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DIGITAL ANALYSIS FOR EVALUATING FUNCTIONS OF FOREST AND AGRICULTURAL LANDS IN A WATERSHED

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ABSTRACT

Digital analysis was used to evaluate functions of forest and agricultural lands for managing watershed environment in the Sakawa (about 670km^2). This study concentrated on the following eight environmental preservation functions :

(a) water conservation function
(b) flood prevention function
(c) water purification function for nitrogen
(d) water purification function for phosphorus
(e) landfall prevention function
(f) soil erosion prevention function
(g) pollutant purification function (decomposition of waste organic matter)
(h) habitation comfortability function.

Many existing environmental data were collected : Landsat MSS data, climate data, ground water maps, soil type maps, geographycal maps, numerical data of the Digital National Land Information, etc.. All these data were stored as 50m grid cells in a UTM coordinates database system.

Each environmental preservation function was digitally evaluated in pixel by pixel base according to the methods which had been reported by other researche workshops. And eight function images were generated.

The watershed Sakawa was divided into fifteen compartments and comparison of the characteristics of these compartements was made collectivelly in consideration of the situations of environmental preservation functions.

INTRODUCTION

In Japan, one of regional boundaries of human activities is a watershed and/or watershed compartments, and then management policy of watershed environment is thought to be very important in forestry planning and in national land use planning.

With the evolution of remote sensing technology and that of geographic information system (GIS) technology, the integration of these two technology is found to be very efficient to monitor natural resources and environmental conditions.

Regarding these technological progress, this paper gives an overview on development of methodology for evaluationg environmental preservation functions of forest and agricultural lands which will be useful for watershed management.

Evaluation equations of environmental preservation functions have been developed cooperatively with many specialists on each field. This study has been carried out in a research project of the Ministry of Agriculture, Forestry and Fisheries through 1982 to 1988.

The procedure employed in this study can be extended to other watersheds in Japan.

STUDY AREA

The river Sakawa is found in the central Japan and runs through two prefectures, Kanagawa nad Shizuoka, and its watershed has an area of approximately 670 km^2. And boundaries of fifteen watershed compartments were delineated in consideration of topographic conditions and tributaries. The sources of the Sakawa are in the Mt. Fuji and the Tanzawa mountaneous region.

Geological characteristics and soil conditions of this area have been strongly influenced by eruptions of the Mt. Fuji.

In the middle of this watershed, the Lake Tanzawa was formed to provide hydroelectric power and to control continuous water supply to agricultural fields and cities in Kanagawa prefecture.

About 70% of this area are covered with forests. One of the major problems of these forests is expansions of landslides which have been caused by earthquakes.

DATABASE CONSTRUCTION

For evaluating the environmental preservation functions of forests and agricultural fields in a watershed, various kinds of information are needed to be analysed collectively. And the integration of remote sensing data and geographic information is essential for effective analysis.

A database of physical characteristics and climatic conditions of the watershed Sakawa was constructed for this study. In order to create a computer database that could be utilized with

