AN INTEGRATED APPROACH OF AHP AND GIS APPLICATIONS TO ANALYZE AND DEVELOP RECREATIONAL ZONING

A study to determine suitability and priority zones in the Aso national park

AHP を用いた GIS によるレクリエーション土地利用計画
—阿蘇地域における土地利用計画に関する研究—

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Zoning policy has been widely used for planning and decision makings in land use for more than a decade. Most of the existed zoning plans are incompetent due to the outdated conditions. In other situations, the MCDM and GIS techniques have been applied for land evaluations. One means of enhancing the zoning efficiency is by applying a similar approach. The aim of this paper is to show how integrated AHP-GIS methodology can be used effectively to support the formulation of recreational zoning. Aso National Park area is selected as a pilot study and selection criteria are developed and evaluated. Two cases of criteria evaluation are used to justify efficiency of the method. Zoning maps are derived and discussed.

Keywords : *Recreation, Zoning, AHP, GIS, Natural resources, Landscape*

レクリエーション, ゾーニング, AHP, 地理情報システム, 天然資源, 景観

1. Introduction

1.1 Background

Zoning, the conventional legal tool of land use monitoring needs to be revised in terms of the processing methodology. In the past, zoning was developed manually either by tracing boundaries of the overlaid map features or using the obvious physical and administration boundaries. This conventional method is insufficient and has limitations because: (1) it limits the number of features to be analyzed; (2) time consumes for update zoning; (3) the existing zoning is incapable to cope with the rapid changes of administration policy and public interest; and (4) intangible values are always being omitted in the zoning process due to insufficient evaluation methods.

A number of land evaluation and classification techniques which are based on conditions of land suitability and capability have been developed to assist planners and decision makers in the formulation of land development policies. McHarg¹⁾, Hopkins²⁾ and Steiner³⁾ for instance have discussed a number of methods to derive land suitability. The multicriteria decision making (MCDM) techniques based on parameters' weight (score) have been introduced and incorporated into the conventional land evaluation method to address recent applications⁴⁾. The rationale is to provide a measure for uncertainty and multiobjective conditions. Advances in the Geographic Information System (GIS) have also aided the application in both methods. Some examples related to these studies are presented by Janssen and Rietveld⁵⁾, Pereira and Duckstein⁶⁾ and Carver⁷⁾. Although a systematic approach to study land suitability has been emerged, the zoning efficiency issues are still remained unsolved.

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Considering those factors and based on the Gold's⁸⁾ statement "... planning today requires more sensitive and sophisticated methods than the application of arbitrary standards and conventional thinking," we believe that the efficiency and effectiveness of zoning can be enhanced by applying the MCDM and GIS methods simultaneously⁹⁾. The MCDM method will be used to evaluate zoning parameters and the GIS will be used to manage huge spatial database and to perform intensive overlays. A number of methods are available for the MCDM analysis but we have selected the Saaty's Analytic Hierarchy Process method (AHP)¹⁰⁾ to accomplish the study. The reasons are: (1) the AHP method provides direct evaluation on the judgement inconsistency which is absent in other MCDM methods (see also Zeleny¹¹⁾, Nijkamp and Voogd¹²⁾ and Vincke¹³⁾ for various MCDM methods); (2) the AHP weight scales used for judging hierarchical criteria of choice are very effective to determine relative judgement thus, evaluation vagueness can be reduced; and (3) since zoning is sensitive to value changes, therefore, it is best to evaluate parameters using the strength of degree of importance.

The authors have already worked on the multicriteria analysis in the earlier publication^{note1)}. This paper is forwarded to improve a previous method based solely on the AHP application, especially for putting weights and measuring the inconsistency of zoning parameters.

1.2 Objective and methodology

The objective of this study is *to propose and demonstrate how the integrated approach of AHP and GIS methods can be used effectively for aiding zoning process and expediting the formulation of zoning policy*. Two cases of evaluation have been used to prove and justify that AHP is a more effective method for evaluating zoning parameters. From the hierarchy of Fig.1, the 'criteria' has been chosen for this experiment, which the selection is based on the following rationales: (1) degree of importance among *criteria* parameters is the most difficult to judge; (2) *criteria* matrix is composed of the largest matrices from those three levels of hierarchy; (3) degree of judgement inconsistency is considerably high for *criteria* matrix compared to *values* and *sub-criteria* matrices; and (4) suitability conditions for preservation (P), conservation (C) and facility (F) *values* are mostly influenced by the *criteria* parameters. The region of Aso is then used as a pilot project for this study.

