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THE FOREST RESOURCES MANAGEMENT STUDY IN THE REPUBLIC OF COLOMBIA

REPORT ON THE RESULTS OF REMOTE SENSING ANALYSIS

AUGUST 1985

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

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Glossary of Remote Sensing Terminology

Words	Explanation
Remote sensing	Technology to collect information on the objects and phenomena from a remote place without directly touching them and to identify or analyze such objects and phenomena.
LANDSAT	The artificial satellites LANDSAT are earth observation satellite, the first of which was launched in July 1972 under the name of ERTS. So far No. 1 - No. 5 satellites have been lanuched.
MSS	Artificial satellite LANDSAT is mounted with sensor called MSS (Multi Spectral Scanner). MSS scans and records the area of 180Km x 180Km as one scene by 4 wavelength bands of visual ray range (green and red) and near infrared range. Minimum resolution is 80m.
Brightness correction	When the image is compared by using the LANDSAT data of 2 different times, the tone of each image must be adjusted. This adjustment is called brightness correction.
Geometric correction	Original data of LANDSAT have various kind of deformation. Geometric correction is to transform the coordinates so that the original data should coincide with the positional relation of geomorphological map.
False color image	LANDSAT MSS data are composed of 4 bands. The false color image is made by color synthesis applying color filters on these data. The false color image expresses the vegetation in red color, and is used for vegetation survey and land use survey.
Ground cover Classification	The objects on the earth surface have unique spectrum property respectively. The ground cover classification means to classify city, farm land, water area, forest and grassland by statistic method taking advantages of this unique property.
Preliminary Processing	This is an image processing carried out to remote sensing data prior to the analysis, such as brightness correction and geometric correction.
Ground control point	This is a point which clearly corresponds between the image and geomorphological map used in geometric correction.
Affine transformation	This is a linear transformation equation, a kind of coordinates transformation formula, which is used in geometric correction.

Word	Explanation
Re-sampling	This means to re-distribute the pixels basing on coordinates transformation formula and by converting image data
Nearest neighbor method	A kind of methods to re-sample data
Least square method	A method to seek for the assumed value which minimizes the sum of square of the balance between assumed value and actual measured value
Rectangular coordinate system	By employing the rectangular coordinate system, it becomes possible to coincide with the mesh of image data.
Transformation coefficient	$a_1 - a_4$ express the revolution and magnification, while $a_5 - a_6$ express the displacement volume.
Training area	Training area is an area of image where items of ground coverage is clearly known in advance. Classification is made basing on the statistical value in this area.
Property of near infrared ray	The reflection rate of near infrared ray becomes higher as the activity of plant is stronger. As near infrared is expressed in red color in the false color image, the color red becomes stronger when the activity of plant is strong.
Ground truth	Each kind of information obtained through the field survey.
Most likelihood method	A kind of statistical method to classify basing on the likelihood of data basing on the assumption that data shows normal distribution.
Image classification	To classify the ground cover by the automatic identification of computer by inputting the training area basing on the result of ground truth.
Image interpretation	To interpret and judge the false color image of LANDSAT by the eyes and brain (knowledges) of analyzer.

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SUMMARY

Summary

Outline of the Study

1. This study has been carried out for the purpose to scientifically grasp the present state of forest distribution and land use at the Central Reserved Forest in Andes region as well as their changes using the LANDSAT data, to establish the techniques necessary therefor, and to transfer such techniques to Colombia.

The object area of this study was the area of 1,600,000 ha. in Central Reserved Forest (study area), but analysis was carried out on the peripheral areas too. Therefore, the areas analyzed totaled to 1,918,300 ha., and we determined this area to be the object area of this study.

2. The study was carried out over 2 years of first study year and second study year.

(1) Preparatory works in Japan and field survey at the actual site were carried out in the first study year. In the preparatory works, we made false color images (refer to 3.3 of this report) and primary ground cover classification (refer to 3.4) which would be the basic materials for the field survey. The field survey was performed from January 14 to March 25, 1989. The investigation for creating image identification standard (refer to 4.1) and investigation for ground cover classification (refer to 4.2) were carried out in the field survey. Basing on the results of these investigations, we discussed about the image identification.

(2) In the second study year, we carried out analytical works in Japan such as summary and analysis of field survey, secondary ground cover classification, creation of LANDSAT analysis map and preparation of the report (refer to 5. Analytical works in Japan). In this investigation, analysis was made on the situation of land use and vegetation in the study object area and their secular changes (refer to 6. Analysis on the study result).

3. The LANDSAT data used for this study are 4 scenes as shown in Table 1. All the LANDSAT data used were in the form of magnetic tape which can be processed by computer, and we selected the scenes of the most proper observation dates. The LANDSAT data were obtained for the purpose to grasp the land use and vegetation as well as the secular change of them. Therefore, we obtained the data of 2 different times of 1970's and 1980's. Please refer to the annexed materials for the details of LANDSAT data (Annexed material 2.

Remote sensing and Glossary of Remote Sensing Terminology are shown in front of the Table of Contents).

4. The topographic maps used for this study were the navigation maps issued by National Ocean Survey of the United States ("L-26" scaled in 1/1,000,000) and the topographic maps of each state. The navigation maps were used (1) to select map coordinate systems used for the geometric correction of LANDSAT data, (2) to select the ground control points necessary for the geometric correction, and (3) to mosaic each of the LANDSAT scenes. On the other hand, the topographic maps of each state were used (1) to sum up the area of land use and vegetation by the classification items, (2) to grasp the topographic features of each state. In addition to these, we collected as many materials as possible during the field survey (refer to 1.7 of this report).

Table 1. LANDSAT data used

Time	Sensor	LANDSAT No.	PATH-ROW	Observation date	Cloud volume (%)
Old	MSS	L-2	9-56	1977. 9.17	50%
	"	L-1	9-57	1976. 2. 1	20%
	"	L-1	9-58	1976. 2. 1	30%
	"	L-1	9-59	1976. 2. 1	30%
NEW	"	L-4	9-56	1987.12.24	30%
	"	L-4	9-57	1987.12.24	20%
	"	L-4	9-58	1987.12.24	20%
	"	L-4	9-59	1987.12.24	50%

5. As stated in 1.8 of this report, we used dedicated digital image analysis system to analyze the LANDSAT data. In addition to the normal image processing function of remote sensing, this system is equipped with the overlay function of images, by which we were able to easily overlay the LANDSAT data of two different times (to grasp the secular changes).

Outline of the study area

1. The study area, namely the area for which the analysis of LANDSAT data was necessary, are as follows:

This study area is composed of 10 states as shown in Table 2. As is clear from the Table 2, the situations are largely different between the northern states and southern states. In the northern states such as Antiquia, Caldas, Risaralda, Quindio, Tolima, and Valle del cauca, the population density is higher comparing with southern states, and the ratio of the persons who are engaged in the primary industry is about 30 -50%. On the other hand, the population density is low (approximately 30 persons/Km^2) in northern states

such as Huila, Nariño and Putumayo, and the most of the population is engaged in the primary industry.

Table 2. Comparison by States

Items \ State	Antiquia	Caldas	Risaralda	Quindio	Tolima	Valle del Cauca	Cauca	Huila	Narino	Putumayo
State capital	Medellin	Manizales	Pereira	Armenia	Ibague	Cali	Popayan	Neiva	Pasto	Mocoa
Area (Km^2)	63,612	7,888	4,140	1,845	23,562	22,140	29,308	19,890	33,268	24,885
Population	4,503,466	896,063	651,677	458,851	1,234,770	3,573,611	882,743	613,587	1,165,792	134,461
Population density (per Km^2)	72.2	113.6	157.3	256.0	52.4	161.4	30.1	31	35	5
Area by zone and climate (Km^2) Tropical	35,622	2,246	366	20	9,771	10,337	9,906	5,528	18,661	No description
Subtropical	16,408	2,770	2,157	1,100	5,848	7,606	10,023	7,713	5,731	No description
Temperate	10,899	1,902	1,314	404	4,905	3,089	6,184	5,290	6,026	No description
Frigid	683	970	303	321	3,038	1,108	3,195	1,359	2,850	No description
Ratio of workers by industry (%) Primary	33.5	44.6	35.3	45.8	52.3	23.5	56.2	51.7	50.3	55.9
Secondary	18.3	7.8	14.8	6.6	6.6	19.4	7.6	6.1	13.4	6.0
Tertiary	41.6	36.5	39.4	36.7	34.8	48.3	25.6	34.5	25.2	33.3
Others	6.6	9.1	10.5	10.9	6.3	8.8	10.6	7.7	11.1	4.8

Preparatory works in Japan

1. The preparatory works were carried out in advance to the field survey and analytical works after the field survey for the purpose to arrange the LANDSAT data and to grasp the overview of the actual sites (refer to Chapter 3 Preparatory works in Japan).

The main investigation items in this preparatory works are as follows:

(1) Preliminary processing of LANDSAT data (brightness correction, geometric correction)

(2) Creation of color image from LANDSAT data (creation of false color image)

(3) Primary ground cover classification

2. As preliminary processing of LANDSAT data, we carried out;

(1) Correction of color and tone of LANDSAT images to be used (in the present investigation, it was necessary to joint the LANDSAT data to south-north direction, but the color and tone are different delicately by each image because of the observation condition of each section. Brightness correction is carried out to make these color and tone coincide with the same standard.)

(2) Geometric correction to make positional coincidence between the LANDSAT data to be used and the geomorphological maps..

3. In the brightness correction of LANDSAT data, the differences due to the observation time and observation conditions were corrected for each 4 scenes of image data of 1970's and 1980's. (refer to 3.2.1 of this report).

In the geometric correction, on the other hand, we selected the ground

control points (GCP) which were clearly identified both on LANDSAT image and topographic maps, and made the conformation between the image coordinates and map coordinates by applying a formula (affine transformation formula, in this investigation). About 10 GCP's were selected for each one scene of LANDSAT data. The accuracy as result of affine transformation was determined to be within 2 - 3 pixels on original image (refer to 3.2.2).

4. We constructed the false color images from the LANDSAT data after the brightness correction and geometric correction (the false color image created by present study is shown in the annexed materials). This false color image is composed of visual rays of green color range and red color range which are expressed by blue and green respectively, and invisible range of near infrared which is expressed in red. The relation between the color of the false color image and items of ground cover is as shown in Table 3.

Table 3. Relation between false color and ground cover

Color of false color image	Classification	Characteristics
Red (light red - dark red)	Forest	Expressed in darker red color when the activity of plant leaf is higher (due to the property of near infrared data)
Pink - violet	Grassland	Expressed in lighter red color because the activity is lower than forest.
Green - dark green	Farm land	Various kinds of green colors reflected from land surface are shown according to the kinds and growth of the plants raised.
Blue - dark blue	Water area	Various kinds of blue color is shown according to the muddiness of the water.
White - (partly) light blue	Clouds	Generally white, but shows light blue where land surface is visible.
Black	Shadow of cloud	Shows almost black color as the sun beam does not reach.

5. Primary ground cover classification is carried out prior to the field survey to input the image identification control points (called "training

area") which are the representative points for each classification items basing on the findings obtained so far and colors of false color image as shown in the above table (Table 3), and to automatically identify the classification items by computer. We employed most commonly accepted Maximum Likelihood Method as the method of automatic identification.

In the primary classification, the ground cover was classified into 6 categories of (1) forest, (2) grassland, (3) farm land, (4) water area, (5) cloud and (6) shadow of cloud. These classification results were confirmed and verified at the filed survey, and second ground cover classification (analytical works done in Japan) was executed basing on these findings.

Field survey

1. We carried the false color images and primary ground cover classification images with us to the field survey, and confirmed, collated and corrected the identification results of images. The field survey was carried out from February 14 - March 25, 1989. The contents of survey can be divided into (1) investigation for the creation of image identification standard and (2) investigation for ground cover classification.

2. In the investigation for the creation of image identification standard, we selected the image identification control point (called "training area") which would be used for the secondary ground cover classification, investigated and recorded the land use, vegetation and land conditions at the point. We determined the training areas to be located around the observation points and to have the area of 5 ha. or more with the ground cover of a representative classification item. The classification items to which the training areas were specified were 6 categories of grassland, natural forest, man-made forest, grazing land, agricultural forest[*1], and farm land. Refer to the explanation of 4.1 and Table 4.1 of this report concerning the details of training areas. We established 60 training areas on the study area.

*1 Agricultural forest: mainly shadowed trees. Bamboo and banana are used as cover tree, under which coffee and sugar cane are grown.

3. In the investigation for ground cover classification, we carried with us the false color images and primary ground cover classification images, and confirmed the appropriateness color and classification results of images at the training area. As a result, the relationship between ground cover (= land use) and altitude has been clarified (see Fig. 1).

The following tendency was observed in the land use by the altitude.

(1) Agricultural forest distributes on the slope land at the mountain foot of altitude 1,200 - 2,000m.

(2) Afforest area of man-made forest is observed at the altitude 1,500 - 2,800m.

(3) In general, the natural forest distributes on the highland of altitude 2,500m or more, but it is observed partly along the valley lower than 2,500m.

(4) Natural grassland is dominant at and over 3,000m.

(5) Grassland distributes widely over the range of altitude 1,000 - 3,600m.

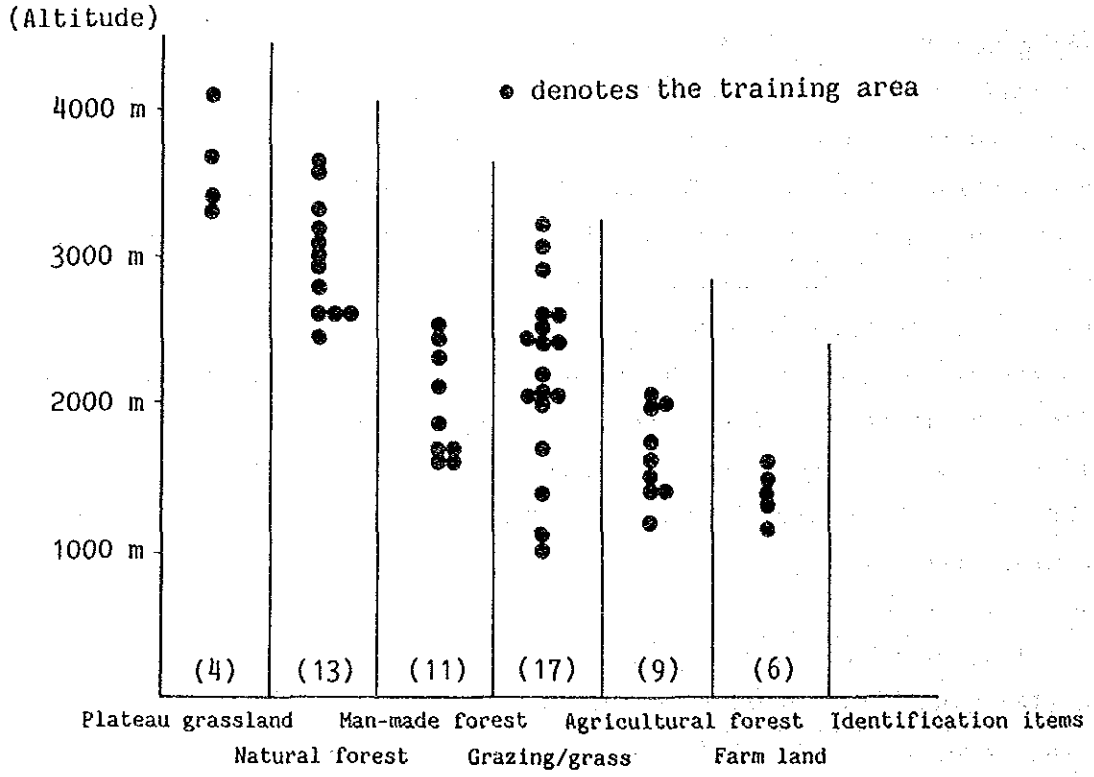

Fig. 1. Relation between classification item and altitude
Number in ( ) denotes the identification control points

4. The relation between the color of false color image and the actual land category at the site would be summarized as follows:

(1) Natural forest and man-made forest are expressed in deep red on the false color image, and were relatively easy to identify them from grazing and grass lands.

(2) As the secondary forest (or the forest which has the characteristics of

secondary forest) where low trees grow mixedly and agricultural forest are expressed in similar color, it was difficult to identify them each other on the color image. However, the ratio of secondary forest was quite small in the study area, and therefore, there was hardly any necessity to discriminate them each other.

(3) With respected to the degraded land on mountain foot, it was considered possible to identify them if they had the area of 3 ha. or more. However, enough discussion should be made as they are expressed in almost same color as cities and colonies.

(4) Slash and burn agriculture is carried out at the low farm land, and it was relatively easy to identify them because they were section in almost square shape.

Taking the above points into account, we discussed the categories of secondary ground cover classification.

Analytical works done in Japan

1. Analytical works in Japan is divided mainly into (1) secondary ground cover classification and (2) creation of LANDSAT analysis map. In the secondary ground cover classification, we established the identification standard basing on the result of primary ground cover classification carried our in the preparatory works and the results of confirmation and verification made in the field survey, and performed the automatic identification with the higher accuracy than the primary ground cover classification.

In the creation of LANDSAT analysis map, we produced the following images basing on the results of secondary ground cover classification.

(1) Land use classification image (scale in 1/250,000)

(2) Vegetation classification image (scale in 1/250,000)

(3) Land use/vegetation secular change classification (sale in 1/250,000)

2. In the secondary ground cover classification, we carried out automatic identification by most likelihood method basing on the classification items as shown in Table 4. The classification image is shown in the annexed materials (annexed materials No. 5)

Table 4. Secondary ground cover classification items

Items	Characteristics on image
Grassland	Shows the color from pink to violet, and is difficult to discriminate from grazing land.
Natural forest	Shows deep red color
Man-made forest	Shows light red or crimson. It is difficult to discrimi-nate from agricultural forest.
Grazing land	Shows the color from pink to violet, and is difficult to discriminate from grassland.
Agricultural forest	Shows green or deep green.
Cloud	Shows white or light blue color.
Shade of cloud	Shows black color.