Figure 1. Location of the study area

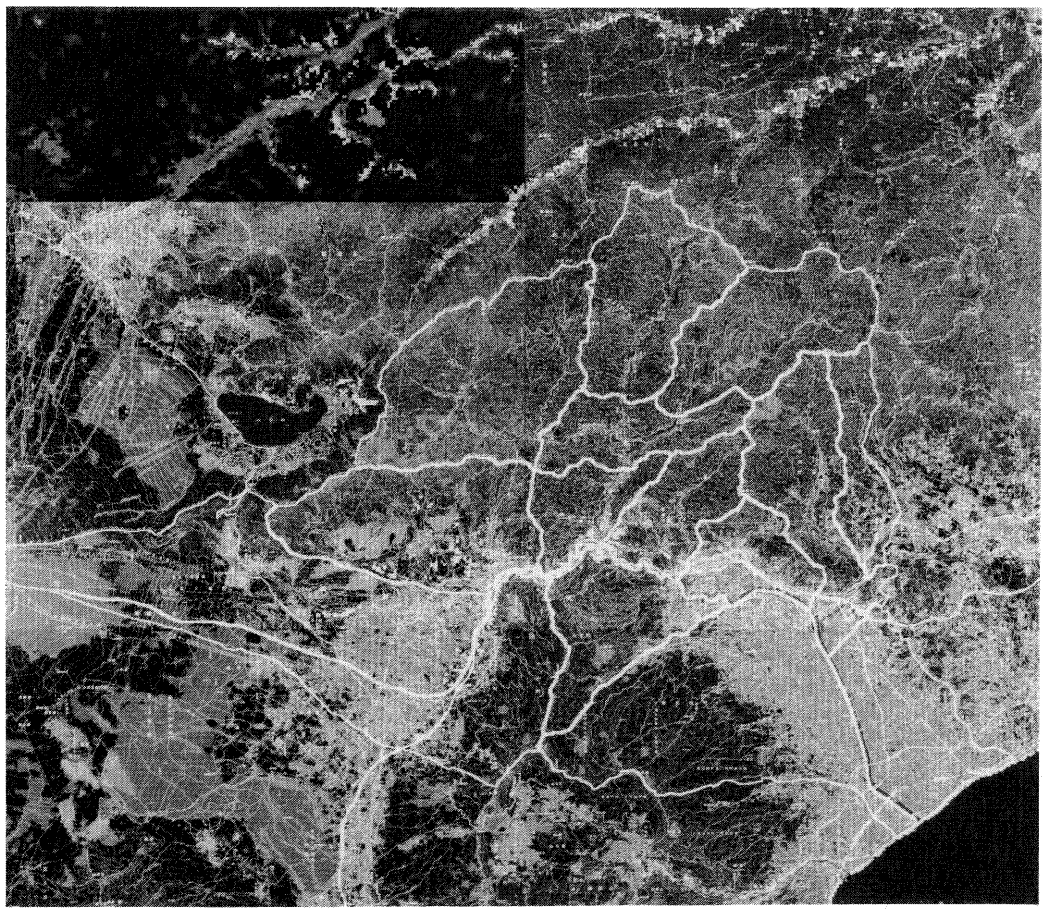


Figure 2. Land use data overlayed with a geological map and boundary lines of the fifteen watershed compartments

Table 1. Data and their sources stored in the database system

Data	abbrev.	Source material or map
Surface cover type	SU	LANDSAT
Land use	LU	D.N.L.I. and Surface cover type data
Relief (Land form)	RE	D.N.L.I.
Ground elevation	GE	D.N.L.I.
Slope angle	SA	Ground elevation data
Slope direction	SD	Ground elevation data
Surface geology	SG	D.N.L.I.
Soil class	SC	D.N.L.I.
Soil type	ST	Soil type map
Amount of rainfall	RA	Weather report
Temparature	TE	Weather report
Ground water level	GW	Ground survey
Watershed boundary	WB	Topographical map
Permeability of soil	PES	Soil class and Land use
Permeability of surface geology	PSG	Surface geology data
Water-hoding capacity of surface geology	WHS	Surface geology data
Denitrification	DEN	Land use data
N-absorption of vegetation	NAV	Land use data
P-absorption of vegetation	PAV	Land use data
N-absorption of soil	NAS	Soil class and Land use data
P-absorption of soil	PAS	Soil type and Land use data
Soil loss	SOL	Relief data
Permeability of N	PEN	Surface geology data
Permeability of P	PEP	Surface geology data
Vegetation cover rate	VEG	Surface cover type data
Soil grain size	SGS	Soil class

(D.N.L.I. :Digital National Land Information)

Table 2. Equations and data used for evaluating the environmental preservation functions

Water Conservation <<---	(water supply) & (water acceptance)
$(\{RA\}+\{LU\}+\{RE\}) * (\{PES\}+(\{PSG\}*\{WHS\})^{1/3})^{1/2}$	
Flood Prevention <<---	(permeability) & (water reservation)
$\{SG\}+\{SA\}+\{RE\}+\{LU\}+\{SC\}+\{RA\}$	
Water Purification (N) <<---	(denitrification) & (removal)
$(\{PES\}+\{NAV\}+\{NAS\}) * (\{SOL\}+\{PEN\})$	
Water Purification (P) <<---	(absorption) & (removal)
$(\{PAV\}+\{PAS\}) * (\{SOL\}+\{PEP\})$	
Land Fall Prevention <<---	(climate),(topography)&(surface)
$\{SG\}+\{RE\}+\{SA\}+\{LU\}+\{RA\}+\{GE\}+\{SD\}+\{VEG\}+\{SU\}$	
Soil Erosion Prevention <<---	(climate),(topography)&(soil)
$\{RA\}*\{SA\}*\{LU\} * (\{SC\}+\{SGS\})$	
Pollutant Purification : Decomposition of waste organic matter <<---	(climate) & (surface condition)
$(\{TE\}+\{RA\}+\{SC\}) * \{SA\}*\{LU\}$	
Habitation Comfortability <<---	(land use) & (topography)
$\{LU\}+\{SU\}+\{SA\}$	

