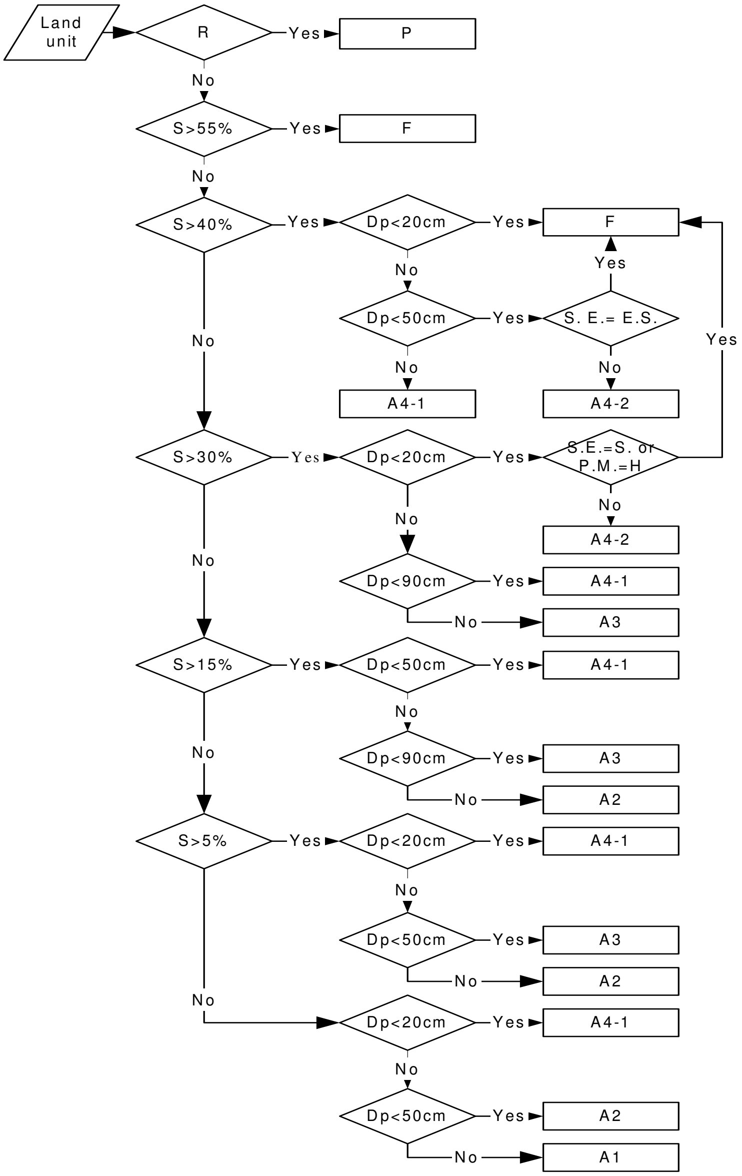


Figure 3. The flowchart of modeling for land capability classification (Liao et al., 2003)

Notes:

R: exposed parent material, severe soil erosion problem and subject to landslides