3. The results of secondary ground ground cover classification were not enough to create the land use classification image and vegetation classification image as clearly shown in LANDSAT analysis maps. Namely, as state in 4 of Field survey, both the natural forest and man-made forest are expressed in deep red, and can be clearly identified from the grassland, it is difficult to identify the natural forest from the man-made forest. Also, the difference in color is not clear on false color image between grazing land and grassland (including plateau grassland). Similarly, the bare land such as degraded land on mountain foot can be visually identified only when it has the area of about 3 ha. or more, but in automatic identification, it would cause the miss-judgment between the cities/towns. Therefore, the classification images were created basing on both result of secondary ground cover classification and interpretation of false color image.

4. In creating the land use classification image (1/250,000), the ground cover was classified into 8 categories of (1) forest, (2) plateau grassland, (3) grazing/grass land, (4) agricultural forest, (5) farm land, (6) city/town, (7) bare/waste land and (8) snow/ice field using the result of secondary ground cover classification and supplementing by the interpretation of images. The

land use classification images were made for 2 different periods of 1970's and 1980's. The results are as shown in the result maps.

5. In creating vegetation classification image (1/250,000), we extracted only the items concerning the vegetation from the land use classification image, and sub-classified the forest into natural forest and man-made forest. As shown in the result maps, the classification was made for two periods of 1970's and 1980's. The identification items were 5 categories of (1) forest (natural), (2) forest (man-made), (3) plateau grassland, (4) grazing/grass land, and (5) cloud.

6. Land use/vegetation secular change image (1/250,000) was created from the result of secondary ground coverage classification and identification of images made from the LANDSAT data of two different times (1970's and 1980's). We were able to grasp the change of land use and vegetation in the study area during these about 10 years.

Result of investigations

1. Summation of areas was carried out to the land use classification image (1/250,000), vegetation classification image (1/250,000) and land use/vegetation secular change image (1/250,000) prepared by the analytical works, basing on which analysis was made to the situation of land use, vegetation and secular change all over the study area.

2. The classification items of land use were 8 categories of (1) forest, (2) plateau grassland, (3) grazing/grass land, (4) agricultural forest, (5) farm land, (6) city/town, (7) bare/waste land and (8) snow/ice field (refer to 6.2 Situation of land use of this report). The general trend of land use is as follows:

(1) The forest is more abundant in the south part of the study area. It is also relatively abundant on the slope land of east side of Andes central mountain range. In the north part of the study area, the forest is specially dense in the east part of Quindio.

(2) Plateau grassland is frequently seen around the mountain ridge of central mountain ridge. It distributes on the high mountains of altitude 3,500m or higher including Mt. Nevado del Ruiz.

(3) Grazing/grass land distributes widely in north part from the mountain foot to mountain top of the central mountain range. In the south part, it distributes relatively frequently around the mountain foot.

(4) Agricultural forest distributes frequently on the slope land at the west

side of central mountain range, and especially frequently in Risalda and Quindio States.

(5) Farm land is only seen in small scale river low land in Antiquia State. Since the study area is located at the highland of altitude 1,500m or more, the farm land of large scale is hardly seen.

(6) Cities and colonies are seen in northern states where population is concentrating. Examples are Manizales, Pereira and Armenia.

(7) Bare/waste land is seen only in the part of Risaralda, Velle del Cauca, Cauca and Narino States.

(8) Snow/ice field is seen in small scale at the high mountain areas of Caldas and Tolima States.

3. The trend of land use by states is as shown in the Fig. 2 (comparison is made by the data of 1970's).

(1) As a general trend of total 10 states (excluding 15% of the area which is covered by clouds), the forests occupies 50% of the total object area of analysis (study area less the area covered by clouds), followed by 26% of grazing/grass land, 14% of plateau grassland, 8% of agricultural forest, and 2% of bare/waste land and snow/ice field.

(2) The type of land use largely varies between northern states and southern states.

Namely, in the states located at the south side such as Cauca, Huila, Narino and Putumayo States, roughly 60% -

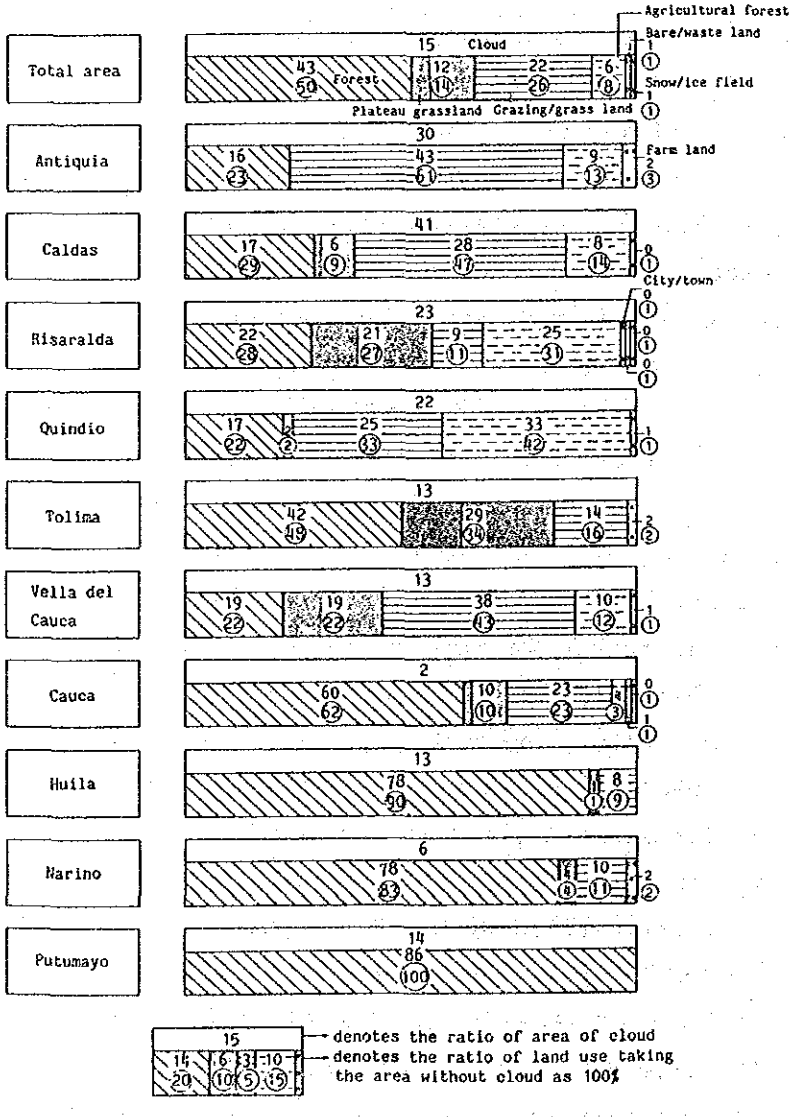

Fig. 2. Comparison of the ratio of land use area by state (1970's)

100% of the object area is forest. On the other hand, in the northern states such as Antiquia and Caldas, the area of agricultural use such as grazing/grassland is larger comparing with the area of forest.

(3) Among the northern states in the study area, the ratio of agricultural forest is large in Risaralda and Quindio State. On the other hand, the type of land use is slightly different in Cauca, Huila, Narino and Putumayo among the southern states. In Cauca State, there are observed not only the forest (62% of the analysis object area) but also the plateau grassland (10%) and grazing/grass land (23%), while in other three states, the forests cover more than 80% of the total analysis object area.

4. As state before, the items of vegetation classification were 5 categories of (1) forest (natural), (2) forest (man-made), (3) plateau grassland, (4) grazing/brass land and (5) others. General trend is as follows (in the following, the analysis object area, namely the area excluding the portion covered by cloud from the study area, is taken as 100%):

(1) Natural forest spreads widely centering around the slope land in east side of central mountain range and mountain ridge, observed more frequently at the south part among the total study area. In the northern states such as Caldas and Quindio, the natural forests are relatively few but they are seen relatively in bulk along the mountain ridges and valleys.

(2) Man-made forests distribute only at a part of slope land in west side of mountains in Caldas, Risaralda and Quindio States. They also distribute in relatively wide range at the north part of Cauca State. In total, the man-made forest occupies 3% or 4,400 ha. in the analysis object area.

(3) Plateau grassland distributes on the highland with altitude of 3,500m or higher, and is observed widely around Mt. Nevado del Ruiz and central mountains.

(4) Grazing/grass lands distribute sparsely all over the area, but are more frequent in the northern area. The grazing/grass land in the northern states such as Antiquia and Caldas are spreading up to closely to mountain top occupying wide range of area. In the south, on the other hand, the grazing/grass lands are observed widely on the slope land at the west side of central mountain range.

5. Fig. 3 shows the trend of vegetation distribution by states (similar to the situation of land use, the comparison is made by the data of 1970's).

(1) As a total of analysis object area (study area less the area covered by

clouds which is 15% of the total), natural forest occupies 49%, while man-made forest shares only 3%. The rest is the area other than forest.

(2) When the trend is seen by states, the man-made forest is limitedly few comparing with the natural forest, indicating the similar trend as (1) above. Especially almost all of the forests are natural forest in Cauca, Huila, Narino and Putumayo States which are located at the south of study area.

6. In general, the secular change of land use and vegetation is as follows (refer to 6.4 of this report):

(1) Among the changes which took place during these about 10 years, the ratio of natural forest converted into grazing/grass land or agricultural forest is the highest.

(2) The area where secular change was observed by this study amounted to 32,700 ha., of which 76% or 24,400 ha. has been converted from forest to other items of land use. In concrete, it is the change from natural forest to grazing/grass land or agricultural forest. Next most conspicuous is the change from the agricultural land to grazing/grass land, farm land and cities, amounting to 5,000 ha. which is 15% of the total area which underwent the change.

7. The secular changes seen by the states are as follows (refer to 6.4 Situation of secular change of land use and vegetation).

(1) Natural forest decreased by 2,800 ha. in Antiquia State, and especially at the slope land in the west side, changes from natural forest to agricultural forest or grazing/grass land is conspicuous.

(2) In caldas State, the natural forests have been converted to grazing/grass land at the mountain area of north, and agricultural forests have been changed to grazing/grass land at the south. In Risaralda State, the change from agricultural forest to city/town is conspicuous at Pereira of south.

(3) In Quindio State, conversion of forests to the agricultural forest or grazing/grass land is conspicuous at the slope land of west side. 3,000 ha. of natural forest has decreased out of total 22,600 ha. (this corresponds to 13% of total natural forest).

In Tolima, only little secular change is observed.

(4) In Vell del Cauca, 1,900 ha. of forest has been converted into grazing/grass land, of which 1,500 ha. from natural forest and 400 ha. from man-made forest.

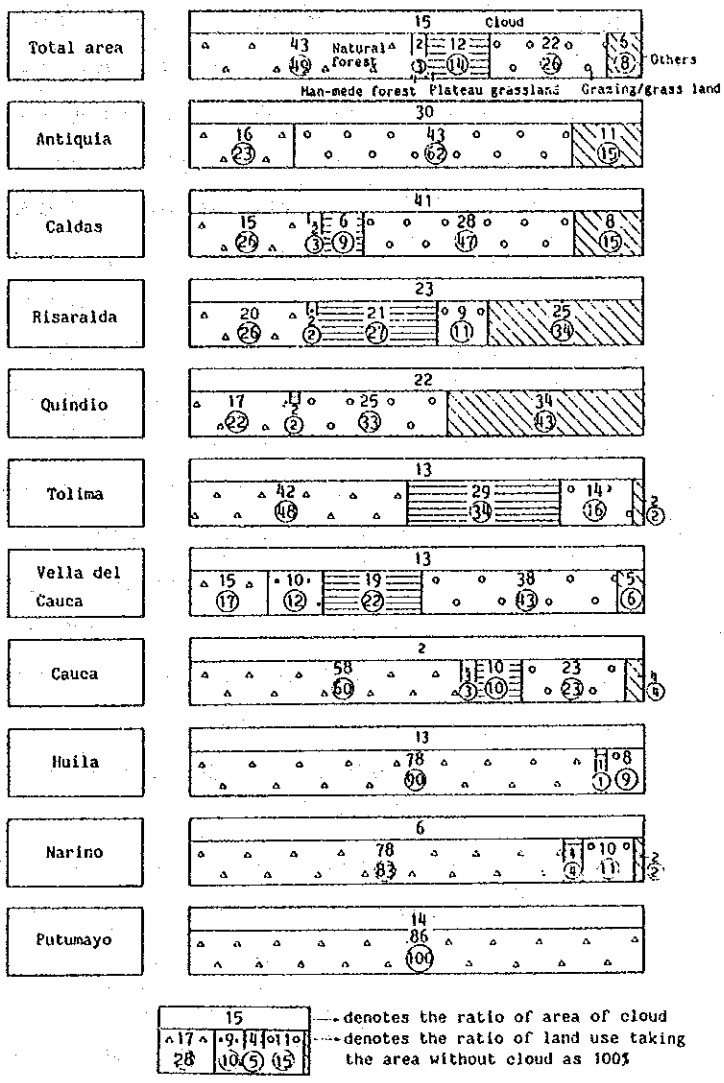

Fig. 3. Comparison of the ratio of vegetation area by state (1970's)

Cauca State is the area where the secular change is observed frequently in other than southern states. In total, 11,900 ha. of natural forest and 1,500 ha. of man-made forest has been converted to grazing/grass land.

(5) In huila, Narino and Putumayo States, the secular change was not much comparing with other states.

Analysis on the study results

1. Analysis was made and regional characteristics were summarized basing on the investigation results as stated in the above. Here, we summarized (1) influence of clouds on the study area, (2) trend of vegetation and land use, and (3) regional characteristics.

2. With respect to the influence of the cloud on the study area, 278,000 ha. which corresponds with 15% of the total area was covered by clouds in the data of 1970's. In the data of 1980's, 649,100 ha. corresponding with 35% of the total area was covered by the clouds. In the analysis of secular change, it is desirous that there is no clouds over the study area for both two periods.

In the present study, we investigated the cloud volume list of LANDSAT data relating to the study area which is observed from 1972 to 1988. As a result, it has become clear that the scenes with cloud volume of 40% or less (volume of cloud distribution per one scene) were only 14 scenes as far as the study area is concerned, which is 8.5% of the total observation scene (165 scenes). In this study, we selected the most suitable data for our study from the scenes with the cloud volume of 40% or less, namely the scenes which have 60% or more of analyzable area. As a result, the selected scenes for Tolima (74%), Caldas (68%) and Velle del Cauca (60%) were equal or above the standard. On the other hand, the scenes of Antiquia, Quindio and Cauca were below the standard, but we judged them to be analyzable because the clouds existed over the areas which had less influences on investigating secular change of forests. However, although Risaralda State had 67% of analyzable area, it could not be used for analysis because much cloud had been covering the forest area.

3. To analyze the relation between land use/vegetation and altitude (see "7.3 Situation of land use/vegetation" of this report), we established traversal lines by 6 measuring lines. As a result, the land use in the study area was summarized by the altitude as follows:

(1) The areas of altitude of 1,500m or less are mainly the distribution area of agricultural forests.

(2) At the altitude 1,000 - 2,000m, grazing/grass land distributes widely.

(3) At the altitude 2,000 - 3,000m, forest area distributes mainly with natural forest.

(4) At the altitude 3,000 - 4,000m, highland plants distributes widely as it exceeds the timber line.

(5) At the altitude of 4,000m or higher, there distributes the snow/ice field.

With respect to the distribution of forests, the timber line is located at around the altitude of 3,000m, and on the other hand, grazing/grass lands are spreading up to 2,500m or even 3,000m. Therefore, it is clear that the distribution area of forest is quite limited. This tendency is more conspicuous at the north of study area.

4. We further grasped the trend of land use distribution in and around the study area (including mountain foot areas) using existing land use maps (shown in 1.7 of this report) as a reference. Fig. 4 shows the schematic diagram of conversion of forest in the study area including the mountain foot areas.

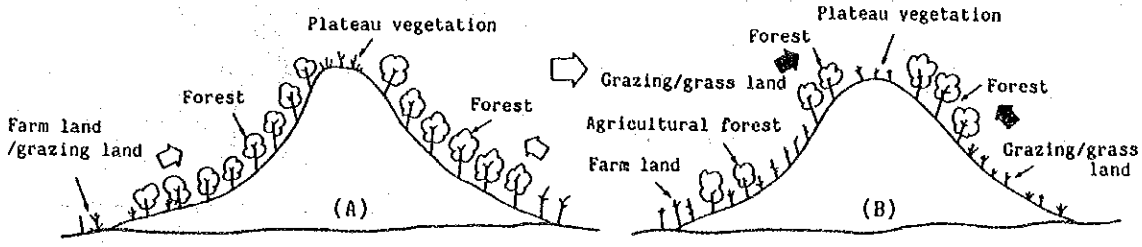

Fig. 4. Schematic diagram of forests up to mountain foot including study area

Farming and grazing which used to be carried out in relatively flat land at the mountain foot spread from mountain foot to mountain breast and even to the acute slope lands on the breast along with the population increase and urbanization (A). It is considered, as a result, that the forests have decreased being converted to grazing/grass land (B).

As stated in 3. above, the timber line is located at around the altitude 3,000m, while the grazing grassland is advancing from mountain foot to upper part of mountain breast, the area of land where natural forest can survive

has been rapidly reduced.

5. When the development of the land use in the study area is discussed, it can be summarized as shown in Fig. 5.

(1) The situation of land use widely differs in east and west sides of the study area. Natural type of land use such as forest and plateau grassland is still remaining at the most part of east side, though grazing/grass land, farm land and agricultural forest are seen in northern part indicating that the land use is relatively advancing.

(2) In the west side of the study area, high graded land use such as coffee plantation and sugar cane plantation is more developing comparing with the east side.

6. Most of the secular change of land use/vegetation shows the pattern that the natural forests are converted to grazing/grass land or agricultural forest. This tendency is specially conspicuous in the states of Antiquia, Caldas, Quindio and Cauca. In general, the secular change is more conspicuous in west than in east, especially in Caldas, Velle del Cauca and Cauca States. Fig. 6 shows the schematic diagram of secular change.