Abbreviations of data name shown in the Table 1 are used
{ } means a one-dimensional linear function

various data sets to evaluate functions of natural resources, all data sets were converted to a raster format compatible with the cell-based software available for the FIAS (Forestry Image Analysis System).

Data of the Digital National Land Information (D.N.L.I.) and many sorts of map sheets (geographical maps, land use maps, soil type maps, geological maps, vagetation maps on scales of 1:5,000 to 1:50,000), aerial photographs and digital Landsat MSS were collected.

These data were stored in 50m grid cell database system. Data of D.N.L.I. which employs the latitude-longitudial map projection system were also converted to the Universal Transverse Mercator projection.

Universal Transverse Mercator projection maps of the study area, such as soil type maps and ground water level maps, and the watershed boundaries were digitized using a digitizing table. These vector map products were converted to raster format (50m grid cell) to form a cartographic database for the 670 km^2 study area. Land cover type classification was performed with the digital Landsat MSS data and the result was also stored in the database system.

Table 1 shows the data used in this study and their original sources.

Because all of the data sets were registered to the same Universal Transverse Mercator projection grid, data could be extracted for each plot from the raster data sets.

FUNCTIONS EVALUATED

The analysis was carried out on the FIAS (Forestry Image Analysis System) which has been developed in these ten years in the Forestry and Forest Products Research Institut in Tsukuba, which belongs to the Ministry of Agriculture, Forestry and Fisheries.

The following eight environmental preservation functions were selected for this study and each of them were evaluated according to several factors:

(a)Water conservation function (WCF):
factors; possibility of water supply and
capacity of water acceptance

(b)Flood prevention function (FPF):
factors; permeability and
water reservation capacity

(c)Water purification function for nitrogen (WPFN):
factors; denitrification capability ,
nitrogen absorption capability of vegetation, and
nitrogen absorption capability of soil

This function indicates the capacity of a plot for purifying water quality which is polluted by materials introduced in a watershed neither for forestry nor for agriculture.

(d)Water purification function for phosphorus (WPFP):
factors; phosphorus absorption capability of vegetation and phosphorus absorption capability of soil
The concept of this function is considered almost the same as the function above.
(e)Landfall prevention function (LFPF):
factors; climate(amount of rain fall), geology, soil, topography, and surface cover(vegetation etc.)
(f)Soil erosion function (SEF):
factors; climate, topography, soil, and land use
There rest influences of agricultural management method and land erosin control policy
(g)Pollutant purification function (PPF):
factors; climate, soil, topography, and land use
(h)Habitation comfortability function (HCF):
factors; vegetation condition and slope inclination angle.

Each concept of equation had been deliberated by specialists. But there were some factors which were too difficult to obtain in the present technological situations, and some of the factors were needed to be replaced by another data which were relatively easy to get. This procedure was made cooperatively with many scientists.

The table 2 summarizes the concepts of evaluations and the data which were used for digital evaluations of the functions for this study.

A categorical evaluation method was employed for the calculation results of the equations which gave real numbers. And four to six categorical classes were given for each function using threshold values between classes.

These categorical classes were given by specialists and were considerd to be effective for most watersheds in Japan.

EVALUATION AND RESULT

With the equations and method described above, an image named "category image" was generated for each function. A category image shows categorical classes of evaluated environmental preservation function in pixel by pixel base.

The number of categorical classes and the percentage of pixels of each class in the watershed are summarized in the Table 3. From this table it is easily noticed that the watershed Sakawa has very poor capacity in pollutant purification and very good capacity in soil erosion preservation.