The following steps are also formulated in order to apply AHP and GIS efficiently to derive zoning (see Fig. 2). Firstly, zoning is classified according to the land use types. For this study, recreation has been selected as a case. After classification, two operations are performed simultaneously. In the AHP operation, evaluation parameters for zoning are identified and defined. This leads to the structuring of hierarchy that indicated the superiority and relationship of elements. The following is to establish comparison matrix for every level of hierarchy and relative strength of the impacts of the elements is judged. The weights for each level is calculated. The AHP operation is ended with calculating the overall overlay weights. Meanwhile, in the GIS operation, the identified evaluation parameters for the lowest level of hierarchy are interpreted into series of maps and captured into computer. The spatial databases are then organized and manipulated for further GIS analyses. The calculated overall overlay weights are installed into the coverage attributes. The overlays are performed to obtain composite coverages of the next upper level of hierarchy. The assigned weights of each coverage are summed and categorized into Low (L), Medium (M) and High (H) suitability ranks. Zones that have similar ranks are combined and overlays are again performed to get a composite map of the next higher level. In the final composite map, zones are derived by combining the similar groups of LMH permutations.

Fig. 1 A hierarchy of influence for recreational zoning

2. Definitions, Concepts and Analysis Methods

2.1 Definition of recreation

Recreational planning has been defined explicitly in many studies and at the macro-level it is also termed as an open space. "Land, air and water resources are indispensable to life and thus constitute values" that was expressed by McHarg

Fig. 2 The methodology

has laid a ground to the study definitions and scopes. Recreation is defined as the land and water areas and facilities that provide opportunities for leisure. In this study we will emphasize more on the resource-based recreation at the macro-scale planning to determine zoning.

2.2 Planning hierarchy and concepts

This study introduces four levels of planning hierarchy to identify appropriate recreational zones through land suitability evaluation. As shown in Fig. 1 and started from the first level, they are *zoning types* (in this case is recreation), *values*, *criteria* and *sub-criteria*. The *recreational values* are comprised of three main characteristics. They are preservation, conservation and facility. 'Preservation' means areas that have great natural values and consequences. 'Conservation' implies areas that have significant cultural values. Finally, 'facility' is areas suitable for developing recreational facilities and can be defined as man-made improvements of recreational site provided to facilitate recreational uses. In the past, land suitability is mostly determined within the framework of two characteristics; that are, development and preservation suitability (Steiner 1983). Development suitability included urban development, agriculture, tourism, commercial-forestry and infrastructure aspects; meanwhile, preservation suitability covered mostly the high natural value and disaster susceptible factors. For this study, the above classifications are still insufficient because there are also factors located in between these two which are appropriate to be safeguarded. We termed it as 'conservation' which means public areas or activities or structures deserved to be protected but still can be utilized. Some of the examples are tangible and intangible cultural assets, scenic and landscape areas and historical sites. The next level is *criteria* and it can be defined as groups of features or elements used to interpret recreational values. *Criteria* provides a broad access to determine land suitability in various perspectives. Factors such as land uses, ecology, physiography, natural resources, landscape and many more are some examples to foresee land suitability. The lowest level of the hierarchy is *sub-criteria* and it is composed mostly the spatial data set related to each *criteria*.

2.3 The AHP method

The MCDM analysis in this study is accomplished using the Saaty's AHP method^{14) 15)}. In this method the weights for all parameters are assessed by performing the pairwise comparisons regarding to their relative importance. This relative importance is rated on a 1~9 scale, where -- 1 represents equal; 3 - moderate; 5 - strong; 7 - very strong; 9 - extreme; 2, 4, 6, 8 for compromise; reciprocals for the inverse comparison; and decimal refinements in between. In addition to this, the method also provides a measure of inconsistency judgement using the *consistency ratio* (C.R). The C.R below 0.10 is still considered consistent^{note2)}. The method is then applied on *recreational values* (level 2), *criteria* (level 3) and *sub-criteria* (level 4) for searching priority ranks and obtaining the overlay weights.

2.4 The overlay weights

Another essential part of this study is to get the weights for overlay processing in the GIS and the formula is:

$$z = V \times C \times W \quad (1)$$

$$Z = \frac{z}{\sum z} \times 100 \quad (2)$$

Where; Z is the final overlay weight; z is the intermediate overlay weight; V is the weights of priority vector for *recreational value* matrix; C is the weights of priority vector ($E.V$)^{note3)} for *criteria* matrix, W is the eigenvector for *sub-criteria* matrix and the multiplication of 100 is to get a weighted sum of 100.

2.5 Suitability derivations

To derive suitability for P , C and F values after map overlay is by classifying the cumulative overlay weights into groups of suitability. Several classifications are commonly used such as -- prime, secondary and tertiary; low, medium and high; percentages; minimum and maximum; and slight, moderate, high and very high groups (McHarg 1969

Suitability Classes	Values Definitions		
	Preservation (P)	Conservation (C)	Facility (F)
Low	Very low naturalness	Very low cultural (landscape) values	Very costly infrastructures development
Medium	Moderate conditions	Moderate conditions	Moderate conditions
High	Very high naturalness	Very high cultural (landscape) values	Less costly infrastructures development

Fig. 3 Suitability definitions for P , C and F values

and Steiner 1983). The low, medium and high classes have been chosen for the reasons of easy to understand and also provides a uniformity of choice. Fig. 3 explains the characteristics of classes' requirements for P , C and F values.