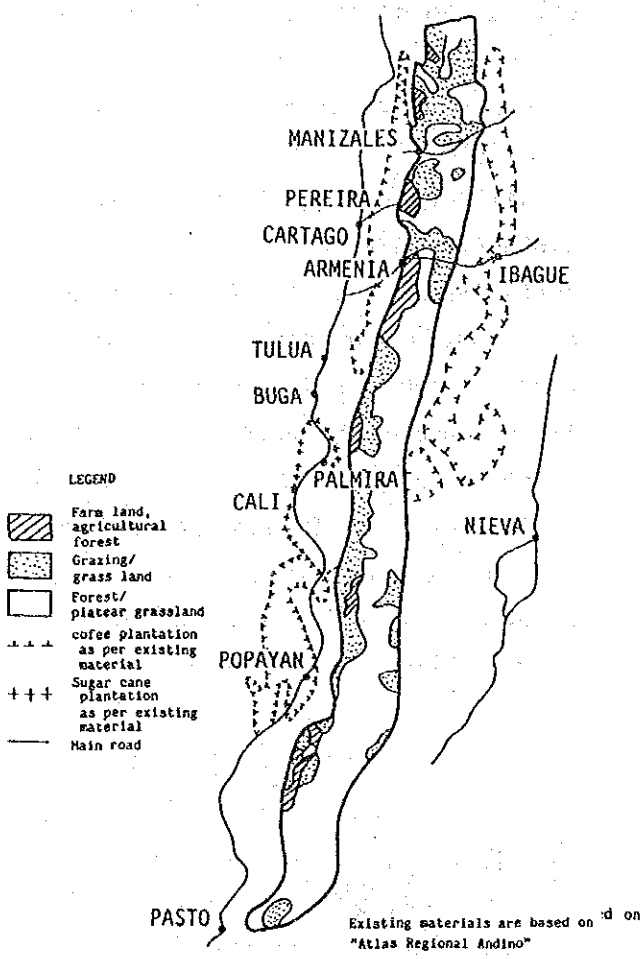

Fig. 5.
Advancement of land use in the study

Diagram a) shows an example in Caldas State where natural forest and agricultural forest have changed to grazing/grass land. The agricultural forest at the foot of mountain and the natural forest around the mountain top have changed to grazing/grass land. Even the acute slope land near the mountain ridge has been changed to the grazing/grass land in this area, indicating the typical example of this trend.

Diagram b) is an example of central region where agricultural forest has been changed to city and natural forest to agricultural forest. The agricul-

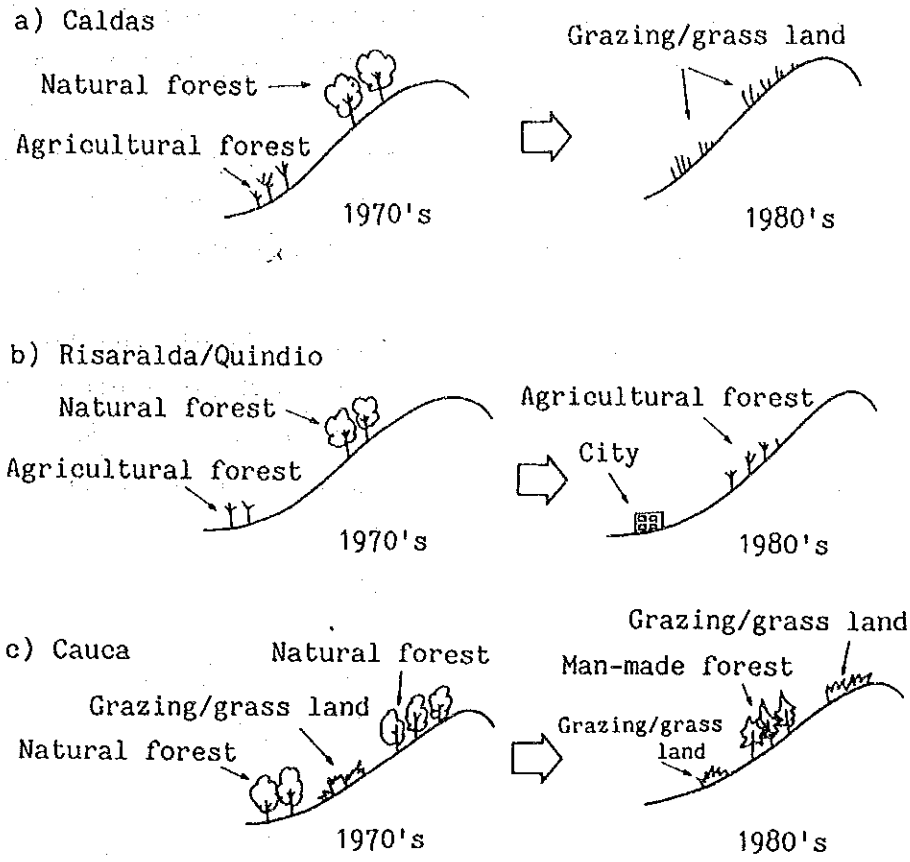

Fig. 6. Schematic diagram of secular change

tural forest has changed to town along with the expansion of city, and the natural forest located at relatively higher altitude was changed to agricultural forest.

Diagram c) is an example in the south of Cauca where natural forest around the foot and top of mountain was changed to grazing/grass land, and grazing/grass land at the breast of mountain was changed to man-made forest. In general, expansion of grazing/grass land is quite active in this area where the conversion from natural forest to grazing/grass land is quite conspicuous.

7. Basing on the analysis on the investigation results as stated in the above, the regional characteristic of this area can be summarized as follows:

(1) Grazing/grass land is expanding nearly to the mountain top in the north part of study area centering around Caldas State. This is an area which has been developed since old times, and the decline of forests is still continuing.

(2) When the east side slope land and west side slope land in the study area are compared, relatively high graded land use is carried out in the west

side slope land in general. Especially, there is wider range of farm land in Cauca basin at the center of study area, and the decline of natural forest is conspicuous there.

(3) Forests are relatively abundant in the south part of study area, and undeveloped area widely expands at the south Amazon region.

(4) In the study area, the forests in Caldas State is considered to be playing important functions and roles such as waterhead reservoir, prevention of soil erosion and prevention of flood considering from the topographic conditions, the State Capital (Manizales) being located near by. This can be said to the area where high effect is expected and the urgency is high as well in formulating the forest resource management plan for proper afforestation.

TEXT

1. Outline of the study

1.1. Background of the study

The area of the forest (53.18 million ha.) of the Republic of Colombia occupies 47% of its total territory (113.90 million ha.). However, in Andes region, the share of forest is only 26% which is substantially lower comparing with Amazon region. In this context, the Government of Colombia designated Central Reserved Forest zone as a model area to carry out proper forest resource management, requested our country to provide the cooperation for:

(1) to scientifically grasp the present state of distribution of forest and land use as well as their secular change, and to establish the technologies therefor;

(2) to take aerial photographs as a basic material and construct geomorphological maps therefrom, basing on which to grasp the present state of forest resources and to obtain basic data necessary for forest management, and to transfer all these technologies to Colombia.

(3) to make plan guideline for forest resource management, and to formulate the model plan of forest resource management by applying the plan guideline to the model area;

This study has been carried out in answer to this request.

This report summarizes the result of remote sensing analysis among the total study. As for the details of the background of study, refer to the Progress Report I.

1.2. Purpose of the study

The purpose of this study is to analyze the LANDSAT data of Central Reserved Forest of Colombia and to grasp the present state of land use and vegetation.

1.3. Areas covered by the study

The area covered by this study is the study area of 1,600,000 ha. in the Central Reserved Forest as stated in the Progress Report I. Total analyzed area amounted to 1,918,300 ha, including the peripheries of the study area. In this report, the analyzed area of 1.9 million ha. is referred to as the study object area.

1.4. Process of the study

The process of the overall study is shown in Fig. 1.1. The study was carried out over two years of first study year and second study year.

In the first study year, the preparatory works in Japan and field survey were carried out. In the second study year, analytical works were carried out in Japan basing on the result of field study.

1.5. LANDSAT data used

The LANDSAT data used for this study were 4 scenes as shown in Fig. 1.2 and Table 1.1. All the data were used in the form of magnetic tape which can be processed by computer, and we selected the data of most suitable observation date. LANDSAT data were used to grasp the present state and secular change of land use and vegetation. For this purpose, we obtained the data of different two times, the new and old.

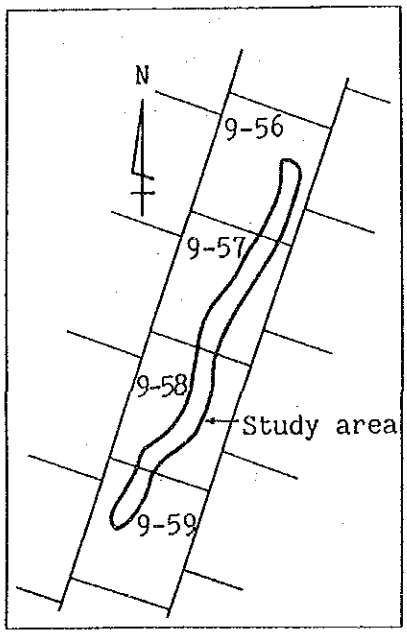

Fig. 1.2 LANDSAT coverage map

Table 1.1. LANDSAT data used

Time	Sensor	LANDSAT No.	PATH-ROW	Observation date	Cloud volume (%)
Old	MSS	L－2	9－56	1977. 9.17	50%
	〃	L－1	9－57	1976. 2. 1	20%
	〃	L－1	9－58	1976. 2. 1	30%
	〃	L－1	9－59	1976. 2. 1	30%
NEW	〃	L－4	9－56	1987.12.24	30%
	〃	L－4	9－57	1987.12.24	20%
	〃	L－4	9－58	1987.12.24	20%
	〃	L－4	9－59	1987.12.24	50%

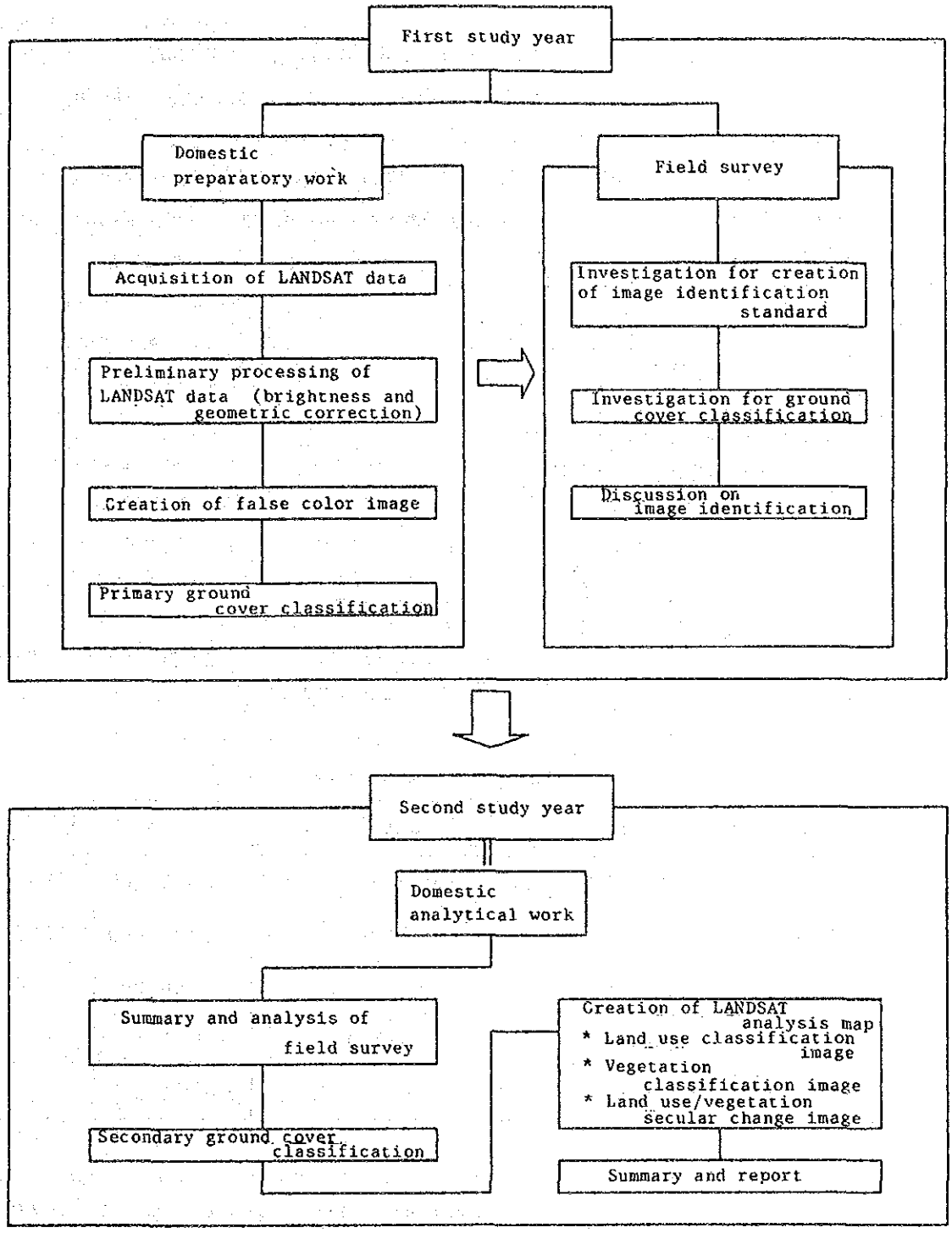

Fig. 1.1. Process of study

1.6. Geomorphological maps used

The geomorphological maps used for this study were as follows:

(1) Navigation map published by National Ocean Survey of the United States (refer to Fig. 1.3)

"L-26" in scale 1/1,000,000 and "L-26A, 26B, 26C, 16D" in scale 1/500,000

(2) State geomorphological maps published by geographical agency of Colombia, AUGUSTIN COSAZZI.

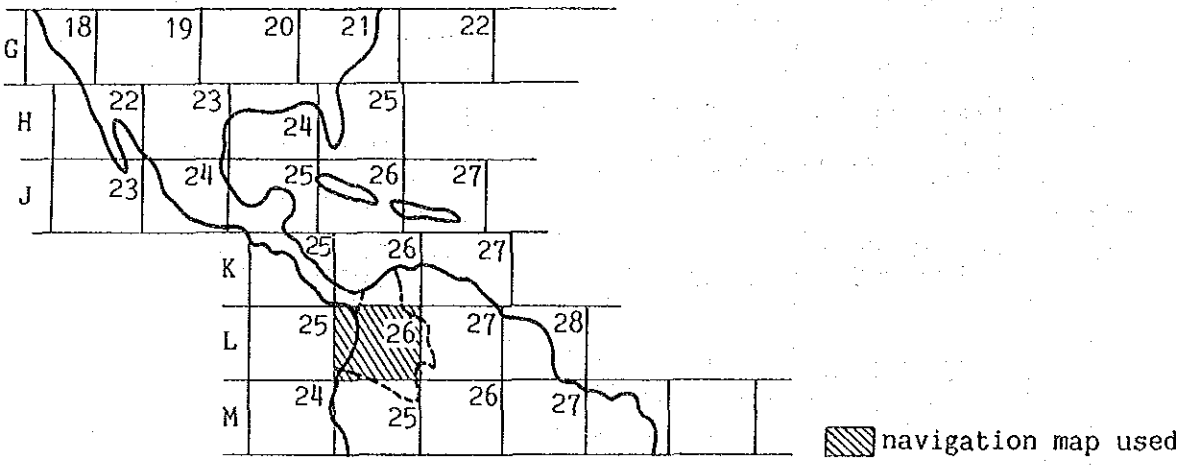

Fig. 1.3. Navigation map used

Table 1.2. List of state maps used

State name	Scale	date of compilation	Sate name	Scale	Date of compilation
ANTIOQUIA	1 : 200,000	1988	VALLE DEL CAUCA	1 : 300,000	1986
CALDAS	1 : 250,000	1985	CAUCA	1 : 400,000	1986
RISARALDA	1 : 200,000	1988	HUILA	1 : 400,000	1985
QUINDIO	1 : 100,000	1982	NARIÑO	(Didn't get)	—
TOLIMA	1 : 400,000	1986	PUTUMAYO	(Didn't get)	—

Navigation maps were used to establish the map coordinate systems necessary for geometric correction of LANDSAT data, to select the ground control points also necessary for geometric correction and to mosaic each of LANDSAT scene as explained later (in 3.2. Preliminary processing of LANDSAT data). On the other hand, state geomorphological maps were used to sum up the area by the classification items of land use and vegetation in each state and to grasp the overview of natural conditions including the topographic

features of each state.

1.7. Materials collected

The materials collected for the study are as follow:

(1) Carta General (base map of territory) 1/500,000

(2) Mapa de Uso Actual de la Tierra (actual land use map) 1/500,000

(3) School text book of geography

* Atlas de Colombia
* Geografia de Colombia
* Geografia (Fisia, General y de Colombia)
* Geografia General y de Colombia
* Geografia (Economica de Colombia)

(4) Classificación de las Tierras poy su Capacidad de Uso, 1986 (Classification concerning the possibility of land use)

(5) Atlas Regional Andio, 1982

(6) Atlas de Caldas, 1987

(7) Analisis Geográficos

(8) Cartográfia Integrada del Medio Natural (Chichina-Manizales), 1987

(9) Los Suelos de las Cordilleras Andibas y su Aptitud de Uso, 1982 (Soil of Andes Mountains and its aptitude for use)

(10) Diagnostico Geográfico de la Cuenca Alto Magdalena, PROCAM-INDERENA (Geographical analysis on Magdalena River basin), 1984

(11) Manual de Percepción Remota en Geografia Fisica, 1984 (Remote sensing manual, in 2 volumes)

1.8. Digital image analysis system

In addition to (1) normal image processing function of remote sensing, the digital image analysis system used for this study is equipped with (2) the function overlay the images each other by the unit of pixel. Overlay processing of image by the unit of pixel is performed to overlay the plural data, according to the intended purpose, which are converted into image by some specified standard. In concrete, it is possible to grasp the secular change of land use and vegetation by overlaying the LANDSAT data (including the classification results based on the LANDSAT data) of two different times. In this study, we created land use/vegetation secular change image using this overlay processing function.

