The Study on Comprehensive Disaster Prevention
around Mayon Volcano

SUPPORTING REPORT (1)

(Part I: Master Plan)

V : Surveying/ Aerial Photo/ Topographic Mapping and Satellite Image Analysis

SUPPORTING REPORT (1) - V

SURVEYING/AERIAL PHOTO/SATELLITE IMAGE ANALYSIS

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1. LONGITUDINAL PROFILING AND CROSS-SECTIONING/AERIAL PHOTOGRAPHY

1.1 Purpose

The longitudinal profiling and cross-sectioning surveys were carried out in the selected rivers of the Study Area so as to obtain their topographic features.

1.2 Rivers Studied

Out of several rivers around Mayon Volcano, 17 rivers in 7 river systems listed below were selected. The locations of each river are shown in Figure V 1.1.

List of the Rivers Studied

River System	Name of Rivers
1. Yawa	Yawa, Pawa-Burabod, Budiao, Anuling, Quirangay
2. Quinali (A)	Tumpa, Maninila, Masarawag, Ogsong, Nasisi
3. Quinali (B)	Buang, Quinali (B), San Vicente
4. Arimbay	Arimbay
5. Padang	Padang
6. Basud	Basud
7. Bulawan	Bulawan

1.3 Work Items and Volume

- Monumentaition : 7 Concrete monuments (20 × 20 × 50cm)
- 3rd Order Levelling : Distance between level and staff, 70m
  Minimum unit of measuring, 1mm
  Double running error, 2cm $\sqrt{S}$ (S = km)
  Closing error, 2cm $\sqrt{S}$
- Longitudinal Profiling : Total distance, 320km with 1km interval
  Accuracy, 3cm $\sqrt{S}$
  Drawing scale, H = 1/1,000, V = 1/100

• Cross-sectioning	:	Width of cross-section, average 150m Total 320sections
• Establishment of Water Level Gauge	:	Drawing scale, H = 1/100, V = 1/100 17 Water Gauge

1.4 Outline of the Respective Work

(1) Monumentation

Seven Bench Marks (BMs) (one BM at one river system) in total were monumented at seven river systems as shown in Figure V 1.1. In consideration of usage of the BM as the basic elevation points in the basins, the locations of BM were selected at down stream where there is no effect from mudflow.

(2) 3rd Order Levelling

The elevations of newly established BM were determined by means of 3rd order levelling on the basis of the results of the existing BM. Accuracy of the existing BM has been checked prior to the 3rd order levelling and selected high accurate existing BMs were used. Route of the 3rd order levelling is shown in Figure V 1.1.

(3) Longitudinal Profiling

River mouths formed at shoreline were regarded as the Beginning Point (BP) for longitudinal profiling in the river which flow into the sea directly. In the branches of main rivers, Yawa river, Quinali (A) and (B) river, the confluences were regarded as BP. However, rivers located south west of Mayon Volcano which are diverged from Cabirogan River in upper stream of Quinali (A) river system, the confluences were regarded as BPs.

Ending Points (EP) for longitudinal profiling were planned up to the most upstream part in each river as much as possible where the safety in the works could be secured. As the change of river–bed was very prominent in the subject river, where several branches existed in the same river system, which were equivalent to the main stream, instruction was given to carry out longitudinal profiling not only at main stream but also at branch streams.

Elevation of ground, artificial structures and flood height on the profiling line were observed by levelling. Instruction was given to carry out GPS survey or traversing for obtaining the planimetric locations of rivers.

(4) Cross-sectioning

Cross-sectioning was conducted with the width of average 150m and 1,000m interval at all 17 rivers in accordance with the results of the longitudinal profiling. Instruction was made to observe all sections where river channels changed at the confluences and upstream and downstream of the bridges. Where the rivers, in which the longitudinal profiling were done, adjoined other rivers, the cross-sectioning was carried out over those adjoined rivers.

(5) Establishment of Water Level Gauges

The points of water level gauges were set up in seventeen rivers are shown in the Figure V1.1. The water level gauges were established basically in the downstream reaches of each river where the observation could be made easily in view of accessibility. The locations of water level gauge were selected at such point as no river channel changes and river-bed changes. In the initial plan one piece of water level gauge would be set up in each river. However, in Pawa-Burabod River, it was difficult to conduct water level observation at downstream stretch of Pawa-Burabod river due to bad accessibility. Therefore, the water level gauge was established in the Yawa river upstream of the meeting point with Pawa-Burabod river.

2. AERIAL PHOTOGRAPHY

2.1 Purpose

In order to grasp the topographic features and land use conditions in and around Mt. Mayon volcano, aerial photographs at a scale of 1:25,000 which would be used for topographic mapping were taken.

2.2 Area

Area covered by aerial photographs around Mayon Volcano is shown in Figure V2.1 with flight plan.

2.3 Aerial Photography

(1) Equipment used

1) Aircraft

The survey aircraft was Aerocommander 680-F (RP-C641) with Bureau of Air Transportation's airworthiness certificate. It was equipped with all the essential GPS navigation system and photographic instruments.

2) Aerial camera

WILD RC10 (Lens No, UAg Ⅰ 6055) was employed as the aerial camera with a precision wide angle lens (6 inches focal length), which had a valid calibration report.

(2) Specifications

Aerial photography was carried out in accordance with following specifications.

- Photograph scale : 1:25,000
- Number of course : 10 courses
- Total length of courses : 163.3km
- Number of Photograph : 81 pcs
- Photographing altitude : 4,750m to 6,200m
- Overlapping : 60%
- Side-lapping : 35%
- Crab : less than 10°
- Tilt : less than 5°
- Displacement of line : less than 10%

(3) Air Base

Legazpi airport was utilized as the air base.