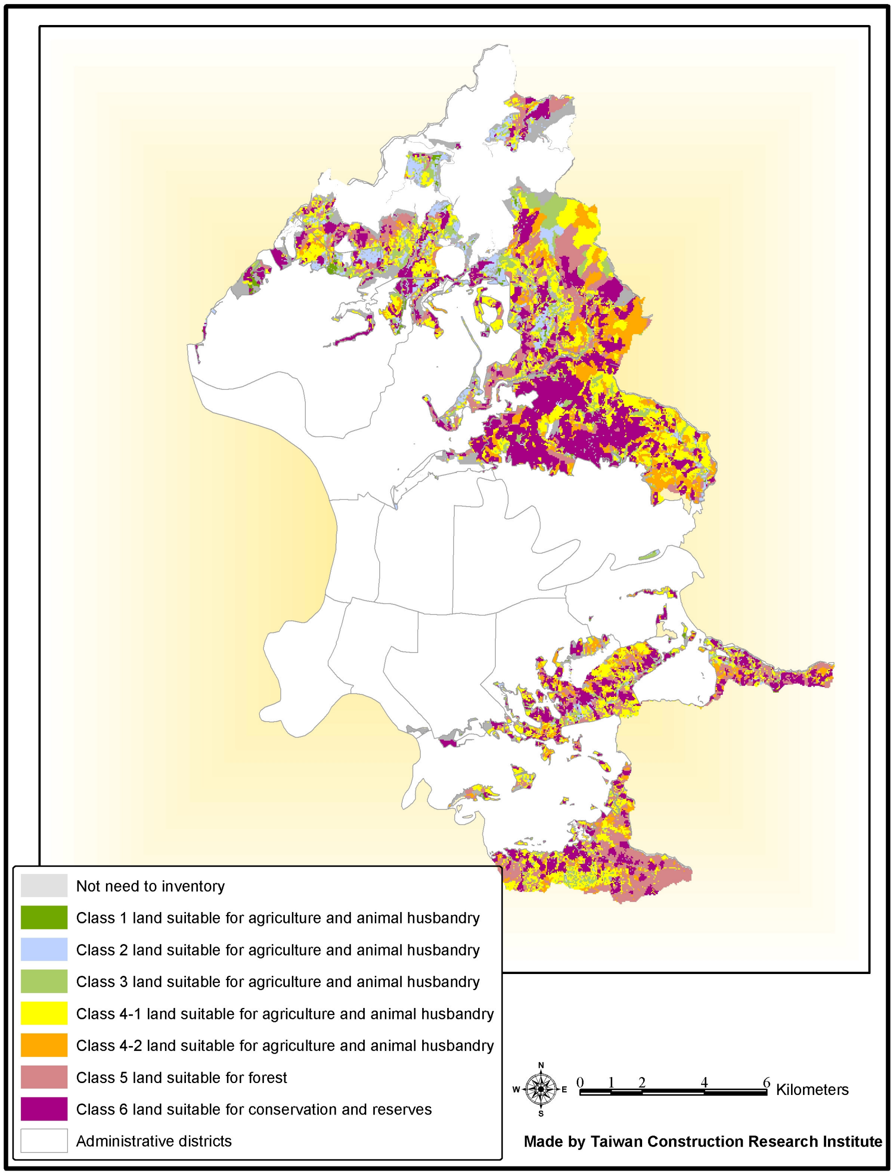


Figure 4. Results of using the model for slope-land capability classification in Taipei

Table 4. Number of eight classifications using LCC model

Classification	Number	Classification	Number
Not need to inventory (land category attributes)	11,144	Class 4-1 land suitable for agriculture and animal husbandry	11,856
Class 1 land suitable for agriculture and animal husbandry	1,279	Class 4-2 land suitable for agriculture and animal husbandry	3,110
Class 2 land suitable for agriculture and animal husbandry	4,864	Class 5 land suitable for forest	6,870
Class 3 land suitable for agriculture and animal husbandry	5,304	Class 6 land for conservation and reserves	5,448

3.2 Systems and Model Building

In the study, two systems are built, including the "inventory data management information system" (Figure 5) and the "computing field-inventory system" (Figure 6) to assist field-workers in slope-land capability extent inventory and classification. The field-workers can use different global positioning system (DGPS) and the positioning function of the "computing field-inventory system" to open cadastre layers, and mark inventory data. By operating synchro-update function of the "inventory data management information system", we could update the "land capability extent classification databases".