3. Case Study: Recreational Zoning in the Aso National Park

3.1 The background

The Aso region was designated as national park in 1934 and in the following years zoning was established and enforced¹⁶⁾. Since then the zoning was modified and the recently used zoning has been established in 1986 using the priority control zones concept. (Fig. 5 shows the study area.) There are five types of zonings according to this priority and from most to least importance are -- *Special Preserve Area* (development is totally prohibited), *Special Area Priority 1, 2 and 3* (limited development is allowed with a proper planning) and *Ordinary Type Area* (development is totally allowed).

3.2 Criteria selection for recreational analysis

To search recreational suitability area through the AHP method, the first step is to identify and classify *criteria* and *sub-criteria* to be used in the selection process. The considered *criteria* and *sub-criteria* have been summarized in Table 1 which emphasized on physical characteristics of the land and local conditions of natural resources, environmental potentials and constraints and cultural values. The selected *criteria* are also based on the empirical study through information gathered from various land evaluation analyses¹⁷⁾ ¹⁸⁾, group discussions as well as the field surveys (observations). The *sub-criteria* that represented the spatial data set are identified and classified from various sources of maps such as the Kumamoto Prefecture Environmental Planning Study maps¹⁹⁾ and topographic maps of scale 1:25,000 and 1:50,000. This information has been classified into thirteen factors and coded from A to M for analysis. (There is no limit to the number of choices although thirteen factors have been selected for this study.) We outline some rationales for these selections: (1) the scenarios of high degree of landscape, natural resources, environmental constraints, social and cultural values and land uses are well distributed and represented for considering appropriate zoning; (2) the identified *criteria* have relative importance to all *values* being judged at the upper level of hierarchy; and (3) thirteen *criteria* are considerably adequate to link *values* with the *sub-criteria*.

3.3 The AHP application for case study

We begin with constructing the first comparison matrix for *values* and judgements are elicited based on the relative importance of each element using the Saaty's scales. In the first matrix, equal importance is considered for P , C and F and as a result each *value* has 0.33 eigenvector. The second matrix is constructed for *criteria*. Two cases are sampled based on the objective to justify the efficiency and effectiveness of this method for deriving zoning. We indicated them as case 1 (C1) and case 2 (C2). The comparative judgements of C1 are performed based on the normal zoning requirements and C2 judgements are solely made based on the importance factors to reinforce each *value*. (An example of the judgement results for *criteria* of P value is presented in Table 2 and 3.) We circled C2 *criteria* where changes have been occurred. From the changes of judgement values, we observed that: (1) physical factors such as slope, physiography, disaster and water resources have gained higher scores in C2- P value; (2) the social factors such as tourism and scenic have contributed higher scores in C2- C value; and (3) the scores for slope of physical factor and land

Table 1 List of criteria and sub-criteria defined for study..