2.4 Photo-Processing

(1) Negative Films

Each aerial negative was marked clearly in the block type lettering approximately one sixth (1/6) inch off the margin of images. Each negative roll was numbered consecutively staring with No.001. Each end of each roll was marked with Project Designation, LUZON, roll number, flight line number and photograph number.

(2) Contact Prints

Contact prints from the negatives of the aerial photography were reproduced on double weight semimatte standard commercial grade photographic paper and trimmed with a margin of approximately one fourth (1/4) inch outside of the photographic image including the space necessary to show the registering instrument clearly.

(3) Photo Index

A photo coverage index of the project area was prepared to check the overlaps and displacement of flight strips as compared with the approved flight plan. The coverage index was prepared on the master reproducible 1:50,000 flight plan sheet.

(4) Inspection

Aerial film processing and single weight contact printing were carried out respectively immediately after the every photographic flight was completed in order to make preliminary inspection of the result. Detailed inspection was conducted on the approved photographs and quality control sheets were made.

2.5 Flight Condition

- The survey aircraft were mobilized on January 30,1999 at Legazpi airport and kept on stand-by.
- The first flight for aerial photography was made on February 12, 1999. Aerial photographs on Line No 6, 7, 8 and 9 were taken in this flight.
- First flight negative film was developed and preliminary inspection was made on February 22,1999.
- The second flight was made on March 10, 1999. Aerial photographs were taken on Line No1, 2 and 3 in this flight.
- The third flight was made on March 12,1999. Line No 4, 5 and 10 were taken in this flight.
- Negative film of second flight and third flight were developed and preliminary inspection was made on March 13,1999.
- As the result of inspection, aerial photographs taken at Line No 4 had a little clouds at northeast part of Mayon Volcano, Line No 5 had many clouds at northeast part and west part was blackish image by shadow. Line No 6 had blackish images by shadow at top of Mayon Volcano, and gap at southwest part due to high elevation of Mayon Volcano. To cover the overlap gap of Line No.6, trial flight of Line No.10 was made. Eventually this Line No.10 also had an overlap gap at the top of Mayon Volcano due to low flight under the clouds. Therefore, instruction for re-flight on Line No 4,5,6 and 10 was instructed to subcontractor. Others had been accepted as the inspected aerial photographs to be used for succeeding work.
- Aircraft and it's crew were kept on stand-by to get chance anytime and anywhere in the project area until April 15,1999; however, aerial photography could not be made, due to no good weather condition for shooting.

3. TOPOGRAPHIC MAPPING

The scale of 1:25,000 Topographic Mapping utilized aerial photographs taken on 1999 was carried out based on the existing topographic maps prepared on previous Mayon volcano project in 1982 and Benchmarks established on December 1998. As a reference, result of aerial triangulation of previous Mayon volcano project 1982 was utilized. Following are the procedure of map production.

3.1 Control Points for Aerial Triangulation

(1) Planimetric Control Point

The proper planimetric control points for the aerial triangulation were not found around Mayon Volcano. There were 14 Benchmarks with coordinates along the Maharlika Highway. However there was no definite information to determine the exact position of Benchmarks due to no Air-photo Signals for the aerial triangulation.

The result of aerial triangulation was taken into account of the scaling of entire project area. But unfortunately there were many changes of topographic feature.

Eventually the planimetric control of aerial triangulation was made with the help of sketches of those Benchmarks only and the approximate position was estimated.

(2) Height Control Point

The height control was carried out with said Benchmarks and Spot heights of the existing map. However the accuracy of Spot height is only ±2 meters of actual ground height taking into account the previous photograph scale. The aerial triangulation was made with these spot heights, especially mountainous area of Mayon Volcano. As a result, the height accuracy was suspected to reach to the accuracy of the map which is prepared with a proper height controls.

3.2 Plotting

The plotting was made on the method of Digital Mapping using of Digital Photogrammetric Workstation. There found model deformation on individual spatial models due to less number of height and planimetric control points. The estimated height accuracy was ±5 meters on actual ground. Planimetric accuracy was suspected to have a error of 10 to 20 meters due to lack of controls.

3.3 Data processing

All planimetric and height information were digitized and edited as a vector data of individual map sheet with a help of field verification data and existing map and downloaded in CD-ROM as one of final products.

3.4 Final Products

The final products to be delivered were as follows:

Original map sheets	1 set
Copies	4 sets
CD-ROM	1 set

4. SATELLITE IMAGE ANALYSIS

4.1 Introduction

Aim of a volcanic mitigation plan is to minimize disaster by protecting natural and social infrastructure through proper planning and execution of appropriate counter measures. Verifying and establishing most suitable counter measure involve various activities. Most important of these are collection of historical and present data, identifying landform changes due to eruption and how they change with time, recognize river changes with sedimentation and possible future channel deviation, quantify sediment production and locate spatial distribution of vulnerable areas.

Satellite remote sensing is a very promising technology that could be used in accessing damage caused by an eruption or monitoring land surface development around volcano before and after eruption. Different satellite systems have been available since early seventies and the future is very promising with the contribution of commercial systems providing very high-resolution satellite data within one or two years time. Infrastructure of different information that could contribute to mitigation could be done by a Geographic Information System (GIS). A GIS system is defined as computer based system that is used to store and manipulate geographic information. These technologies provide capabilities in multidisciplinary data handling, data management, data manipulation, modeling and analysis, visualization of a given phenomenon and production of various thematic maps.