Rates of pixels of categorical classes in a compartment were calculated from a category image and were summarized in a table. With this table, the characteristics of the fifteen watershed compartments were analysed and the compartments were classified into following four types regarding environmental preservation capacity as shown in the figure 3:

type 1 ; relatively low capacity
type 2 ; medium capacity
type 3 ; relatively high capacity
type 4 ; mixed (no peculiarity)

The figure 3 summarizes ,as an example, the method of evaluation of the compartments on the water purification function for nitrogen. And tables and images which were generated during the procedure are also shown.

With these methods, each compartment was evaluated on the eight functions (figure 4)and the results were summarized in the table 4. From this table, the characteristics of a compartment is obtained. For example, the watershed No.1 is good in flood preservation, landfall preservation, and soil erosion but is not good in habitation comfortability.

Using this table, characteristics of compartment can also be compared with each other. A simple method was used for calculating similarities between watershed compartments as described in the table 4. And the result is shown in the figure 5.

CONCLUSION

The integration of remote sensing data and database technologies allowed the utilization of a database to evaluate environmental preservation functions in a watershed.

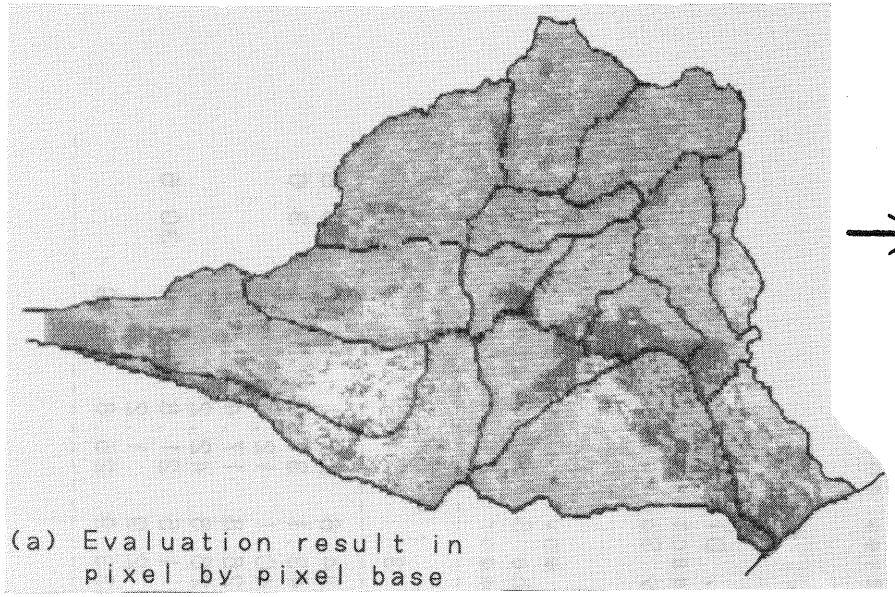
The procedure employed in this study will be adaptable to other watersheds in Japan. And it will also be very effective to monitor and simurate the changes of environmental preservation functions caused by expansions of cities and/or developments of forests.

REFERENCE

Sawada, H., I.Ohnuki, Y.Awaya (1983), Digital Image Processing for Watershed Environment,Transactions of th 94th Annual Meeting of the Japanese Forestry Society

Table 3 Evaluation results of environmental preservation functions in the Sakawa watershed (% appeared in each categorical class)

function	number of classes	(inferior) class 1	2	3	4	5	(superior) 6
(a) WCF	6	1.3	24.8	34.6	22.1	17.6	0.6
(b) FPF	6	2.4	9.5	43.1	31.0	11.0	3.0
(c) WPFN	5	16.4	26.6	40.1	12.7	4.1	
(d) WPFP	5	13.5	25.4	26.8	17.4	16.7	
(e) LFPF	5	4.1	23.2	26.8	42.2	3.7	
(f) SEPF	6	1.6	1.7	1.5	21.8	41.4	30.6
(g) PPF	4	71.4	24.3	2.9	1.2		
(h) HCF	5	9.6	26.8	33.9	25.8	3.9	



(a) Evaluation result in pixel by pixel base

Evaluation result of water purification function (WPFN) of each compartment (rate of pixels assined to each class in a compartment, %)