Main Code	Main Criteria	Determinant Factors that based on:	Sub-Code	Sub-Criteria (Maps' Ranking & Classes)	Remarks on data generations (Data sources & productions)
A	Slope	- Gradients (in degrees).	A - 1 A - 2 A - 3	15° below (Gentle) 15° - 30° (Steep) 30° above (Very steep)	• Isoline data of contours are extracted from the topography maps of scale 1:50,000 and the slopes are then derived by using TIN subsystem.
B	Physiography	- Uniqueness - Scenic value - Scarcity - Distinctive Characters - Vulnerability - Gradients - Elevations	B - 1 B - 2 B - 3	Hilly areas with very steep slope. Undulating terrain with moderate slope. Low lands and flat areas.	• Data derived from the slope study has been incorporated with other data sources available from the Kumamoto Prefecture Basic Environmental Study (KPBE) to produce isolines on three significant conditions of physiography that stated on the left.
C	Disaster Prone Areas	- Occurrence (Incidence) - Locations - Susceptibility (Stability) - Foundation conditions	C - 1 C - 2 C - 3	Most risky & highly dangerous areas due to the phenomena of: - <i>Landslide.</i> - <i>Potential collapse of steep slopes.</i> - <i>Dangerous mountain side mud flows.</i> - <i>Dangerous land flows/collapse areas.</i> Moderate risk zone due to conditions of: - <i>Potential soil and gravel flow areas.</i> - <i>Erosion susceptible areas.</i> - <i>Steep slope areas.</i> Least risky zone.	• The zones are derived from various information such as slope study, site observations, topography maps of scale 1:25,000 and the disaster prone area map developed by the Kumamoto Prefecture Government Office.
D	Water Resources	- Availability - Quality - Environmental sensitivity	D - 1 D - 2 D - 3 D - 4 D - 5	First order streams. Main streams (Kurokawa & Shirakawa). Other importance water sources. Water catchment areas. Less drained areas.	• The zones are derived from three classes of data, i.e., the buffering of streams (50~100 meters), the buffering of water source spots (100 meters) and zoning of water resource areas.
E	Wildlife Habitat Areas	- Quantity (Scarcity) - Quality - Protected zones	E - 1 E - 2 E - 3	Wildlife protection areas. High wilderness areas. Low wilderness areas.	• The data is extracted from scarce nature map of the KPBE study.
F	Scarce Nature	- Scarcity - Value (Importance) - Types - Distributions - Availability (based on number of frequencies)	F - 1 F - 2 F - 3 F - 4 F - 5 F - 6	One feature existed. Two features existed. Three features existed. Four features existed. Five features existed. No feature existed.	• The zones are derived based on numbers of overlapping features/values. • Sources of data are from the KPBE study and have been classified according to natural landscape resources, plants community, wildlife habitat & major water bodies.
G	Outstanding Natural Resources	- Distributions - Local perceptions - Phenomena occurrence - Distinctive characters - Classes of existence	G - 1 G - 2 G - 3 G - 4 G - 5 G - 6	One value existed. Two values existed. Three values existed. Four values existed. Five values existed. No value existed.	• The zones are derived based on numbers of overlapping features/values extracted from the outstanding nature map of KPBE study.
H	Tourist Attraction & Recreation Areas	- Scenic areas - Existing public open space or institutions - Availability of values or features (in numbers) - Tangible/Intangible value - Potentiality (Prospect) - Importance	H - 1 H - 2 H - 3 H - 4 H - 5	No related features or values available. Natural environment preservation areas or underground water protection areas that related to recreational activities. One value existed outside areas of para H - 2 and included roads related to the tourism activities. Two values existed either one value located in the natural environment preservation areas and wildlife protection areas. More than two values existed.	• The classification and mapping of criteria are based on two aspects: i. The availability of values related to tourism and recreational activities such as cultural assets, hot spring, trails, volcanic view, etc. ii. Availability of natural values to enhance and promotes tourism activities. These include areas rich of natural landscape, underground water supply, wildlife habitats, flora, etc. • The derived zones are based on numbers of overlapping features/values.
I	Scenic Areas	- Visual quality - Distinctive characters - Type of features - Scenic elements	I - 1 I - 2 I - 3 I - 4 I - 5	Zone class 1 - most significant view. Zone class 2 - significant view. Zone class 3 - moderate view. Zone class 4 - least to moderate view. Zone class 5 - least view.	• Data on contours, elevations and landscape visibility study are used to determine scenic zones.
J	Landscape Visibility Zones	- Numbers of visible areas - Landform - Public or major nodes - Visual corridors - Vista (sighting) - Zones	J - 1 J - 2 J - 3 J - 4	Not visible from any sampling (observation) spots. Low visibility Moderate visibility High visibility	• The visibility study has been done using TIN and VIEW systems. The zones are derived based on visibility calculated from several vantage points located along roads of Kikuchi-Aso Skyline, National Route 57, National Route 325, Mt. Tawara and Daikanbo View Parks.
K	Forest Areas	- Quantity - Quality - Distributions - Types	K - 1 K - 2 K - 3	Forest reserved areas. Forest areas (for productions). Built-up areas (outside forest areas).	• The zones are derived from the existing land use map.
L	Prime Agriculture Lands	- Quantity - Quality - Distributions - Types	L - 1 L - 2 L - 3	Intensive agriculture lands. Other agriculture areas (less intensive). Outside agriculture areas.	• The zones are derived from the existing land use map.
M	Infrastructures	- Proximity - Distances	M - 1 M - 2 M - 3 M - 4	Existing built-up areas. Within 100 meters buffer from the existing roads & outside the built-up areas. Low populated or cultivation areas. Undeveloped areas.	• The zones are derived based on proximity to the existing infrastructures and facilities. The existing built-up areas are considered as a highest infrastructure ranking and followed by distance from the existing roads.

use factors such as agriculture and infrastructure have increased to show strong influence on C2-F value. Both cases have also kept a judgement consistency below acceptable level of 0.10. In terms of priority ranks obtained from the matrix's eigenvector, changes have been occurred in the C2 for *criteria* (See Fig. 4.) -- B, F, G, and K of P value; A, B, C, D, E, F, G, K and M of C value; and E, F, G, J and L of F value. These determinations indicated that there are *criteria*

Table 2 The C1-P criteria matrix

Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	E.V
A:	1	1	1/3	1/2	3	1	1	5	3	5	3	7	7	0.11
B:	1	1	1/2	1/4	2	1	1	5	2	3	3	5	7	0.09
C:	3	2	1	1	5	5	5	6	5	6	3	8	9	0.21
D:	2	4	1	1	3	3	3	5	3	5	1	5	5	0.15
E:	1/3	1/2	1/5	1/3	1	1/2	1	5	3	7	1	5	5	0.07
F:	1	1	1/5	1/3	2	1	1	5	3	5	2	5	5	0.09
G:	1	1	1/5	1/3	1	1	1	5	3	3	2	5	5	0.08
H:	1/5	1/5	1/6	1/5	1/5	1/5	1/5	1	1/3	1/2	1/5	3	1	0.02
I:	1/3	1/2	1/5	1/3	1/3	1/3	1/3	3	1	1	1/2	3	5	0.04
J:	1/5	1/3	1/6	1/5	1/7	1/5	1/3	2	1	1	1/5	3	2	0.03
K:	1/3	1/3	1/3	1	1	1/2	1/2	5	2	5	1	5	5	0.07
L:	1/7	1/5	1/8	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/5	1	2	0.02
M:	1/7	1/7	1/9	1/5	1/5	1/5	1/5	1	1/5	1/2	1/5	1/2	1	0.02