4.2 Objectives of Remote Sensing and GIS Analysis

The objectives of satellite data analysis and GIS database development can be enumerated as follows:

1) Creation of a GIS database for integrating satellite data and published map information for easy comparison and map production.
2) Land cover change analysis as a result of 1993 volcanic eruption
3) Identify change of geological features, lava, and pyroclastic deposition as a consequence of the eruption.
4) Chronological change analysis of riverbed movement.
5) Estimation of deposition movement potential of remaining lava in triggering disastrous events.
6) Creation of 3-D graphical images for better visualization of events.

In order to carryout the objectives the following works were completed:

1) Collection of existing maps and aerial photographs
2) Conversion of analog maps into digital GIS database
3) Selection and acquisition of best suitable satellite data for present and past status of the volcanic disaster analysis
4) Carryout necessary correction to rectify satellite data for variation in sensor geometry and integrate in GIS database
5) Image processing and classification to extract required land cover information that is most appropriate to this study
6) Carryout field work that is required for satellite data analysis and verification of results
7) Conduct seminars that required to transfer the technology to local staff
8) Preparation of report including data rectification methods, analysis methods, field information, results and recommendations.

4.3 Potential of Remote Sensing and GIS

Satellite remote sensing is a potential tool in identifying earth surface change in a very large area minimizing data acquisition cost. Optical data source and radar data sources are the main division in satellite remote sensing for land resource management and monitoring. Optical sensor are popular among these two as these data produce image as maps that are very much similar to aerial photograph in color and image content but with course ground resolution. These data cannot be obtained during a cloudy day. Information content on these data is not similar to optical data as they produce an image showing how transmitted energy from a sensor interacts with the surface. This interaction depends on surface orientation, surface roughness to transmitted wavelength, moisture content, etc.

GIS is a computer-assisted system for acquisition, storage, analysis and displaying of geographic data. Comprehensive disaster mitigation project requires handling of huge volumes of spatial data and extensive spatial analysis. With its inherent power to store, manage, manipulate and present spatial data, the GIS technology is increasingly preferred in natural disaster monitoring and mitigation projects. The performance of this technology has been appealing owing to the improved capabilities of computer hardware. The enormous amounts of spatial data such as maps and drawings to represent natural resources information and human activities such as topography, rivers, forest cover, land use, houses, utility facilities can be efficiently input, stored and managed in an intelligent database. GIS can perform a variety of spatial operations such as polygon overlays, proximity analysis and surface modeling. Moreover, these operations can be performed at much better speeds and higher spatial accuracy than are possible by conventional and manual methods.

4.4 Database Creation and Method of Analysis

(1) Acquisition of Data

The basic information and data collected for the Study are summarized below.

Basic Information and Data Collected

Satellite Data

Date	Sensor	Spatial Resolution (m)	Remarks
1988.10.28	MOS-MESSR	50	Pre-eruption
1989.10.03	MOS-MESSR	50	Pre-eruption
1992.04.06	SPOT-XS	20	Just before eruption land cover status
1993.04.21	ERS-SAR	25	Coherence analysis
1993.09.09	ERS-SAR	25	Coherence analysis
1994.02.18	Landsat-TM	30	Just after eruption optical data
1994.02.18	SPOT-XS	20	Just after eruption optical data
1995.09.09	JERS-SAR	18	Change analysis
1996.05.20	ERS-SAR	25	Coherence analysis
1996.05.21	ERS-SAR	25	Coherence analysis
1996.12.10	JERS-SAR	18	Change analysis
1997.10.10	ERS-SAR	25	Coherence analysis
1997.10.11	JERS-SAR	18	Change analysis
1996.12.10	RADARSAT-SAR	12.5	Change analysis

Base Maps

Topographic Maps	(1:25,000)	prepared by project experts
River Systems	(1:25,000)	
Land Use Maps	(1:25,000)	
Geo-Morphology	(1:25,000)	

Photograph

1949	Aerial photographs of lower part of Maninila river
1980	Aerial photographs of the Study Area
1998	conventional photograph with GPS information
1998	Photographed from a helicopter

Filed Visit

1998	Notes and conventional photographs of the visited place

(2) Database Creation and Method of Analysis

Database creation with multidisciplinary data and main steps of the analysis procedure is shown in Figure V4.1. Main steps in database creation and the analysis procedure are enumerated below:

1) Main steps in developing GIS database

- Identify the map projection. For the projection of topographical maps, the PTM was used to have the conformity with other available information
- Digitize information into different layers, contour, river, roads, land use, geo etc.
- Geometric correction of near-nadir viewing satellite data using Ground Control Points
- Geometric correction of oblique viewing satellite data using Ground Control Points, sensor geometry and digital elevation data generated by contour data.
- Geometric correction of aerial photograph

Figure V4.2 shows the Study Area with basin boundaries overlaid with rivers and roads that are incorporated in the GIS database created for the Study.

2) Main Steps in Analysis

- Establish reference information using field observed data to supervise the classification of satellite data for pre-defined classes
- Generate statistical parameters for each reference classes and verify the separation among pre-defined classes.
- Use other information such as NDVI for enhance classification in vegetated areas.

- Establish spectral information for each defined class for each satellite dataset and classify.
- Generate land cover map of before and after eruption and identify changes
- For deposition moment assessment, contour data is converted into digital elevation model, (DEM) and surface parameters such as slope, gradient is calculated. These information together with land cover and river network is used for estimate the probable hazardous areas.
- Lava Flow, vegetation changes are compared with slope maps for investigate activities with relation to slope.

- Created DEM is use for generation 3-D vies of each of the results and original satellite data.