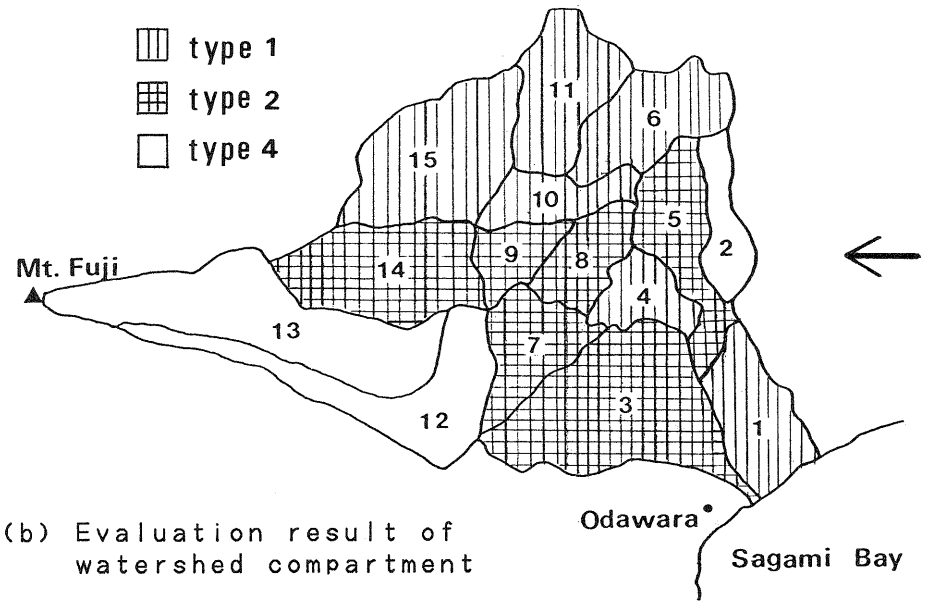
class	watershed compartment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total area
1	38	4	21	46	15	4	19	13	15	6	4	19	23	9	7	16
2	11	29	8	8	22	72	12	17	13	52	65	11	15	26	51	27
3	33	44	51	40	54	17	55	61	64	36	23	37	35	48	30	40
4	15	20	17	5	8	7	13	8	7	5	8	20	14	14	12	13
5	3	3	3	1	1	0	0	2	1	1	0	13	13	3	0	4

level of environmental preservation capacity
class 1 : very low class 2 : low
class 3 : medium class 4 : high
class 5 : very high

Distribution types of evaluated classes of each compartment

watershed compartment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total area
1	4	2	1	2	1	2	2	2	1	1	4	4	2	1	1

environmental preservation capacity of a compartment
type 1 :relatively low (>80% in class 1, 2 & 3)
type 2 :medium (>50% in class 3)
type 3 :relatively high (>80% in class 3, 4 & 5)
type 4 :mixed (other case)



(b) Evaluation result of watershed compartment

Figure 3. Flow of evaluation of an environmental preservation function of watershed compartments (example of the water purification function for nitrogen)