 λ_{max} 14.1

C.R: 0.06

Table 3 The C2-P criteria matrix

Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	E.V
A:	1	3	1/5	1	3	1	1	7	5	5	1	7	9	0.11
B:	1/3	1	1/5	1/3	1	1	1	5	2	3	1	5	7	0.07
C:	5	5	1	3	5	5	5	5	5	6	5	8	9	0.25
D:	1	3	1/3	1	3	3	3	5	5	5	1	7	9	0.14
E:	1/3	1	1/5	1/3	1	1	1	5	3	5	1	5	9	0.07
F:	1	1	1/5	1/3	1	1	1	5	3	5	2	7	9	0.09
G:	1	1	1/5	1/3	1	1	1	5	3	3	2	7	9	0.08
H:	1/7	1/5	1/6	1/5	1/5	1/5	1/5	1	1	1/2	1/5	3	5	0.02
I:	1/5	1/2	1/5	1/5	1/3	1/3	1/3	1	1	1	1/2	3	5	0.03
J:	1/5	1/3	1/6	1/5	1/5	1/5	1/3	2	1	1	1/5	3	2	0.03
K:	1	1	1/5	1	1	1/2	1/2	5	2	5	1	5	7	0.08
L:	1/7	1/5	1/8	1/5	1/5	1/5	1/5	1/3	1/3	1/3	1/5	1	2	0.01
M:	1/9	1/7	1/9	1/9	1/9	1/9	1/9	1/5	1/5	1/2	1/7	1/2	1	0.01

 λ_{max} 14.0

C.R: 0.05

in the P, C and F values deserved to be located in the appropriate ranking to show their strong influences on the values. Finally, the sub-criteria pairwise judgements also have been done pertaining to the criteria and values conditions (the results are not display here).

3.4 GIS based analysis to derive zoning

The spatial analysis and database management for the suitability and zoning has been done using the ARC/INFO, GIS package. (See Fig. 2 and Table 1.) In this study, the overlay has been done in two phases. The first phase is to get the results of LMH suitability for P, C and F values. The overlay is performed and groups of suitability are then derived from the cumulative overlay percentage to produce three composite maps. (See Table 4 for the CSI results.) The second phase is to produce a zoning map. This is done by superimposing all the three maps into one and the LMH permutations are grouped according to the proposed zoning classes illustrated in Table 5.

3.5 Results and discussion

Fig. 5 shows the existing characteristics of the Aso region. The C1 and C2 zoning maps resulted from applying the LMH permutation method with the AHP derived weights are depicted in Fig. 6 and 7. From the figures it can be observed that zone 1 (z1) covers most of the highly preserved area located along the caldera hillslopes (wall) and southern foot of the volcanic cones. Besides having natural constraints (i.e., comprised highly erosion susceptible area) the area also covers important watersheds thus, it should be preserved naturally as a part of water catchment area in the region. The z2 encompasses areas around the northern and southern caldera wall as well as the central volcano of Mount Aso. This zone possesses most scenic features and distinctive geographical characteristics for recreation. Nevertheless, the area should be highly safeguarded from any mass development that could jeopardize the existing naturalness. Both figures also show that z3 and z4 comprised the most undulating areas located at northern Kikuchi-Aso plateau and northwest portion of the central volcano. For this type of zoning, development related to tourism activities could be allowed by having appropriate planning and design guidelines. Finally, the z5 which is considered as an ordinary area and ripe for development are mostly distributed in the Aso Valley and Nango Valley. The figures also provide some decision policies regarding recreational suitability in the Aso National Park area which in turn can be formulated as a preemptive step towards protecting the existing landscape and environmental resources. To justify the effectiveness of this method, a comparative evaluation has also been made on C1 and C2 zoning areas. It can be resolved that the change

Fig.4 The ranking result based on C1 and C2 judgements.