4.5 Land Cover Map Creation

Land use map available for Mayon Volcano area and its surrounding was created in 1983 using aerial photographs acquired in 1980. Information on these maps are obsolete in some parts of the area due to volcanic eruptions and other human activities. Therefore, it was decided to create and update land use map of the Study Area for the most recent volcanic eruption that took place in February to March 1993. This was carried out with SPOT data of 1992 April and Landsat TM data of 1994 February. These data have been acquired from two different sensors in different viewing and atmosphere conditions. Therefore, it was decided to generate low cover maps individually, and compare low cover classes rather than comparing satellite data itself.

In classifying satellite data, emphasis was given to land cover classes in the mountain slopes and in the areas where the activities of sedimentation, lava distribution and lahar flow is visible. Further, in classifying land cover classes where most of the area is dominated by vegetation, attempt was made to establish areas with different surface cover densities as it is one of the key feature of surface erosion. With reference to field visit information, helicopter photograph obtained in the field, it was observed that most predominant low cover classes were in the disaster prone areas as summarized below.

Land Cover Classes Observed in the Study Area

Category	Description
Mixed Forest	Different Species in mountain slopes
Bush	Small three scattered, in between grass land. Lower surface cover than mixed forest
Grass	Grass fields with variety mixture of bush or boulders. These was a very high variation in the surface exposure
Coconut Plantation	Coconut plantation with some other fruit threes including houses
Bare Land	These are the areas where the surface expose is very high. Relatively low percentage of these areas in the disaster prone areas
Lahar	Old and new deposits along riverbed
Lava	Old and new
Paddy	Predominant in the lower land. Classification difficulty with the season
Developed Areas	Cities and village

In order to classify these defined classes, reference samples were selected using filed visit information and distribution of digital counts of satellite data were compared. Distribution of digital counts of SPOT data for the selected land cover reference classes are shown in Figure V 4.3. Vegetation cover is increasing from (a) to (b), and (b) to (c). (a) shows that the bareland, lava and riverbed areas are easy to separate. (b) and (c) show similar distribution, except for relatively low reflection in infrared band. These distributions together with NDVI were used for classification as NDVI could help to establish vegetation densities or land exposure. Therefore, the patterns were interpreted together with NDVI. Among these categories, paddy and developed areas were included in the classification to have the completeness of the land cover areas, but more attention was paid to establish other land cover classes where disaster due to eruption are high. Further, it was not possible to classify the entire paddy field only with one season data. Combination of middle infrared wavelength in the TM sensor provided some chances to identify paddy areas, but with SPOT data it was not possible to separate paddy from grass with current datasets.

Similarly, 1994 Landsat TM dataset was classified into land cover categories defined earlier using the same procedure. Lava, lahar, barelands, forest areas were classified with reasonable accuracy, but there was very high class mixture was observe in Coconut Plantation, grass lands and bush lands. Classified land cover maps for 1992 and 1994 are shown in Figure V 4.4 and Figure V 4.5.

4.6 Assessment of River Channel Changes

Devastating effect of an eruption could occur due to pyroclastic flow and the lahar flow at the time of eruption, and secondary events followed with a short period of time. Lahar and mudflow that could wash out deposited materials during an eruption could take place with heavy or continuos rainfall even after considerable time. River network could alter or change their courses due to deposition of lava, and lahar flow forming new streams draining in directions damaging life and property or expanding riverbed areas. In this Study an attempt was made to map changes of stream network of the Study Area using satellite data and obtained aerial photographs.

Following table shows the data used to map and estimate the changes of stream network of the Study Area. Aerial photographs of 1949 obtained from National Mapping Agency of Philippines (NAMRIA) covered the downstream streches of Mininila, Quirangay, Tumpa and Masarawag rivers. Photographs taken in 1980 were available for the whole Study Area, but few were selected for areas where major changes took place in 1993 eruption.

Data	Date	Description
Aerial Photographs	1949	Lower part of Mininila, Quirangay, Tumpa
Aerial Photographs	1982	Pawa Burabod and Arimbay rivers
SPOT-XS	1992 April	Whole Study Area
Landsat TM	1994 February	Whole Study Area

Rectified satellite data and Geo-coded aerial photograph using GCP as there were no photo information to carry out proper orientation and correction were visually analyzed in establishing river flow in four dates. Major changes observed are summarized below:

1) At the confluence with sea, Basud riverbed area has increased with little shift to southern side between 1992-94.
2) Width of the Arimbay river has been increased, between 1992-1994.
3) New channel has been developed draining into Pawa Burabod after 1993 eruption. This is starting below the 93 lava terminated point. Further, the riverbed area of Pawa Burabod has been increased in the lower reach just above the confluence point of Yawa river.
4) A stream has been developed from Anuling C to Anuling B. This shows high lahar activity in this area.
5) Quirangay riverbed has increased from 92 to 94 without channel migration.
6) Riverbed expansion is observed in Masarawag river also. The western sub-stream of Masarawag has become more active in 1994.
7) Increased of rivebed area of the Ogsong river is observed.

8) 1949-92 period, Masarawag, Maninila, Tumpa and Quirangay river have shifted east. Larger shift in lower reach with 225 m shift found in Quirangay.
9) 1949-92 the lower reach of Pawn Burabod has changes its flow to east. 1982-94 expansion of riverbed area was observed.

4.7 Vegetation Changes in Hazardous Areas

Attempt was made to identify changes in vegetation cover to be used an indication for activities in lava and lahar areas. Re-growth of vegetation could be used as an indicator of stability of an area, where as any decrease in the vegetation cover that is not due to human interaction could be interpreted as a consequence of eruption or mudflow activity.

In this Study, it is important to estimate the exposure of surface to rainfall and surface runoff as these events are directly related to lahar and mudflow. Therefore, the density of vegetation cover in a given spatial locality, specifically around river channels, lahar deposited and lava deposited areas are important to further analysis to identify the areas that could contribute to erosion and areas that are becoming stable with re-growth of vegetation.