The digital image analysis system which was actually used in this study is

as shown in Fig. 1.4. The main components of this system are host computer and image processor. Besides them, magnetic tape drive, drum scanner, video digitizer and digitizer were used as input devices, and color display, photo-printer, graphic camera and hard copier were used as output devices.

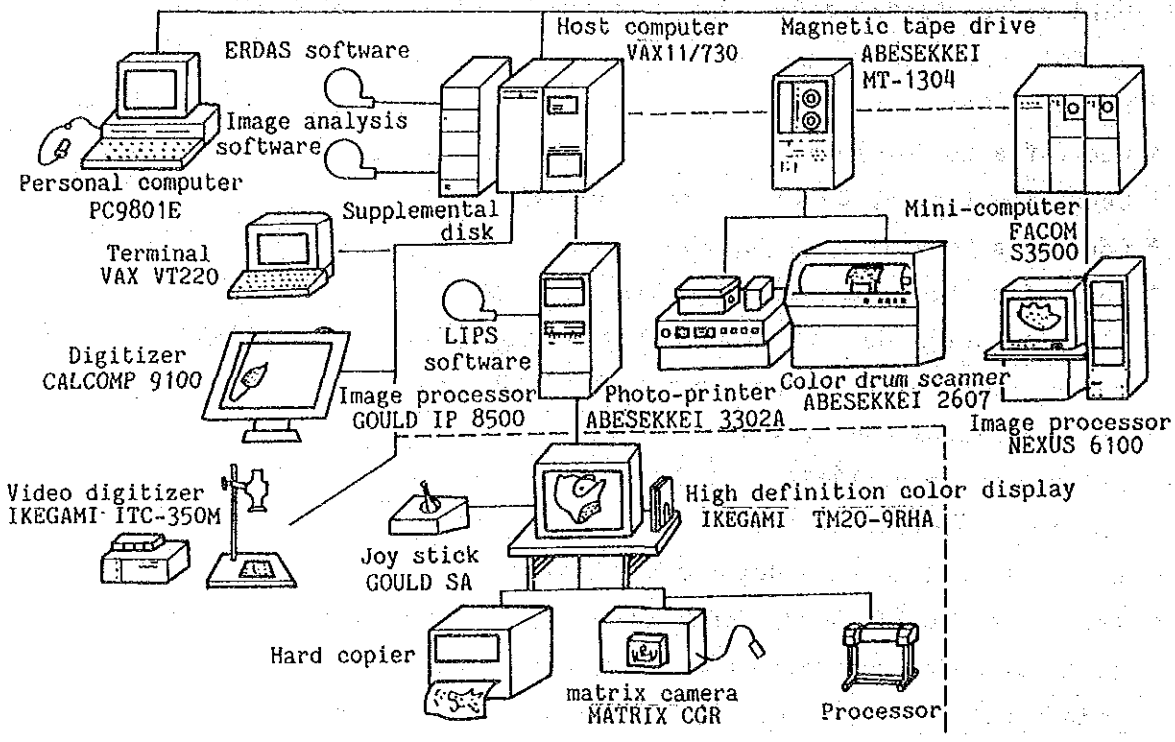

Fig. 1.4. Digital image analysis system used for the study

2. Outline of study area

As shown in Fig. 2.1 and Table 2.1, the area for which LANDSAT data are analyzed is composed of 10 states. From the north, they are Antiquia, Caldas, Risaralda, Quindio, Tolima, Velle del Caica, Cauca, Huila, Narino and Putumayo.

We summarize the the study area by each state in the following:

(1) Antiquia State

Antiquia is located at the north edge of study area. Most of the state belongs to Andes Mountain Range, but low humid zones are formed at some parts of the state. In general, this state is consisted of the topography with abundant reliefs and changes. As shown in Table 2.1, this state is characterized by the larger volume of agricultural products such as coffee and banana comparing with other states.

The study area occupies a part of mountain area at the south edge of the state. With the mountain ridges of around altitude 3,000m as the borderline, plateau slope land develops gradually on the west side, and there are diffracted acute slope lands at the east side. The natural forest distributes centering around the highlands along the mountain ridges, and the distribution changes from forest to farm land towards the low lands of east and west.

(2) Caldas State

Andes Mountain Range runs through the center of state from south to north, and slope lands expand and main rivers flow at both west and east sides of it. As the borderline of the state, Magdalena River runs at the east side, and Cauca River at the west side, both from south to north. The study area is located at the mountain area in the center of state. Some of mountain ridges exceed the altitude of 4,000m, and the altitude of low land is 750m. Diffraction is developing to high extent, and land shape is formed by acute slope lands except a part of mountain ridge. With respect to land use, plateau grassland distribute widely at the mountain ridges, which changes to grazing/grass land and farm land as the altitude becomes lower. Forests distribute widely at the slope lands of altitude 2,500 - 3,000m, being placed between plateau grassland at the mountain ridges and grazing/grass land and farm lands at the low land.

(3) Risaralda State

The characteristic of this state is high population density comparing with above two states of Antiquia and Caldas (157 persons/Km^2 in Risaralda, while

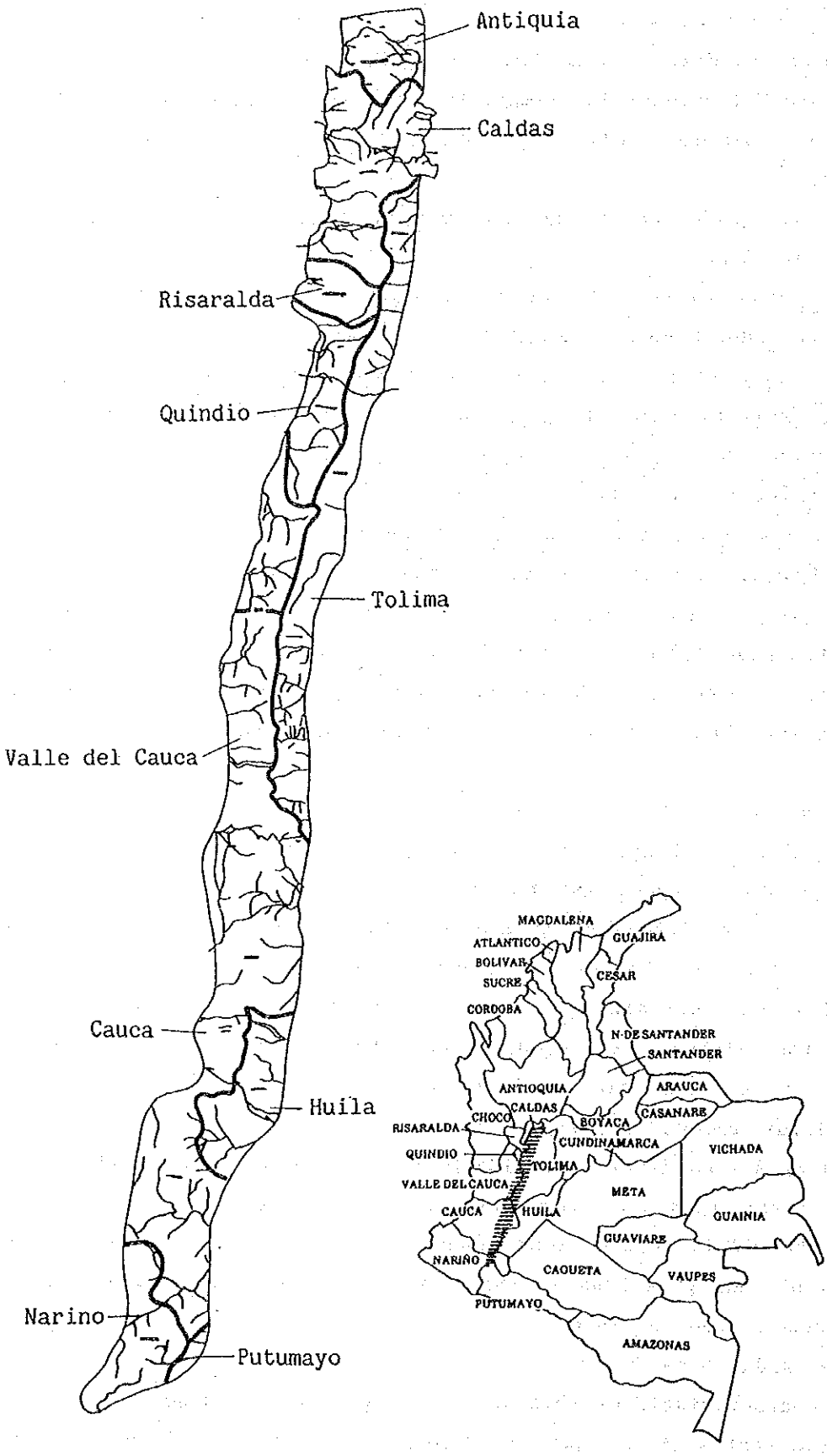

Fig. 2.1. Location map of study area

Table 2.1. Comparison by states

State / Items	Antiquia	Caldas	Risaralda	Quindio	Tolima	Velle del Cauca	Cauca	Huila	Narino	Putumayo	Remarks
State capital	Medellin	Manizales	Pereira	Armenia	Ibague	Cali	Popayan	Neiva	Pasto	Mocoa	
Area (Km^2)	63,612	7,888	4,140	1,845	23,562	22,140	29,308	19,890	33,268	24,885	
Population	4,503,466	896,063	651,677	458,851	1,234,770	3,573,611	882,743	613,587	1,165,792	134,461	As of 1985
Population density (per Km^2)	72.2	113.6	157.3	256.0	52.4	161.4	30.1	31	35	5	
Area by climate zone (Km^2) Tropical	35,622	2,246	366	20	9,771	10,337	9,906	5,528	18,661	↑	
Subtropical	16,408	2,770	2,157	1,100	5,848	7,606	10,023	7,713	5,731	No	
Temperate	10,899	1,902	1,314	404	4,905	3,089	6,184	5,290	6,026	description	
Frigid	683	970	303	321	3,038	1,108	3,195	1,359	2,850	↓	
Ratio of (%) workers by industry Primary	33.5	44.6	35.3	45.8	52.3	23.5	56.2	51.7	50.3	55.9	
Secondary	18.3	7.8	14.8	6.6	6.6	19.4	7.6	6.1	13.4	6.0	
Tertiary	41.6	36.5	39.4	36.7	34.8	48.3	25.6	34.5	25.2	33.3	
Others	6.6	9.1	10.5	10.9	6.3	8.8	10.6	7.7	11.1	4.8	
Agricultural products 1980 - 1981 Coffee	1,627,158		675,869	798,308	1,071,763	896,683	347,490	450,638	119,045	↑	
Banana	844,200									|	
Sugar cane	238,140	42,000	599,200	3,240	4,200	8,585,900	2,550,900	49,000	74,800		
Platano	202,100		82,000	250,000			28,190	50,000	45,900	No report	Banana for cooking
Potato	180,250		70,000	70,000	90,300				358,900		
Rice	16,750	3,370			491,300	39,400	14,700	191,200			
Soya bean		351	7,503		500	143,629	1,749				
Yuca	126,000	3,570	7,700	32,000	96,000		105,400	165,000	2,800		
Maize			3,750	89,500	130,200		23,350			|	
Cotton				52,880	39,092		3,630			↓	

Source: Atlas Basico de Colombia

72 persons/Km^2 in Antiquia and 113 persons/Km^2 in Caldas). With respect to the topographic feature, Risaralda River runs through the center of state from south to north, and the east of it is acute slope lands of the west side of Andes mountain, while the west of the river is the gradual plateau mountain area. Around them, the slope lands with advanced diffraction distribute at the altitude of 1,500 - 3,500m. The forests distribute mainly at the altitude of 3,000 - 4,000m, but they partly distribute at relatively low land of altitude 2,000m along Otoun River. At the border of this state and Tolima State, there is Mt. Nevado del Ruiz (5,400m) where snow/ice field forms the highland.

(4) Quindo State

Quindio is the smallest state (1,845 Km^2) out of the 10 states. The area corresponds with 3% of the largest state Antiquia (63,612 Km^2). However, there are large cities such as Armenia in the state, and therefore, the population density is 256 persons/Km^2, which is the highest of the 10 states. Being placed in the milder climate zone comparing with other states and having abundant agricultural laborers as the background, this state produces substantially high volume of coffee (e.g. coffee production of this state corresponds with 50% of that of Antiquia). The study area is located at the mountain area, the east of main road which runs longitudinally at the center of the state connecting Pereira and Armenia. West-sided slope lands continue from mountain ridges of altitude about 3,500m at the north edge of the state to the main road of altitude about 1,500m. Diffraction is not developing much, showing gradual land shape. Plateau grassland distributes at the high lands of altitude 3,000m or more, and grazing/grass land spreads from there to the altitude of 2,000m, while farm lands are distributing along the main road.

(5) Tolima State

Magdalena River runs longitudinally from south to north at the low land in the center of Tolima. The mountain ridges of Andes Central Range are located at the west edge of the state, and the gradual slope land facing eastward distributes towards the low land of center of the state. Mountains with low altitude like a hill are distributing at the east side of Magdalena River. Farm land grazing/grassland are mixedly distributing at the central low land, and the forests distributes at the mountain areas in the west and east. The area of Tolima State is almost comparable to that of Velle del Cauca, but the population is less that one-third of it.

The study area is located at highland area of mountain range in the west

of state. There are some mountain ridges in the west edge of the state which exceed the altitude of 5,000m. The acute slope land with advanced diffraction from the mountain ridges to the altitude of about 2,000m occupies the most of the state, on which valleys are engraved from east-west direction. Plateau zones distribute at the highland of altitude 3,000m or more along the mountain ridges, and forests distribute as if to enclose them. Farm land and grassland are hardly seen inside the study area.

(6) Velle del Cauca State

Velle del Cauca has the area of about 22,140 Km^2 in total and is located at almost the center of the study area. The population density is 161 persons /Km^2 which is almost the same as Risaralda mentioned in the above. A trend in this state which is not seen in other 9 state is that the ratio of workers engaged in tertiary industry (48.3%) is higher than that of primary industry (23.5%). With respect to topographic features, Andes Mountain Range forms the border of east side, Cauca River flows from south to north at the center, and flat land spread at the west of Cauca River. As for land use, all of the study area is covered by forest except the farm lands observed around Palmila in the south.

(7) Cauca State

The population density against the land area in Cauca is about 30 persons/ Km^2, which is almost similar to Huila, Narino and Putumayo. Main agricultural product is sugar cane, but coffee is also grown besides it. In the east of state, ridges of Andes Mountains are lying forming mountainous area together with mountains of relatively low altitude which run through the center of state from south to north. West end of the state is a coast line from which flat land expands to the foot of mountains. Tropical rain forest covers the flat land from the west to around the ridges of mountains in the center, and no other land use is observed. Forests, farm lands, and grazing/grass land are distributing mixedly along the main road at the center, and the forests are observed at the vast area along the mountain ridges in the east edge.

The study area is located at the main mountain ridges of Central Andes range which traverses the east part of state from north-east to south west. The diffraction is advancing to high extent from north part to central part, and the lands show complicated shapes. The area is located at the range of altitude 2,000 - 3,500m, but there are some volcanoes which have the altitude of about 5,000m. Highland of altitude of 3,500m or more is mostly the plateau grassland, around which forests distribute towards the low lands. In the

central area, farm lands are developing up to substantial high altitude, mixing with forests. The south part of the state has lower altitude (1,500m - 3,000m), forming gradual mountain area with less diffraction, being covered up with forest.

(8) Huila State

The population density of Huila is about 30 persons/Km^2, just like Cauca as stated in the above. Main agricultural products are rice and Yuca. Different from Cauca, production of coffee is larger than sugar cane. The state of Huila is stretching long from north-east to south west, forming a mountainous area west side of which is placed between the Andes Mountain Ranges. Main range of Central Andes runs through the west part of state, while in the east are located branch ranges with relatively lower altitude and gradual shape. Magdalena River flows between these mountain ranges forming low lands with its valley bottom. With respect to land use, forests occupy about 50% of the total, and therefore, this state can be defined as the state of abundant forests. Farm lands and grazing/brass lands are mixedy distributing at the low land of valley.

The study area is located at the south-west edge of the state, and its area is small. The most of the area is occupied by the highland of altitude 2,500m or more, forming mountainous zone with the peaks ranged by several volcanoes exceeding 4,000m. As for land use, almost all the area is forest, except that plateau grassland distributes the the highland of 4,000m or more.

(9) Narino State

With the border of branch range of Central Andes which runs through the center of the state from north-east to south west, the situation is different in north-west part and south-east part of the state. In the north-west side, flat land expands from the branch rage to the sea coast, most of which being covered by tropical rain forest. Farm lands and grazing/grass lands are only observed along the river, and forests do not exist at all. The south-east part is mountainous area consisted of the main range of Central Andes, where there are high peaks exceeding 4,000m. Although the forest occupies 60% of the area, farm lands are also developing among the forest up to substantially high altitude.

The study area in this state is very small located at east edge of the state. The area is a mountainous zone with the mountain peaks exceeding 4,000m, and almost the total area is covered by forest.

(10) Putumayo State

Putumayo faces with the national border line of Colombia in the south, lying long and narrow from east to west along the border line. The total area is 24,885 Km^2 which is comparable to Tolima (the area of Tolima is 23,562 Km^2), but they are largely different in population density. namely, while the population density of Tolima is 52 persons/Km^2, that of Putumayo is only 5 persons/Km^2. The state in general is composed of low flat land, the study area is located at the mountainous zone at the north-west edge of the state. Putumayo shares only a small part of the study area.

3. Preparatory works in Japan

3.1. Outline

The preparatory works were carried out prior to the legitimate study such as field survey and analytical works which would be done in Japan after the field survey, and the purpose of it was to prepare the LANDSAT data and to grasp the overview situation of the actual sites. Therefore, we pigeonholed the information concerning the natural conditions at the site basing on the materials collected at the preliminary survey and the materials obtained in Japan. In this stage in advance of the legitimate survey, we grasped the situation of ground coverage which is one of the natural conditions of the site, through the image analysis of data of artificial satellite LANDSAT data. Fig. 3.1 shows the flow chart of the preparatory work.