Table 4 The CSI (Cumulative Suitability Index) results for C1 and C2

Suitability	Value P		Value C		Value F		Graph Key
	C1	C2	C1	C2	C1	C2	
Low	< 16	< 16	< 17	< 16	< 28	< 28	
Med.	16 ~ 21	16 ~ 25	17 ~ 21	16 ~ 20	28 ~ 37	28 ~ 37	
High	≥ 21	≥ 25	≥ 21	≥ 20	≥ 37	≥ 37	

Table 5 LMH permutation groups for determining zoning note4)

LMH Groups for Zoning	Zones	Zoning Descriptions
HLL, HLM, HLH and MLL	Zone 1	• High preservation area.
HHL, HHM, HHH, HML, HMM, MHL and MML	Zone 2	• High resources based recreational area.
HMH, MHM, MHH, MMM, MMH, LHH, LHM, LHL, LML, LMM and LMH	Zone 3	• Intermediate resources based recreational area.
MLM, MLH, LMH and LLL	Zone 4	• Active recreational area.
LLM and LLH	Zone 5	• High facility area or urban based recreational area.

Fig. 5 The existing characteristics of study area

of sizes occurred from C1 to C2 is -- down 0.01% for $z1$, up 3.08% for $z2$, up 4.0% for $z3$, down 0.83% for $z4$ and down 6.24% for $z5$. This means that most of the previous identified ordinary land ($z5$) has been taken up for conservation and as a result $z3$ and $z4$ gained more recreational areas. (Refer Fig. 8.) A minor decreased in $z1$ area has contributed additional land for $z2$. Due to this, there are more areas could be included as recreational potential instead of totally prohibited in the $z1$ case.

4. Conclusion

We may conclude from the foregoing analysis that zoning map and policy can be effectively developed through a quantitative spatial analysis within a framework of AHP-GIS application. It can be conceived from the case study; (1) the AHP method provides a function to evaluate and interface different dimension of zoning parameters through pairwise judgements and also keeping the judgement consistency which is difficult to conduct in the manual methods; (2) an integrated AHP-GIS approach assists to analyze

Fig. 6 Zoning for C1 result

Fig. 7 Zoning for C2 result

Fig. 8 Change of zoning areas for C1 and C2

multitude of zoning factors for policy making. These include quantify parameter importance within a framework of hierarchy, computes weights and overlays vast map features; (3) The approach develops 'one map interprets many meanings and forms' map. In this map, zoning can be interpreted and defined variously to show different conditions of land suitability for recreation; (4) the wide variety of factors with different suitability zone units that overlaid in a composite map helps to trace appropriate boundary for zoning; and (5) the method also provides a framework for updating,

evaluating and modifying zoning when there is a change of information. This expedites the zoning development.

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Note

- 1) The MCDM technique used in the prior publication was based on the combination of Saaty's AHP and McHarg's landuse-environment compatibility method and the judgement scales have been adjusted according to the 'importance-compatibility' condition. This has led to two different evaluation's conditions, the first is related to the measuring of strength of influences among parameters and the second is on determining the degree of compatibility between hierarchy levels. In the previous method, judgement consistency is not measured and overlay weights are only assigned to the compatible parameters in the hierarchy²⁰⁾.

- 2) The basic requirement of Saaty's AHP analysis is the construction of an evaluation matrix A ($n \times n$ matrix) in the form:

$$A = (a_{ij}) \quad i, j = 1, 2, 3, \dots, n \quad (1)$$

$$\text{where,} \quad a_{ij} = w_i / w_j \quad \text{for } i, j = 1, 2, 3, \dots, n; \quad (w \text{ is the judgement weight}) \quad (2)$$

$$\text{The reciprocal of the matrix is} \quad a_{ij} = 1 / a_{ji} \quad (3)$$

If C_i is judged to be of equal relative importance as C_j , then $a_{ij} = 1$ and $a_{ji} = 1$. The diagonal entries are unity,

$$a_{ii} = 1 \quad \text{for all } i \quad (4)$$

The matrix A is consistent if w is known, that is:

$$a_{ik} = a_{ij} \circ a_{jk} \quad \text{for all } i, j, k \quad (5)$$

$$\text{If equation (4) applies, then:} \quad \sum_{i=1}^n \lambda_i = n \quad (6)$$

that is, in the consistent case, n is the largest eigenvalue of A . This property also provides a measure of the accuracy of the estimation λ_{max} and w . The closer the value of λ_{max} to n (i.e., the number of criteria in the evaluation matrix) the more consistent is the result. In other word, if A is consistent, the small variations of the a_{ij} keep the largest eigenvalue, λ_{max} close to n . When there is inconsistency $\lambda_{max} > n$. If A is the matrix of pairwise comparison values, in order to find the priority vector, we must find the vector w (E.V) which satisfies:

$$Aw = \lambda_{max} w \quad (7)$$

A unique solution is obtained upon normalization of w ; each w_i entry is divided by the column total:

$$\sum_{i=1}^n w_i = 1 \quad \text{for } i = 1, \dots, n. \quad (8)$$

Hence, deviation from consistency is measured by an index called *consistency index* (C.I):

$$C.I = (\lambda_{max} - n) / (n - 1) \quad (9)$$

This value is then compared with its average value or *random index* (R.I) that derived from the Saaty's scale. The ratio of C.I to the average R.I for the same order matrix is called the *consistency ratio* (C.R). This comparison (i.e., $C.R = C.I / R.I$) indicates whether the ratio estimates in the pairwise comparison matrix is closer to being logically consistent or random. In the AHP method the maximum limit of C.R is 0.10 which considered acceptable as consistent. (See Saaty 1980 & 1987 and Zahedi 1986.)