Normalized Difference Vegetation Index (NDVI), which is most popular vegetation index in evaluating and estimating vegetation cover was used to identify vegatation changes. In this Study the Normalized Difference Vegetation Index (NDVI), which is most popular vegetation index in evaluating and estimating vegetation cover was used. This was first introduced in 1974 using Landsat data and has been widely used in other sensors that area housed with red and near-infrared bands of the electromagnetic spectrum. In order to ease the graphical display and work with other digital data such as satellite spectral digital the following equation was used in this study:

$$\mathrm{NDVI} = \left(\frac{(\mathrm{NIR} - \mathrm{R})}{(\mathrm{NIR} + \mathrm{R})} + 1 \right) \times 100$$

NDVI maps were generated for the whole Study Area using 1992 April (SPOT) and 1994 February (TM). Spectral differences in the two days dataset was normalized by histogram matching. NDVI data were classified into five categories according to their NDVI values and comparing sample sites selected for land cover classification as below:

NDVI Range	Description
NDVI < 0.05	Bare lands
0.05 < NDVI < 0.15	Grass very low density
0.15 < NDVI < 0.30	Grass medium vegetation cover
0.30 < NDVI < 0.42	Scattered bush-grass with relatively high cover
0.42 < NDVI < 0.55	Mainly coconut plantation
0.55 < NDVI	Bush – Mixed Forest

1) Quinali(B) River Basin

A decrease of vegetation in the surrounding of Buang lower reach was observed. Appreciable change can not be observed in the vicinity of San Vicente river.

2) Bulawan River Basin

In the lower reach of the Bulawan river, bordering sea an increase of lahar is observed after eruption. Vegetation cover around the river system did not show appreciable change except for some portion in the mountain slope.

3) Basud River Basin

No appreciable change is seen in the mountain slope except near the summit. Near the summit area, the vegetation cover has been decreased.

4) Padang River Basin

This river system is affected by the 1993 eruption and secondary hazards due to lahar flow. Change of riverbed areas is very clear in the lower stream. The vegetation change in the origin of this also very high due to the lava flow and pyroclastic deposit.

5) Arimbay River Basin

This is the river system, which is directly affected by the main lava flow of 1993. Vegetation in the mountain slopes, just below the lava deposited areas have been drastically damaged. Mountain slope of this watershed is dominated by lava and barelands after eruption.

4.8 Estimation of Sediment Volume

The volume of sediment, which is crucial for establishing countermeasure plans, were estimated. To facilitate establishing the target volume for the countermeasure, two types of volume were calculated, which are 1. "The Pyroclastic Deposition Volume Estimation Based on the Current Deposition Distribution and its Depth".

and 2. "The Movement Volume Estimation based on Erosion Models", respectively.

(1) The Pyroclastic Deposition Volume Estimation Based on the Current Deposition Distribution and its Depth

The volume of pyloclastic deposition was estimated. It is to know the total volume of the deposition which has a potential to move. The distribution of pyroclastic deposition is surrounding the summit. The lowest elevations of the pyroclastic deposition area and the maximum and average depth of the deposition were estimated based on field survey, river cross sectional survey and aerial photograph interpretation at each of the 7 basins and 16 subbasins. The area was extracted from digital elevation model and the depths were multiplied. The lava area was excluded from the calculation because the erosion is not expected from lava area. The result is shown in the following table.

Estimation Results of the Deposition Volumes

Basin	Lowest Elevation of Pyroclastic Area (m)	Pyroclastic Area (sq.km)	Lava Area (sq.km)	Pyroclastic minus Lava (sq.km)	Maximum Depth (m)	Average Depth (m)	Volume for Maximum Depth (Million cubic m)	Volume for Average Depth (Million cubic m)
Quinali(A)	300	38.747	1.295	37.452	50	30	1,873	1,124
Quinali(B)	300	28.904	0.010	28.894	50	30	1,445	867
Yawa	300	14.323	0.914	13.409	50	30	670	402
Padang	300	6.541	0.540	6.001	50	30	300	180
Bulawan	300	18.131	1.856	16.275	50	30	814	488
Basud	300	10.079	2.778	7.301	50	30	365	219
Arimbay	300	5.576	1.196	4.379	50	30	219	131

Sub-Basin	Lowest Elevation of Pyroclastic Area (m)	Pyroclastic Area (sq.km)	Lava Area (sq.km)	Pyroclastic minus Lava (sq.km)	Maximum Depth (m)	Average Depth (m)	Volume for Maximum Depth (Million cubic m)	Volume for Average Depth (Million cubic m)
Nasisi	280	8.640	0.000	8.640	48	30	415	259
Buga	300	4.052	0.000	4.052	48	30	194	122
Ogsong	360	3.179	0.000	3.179	20	14	64	45
Masarawag	360	4.702	0.002	4.700	36	31	169	146
Maninila	400	3.812	0.186	3.626	31	11	112	40
Quirangay	330	3.641	0.733	2.908	24	24	70	70
Anuling A	300	4.313	0.102	4.211	28	20	118	84
Anuling B	300	2.876	0.545	2.331	33	23	77	54
Anuling C	240	3.055	0.285	2.770	40	23	111	64
Budio	330	1.613	0.017	1.596	28	24	45	38
Pawa Burabod	340	5.098	0.441	4.658	37	16	172	75
Padang	320	5.996	0.917	5.078	36	22	183	112
Basud	460	5.366	1.915	3.451	52	39	179	135
Bulawan	220	15.771	0.709	15.061	47	29	708	437
San Vicente	260	15.089	0.003	15.086	45	33	679	498
Buang	240	19.646	0.003	19.644	24	19	471	373

(2) The Movement Volume Estimation based on Erosion Models

The mechanism of production of sediment, which has high moving potential, is considered based on observation in two major mechanisms. The two mechanisms are surface erosion and bank erosion.