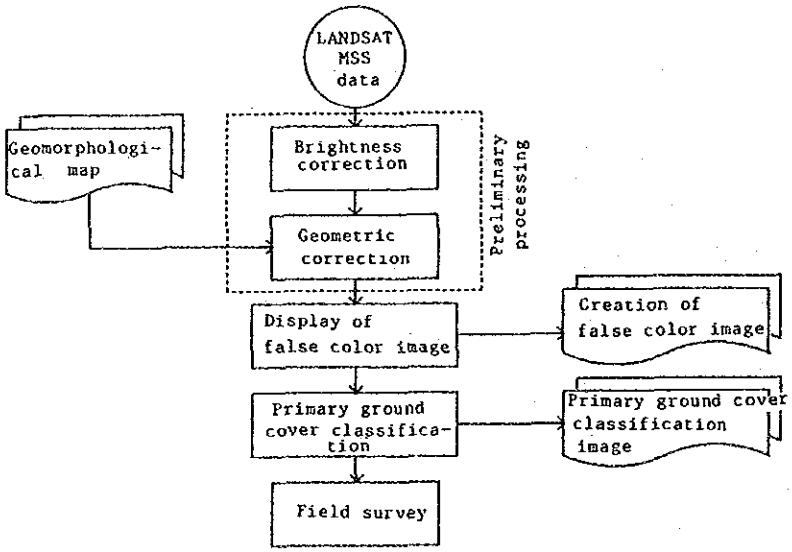

Fig. 3.1. Flow chart of domestic preparatory works

The main investigation items of preparatory works are as follows:

(1) Preliminary processing *1 of LANDSAT data (brightness correction and geometric correction)

(2) Creation of color image of LANDSAT data (creation of false color image *2)

(3) Primary ground cover classification *3

*1 Preliminary processing ... Corrective processing carried out prior to final processing to enhance the efficiency and accuracy.

*2 False color image ... Image synthesized in a manner to convert the near infrared data of LANDSAT into the visual color.
*3 Ground cover classification ... A method to judge the difference of color on the image by computer and to classify the coverage of ground surface.

3.2. Preliminary processing of LANDSAT data

To grasp the situation of ground cover at the site in advance, it is necessary (1) to create color image from the observation data of LANDSAT and (2) to automatically classify these images by computer. In advance to this series of image processing, we carried out (1) correction of LANDSAT images to be used (namely, in this study, there was a necessity to joint 4 LANDSAT scenes from south to north, and each of the scenes had delicate difference in color and tones (due to the difference of observation time, etc.); the correction of this difference is called brightness correction) and (2) correction to keep the topographic and positional conformance (geometric correction).

3.2.1. Brightness correction

When the original data of LANDSAT is directly displayed or converted into image, there are cases where colors are too bright or too dark. It is quite

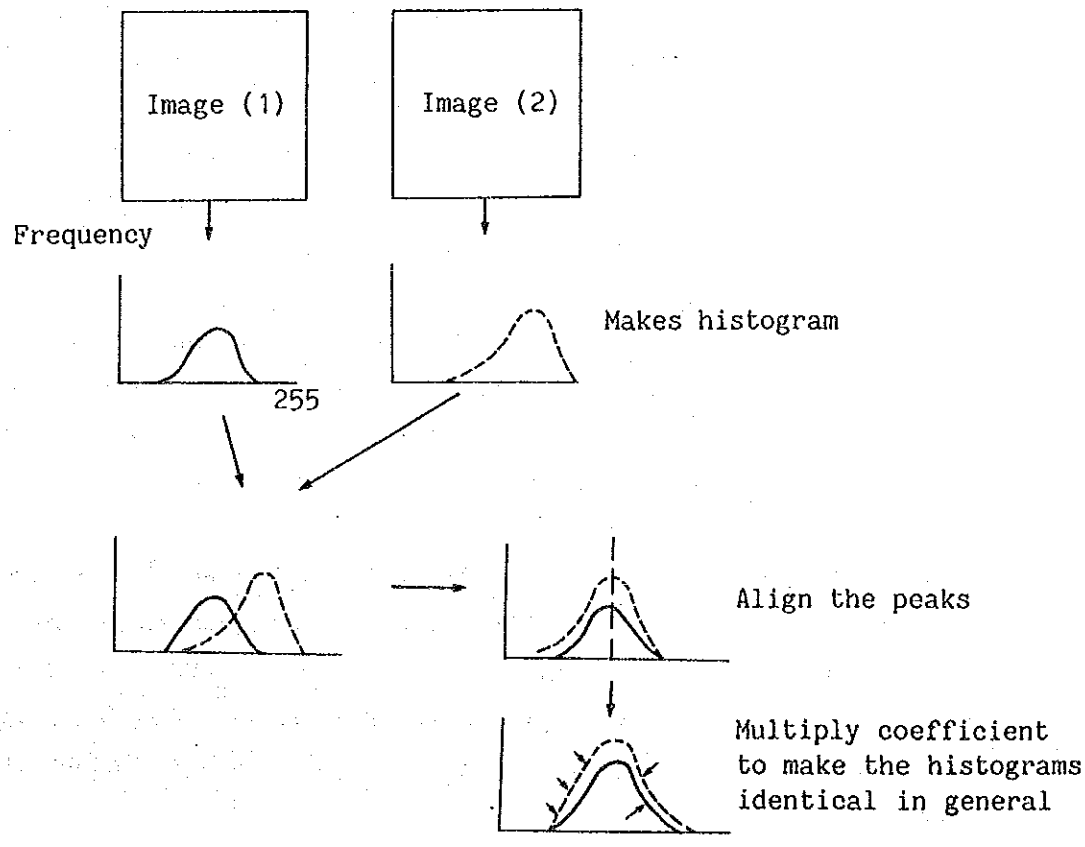

Fig. 3.2. Conceptual diagram of brightness correction

inappropriate especially when the images of two or more different times are compared and discussed. Therefore, brightness correction is normally made so that these images can be correctly interpreted.

In this stage, we carried out the brightness correction to the image data of each 4 scenes of two different times of 1970's and 1980's. The seasons and weathers of the observation of these 4 scenes each of 2 periods are different each other, but such chronological difference can be corrected to some extent by correcting the brightness. Fig, 3.2 shows the conceptual diagram of brightness correction.

The procedures of brightness correction are as follows:

(1) Make histogram against the images of same area of 2 different times.
(2) Using one of the histogram as a reference, align the peak of histogram each other.
(3) Next, by multiplying a coefficient, make the both histogram alike in general.

3.2.2. Geometric correction

Each of the LANDSAT data has geometrical (geographical) deformation due to the flying conditio of satellite at the time of observation, and is therefore not conforming with normal geomorphologocal maps. As there was a necessity to compare the data of different observation times and to measure the area in this study, we carried out geometric correction to the data so that positional relation would coincide between image and geomorphological map.

Geometric correction was done in the following procedures.

(1) Establishment of map coordinate system

First of all, it is necessary to establish rectangular coordinate system[*1] on the geomrphological map which is used as the reference. In this study, we used the geomorphological map of scale 1/250,000 and established the coordinates so that the study area would be included inside.

(2) Selection of GCP (Ground Control Point)[*2]

We selected the points which could be clearly identifiable and correspond each other on both image and geomorphological map, and measured their image coordinates (u, v) and map coordinates (x, y). In this study, characteristic points such as river, swamp, valley line were selected as GCP. We paid attention to place these points evenly over the study area, and set about 10 points per one scene.

(3) Orientation of image

We worked out the relative formula between the image coordinates and map coordinates. In this study, affine transformation*3 was used, which is given by:

$$x = a_1 u + a_2 v + a_5$$
$$y = a_3 u + a_4 v + a_6$$

Where, the six transformation coefficients*4 $a_1 - a_6$ were determined by least square method*5 using the value of coordinates of 4 or more pairs of ground control points. The error of least square was confined within 2.3 - 2.5 pixels (230 - 250m).

(4) Re-sampling*6

Image data were re-sampled by the transformation coefficients thus worked out. There are some methods in re-sampling, but we used the nearest neighbor method*7 with which the value of image data is not influenced by neighboring data, because the classification should be made by the unit of pixel in this study. This is a method to use the original data which is located nearest to the coordinate value after transformation as the output data. The size of pixel was determined to be 100m. The outline of the image before and after re-sampling is as shown in Fig. 3.3.

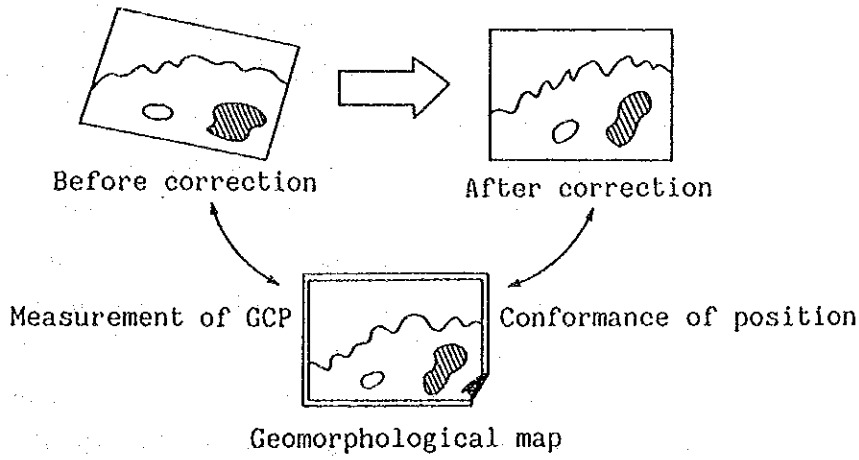

Fig. 3.3. Outline of images before and after transformation

*1 Rectangular coordinate system: By using the rectangular coordinate system, it is possible to conform with the mesh of image data.
*2 Ground control point: It is necessary to select the points where the object on the image coincides with the expression on the map.
*3 Affine transformation: A kind of linear transformation, by which straight line is transformed into straight line.
*4 Transformation coefficient: $a_1 - a_4$ denotes the revolution and magnification, and $a_4 - a_6$ denote the displacement volume.

*5 Least square method: A method to work out assumed value so that sum of square of difference between assume value and actual value should become least.
*6 Re-sampling: To make image data with new disposition by re-aligning the disposition of image data.
*7 Nearest neighbor method: A kind of making re-sampled data. Besides this, there are bi-linear method, cubic method and convolution method.

3.3. Creation of false color image

False color images were constructed by the data processed as described so far.

Table 3.1 shows the details of each band of LANDSAT MSS data as well as the bands and color expression which were used for false color image.

Table 3.1. Specifications of each band of LANDSAT MSS data

Band name	Wavelength range (um)	Ray range	False color expression
Band 4	0.5 - 0.6	Visible green	Blue
Band 5	0.6 - 0.7	Visible red	Green
Band 6	0.7 - 0.8	N. Infrared	(not used)
Band 7	0.8 - 1.1	N. Infrared	Red

False color image can be visually seen when it is displayed on screen or processed photographically. This is necessary for interpretation of objects on the ground or for setting training area*1 in ground cover classification. (On the false color image, the portion where vegetation activity is strong is expressed in red due to the wavelength property of infrared data, and water area is expressed in black. Therefore, it has a characteristic to more easily identify the situation of vegetation and the difference of land and water comparing with natural color image.)

The false color images of each scene created by the procedures as above-mentioned are shown in annexed materials. Table 3.2 shows the relation between the color on false color image and items of ground cover classification (there are some items of ground cover that cannot be clearly determined as these are the classification items before the field survey).

Table 3.2. Relation between false color and ground cover classification item

False color on image	Classification	Characteristics
Red (light - dark red)	Forest	The color red is deeper when the activity of vegetation is stronger. (Due to the property of infrared data*2)
Pink - violet	Grassland	Color red is lighter as the activity is lower than forest.
Green - deep green	Farm land	Various kinds of green is displayed according to the kind and extent of growth of plant which have different surface reflection.
Blue - dark blue	Water area	Various kind of blue is displayed due to the muddiness of water.
White - (partly) light blue	Cloud	Generally white; but the portion where the land surface is visible is expressed in light blue.
Black	Shadow of cloud	Expressed in almost black as the sun beam does not reach there.

*1 Training area (trainer): Refers to the portion of image where classification item to which it should be classified is known beforehand. Classification is done basing on this statistic volume.

*2 Property of near infrared data: The reflection rate of near infrared ray is higher as the activity of plant is stronger. As the near infrared is expressed in red on false color image, the red becomes stronger when the vegetation activity is strong. (Refer to Table 3.1.)

The characteristics of each false color image will be explained in the following:

(1) Path 9 - Row 56 1977.9.17

1) Cauca River runs through the center of this scene from south to north, and lakes and swamps are scattering around it.
2) Flat land is formed along the river, which is used as farm land.
3) Farm lands are observed frequently at the area close to the river, but grazing/grass land distributes more frequently towards the inland.
4) Most of the mountain area is covered by forest.
5) Difference of vegetation is observed on the false color image according to the difference of altitude; this is considered due to the difference

of kind of woods.

6) The study area in this scene includes Manizales and mountains north of it, where farm lands scatter enclosed by the forests.

(2) Path 9 - Row 57 1976.2.1

1) Cauca River rins through the center of this scene, and wide flat land is formed along the river.

2) Besides a large lake located in the south, there scatter large and small lakes on the flat land.

3) With respect to land use, large scaled farm lands are formed utilizing this flat land.

4) The flat land forms gradual slope land towards the mountain foot, and the area which is not used as farm land is grassland.

5) Mountain area is also covered by forests, and the density of forest becomes higher towards the mountain peak.

6) The study area in this scene is mountain area centering around Armenia, where forest is dominant. But farm land and grazing/grass land distribute conspicuously at the mountain foot.

7) There are many clouds over the mountain at the peripheries of this scene, but the picture quality is excellent at the central parts.

(3) Path 9 - Row 58 1976.2.1

1) Cauca River meanders acutely in this scene, and wide flat land is formed along the river.

2) Farm lands distribute widely on the flat land, and grazing/grass lands spread towards the mountain foot.

3) The majority of mountains is covered by forest, but there are some parts of mountain foot where lumbering is developing, which is clearly identified on false color image.

4) The land after lumbering is used as farm land.

5) The study area in this scene is inland mountain area from Cali to Popayan, where forest together with grazing/grass lands distribute frequently centering around the mountain foot.

(4) Path 9 - Row 59 1976.2.1

1) In this scene, Patia River flows at the west side forming flat lands.

2) There is a tributary of Amazon River at the south of this scene, and the large scaled flat land develops at the south side of it.

3) Farm lands distribute widely along Patia River, and most of the flat lands in the south are grazing/grass land.

4) Mountains are covered by dense forests, showing clear contrast against flat land area.

5) The study area is located on mountain zone with Pasto at its south end, where there are dense forest except at the mountain foot.

(5) Path 9 - Row 56 1987.12.24

1) Along the river are located large cities such as Medellin, while farm lands and grazing/grass lands are widely distributing on the flat land.

2) The density of forest on mountain becomes higher as the altitude goes high. But even in the mountain area, there scatters the places where lumbering is developing being converted into farm land.

3) Although the dominant part of study area is mountain, there are advancing the farm lands from the mountain foot.

(6) Path 9 - Row 57 1987.12.24

1) Large scaled farm lands are expanding along Cauca River.

2) The distribution range does not show much difference from the scene of 1976, but the shape of individual portion has changed largely, indicating the intensive change which took place during the 10 years.

3) Mountains are covered by forests, but lumbering is progressing intensively comparing with 1976.

4) Also in the study area, lumbering is conspicuous centering around the mountain foot, and the area after lumbering is used as farm lands, etc.

(7) Path 9 - Row 58 1987.12.24

1) Farm land and grazing/grass land distribute on the flat land along Cauca River at the north part.

2) Most of the other part are mountains, forming forest areas.

3) Much difference is not observed comparing with the scene of 1976, only the difference is the farm lands which are distributing at mountain foot.

4) No indication of large scaled lumbering is observed.

5) The study area is mountain zone, and most of it is occupied by forest.

(8) Path 9 - Row 59 1987.12.24

1) Farm land and grazing/grass land distribute along the river at the west of the scene.

2) Mountains are mostly covered by forest, but lumbering is progressing at the mountain foot, which is clearly identified on false color image.

3) The study area included in the mountain zone is not an exception, and lumbering is observed at low land areas.

3.4. Primary ground cover classification

Representative methods of automatic classification of remote sensing are the classification to use ground truth data*1 (to clarify the relation between image data and objects on the ground by investigating the objects on the ground corresponding the image data and its surroundings) and the method without using such data but to classify according to the physical property of image data. There are Maximum Likelihood Method*2 classification and Tree Type classification in the former, and main component analysis method and density analysis (slicing) method in the latter. Maximum likelihood method is mostly used for the ground cover classification in the investigation of forest where the ground truth data can be prepared. In this study too, maximum likelihood method was used for the primary ground cover classification.

The procedures of maximum likelihood method are as follows:

(1) Determines the classification items using false color image and ground truth data.

(2) Picks up the area on the image where the ground cover is clearly identified as the trainer (training area), and calculate the statistic volume (average, variance) of pixel with in the trainer.

(3) Carries out classification by the unit of pixel within the trainer, and calculates the identification efficiency by each classification item. If the identification efficiency is not proper, picks up again another trainer.

(4) Using only the trainers which have appropriate identification efficiency, the classification is carried out to total images.

Since the primary ground cover classification was carried out in advance to the field survey as stated in the above, we picked up the ground points where the ground cover is confirmed basing on the color of false color image as shown in Table 3.2 (in the above), and automatically judged by computer by inputting those points as trainer.

In the primary ground cover classification, the ground cover was classified into 6 categories of (1) forest, (2) grassland, (3) farm land, (4) water area, (5) cloud and (6) shadow of cloud. This classification results were confirmed and verified at the field survey, and secondary ground cover classification (analytical works done in Japan) was carried out basing on the findings at the field survey.