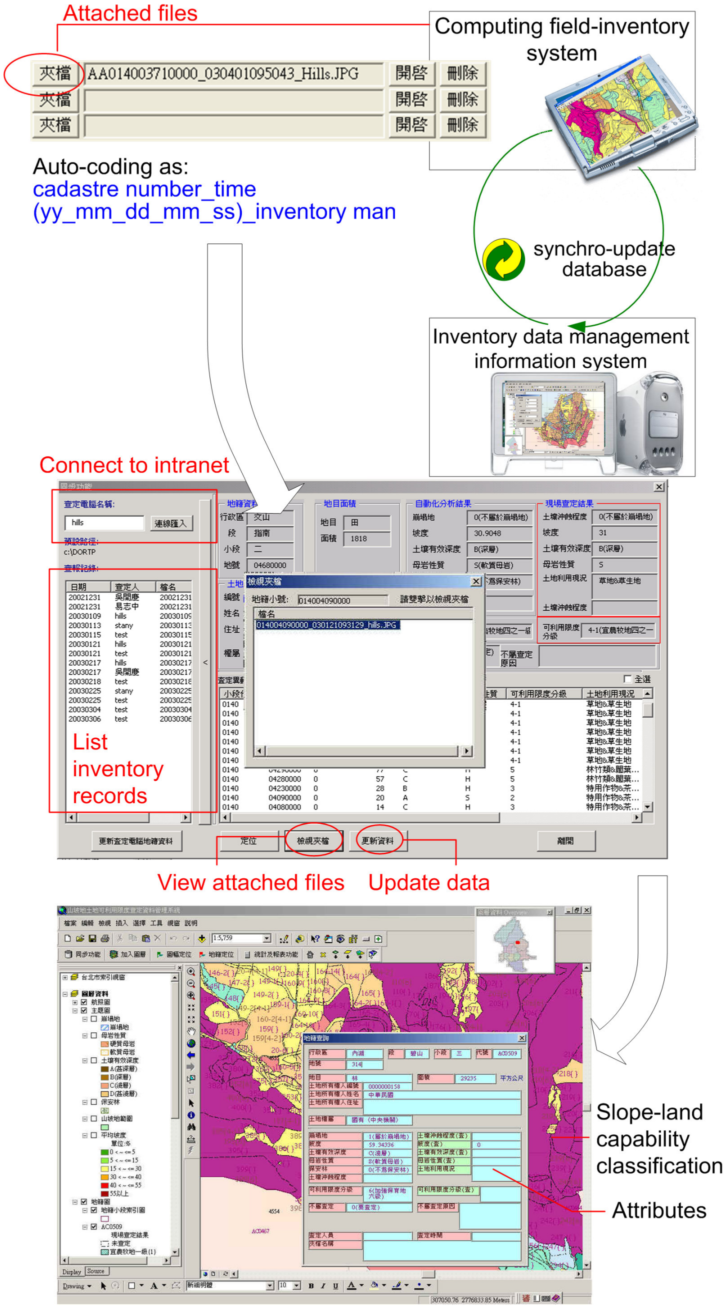
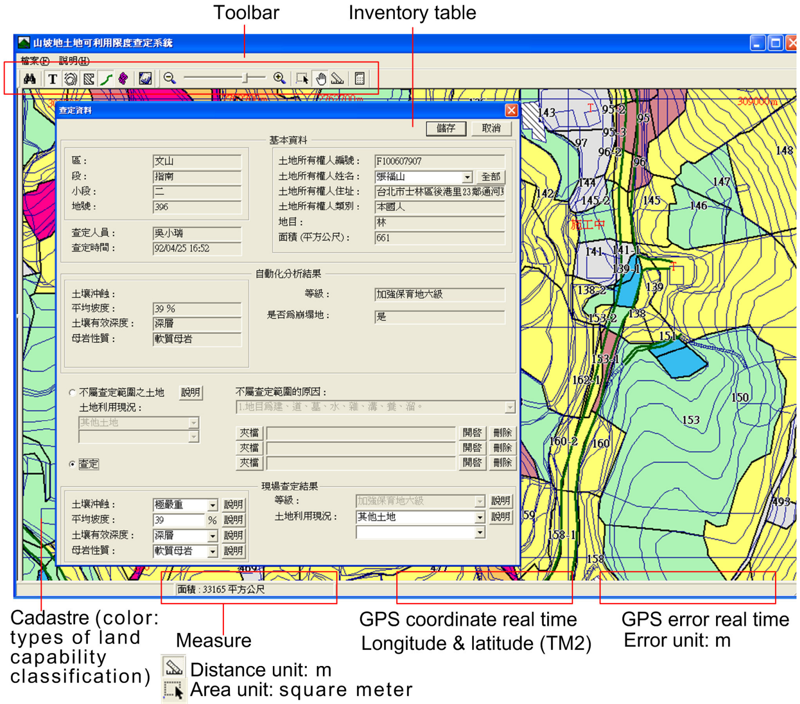


Figure 5. Inventory data management information system



基本資料

區：文山
段：指南
小段：二
地號：396
查定人員：吳小瑞
查定時間：92/04/25 16:52
土地所有權人編號：F100607907
土地所有權人姓名：張福山
土地所有權人住址：台北市士林區後港里23鄰通河
土地所有權人類別：本國人
地目：林
面積 (平方公尺)：661

自動化分析結果

土壤沖蝕：
平均坡度：39 %
土壤有效深度：深層
母岩性質：軟質母岩
等級：加強保育地六級
是否爲崩塌地：是

○ 不屬查定範圍之土地
土地利用現況：其他土地
不屬查定範圍的原因：1.地目爲建、道、墓、水、雜、溝、養、溜。
● 查定

現場查定結果

土壤沖蝕：極嚴重
平均坡度：39 %
土壤有效深度：深層
母岩性質：軟質母岩
等級：加強保育地六級
土地利用現況：其他土地

面積：33165 平方公尺

Figure 6. Computing field-inventory system

3.3 Analysis Results Verification

It is necessary to quantify the parameters to define the mathematical equations that assemble the model. According to the LCC scheme (see Table 2 and Table 3), the value of average gradient has a major effect on the model output. The following is the description of statistical method to verify the four inventory factors and the classification results.