The surface erosion is taking place where land cover is poor and the slope is steep. The surface erosion is estimated by a model that takes vegetation index derived from remote sensing data and slope as parameters. The bank erosion takes place when river flow erodes river bank. The bank erosion is estimated by a bank slope failure model. This model is calculated in the eroding area using the data of river network and vegetation index along the riverbed.

The amount is considered as the increase of high potential deposition that is easily transported downstream by water flow. In the events of big rain, this high potential sediment deposition is produced and transported downstream. If it is assumed that the production and discharge is balanced, this amount could be considered as the discharge of the sediment.

One of the volumes is selected or both would be added at the appropriate proportion to set target volume for countermeasure. Since the surface erosion is considered as an average of the increase of the high potential deposition, the amount of surface erosion in certain period, for example 50 years, would be used as a planned sediment volume in long term countermeasure. On the other hand, for the bank erosion model at the flood events, it would be considered as a planned sediment volume in a short time span.

1) Surface Erosion Model

The model shown below was applied for whole basin to estimate annual surface erosion.

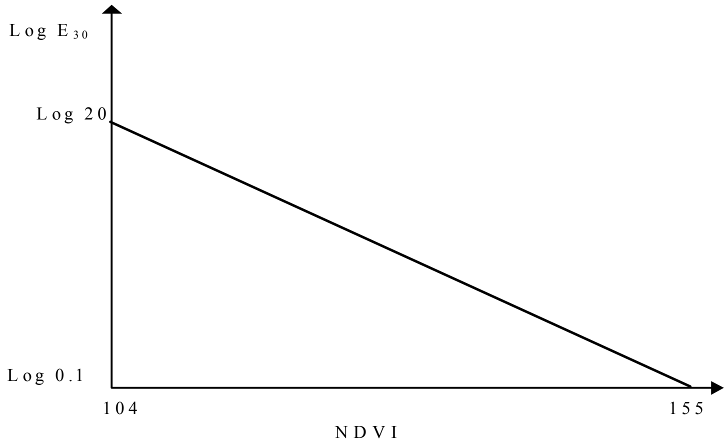
$$E = E_{30}\left(\frac{S}{S_{30}}\right)^{0.9}$$

Where E_{30} is the rate of denudation at a slope of 30°

S gradient of the surface point under consideration

S_{30} tan (30°)

While E_{30} in the Mt. Mayon area is assumed as a function of NDVI as shown below:



Calculation of Rate of Denudation E_{30} Using NDVI

2) Bank Erosion Model

Several datasets to provide the model with necessary model factor were developed. River bed, river network (thinned river bed area), river buffer are defined. The river bed (area) was defined from 1994 Landsat data with the help of 1982 topomap. The area was thinned and river network data (raster in 25m resolution) was produced. In the area where riverbed of two basins are connected, the field survey data and aerial photographs in 1982 is used to identify whether the river system is connected or separated.

River buffer is produced to estimate landcover along river bed. The distance of 50m from both sides are used to produce the buffer.

Eroding Area was defined as area where bank erosion model is to be applied. From this point to upstream is considered to be an area where eroding activity is dominating as a result of bank slope failure. On the other hand, the area below this point to downstream is area where sedimentation activity is dominating.

Riverbank Slope Failure Model was developed and applied. The height of riverbank is assumed to be 10m. The slope of the riverbank is assumed vertical and the slip surface is assumed as a line of 60° slope. It means that the triangular section which has 30° angle and 10m height is considered as a cross sectional area of slope failures. The probability of slope failure is not 100%. It is assumed that if land cover along riverbed is the worst, the probability is 20% while it is 1% when the land is well covered by vegetation. The status of land cover was evaluated by average of NDVI calculated within the river buffer inside of eroding area.

The probability is calculated as follows.

probability = exp((log(MAXVIPOS) - log(MINVIPOS))/(MAXVI-MINVI) * (vi - MINVI) + log(MINVIPOS));

MAXVI 150	:	Maximum Vegetation Index which represents the best land cover
MAXVIPOS 0.01	:	Slope Failure Probability at MAXVI
MINVI 125	:	Minimum Vegetation Index which represents the worst land cover
MINVIPOS 0.2	:	Slope Failure Probability at MINVI
vi	:	The Average Vegetation Index in river buffer

The result of the model calculation is summarized in the following table. Probability of bank failure shows the condition of the land cover along rivers.

Results of the Model Calculation

Basin	Whole Basin Area (sq.km)	Surface Erosion (cub.m/year)	Surface Erosion (mm/year)	Surface Erosion for 50 yrs (cub.m)	Eroding Area (sq.km)	Bank Failure Probability	Bank Erosion (cub.m)	Bank Erosion (mm)
Quinali(A)	191.156	80,840	0.42	4,042,000	37.259	0.041	261,300	1.37
Quinali(B)	134.046	31,910	0.24	1,595,500	26.316	0.011	44,930	0.34
Yawa	75.670	33,890	0.45	1,694,500	19.312	0.049	199,500	2.64
Padang	17.422	10,900	0.63	545,000	9.818	0.032	61,330	3.52
Bulawan	54.266	21,790	0.40	1,089,500	18.959	0.010	34,770	0.64
Basud	30.363	18,310	0.60	915,500	16.685	0.021	65,480	2.16
Arimbay	17.169	27,140	1.58	1,357,000	6.614	0.200	206,800	12.05