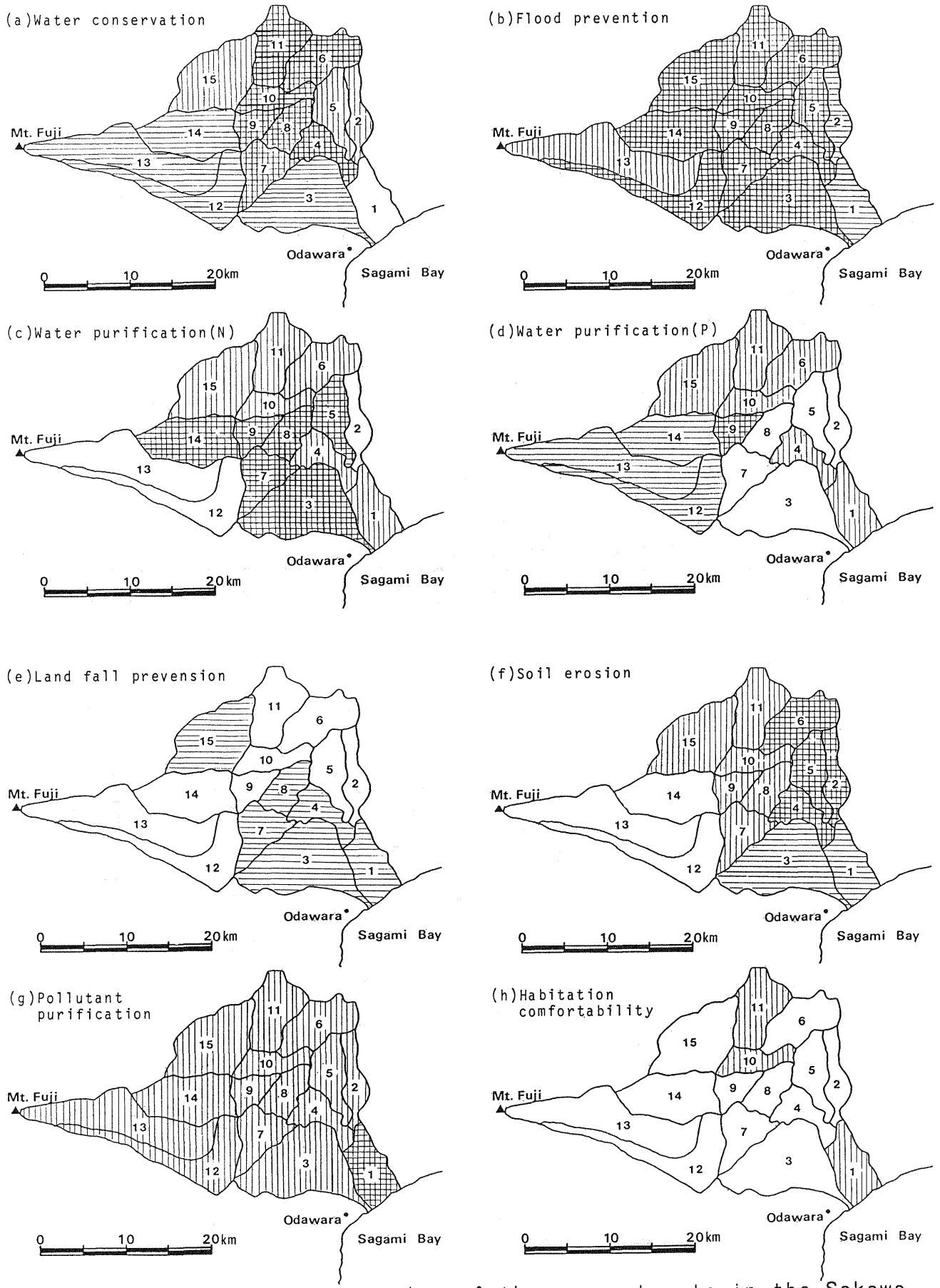


Figure 4. Evaluation results of the compartments in the Sakawa watershed on the eight environmental preservation functions (categories are the same as that of figure 3)

Table 4 Evaluation results of environmental preservation functions in watershed compartments

function	watershed compartment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
water cons. (WCF)	4	1	3	2	1	2	2	2	2	2	2	3	3	3	1
flood prev. (FPF)	3	3	2	2	2	2	2	2	2	2	2	2	1	2	2
water pur.N (WPFN)	1	4	2	1	2	1	2	2	2	1	1	4	4	2	1
water pur.P (WPFP)	1	4	4	1	4	1	4	4	2	1	1	3	3	3	1
land fall p.(LFPF)	3	4	3	3	4	4	3	3	4	4	4	3	4	4	3
soil erosion(SEPF)	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
pollut. pur.(PPF)	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
habit. comf.(HCF)	1	4	4	4	4	4	4	4	4	1	1	4	4	4	4
Total Number of 1s	3	2	1	3	2	3	1	1	1	4	4	1	2	1	4
Number of 3s	3	2	3	2	1	1	2	2	0	1	1	4	3	3	2
group based on the similarity > 6.5	a	b	c	d	b	d	c	c	e	d	d	c	f	f	d