3.3.1 Average gradient Verification

We compared five classes of average gradient (samples under 5% gradient are not sufficient for statistical analysis) that computed by spatial-analyst method of Digital Elevation Models (DEM) and square-land method of contours with paired t-test statistics in the case studies. Each degree of average gradient was selected for ten samples. All t values are in the accept region because results show two paired samples having no significant different in 95% confident level. Therefore, we can accept the results calculated with spatial-analyst method of DEM in replace of that with square-land method of contours.

Table 5. The gradient verification in case studies

Average gradient classification	Accept region	t
5%＜gradient≦15%	-2.365 ＜t＜2.365	1.151
15%＜gradient≦30%	-2.262 ＜t＜2.262	1.402
30%＜gradient≦40%	-2.262 ＜t＜2.262	1.861
40%＜gradient≦55%	-2.262 ＜t＜2.262	0.806
55%＜gradient	-2.262 ＜t＜2.262	0.575

3.3.2 Soil Depth Verification

75 data are different between two groups of data that obtained from the 172 soil depth data from field surveys and the 1:25000-scale soil maps. Verifying the correlation of the soil depth in the soil maps and that from field surveys with χ^2-test, the correlation coefficient shows low correlation value of 0.225 with 95% confident level. The flowchart of LCC (Figure 3) shows that soil depth in different LCC in each range of gradient. Therefore, we can calculate the correlation coefficient of one gradient class and the mapping soil depth class which cause different solpe-land capability classification in the gradient class. Limited by number of field-survey sampling, it can be verified that the soil depth from soil maps, field surveys on the 15 to 30 percent gradient and the 40 to 55 percent gradient. The correlation coefficient has a range of 0.329 to 0.378 with 95% confident level.

3.3.3 Soil Erosion Verification

Only four cadastres were with landslide among the 172 inventory data, but there are thirty on cadastres with potential landslide zoned in the geologic hazard prone map made by the Taipei City Government. The correlation coefficient is 0.223 with 95% confident level.

3.3.4 Parent Material Verification

In the current field survey, all parent material parameters on gentle gradient are classified to be soft. The parent material parameters of modelling, consequently, are defined as the soft in case studies.

3.4.5 Classification Verification

Finally, we should verify the types of land capability classification were calculated by the modelling and field survey. The correlation coefficient is high with value of 0.805 of the 95% confident level. It demonstrates that the application of GIS in slope-land capability classification is reliable.

All the analysis supports that there is a statistically significant correlation existed among field-surveyed and modelling results for average gradient, soil depth, soil erosion, parent material and land capability classification.

4. CONCLUSION

The emphasis of the slope-land capability classification should cover the aspects of the agricultural production and the protection of environmental resources. Classification parameters, relying in the regional basis, include topography, geology, land-use for the entire region.

When GIS data proved high precision, accuracy, and resolution, land capability inventory work can be computed to save manpower and cost price. That would promote to build the standard of inventory procedure and prime check mechanism. The classification parameters and classification were verified to show results from field surveys and from modelling in the case studies. The statistical results were proved to have significant level. However, application of GIS on land management is still limited by the data accuracy and spatial-analysis method. Some difficulties, however, still exist in the process.

1. On the aspect of the gradient analysis, gradient parameters that calculated them the square-land method are counting the nodes of each counter across the edge of grid. When the spacing of grid is decreased, the data accuracy would be increased with high calculation complexity. The square-land method has not translated to efficient algorithm, but information extracted from grid-based DEM has been applied to the terrain classification and analysis for a long time.

It has been proven that the gradient computed by spatial analyst of DEM and square land of contour have no significant different in 95% confident level. Therefore, average gradient layer with the spatial analyst of grid-based DEM were used to the model for slope-land capability classification.

2. On the aspect of the soil depth measurement, the 1:25,000-scale soil maps surveyed from 1980 to1986 show large different from the current field survey. In the flowchart of modelling for land capability classification, the average gradient parameter and soil depth parameter are two critical factors. Average gradient is a critical parameter that requires high accuracy. With high accuracy on parameters, the application of GIS in land capability classification can then be reliable.
3. On the aspect of the parent material definition, when soil depth parameter is very shallow with hard on soil lithological classification, the parent material parameter is hard. The definition of parent material in this study is for the purpose of agricultural use. As a result, it is important to define an approach to extract parameters from soil and geologic maps for modelling agricultural environment.
4. On the aspect of the soil erosion evaluation, although currently there is no GIS data for evaluating the class of soil erosion. However, the potential evaluation of soil erosion in Taiwan using Universal Soil Loss Equation (USLE) which has been developed for a long time. In the future, this process can be calculated potential soil loss by mapping real soil loss cases to construct the degree of soil erosion models.

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