Sub-Basin	Whole Basin Area (sq.km)	Surface Erosion (cub.m/year)	Surface Erosion (mm/year)	Surface Erosion for 50 yrs (cub.m)	Eroding Area (sq.km)	Bank Failure Probability	Bank Erosion (cub.m)	Bank Erosion (mm)
Nasisi	16.630	12,460	0.75	623,000	6.731	0.030	34,000	2.05
Buga	8.547	7,797	0.91	389,850	3.504	0.019	15,250	1.78
Ogsong	9.820	2,442	0.25	122,100	3.785	0.020	15,210	1.55
Masarawag	24.868	9,364	0.38	468,200	6.504	0.027	22,590	0.91
Maninila	12.687	22,210	1.75	1,110,500	5.389	0.068	92,900	7.32
Tumpa	6.890	1,410	0.21	70,500	0.943	0.183	23,020	3.34
Quirangay	11.844	10,820	0.91	541,000	5.081	0.108	121,900	10.29
Anuling A	10.251	12,350	1.21	617,500	5.433	0.033	41,640	4.06
Anuling B	4.317	11,660	2.70	583,000	3.358	0.089	76,210	17.65
Anuling C	6.438	2,721	0.42	136,050	3.150	0.049	37,270	5.79
Budio	10.475	2,234	0.21	111,700	2.985	0.093	50,230	4.80
Pawa Burabod	20.836	24,980	1.20	1,249,000	7.257	0.200	227,700	10.93
Arimbay	5.778	1,985	0.34	99,250	0.676	0.064	4,189	0.73
Padang	17.253	12,600	0.73	630,000	9.501	0.039	66,560	3.86
Basud	22.862	18,660	0.82	933,000	13.283	0.030	72,470	3.17
Bulawan	22.579	17,470	0.77	873,500	13.214	0.010	26,240	1.16
San Vicente	52.382	13,790	0.26	689,500	11.348	0.010	25,750	0.49
Buang	28.602	11,400	0.40	570,000	14.446	0.024	34,010	1.19

4.9 3D Computer Graphics

3D computer graphics help to understand the information associated with topography. It is very helpful to those who are not specialists in a specific field, but need to understand disaster phenomenon for their safety or the betterment of the society. Also, experts could use different viewpoints to investigate phenomena such as lava flow and lahar flow with respect to geormorphology of the area. A series of 3D Computer Graphics images were developed to help with understanding the analysis result more with the topographic nature of Mt. Mayon as shown in Figure V 4.6.