- 3) Eigenvector (E.V) is a vector of priority from the given matrix. In the AHP, eigenvector (vector of priorities) is termed as a normalized value of a set of calculated parameters. While, eigenvalue or principle value (λ_{max}) is calculated from the sum of the vector components and divided by the number of components that is used to estimate the matrix's consistency.
- 4) A hypothetical model of LMH permutation groups is based on preservation, conservation and facility suitability order. Further study on this grouping to produce appropriate zones will be done in the future.

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和文要約

1. はじめに

自然地の開発においては、土地条件に関する多くの環境的、人為的要因を場所と対応付けながら総合的に評価する作業が重要である。しかも多様な視点からの検討が求められている。このような課題に対して、主題図を迅速かつ効率的に作成、更新、重ね合わせなどの分析・処理が容易に行なえるGISを活用し、また、土地分級の過程においては多基準意思決定法(MCDM: Multi Criteria Decision Making)を導入する試みが多く報告されている。特に、単一の主題図の多視点からの評価、複数の主題図間の評価基準の統合、等にMCDM導入の効果が期待されている。

従来の、自然地の土地利用計画のための土地分級の作業手法は、以下のような問題点が指摘できる。

- ①主題図作成や更新の作業は繁雑であり、土地分級のベースとなるべき多くの地図資料を分析に活用できない
- ②土地利用現況や行政界などの人為的境界が、土地分級の重要な基準の一つになっており、計画においてもこれらの制約を受けて、土地条件に十分対応した区分を設定できない
- ③主題図の縮尺が様々であり、土地利用計画の目的に応じて変更することが困難である
- ④ゾーニングのポリシーは時代と共に変化するものであり、政策的価値基準の変更に柔軟に対応できるシステム構成が求められている
- ⑤判断基準の異なる情報を統合する手法が導入されていなかったため、複数の情報を同一基準で評価できなかった

本研究は上記の諸問題に対して、MCDMの手法の中からSaatyの提案したAHP(Analytical Hierarchy Process)を採用し、AHPとGISを統合した土地利用計画支援手法の提案を目的とする。具体的には、自然地の開発におけるレクリエーション土地利用の可能性と潜在性に着目し、

- ①土地利用適性の分級に関わる様々な要因を土地の評価基準に対応させる手法、
 - ②AHPを用いて、考慮すべき要因相互の評価の重み付けを調整する手法、
 - ③GISのオーバーレイの機能を用い、評価結果を統合した土地分級図を作成する手法、
- について検討することであり、複雑な要因を考慮しながら

ら計画を進めるための作業手法を提案する。本報では、手法の提案と、熊本県阿蘇地域におけるレクリエーション土地利用計画支援のケーススタディを通じた有効性の検討について報告する。

なお、本論文は、既報^{1,2)}に提案した手法を発展させ、オーバーレイウェイトの配分および評価マトリクスの整合性の保持に関して改善を行なったものである。

2. システムの概要

近年のレクリエーション開発は、対象地の自然や景観が地域の環境資源であるとの認識から、その保全を充分考慮することが社会的な要請となっている。本研究においても、自然資源、景観資源等を重視したレクリエーション適性の評価を考慮している。

本研究で提案した、AHPを用いたレクリエーション土地利用計画のための土地分級手法の評価ダイアグラムはFig. 1に示すものである。評価は4段階の階層からなり、レベル1の土地利用目的はレクリエーション利用に固定している。レベル2では、保全地域(P: Preservation)、保全型開発地域(C: Conservation)、開発型地域(F: Facility)の3種類の評価視点間の評価の統合を行なう。ここで、保全地域とは、高い自然的価値を持つ地域であり、保全型開発地域とは文化的価値を有する地域、開発型地域とは、一般的用途の建物等の人為的利用に必要な都市基盤整備の受け入れに適すると判断される地域である。この考え方は、従来の保全か開発かという2者択一的な判断ではなく、自然や文化遺産との共生といった多段階の適性基準を導入するものである。レベル3では各種の主題図間の評価がレベル2の視点から統合される。ここでは、地形や、自然資源、景観等の環境要因と、土地利用等の文化的、人為的要因を併せて考慮することになる。レベル4では各主題図に示された土地分類項目間の評価を統合する。

これらの各レベルの評価は、AHPの手法を適用することで一対比較の形式に還元されるため、評価基準の異なる視点間や主題図間、土地分類項目相互の重要度を、整合性をチェックしながら評価することができる。

上記の過程で作成された評価結果は、レベル4の"Sub-Criteria"単位に属性として保持され、GISの機能を用いて複数の主題図をオーバーレイすることによって、土地分級を行なう。この間のデータ処理のフレームをFig. 2に示す。