The definition of 6 classification items are as follows:

Table 3.3. Definition of primary classification items

Items	Definitions
Plateau grassland	Natural grassland generally located at altitude 3,000m or higher
Natural forest	Natural forest and secondary forest
Man-made forest	Afforested woods such as pine tree and cypress
Grazing/grass land	Natural improved grassland for cattle grazing and natural grassland
Agricultural forest	Shaded trees mainly such as coffee and sugar cane
Farm land	Agricultural farm land

*1 Ground truth: Confirmed information obtained by field survey.
*2 Maximum likelihood method: A kind of statistical method, by which the data is assumed to show normal distribution, and classification is made by maximum likeliness.

4. Field survey

Field survey was carried out basing on the preparatory works done in the first study year in Japan. The false color images and primary ground cover classification images were carried over, and confirmed and verified at the actual site.

The field survey can be divided into the investigation for creation of image identification standard and investigation for ground classification.

In the investigation for creation of image identification standard, we determined the image identification control point (called training area) which would be used for the secondary ground cover classification to be carried out in the second study year, and investigated the land use, vegetation, land condition and environmental condition at and around the control points.

In the investigation for ground cover classification, on the other hand, we discussed the appropriateness of color expression and classification results using the false color images and primary ground cover classification images made in the preparatory works.

4.1. Investigation for creation of image identification standard

In the investigation for creation of image identification standard, we established training areas and carried out investigation on these areas.

(1) Establishment of training area

1) We selected observation points which can be clearly identified on both image and map, and where all of four directions can be observed.
2) We determined the training areas to be located around the observation point, and to have at least 5 ha. of representative ground cover on its ground surface.
3) The items for which the training area was established were determined to be 6 categories of plateau grassland, man-made forest, grazing/grass land, agricultural forest and farm land.
4) The observation points around which the training areas were established were numbered as shown in Fig. 4.1. The number of observation points is 37 in total, and the number of training area amounted to 60 in total as shown in Table 4.1.

(2) Investigation on training area

With respect to the training areas thus selected, we made geographical measurement on their position and altitude, observed and recorded the

vegetation, forest and land use on and around them, and took photograph of them.

(3) Others.

In the secondary ground cover classification, the identification items of bare land such as barren land and degraded land, city and colony, river and lake/swamp would be added to the ground cover classification items of training area of this time. No training areas were specially established for these items, but they were confirmed of their position on false color image and maps, and the photographs of their actual site were taken, and were used as materials for interpretation works.

Originally, we had been planning to establish 4 scenes x 5 items x 3 points = 60 training areas. However, there were some placed in the south of Cauca and mountain zone at the east of Cali City where the investigation was impossible. Moreover, it became clear that 6 items instead of 5 were necessary for identification standard. Therefore, we changed the policy to select the points by area and selected the points mainly by the identification items.

As a result, priority was placed on the intensive area in establishing the training area, and 31 training areas were established in the intensive area, and 29 areas in outside the intensive area. But any way, the number of areas necessary for identification processing was satisfied. (Refer to annexed materials.)

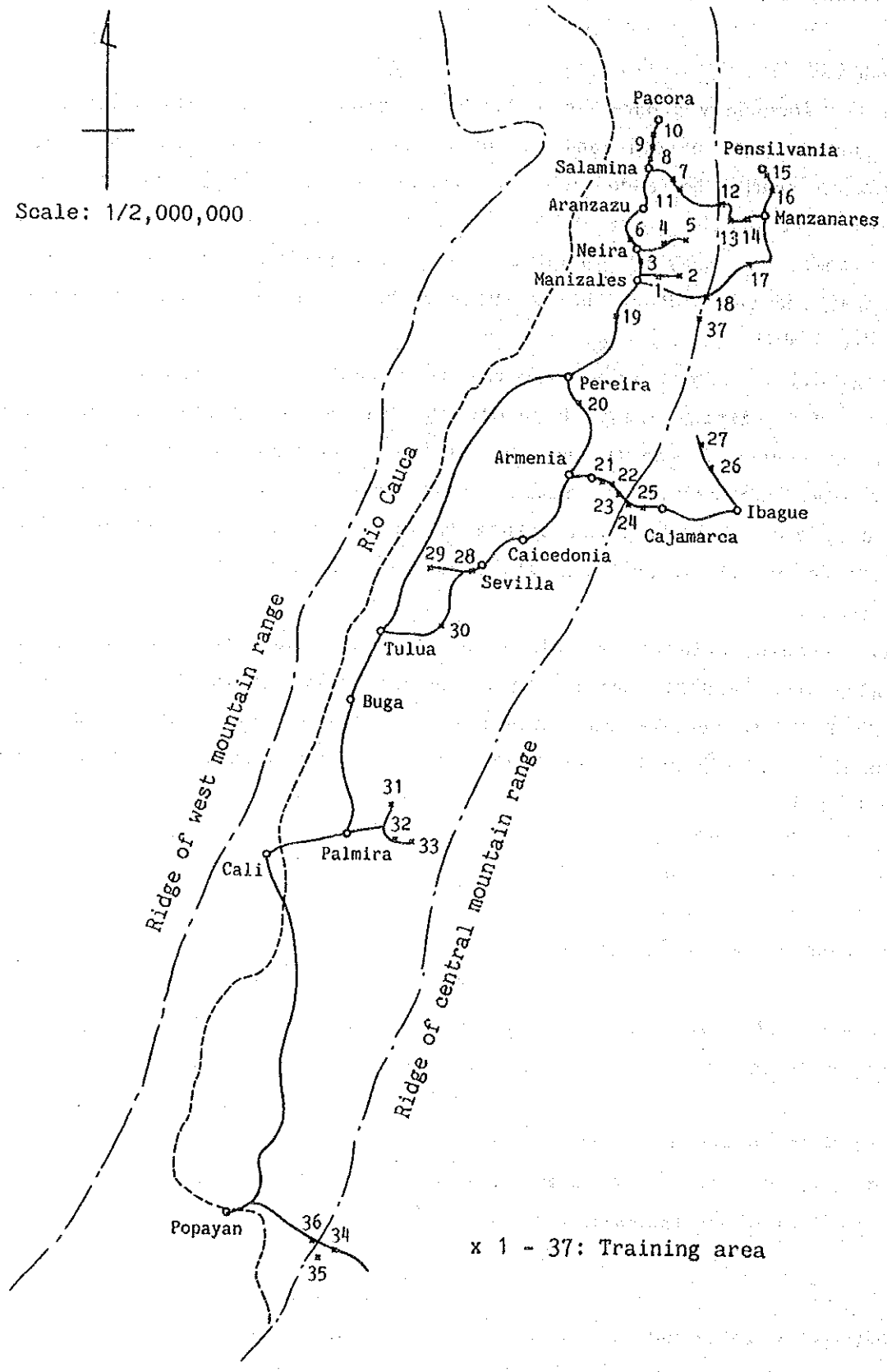

Fig. 4.1. Map of training area

Table 4.1. List of training area (No.1)

No.	Location of observation	Alti-tude	Plateau grassland	Natural forest	Man-made forest	Grazing grassland	Agricultural forest	Farm land	Remarks
1	Manizales waterhead forest	2400			O	O			Man-made forest of cypress, grazing land with partly farm land (potato)
2	〃	2600		O					About 200m from forestry road
3	Neira	2000				O	O		
4	Neira quarry	2400		O		O			
5	La Cristalina	2600		O		O			
6	Rio Tapias	1570					O	O	Panela farm land
7	South of Salamina	2280				O			
8	North of Salamina	1400				O	O	O	Panela farm land
9	〃	1230					O	O	Panela farm land
10	〃	2180			O	O	O		Man-made forest of pine tree
11	Salamina - San Félix	2400				O			
12	East of El Paramo	3040		O		O			With highland palm trees
13	Marulanda	2820		O		O			Man-made forest of pine tree
14	Manzanares	2350			O				
15	Pensilvania	1800			O				
16	La Lioja	1560			O				
17	La Palma	2060			O				
18	Letras	3640	O	O					Natural forest with low trees
Sub-total			1	6	6	10	5	3	Inside the intensive area: Total 31
19	Chinchina	1420						O	Coffee field
20	Pereira	1650			O				Man-made forest of pine tree
21	〃	2000					O		
22	Armenia	2100			O				Pine tree, eucalyptus
23	〃	2500			O	O			
24	LaLínea	2700		O					
25	〃	3200		O		O			With highland palm trees
26	Juntas	2100		O		O			
27	Parque nacional	2600		O		O			
28	Barcelona	1300					O	O	Yuca, sugar cane
29	La Uribe	1200				O			
30	Ceilán	1050				O			
31	La Quisquina						O	O	Sugar cane

Table 4.1. List of training area (No.2)

No.	Location of observation	Altitude	Plateau grassland	Natural forest	Man-made forest	Grazing grass land	Agricultural forest	Farm land	Remarks
32	La Quisquina	1600			○				Pine tree, cypress, eucalyptus
33	〃	1450			○	○	○		
34	Puracé	3000		○					
35	Parque nacional	3300	○	○					
36	〃	3350	○	○					
37	Nevado del Ruiz	4050	○						
Sub-total			3	7	5	7	4	3	Outside the intensive areat Total: 29
Total			4	13	11	17	9	6	Total: 60

4.2. Investigation for ground cover classification

Investigation for ground coverage classification was carried out to discuss the appropriateness of color and classification result carrying the false color image and primary ground cover classification image to the actual observation points.

In the field survey, especially at each observation point, the investigation was carried out placing emphasis on the actual state of land use, vegetation and forest. Furthermore, investigation was carried out on the basic condition and environment which were necessary for secondary ground cover classification by observing and recording the situations in the area between such observation points.

As a result of these investigation, it has become clear that the situation of ground cover and land use in the study area have strong relationship with the altitude. Fig. 4.2 shows the relation between altitude and the training areas by identification item.

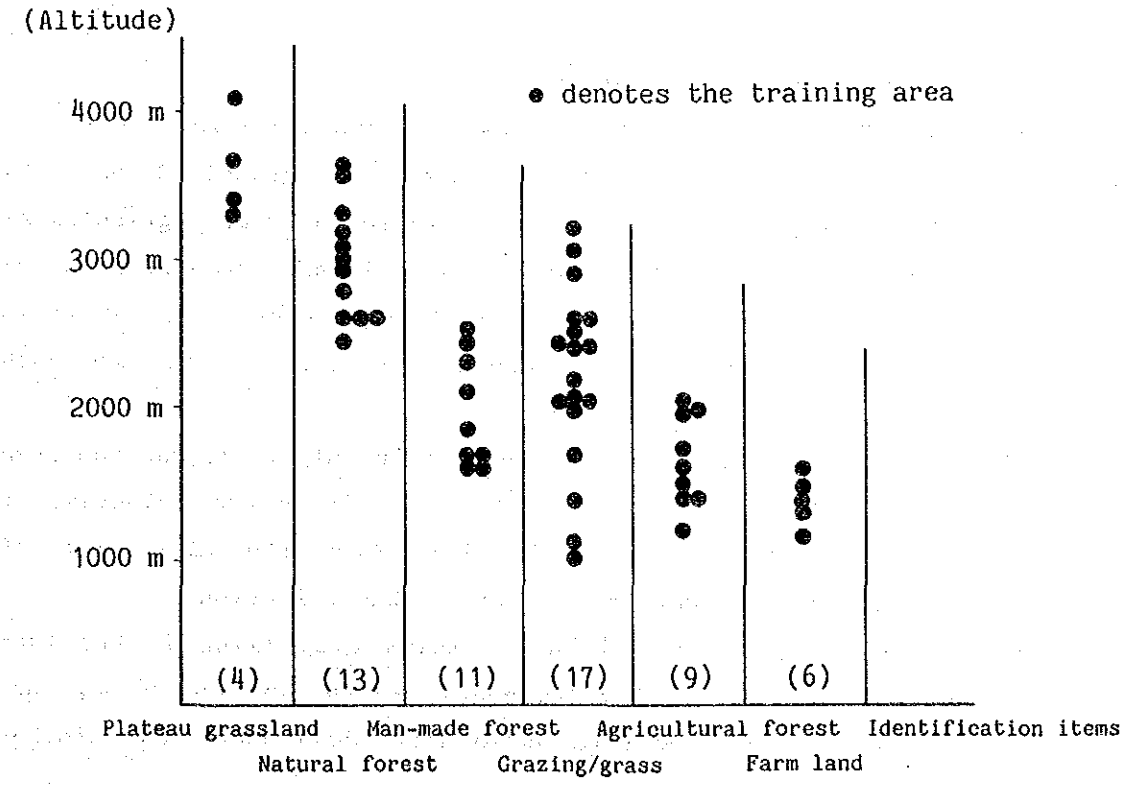

Fig. 4.2. Relation between identification items and altitude

The following tendency is clear from the above diagram.

Farm lands distribute frequently on the flat land of altitude 1,000 - 1,200m, and sugar cane fields are dominant among them. Paddy fields are also seen in the south.

There are many agricultural forests on the slope land at the mountain foot of altitude 1,200 - 2,000m. Most of them are shaded trees, and bamboo and banana are used as cover trees, under which coffee, sugar cane and panela are planted.

Man-made forests are mainly created at the altitude of 1,500 - 2,800m, while the natural forests are mostly seen at highland of altitude 2,500m or more, except that only few are remaining at low land along the valleys.

Grasslands are widely distributing at the altitude 1,000 - 3,600m.

Natural plateau grassland is observed at only at the highland of altitude 3,000m or more.

From these facts, it is possible to assume to some extent the land use, kind of vegetation and main products at a certain area from its topography and altitude.

4.3. Some problems in image identification

Since the natural forest and man-made forest are expressed in dark red on the false color image, they can be discriminated from grassland which is expressed in light red or yellow. But the secondary forest where agricultural forest and low tree are mixing is impossible to discriminate because it shows similar color. However, since the ratio of the latter is extremely small in the study area, it is considered that there is no necessity to make such discrimination.

Degraded land at the mountain foot is identifiable only if it has the area of 3 ha. or more. But as its color is similar to cities and colonies, it should be necessary to pick them up by discussing the difference of reflection spectrum in the secondary ground cover classification.

On the other hand, many slush and burnt fields are mixing in the farm lands on the low land, but since they are mostly in rectangular shape, they are not considered to be confused with humid land which shows the similar color.

In the primary ground cover classification, natural forest, man-made forest and agricultural forest are all grouped in one category of forest. Furthermore, the difference of farm land and grazing land is not clear

either. In addition, confirmation of position and collation with actual objects at the actual site were impossible because the shadows were erased by the land shape and direction.

These points were taken into consideration in the secondary ground cover classification and image interpretation carried out in the second study year.

5. Analytical works in Japan

5.1. Outline

Analytical works can be divided into secondary ground cover classification and creation of LANDSAT analysis map. The main items in this investigation are shown in the following:

(1) Secondary ground cover classification

The secondary ground cover classification was analyzed using the result of primary ground cover classification carried out in the preparatory works and the result of field survey.

(2) Creation of LANDSAT analysis map

Following LANDSAT analysis maps were compiled basing on the result of (1) above.

a. Land use classification image

b. Vegetation classification image

c. Land use/vegetation secular change image

The scale of these images was 1/250,000 respectively.

5.2. Secondary ground cover classification

Just like the primary ground cover classification, the secondary ground cover classification was carried out using maximum likelihood method, by setting 8 identification items as shown in Table 5.1 basing on the result of field survey. the classification was carried out on the wide area including the study area. The secondary ground cover classification image is shown in the annexed material.

Table 5.1. Secondary ground cover classification items

Items	Characteristics on image
Grassland	Shows the color from pink to violet, and is difficult to discriminate from grazing land.
Natural forest	Shows deep red color
Man-made forest	Shows light red or crimson. It is difficult to discrimi-nate from agricultural forest.
Grazing land	Shows the color from pink to violet, and is difficult to discriminate from grassland.
Agricultural forest	Shows green or deep green.
Cloud	Shows white or light blue color.
Shade of cloud	Shows black color.

To interpret the image, it is necessary to display the false color image on a display of the system and to establish a training area for each classification item. Here, we picked up the area which has the characteristic as shown in Table 5.1. To determine the appropriateness as the training area, we obtained the classification efficiency by calculating statistic volume of these areas by classification items. The results of calculation is shown in Table 5.2.

5.3. Image interpretation

The result of secondary ground cover classification by automatic identification is not itself enough for the compilation of land use classification image. Namely, as already explained in "4. Field survey," natural forest and man-made forest are expressed in deep red on false color image and can be clearly discriminated from grazing/grass land. But it is not enough to automatically identify natural forest and man-made forest by the image processing of computer only based on the spectrum data. Also, the difference between grazing land and grassland (including plateau grassland) is not clear either on the image.

Also, the bare land such as degraded land can be visually identified if it has the area of about 3 ha., but in automatic identification, there is a possibility that its spectrum is miss-judged as the same category as cities.

Table 5.2. Standard number of pixels and classification efficiency in second land cover classification

Scene	Classification	Grass-land	Natural forest	Man-made forest	Grazing land	Agri. forest	Farm land	Cloud	Cloud shadow
Row 56, 57 (1970's)	Grassland	87.1			10.3		2.9		
	Nat. forest		100.0	18.6		16.9			4.0
	Man-made frst.			81.4					
	Grazing land	12.9			89.7				
	Agri. land					83.1			
	Farm land						97.1		
	Cloud							100.0	
	Cloud shadow								96.0
	No. of pixels	54	64	62	52	35	58	131	62
Row 58, 59 (1970's)	Grassland	100.0							
	Nat. forest		97.4	5.8		1.4			
	Man-made frst.		2.6	94.2					
	Grazing land				100.0				
	Agri. land					98.6			
	Farm land						100.0		
	Cloud							100.0	
	Cloud shadow								100.0
	No. of pixels	51	149	114	46	68	60	192	71
Row 56, 57 (1980's)	Grassland	85.7					15.0		
	Nat. forest	5.3	94.7	17.8					
	Man-made frst.			82.2					
	Grazing land				100.0		4.7		
	Agri. land					100.0			
	Farm land						80.3		
	Cloud							100.0	
	Cloud shadow								100.0
	No. of pixels	102	54	28	25	59	53	121	62
Row 58, 59 (1980's)	Grassland	99.0			3.6				
	Nat. forest		88.1	18.2		5.9			
	Man-made frst.		11.9	74.6					
	Grazing land	1.0			96.4				
	Agri. land					94.1			
	Farm land			7.2			100.0		
	Cloud							100.0	
	Cloud shadow								100.0
	No. of pixels	195	74	44	54	32	60	117	148

Note) Classification efficiency has been calculated by the pixels included in the training area. Therefore, not all the pixels can be classified by the above efficiencies.