Similarity of evaluated types of environmental preservation functions (SM) is estimated by the following equation:

$$SM = \sum_{k=1}^{8} \{F_{ij}\}_k$$

where $\{F_{ij}\}_k$: 1 if $\{function\}_{ki} = \{function\}_{kj}$
0.5 if $\{function\}_{ki} = 2$ and $\{function\}_{kj} = 4$
if $\{function\}_{ki} = 4$ and $\{function\}_{kj} = 2$
0 another case
i,j : Compartment number
k : number of environmental preservation function
$\{function\}_k$: evaluated type of environmental preservation function k (Fig.3)

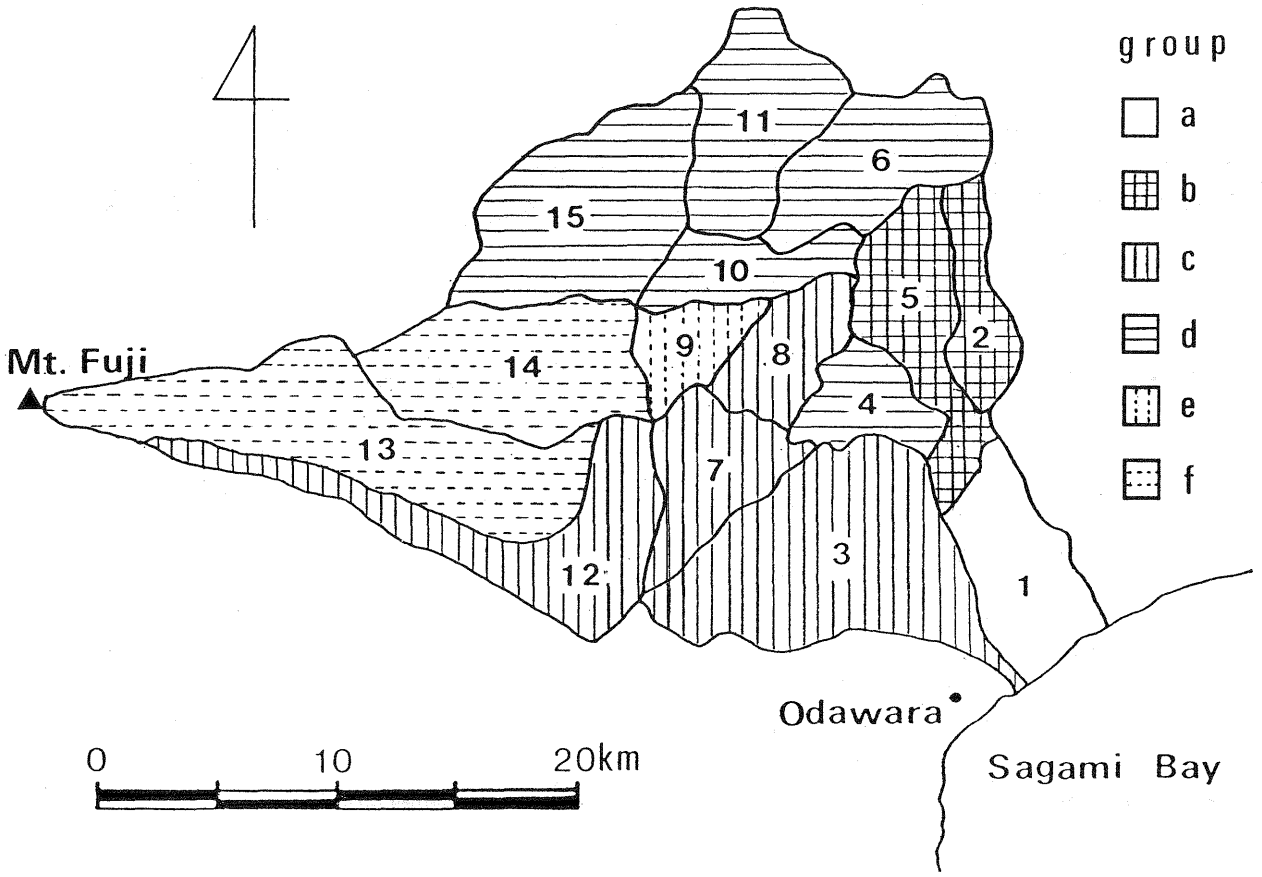


Figure 5 Result of grouping of compartments by the similality based on the table 4