3. 阿蘇地域におけるケーススタディ

3. 1 ケーススタディの対象地

ケーススタディの対象とした阿蘇地域は、昭和9年に国立公園に指定され、同時に土地利用分級が定められた。その後、1986年まで土地利用分級は幾たびか改定され、現在は特別保護地域（開発の全面規制）から、普通地域（開発規制なし）までの5段階に分けられている。

今回の検討には、熊本県環境保全局が作成した「熊本県環境特性図」をベースとして、地形図やGISの機能を用いて作成した、Tab. 1に示す13（A～M）の環境要因に関するデータを作成した。

3. 2 ケースの設定

ケーススタディは、レクリエーション土地利用の適性に関して標準的と考えられる評価と、P、C、Fそれぞれの観点からの特徴を強調した評価の2つのケースを仮定した。そして、評価の差異が土地分級にどのように反映されるかを通して、手法の有効性を検討した。

ここで、ケース間の評価の変更は、Fig. 1のダイアグラムのレベル3の“Criteria”マトリクスを対象として行なった。これは、レベル3のマトリクスが、

①全階層中で最大のものであり、変更の影響を予測し難いこと、

②主題図間の土地利用適合性の比較という、評価の整合性を特に考慮する必要があること、

③評価結果がレベル2の評価マトリクスのパラメータに大きく影響すること、

等の理由による。例として、Tab. 2とTab. 3にPの評価マトリクスを示す。両ケース共にC、R（Consistency Ratio）値は0.1を下回っており、評価の整合性が保たれていることを示している。また、この変更に伴う各評価要因の評価ウェイトの順位の変動をFig. 4に示す。上記のマトリクスの変更が、土地利用適性の評価に及ぼす影響が端的に示されたことが読み取れる。

今回の報告では、評価結果を土地分級図に統合するために、2種類のオーバーレイを用いた。第1は、P、C、Fの各評価をL（Low）、M（Medium）、H（High）の評価値に分割するものであり、P、C、F別に作成したオーバーレイマップのサブゾーン別の面積を累積し、全体を等分割する評価値の境界を設定した（Tab. 4）。第2は、最終的な土地分級図を作成するものであり、P、C、Fの主題図を合成するために上記のL、M、Hの評価値の組み合わせを、Tab. 5に示す分類を仮定して、5種類の土地利用分級に統合した。

なお、AHPを用いた各パラメータの重要度の評価は9段階とし、1：同じように重要、3：やや重要、5：かなり重要、7：非常に重要、9：極めて重要、として2、4、6、8、はそれらの中間値とした。また、本研究では、GISのプラットフォームとしてARC/INFO

FOを用いた。

3. 3 結果の考察

Fig. 5に阿蘇地域の地形を示す。ケーススタディで作成したレクリエーション土地利用適性図の、ケース1をFig. 6に、ケース2をFig. 7に示す。

2つのケース共に全体としては、最も保全が望まれるゾーン1はカルデラ壁面と中央火口の南斜面に分布し、自然に配慮したレクリエーション利用が可能なゾーン2は、カルデラの斜面全域と中央火口付近に広がっており、景観的に優れた地域に対応している。よりアクティブなレクリエーション利用に適したゾーン3とゾーン4は、菊地阿蘇高原と中央火口丘北西部に分布し、人為的土地利用や施設開発を適切に誘導すべき地域を示している。一般的開発に適した地域を示すゾーン5は、南郷谷と阿蘇谷と呼ばれる平坦地に広がっており、現状でも都市的土地利用が進んでいる。

詳細に見ると、ケース1に比してケース2はゾーン2と3が増加しており、開発適地であるゾーン5が大きく減少し、ゾーン1も僅かながら減少している。これは、地域の特性を強調して評価するという政策的価値の変更によって、利用形態に注意が必要であるが、レクリエーション土地利用の可能性が増加していることを示す結果となっている。

4. 結論

上記に見るように、AHPの手法とGISを用いた地図のオーバーレイ機能を組み合わせる手法が、複雑な要因間の関係を考慮した土地利用適性の評価と、総合的な土地分級図の作成に優れた手法として利用できることを示した。本研究で提案した手法の利点をまとめると次の通りである。

（1）土地利用適性に係わる要因のように価値基準の異なる指標間の評価の統合を、一対比較に還元して行なうAHPの導入によって、評価の整合性を保ちながら行なうことができる

（2）ゾーニングのための評価基準を階層的に扱うことで、環境要因間の関係を階層別のマトリクスとして整理でき、多くの条件を考慮することができる

（3）単一の主題図を複数の視点から評価し、それらを上位の目的に対応して統合できる

（4）詳細な土地分類が評価基準の体系に対応づけられ、その評価結果をオーバーレイすることで、きめ細かい土地分級の境界設定が可能となる

（5）土地分級のための評価構造が地図情報と独立しているため、環境要因のデータが更新されても、評価構造を変えなければ土地利用適性の分級が速やかに更新できる