Therefore, we removed the errors of automatic identification made by computer by adding image interpretation based on the result of secondary ground cover classification. Image interpretation was not only implemented on the false color image, but efforts were made to interpret more in detail by emphasizing on the display the color of the portion where the color and tone was unclear.

Considering the items of secondary ground cover classification, the items of image interpretation were determined to be 9 categories of (1) Farm land, (2) Agricultural forest, (3) forest (man-made), (4) forest (natural), (5) grazing/grass land, (6) Bare/waste land, (8) city/town and (9) snow/ice field.

Table 5.3 shows the color on the false color image and its cjaracter-istics.

Table 5.3. Image interpretation standard and color

Classification	Color	Characteristics
Farm land	Light red	Gradual shape. Paddy fields are expressed in mosaic blue color.
Agricultural forest	Red - dark red	Fine pattern on gradual slope land
Forest (man-made)	Red brown-light red	Fairly coarse pattern on slope land in mountain area
Forest (natural)	Red brown-dark red	Coarse pattern on slope land in mountain area
Grazing/grass land	Crimson	Gradual shape
Plateau grassland	Green-light brown	Irregular pattern on mountain ridges
Bare/waste land	Light green-light brown	Small spot or linear shape on a slope land
City/town	Blue	Irregular shape
Snow/ice field	White - blue	Seen on mountain top or ridges

Fig. 5.1.shows an example of image interpretation.

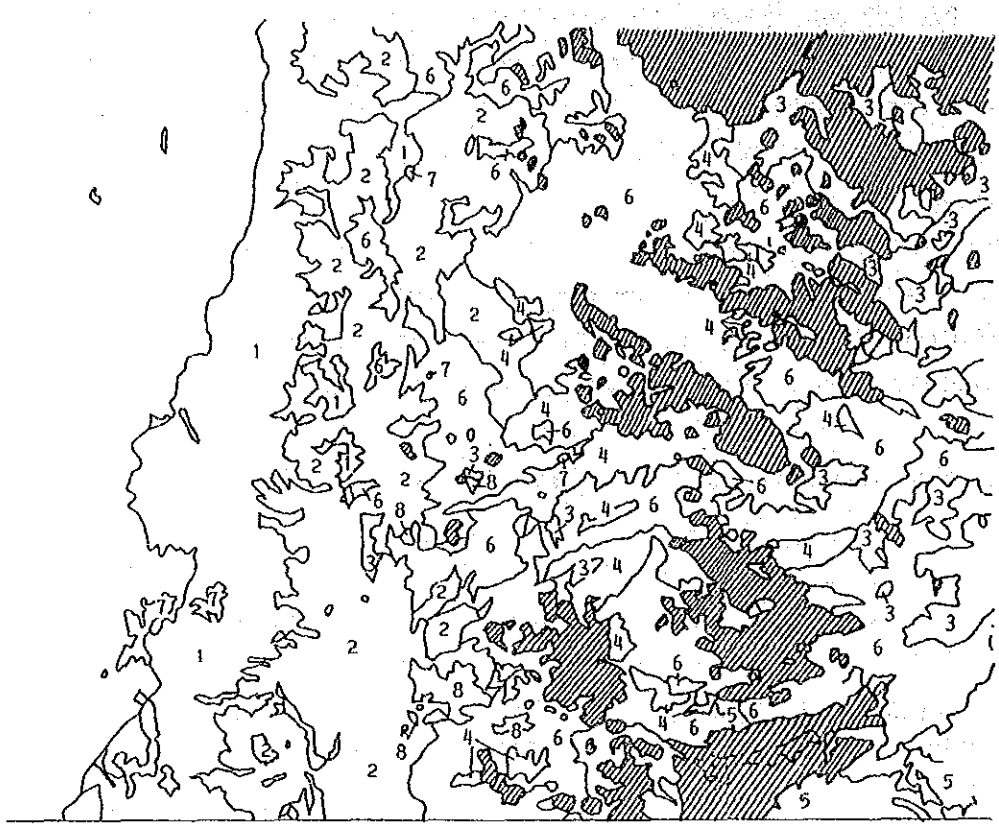

Fig. 5.1. Example of image interpretation (around Manizales)
(1. Farm land; 2. Agricultural forest; 3. Man-made forest; 4. Natural forest; 5. Plateau grassland; 6. Grazing/grass land 7. Bare/waste land 8. Cities)

5.4. Compilation of LANDSAT analysis map

LANDSAT analysis map was created using the result of secondary ground cover classification and image interpretation.

(1) Land use classification image

The identification items of land use classification image were 8 categories of forest, plateau grassland, grazing/grass land, agricultural forest, farm land, city/town, bare/waste land and snow/ice field. The scale of image is 1/250,000, and main water routes, main road and main cities were added thereto. The land use classification image was made for the two periods of 1979's and 1980's.

Table 5.4 shows the items of land use classification.

Table 5.4. Items of land use classification

Items	Characteristics
Forest	Natural forest and man-made forest are grouped into one category of forest.
Plateau grassland	The grassland which distributes on ridges of mountain
Grazing/grass land	Grazing and grass land which widely distribute on the slope land of mountain
Agricultural forest	Under trees such as coffee and sugar cane are grown under the cover trees such as shading tree and bamboo.
City/town	Cities such as Manizales
Bare/waste land	Large scaled degraded land and waste land
Snow/ice field	The area covered by snow and ice

(2) Vegetation classification image

Comparing with the land use classification image, only the items concerning the vegetation are picked up in the vegetation classification image, and forest is further sub-divided into natural forest and man-made forest. The identification items of vegetation classification were determined to be 5 categories of forest (natural), forest (man-made), plateau grassland, grazing/grass land and others.

The procedures to make the image are the same to those of land use classification image. The vegetation classification images were also made in the scale of 1/250,000, and for two period of 1970's and 1980's.

Table 5.5 shows the items of vegetation classification.

Table 5.5. Vegetation classification items

Classification	Details and characteristics
Natural forest	Natural trees and woods
Man-made forest	Afforested trees and woods
Plateau grassland	Natural grassland distributing on mountain ridges
Grazing/grass land	Grassland distributing widely on slope land of mountain

(3) Land use/vegetation secular change image

It is possible to grasp the situation of change of land use/vegetation by superimposing LANDSAT data of two different times. In this study, we grasped the change of land use and vegetation over about 10 years from 1970's to 1980's, and compiled them into the land use/vegetation secular change image in the scale of 1.250,000.

6. Result of the study

We summed up the area by each category and grasped the regional characteristics basing on the land use classification image, vegetation classification image and land use/vegetation secular change image made in the previous chapter.

6.1. Outline

In this study, the analysis was made on the analysis object area of 1.9 million ha. which includes 1.6 million ha. of study area in the Central Reserved Forest and peripheral areas of it. The study area includes 10 states indicating various regional characteristics.

Here, we analyzed the situation of land use, vegetation and secular change of land use and vegetation. In implementing the analysis, we grasped the situation of total study area and that of each state.

6.2. Situation of land use

Basing on the land use classification image made in Chapter 5, we grasped the situation of land use in the total study area, as well as the general situation of study area and each state.

Classification items of land use were 8 categories of forest, plateau grassland, grazing/grass land, agricultural forest, farm land, city/town, bare/waste land and snow/ice field as stated in Chapter 5.

We summed up the areas by classification items to grasp the situation of land use by each state. Table 6.1 and Table 6.2 show the lists of area by land use of respective periods of 1970's and 1980's. Fig. 6.1 and Fig. 6.2 show the comparison of land use areas by each state.

The situation of land use in total area and in each state is explained in the following:

(I) General situation

the general situation through 1970's and 1980's is summarized as follows:

1) Among the analysis object area of 1,918,300 ha., the area for which the situation of land use was grasped was 1,640,000 ha. (the area after deducting the clouded area of 278,300 ha. from the analysis object area) for 1970's and 1,269,200 ha. (similarly the area after deducting 649,100 ha.) for 1980's. This area is called "analyzed area" in the following.
2) The forest grasped was 833,300 ha. in 1970's and 514,000 ha. in 1980's. This corresponds with 43% and 27% of analysis object area respectively.

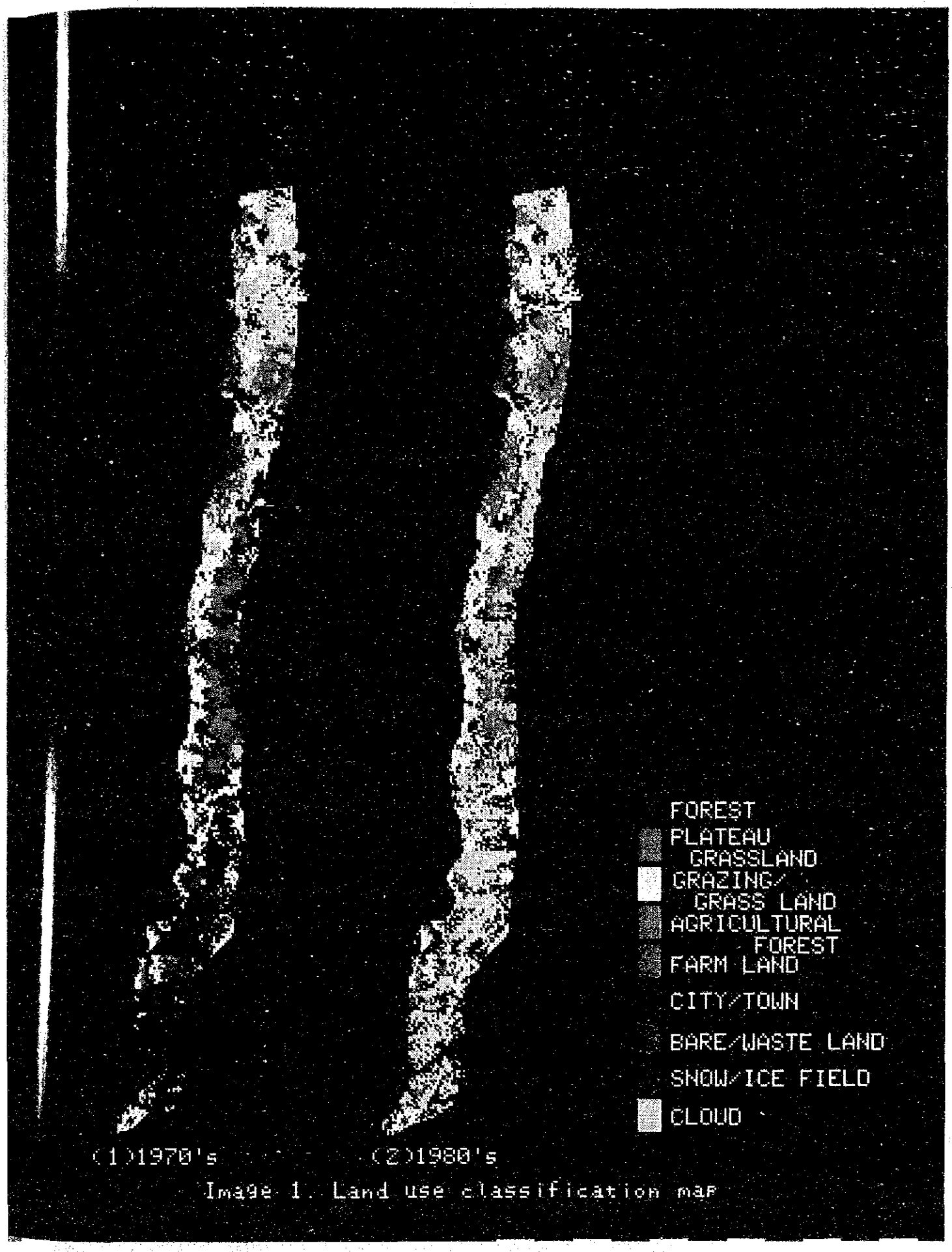

Image 1. Land use classification map

Table 6.1. List of area by land use classification items (1970'S)

Upper column:area(ha)

Lower column:ratio(%)

State / Item	Antiquia		Caldas		Risaralda		Quindio		Tolima		Velle del Cauca		Cauca		Huila		Narino		Putumayo		Total	
Forest	14,900		42,000		14,800		20,800		127,200		40,500		360,100		103,900		96,100		13,000		833,300	
	16	23	17	29	22	28	17	22	42	48	19	22	60	62	78	90	78	83	86	100	43	50
Plateau grass land	0		13,900		14,200		2,000		89,000		41,000		59,500		900		5,000		0		225,500	
	0	0	6	9	21	27	2	2	29	34	19	22	10	10	1	1	4	4	0	0	12	14
Grazing Grass land	38,900		68,300		5,800		30,800		42,700		81,000		137,000		10,800		13,100		0		428,400	
	43	61	28	47	9	11	25	33	14	16	38	43	23	23	8	9	10	11	0	0	22	26
Agricultural forest	8,100		20,200		16,700		39,400		0		22,500		20,400		0		0		0		127,300	
	9	13	8	14	25	31	33	42	0	0	10	12	4	3	0	0	0	0	0	0	6	8
Farm land	1,600		0		0		0		0		0		0		0		0		0		1,600	
	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
City Town	0		600		400		1,100		0		0		0		0		0		0		2,100	
	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bare land Waste land	0		0		300		200		0		1,900		5,900		0		2,600		0		10,900	
	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	2	2	0	0	1	1
Snow field Ice field	0		1,400		300		300		5,500		0		3,400		0		0		0		10,900	
	0	0	0	1	0	1	0	0	2	2	0	0	0	1	0	0	0	0	0	0	1	1
Analyzable area excluding clouds	63,500		146,400		52,500		94,600		264,400		186,900		586,300		115,600		116,800		13,000		1,640,000	
	70	100	59	100	77	100	78	100	87	100	87	100	98	100	87	100	94	100	86	100	85	100
Cloud	28,700		102,000		14,900		26,100		38,500		29,200		13,500		17,200		7,000		2,200		278,300	
	30		41		23		22		13		13		2		13		6		14		15	
Total	91,200		248,400		67,400		120,700		302,900		216,100		599,800		132,800		123,800		15,200		1,918,300	
	100		100		100		100		100		100		100		100		100		100		(100)	

Table 6.2. List of area by land use classification items (1980'S)

Upper column:area(ha)

Lower column:ratio(%)

State / Item	Antiquia		Caldas		Risaralda		Quindio		Tolima		Velle del Cauca		Cauca		Huila		Narino		Putumayo		Total	
Forest	12,900		56,400		15,200		22,600		72,800		38,300		191,900		48,600		45,700		9,600		514,000	
	14	21	23	28	23	29	19	22	24	44	18	21	32	53	37	83	37	73	63	100	27	40
Plateau grass land	0		15,500		12,700		2,200		61,900		28,600		37,200		200		4,100		0		162,400	
	0	0	6	8	19	24	2	2	20	36	13	15	6	10	0	0	3	6	0	0	8	13
Grazing Grass land	38,400		97,300		6,900		37,200		27,600		92,000		109,400		9,900		11,300		0		430,000	
	42	63	39	47	10	13	31	37	9	16	43	49	18	30	7	17	9	18	0	0	22	34
Agricultural forest	7,700		30,300		15,700		38,500		0		25,300		16,500		0		100		0		134,100	
	8	13	12	15	23	29	32	38	0	0	12	14	3	5	0	0	0	0	0	0	7	11
Farm land	1,600		200		0		0		0		0		0		0		0		0		1,800	
	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
City Town	0		2,100		1,900		600		0		0		0		0		0		0		4,600	
	0	0	1	1	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bare land Waste land	0		100		400		200		0		2,100		4,000		0		2,200		0		8,000	
	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0	0	2	3	0	0	0	1
Snow field	0		2,000		200		200		7,500		0		3,400		0		0		0		13,300	
	0	0	1	1	0	0	0	0	2	4	0	0	0	1	0	0	0	0	0	0	1	1
Analyzable area excluding clouds	60,600		203,900		53,000		101,500		169,800		186,300		362,400		58,700		63,400		9,600		1,269,200	
	66	100	82	100	79	100	84	100	55	100	87	100	60	100	44	100	51	100	63	100	65	100
Cloud	30,600		44,500		14,400		19,200		133,100		29,800		237,400		74,100		60,400		5,600		649,100	
	34		18		21		16		45		13		40		56		49		37		35	
Total	91,200		248,400		67,400		120,700		302,900		216,100		599,800		132,800		123,800		15,200		1,918,300	
	100		100		100		100		100		100		100		100		100		100		100	

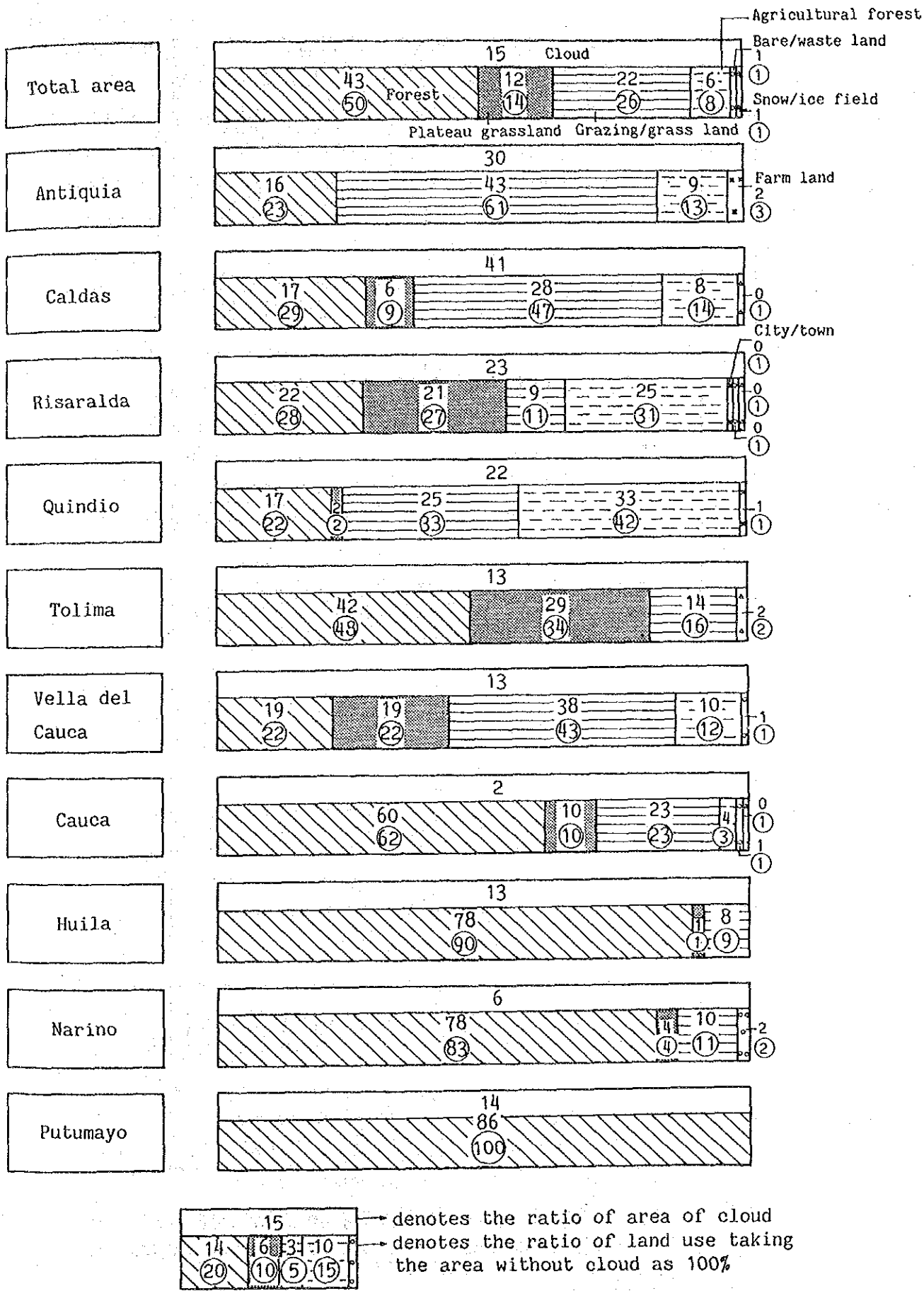

Fig. 6.1. Comparison of the area of land use by states (1970's)

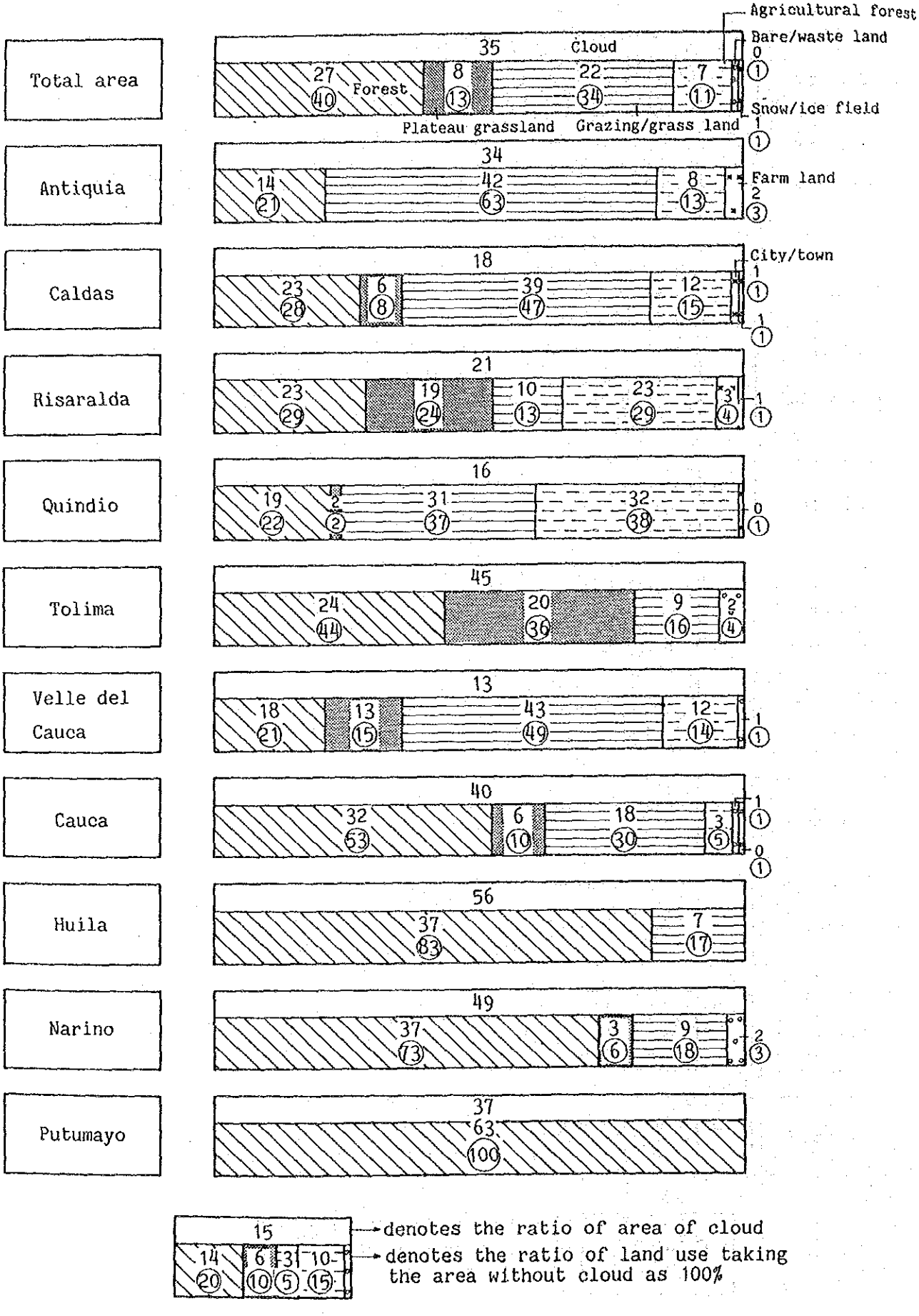

Fig. 6.2. Comparison of the area of land use by states (1980's)

Similarly, they correspond with 50% and 40% of analyzed area respectively, indicating that the forest has decreased to some extent. The forests are more abundant in the south than in the north within the analysis object area. Also, they are more abundant at the east side slope land than the west side slope land of the Central Mountain range.

3) Plateau grassland grasped was 225,500 ha. in 1970's and 162,400 ha. in 1980's. They correspond with 12% and 8% of analysis object area respectively, and 14% and 13% of analyzed area respectively, indicating that it remains almost at the same level.

   The plateau grassland is observed around the mountain ridges at the central part, distributing at the highland of altitude 3,500m or higher including Mt. Nevado del Ruiz.

4) The grazing/grass land grasped was 428,400 ha. in 1970's and 430,000 ha. in 1980's. They correspond each with 22% of analysis object area respectively. However, as they correspond with 26% and 34% of analyzed area, it is known that the grazing/grass land is increasing.

   Among the analysis object area, the grazing/grass land distributes widely from mountain foot to adjacent area of mountain top in the north part. In the south. it distributes relatively frequently around the mountain foot.

5) The agricultural forest grasped was 127,300 ha. in 1970's and 134,100 ha. in 1980's. They correspond with 6% and 7% of analysis object area, showing almost the same level. In comparison with the analyzed area, on the other hand, they are 8% in 1970's and 11% in 1980's indicating that the agricultural forest is fairly increasing.

   The agricultural forest distributes more frequently on the west side slope land of Central Andes Mountains, especially in Risaralda and Quindio.

6) Farm land grasped was 1,600 ha. in 1970's and 1,800 ha. in 1980's. They are 0% against both analysis object area and analyzed area, showing that their scale is very small. For the reference, the farm land distributes only in Antiquia.

7) The cities/towns grasped was 2,100 ha. in 1970's and 4,600 ha. in 1980's. Their ratio is also 0% against both analysis object area and analyzed area. It can be said, however, that the city area has increased in 1980's comparing with 1970's. The cities/town distributes at the north part of the analysis object area, such as Manizales, Pereira and Armenia.

8) Bare/waste land is at the almost same level of 10,900 ha. in 1970's and 9,000 ha. in 1980's. Bare/waste land is only seen at a part of Risaralda, Velle del Cauca, Cauca and Narino. They correspond with 1% of the analysis object area.

(9) Snow/ice field grasped was 10,900 ha. in 1970's and 13,300 ha. in 1980's. Both of them correspond with 1% of the analysis object area. It is seen around the highlands in Caldas and Tolima.

The situation of land use of each state is explained in the following:

(II) Situation of each state

(1) Atiquia

1) The analysis object area is located at the mountain area in the south edge of the state, and as the altitude is relatively low (maximum altitude is about 3,000m), the most of the area is occupied by grazing/grass land, and the ratio of forest is relatively low. This is a state where coffee and banana are grown actively, but they are observed at a only part of the analysis object area.

2) Analyzed area excluding the area covered by the clouds was 63,500 ha. in 1970's and 60,600 ha. in 1980's, representing 70% and 66% respectively of the analysis object area of 91,200 ha.

3) The forest was 14,900 ha. in 1970's and 12,900 ha. in 1980's. These correspond with 16% and 14% of analysis object area (23% and 21% of analyzed area), showing that the forest is decreasing slightly.

4) The forests in this state distribute relatively widely on the west side slope lands near the ridges of mountain range, but they also distribute, though very few, on the east side slope land near the mountain ridges.

5) The grazing/grass land grasped was 38,900 ha. in 1970's and 38,400 ha. in 1980's. They correspond with 43% and 42% of the analysis object area (61% and 63% of the analyzed area) respectively, indicating the trend, when the ratio against the analyzed area is concerned, to increase slightly.

The grazing/grass land is dominant on the slope lands at the east side of mountain range, while on the slope lands at the west side, it shares almost the same area as forest and agricultural forest centering around the mountain breast.

6) The agricultural forest was 8,100 ha. in 1970's and 7,700 ha. in 1980's, corresponding with 9% and 8% of the analysis object area (each 13% of analyzed area) respectively, showing hardly any change.

In this state, the agricultural forest distributes centering around the

west side mountain foot.

7) Besides the above, the farm land grasped was 1,600 ha. in both 1970's and 1980's. This corresponds with 2% of the analysis object area (3% of the analyzed area). Farm land is observed along the river at the mountain foot.

(2) Caldas

1) As the analysis object area in this state includes the main ridge of the mountain range and various areas from highland to low land which have different climate conditions, the distribution range of land use is quite cimplicated.

2) The analyzed area in Caldas state was 146,400 ha. in 1970's and 203,900 ha. in 1980's which are 59% and 82% of the analysis object area of 248,400 ha.

3) The forest was 42,000 ha. in 1970's and 56,400 ha. in 1980's. These correspond with 17% and 23% of analysis object area respectively. But they correspond with 29% and 28% respectively of the analyzed area, indicating the decrease, though very small.

With respect to the distribution, the forests are sparsely observed around ridges of central mountain range, while they are observed widely around Pensylania in the north-east and at the area from Agudas to Salamina in the south-west.

4) The plateau grassland was 13,900 ha. (6% of the analysis object area) in 1970's and 15,500 ha. (6% of the same) in 1980's which correspond with 9% and 8% respectively of the analyzed area, indicating hardly any change. The plateau grassland distributes at the ridges of mountain range.

5) Grazing/grass land was 68,300 ha. (28% of the analysis object area) in 1970's and 97,300 ha. (39% of the same) in 1980, which correspond with 47% of the analyzed area of both year, indicating that there has been almost no change.

The grazing/grass land is observed all over the area except the areas where forest distributes sparsely and mountain foot where agricultural forest distributes.

6) Agricultural forest was 20,200 ha. (8% of the analysis object area) in 1970's and 30,300 ha. (12% of the same) in 1980's. As they correspond with 14% and 15% respectively of the analyzed area, it can be said that the agricultural forest is increasing slightly. The agricultural forests distribute mainly at the west side slope land at the foot of mountain

range.

(3) Risaralda

1) In Risaralda, population density is high and production of coffee and sugar cane is active. Also in the analysis object area, the agricultural forest distributes extensively over the wide area, having state capital Pereira at the background. As it has the areas of various conditions from the altitude of 1,500m to 5,000m, the items of land use shows relatively even figure.

2) The analyzed area in Risaralda State was 52,500 ha. in 1970's and 53,000 ha. in 1980's which correspond with 77% and 79% of the analysis object area of 67,400 ha.

3) The forest was 14,800 ha. in 1870's and 15,200 ha. in 1980, which correspond with 22% and 23% of analysis object area respectively and 28% and 29% of the analyzed area respectively. Therefore, it can be said that the forest is decreasing slightly.

The distribution of the forest is seen on the west side slope land at the breast of central mountain range.

4) Plateau grassland was 14,200 ha. in 1970's and 12,700 ha. in 1980's, corresponding with 21% and 19% respectively of the analysis object area. Since they correspond with 27% and 24% respectively of the analyzed area, it can be said that the plateau grassland is slightly decreasing.

The plateau grassland distributes around the mountain top.

5) The grazing/grass land was 5,800 ha. in 1970's and 6,900 ha. in 1980's, corresponding with 9% and 10% respectively of the analysis object area, and 11% and 13% respectively of the analyzed area. Therefore, it can be said that the grazing/grass land has increased slightly. The grazing/grass land distributes from the breast to the foot of west part of central mountain range.

6) The agricultural forest was 16,700 ha. in 1970's and 15,700 ha. in 1980's, corresponding with 25% and 23% respectively of the analysis object area. They are 31% and 29% of the analyzed area, indicating that agricultural forest is decreasing slightly. The agricultural forests distribute at the west side foot of mountain range.

7) Besides the above, city/town, bare/waste land and snow/ice field are observed but very small in scale.

(4) Quindio

1) As Quindio has small area and the highest population density among the 10

states, agricultural production, mainly the production of coffee, is active there. As the state capital, Armenia, is included in the analysis object area, the most of the area is occupied by grazing/grass land and agricultural forest. As a consequence, the ratio of forest is relatively low. Also, as the altitude is relatively low (1,500 0 3,500m), there hardly distributes the plateau grassland.

2) The analyzed area in Quindio was 94,600 ha. in 1970's and 101,500 ha. in 1980's, which correspond with 78% and 84% of the analysis object area of 120,700 ha.

3) The forest was 20,800 ha. in 1970's and 22,600 ha. in 1980's, corresponding with 17% and 19% respectively of the analysis object area. As they represent 22% of analyzed area of both decades, it shows that there has been no change in the forest. The forests distribute mainly at the breast of west side slope land of the central mountain range.

4) Plateau grassland was 2,000 ha (2% of the analysis object area) in 1970's and 2,200 ha (2% of the same) in 1980's. They were also 2% of the analyzed area for both decades. It slightly distributes at the mountain ridges of altitude 3,000m or more.

5) The grazing/grass land was 30,800 ha. (25% of the analysis object area) in 1970's and 37,200 ha. (31% of the same) in 1980, corresponding with 33% and 37% respectively of the analyzed area, showing a trend of slight increase. It distributes widely and in bulk on the mountain slope land of altitude 2,000m - 3,000m.

6) The agricultural forest was 39,400 ha. (33% of the analysis object area) in 1970's and 38,500 ha. (32% of the same) in 1980, corresponding with 43% and 38% respectively of the analyzed area, showing a trend of slight decrease. The agricultural forest occupies the largest share in the analysis object area, distributing widely at the low land of altitude 2,000m or less.

7) The area of city/town is as large as 1,100 ha. (in 1970's) due to the existence of state capital Armenia, but it is as small as only 1% in terms of percentage against the analysis object area.

8) Bare/waste land and snow/ice field share only a small area, distributing at the mountain highland in the north edge of the state.

(5) Tolima

1) The analysis object area is located at the mountain zone at the west edge of the state. And as it does not include the low land which is the center

of agricultural production, the most of the analysis object area is occupied by forest and plateau grassland.

2) The analyzed area in Tolima was 264,400 ha. in 1970's and 169,800 ha. in 1980's, which correspond with 87% and 55% respectively of the analysis object area of 302,900 ha.

3) The forest was 127,200 ha. (42% of the analysis object area) in 1970's and 72,800 ha. (24% of the same) in 1980, which correspond respectively with 48% and 44% of the analyzed area, showing a trend of slight decrease. The forest shares the largest portion of the analysis object area, distributing widely on the east side slope land of mountains at altitude 3,000m or less.

4) Plateau grassland was 89,000 ha. (29% of the analysis object area) in 1970's and 61,900 ha. (20% of the same) in 1980's, which correspond respectively with 34% and 36% of the analyzed area, indicating a trend of slight increase. Plateau grassland covers the mountain area at the center of analysis object area and all over the highland of altitude 3,000m or more around Mt. Nevado del Ruiz.

5) The grazing/grass land was 42,700 ha. (14% of the analysis object area) in 1970's and 27,600 ha. (9% of the same) in 1980's, both of which correspond with 16% of the analyzed area, indicating that there was no change in it. Grazing/grass land distributes in bulk from the center of analysis object area to the low land in the north.

6) Snow/ice field is observed widely centering around the mountain top of Mt. Nevado del Ruiz, sharing about 2% of the analysis object area.

7) Agricultural forest, farm land, city/town and bare/waste land are not observed in this analysis object area.

(6) Velle del Cauca

1) The population density is high and production of sugar cane is active in Velle del Cauca, but as the analysis object area is located only at the mountain zone, the area of farm land is small in this area. Grasslands such as grazing/grass land and plateau grassland shares the substantial area, while the share of forest is relatively low.

2) The analyzed area in Velle del Cauca was 186,900 ha. in 1970's and 186,300 ha. in 1980's, both of which correspond with 87% of the analysis object area.

3) Forest was 40,500 ha. (19% of the analysis object area) in 1970's and 38,300 ha. (18% of the same), which correspond with 22% and 21%