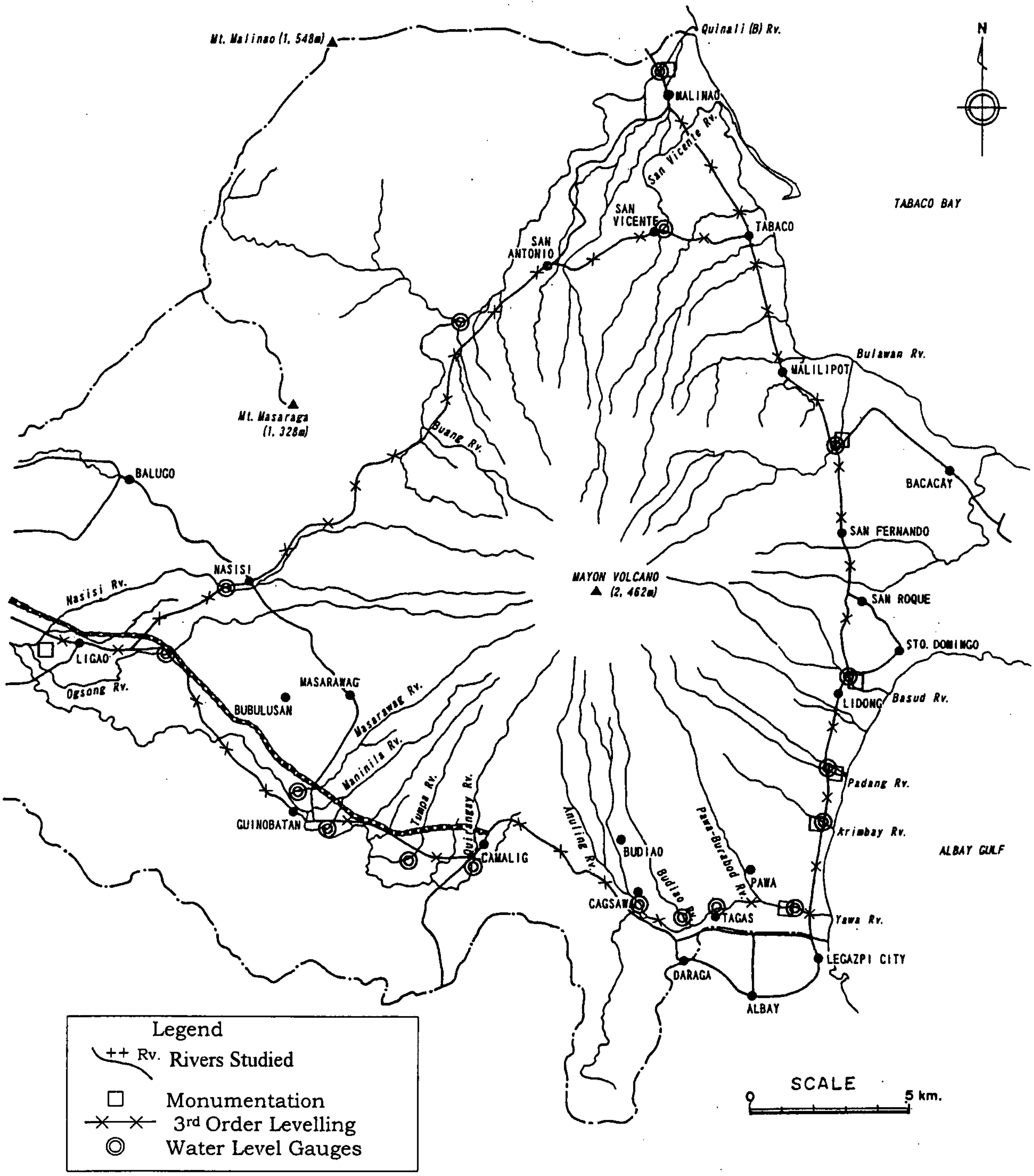
4.10 Conclusion and Recommendations

This study was carried out to investigate the status of volcanic eruption related activities and their chronological changes. Analysis was carried out with various datasets including satellite data, aerial photographs and published map information integrating into a GIS database. It was possible to analyze any of the used data digitally, retrievable to produce thematic maps in desired scale and update with new information for monitoring purposes efficiently and cost effectively. The major findings are summarized below:

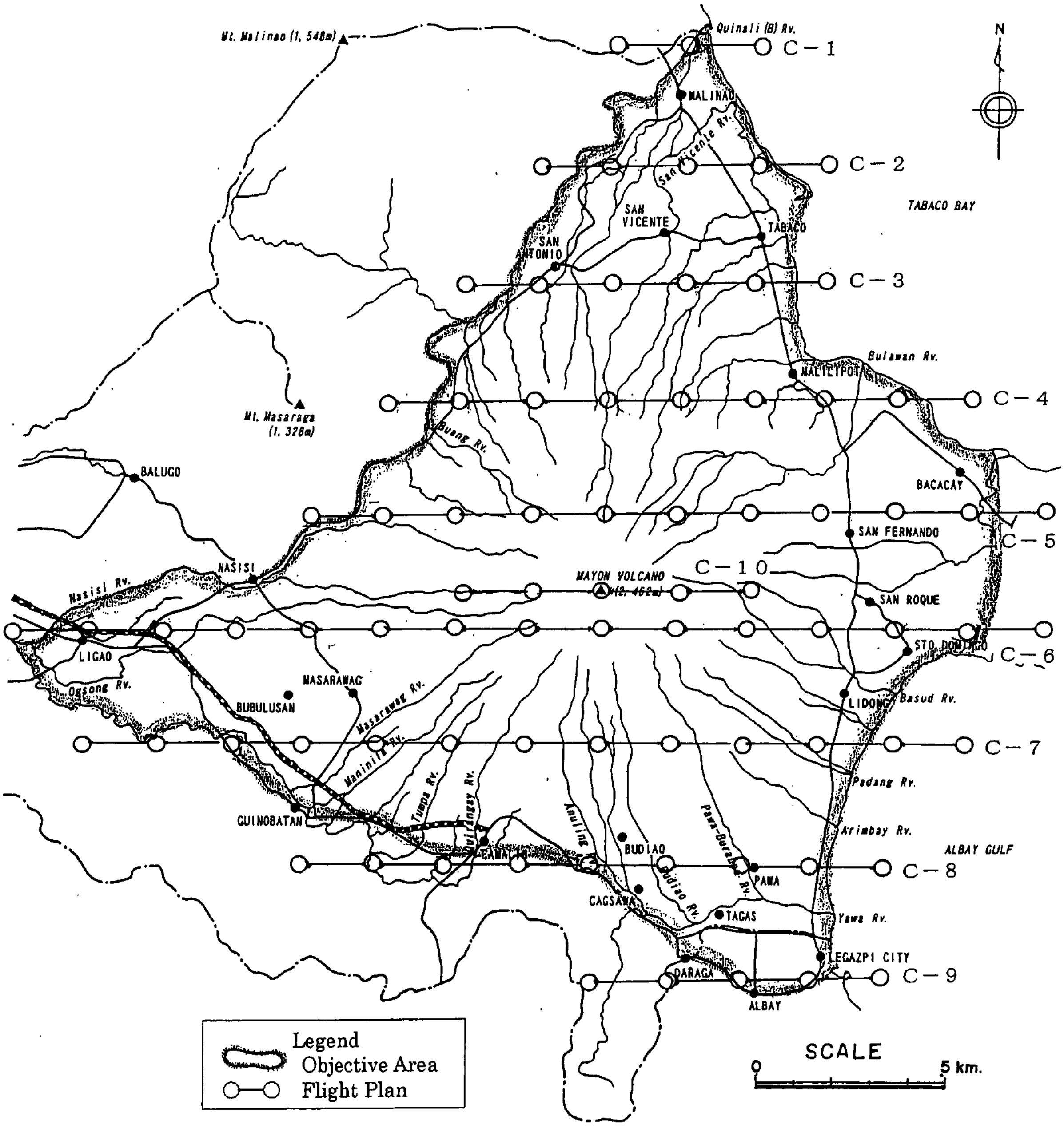
1) Major changes in vegetation and geomorphology due to 1993 eruption had been occurred in the southern slope of the volcano
2) Predominant vegetation changes were taken place in the upper reach or the mountain slopes of Yawa and Arimbay subbasins due to 1993 eruption.
3) Vegetation around Maninila, Tumpa, and Quirangay river areas, falling in the medium slope area had been damaged during 1993 eruption and related lava and lahar flows. Even before the eruption, vegetation density of this was low, and this could be due to damage that had been occurred early eruptions also.
4) In Arimbay sub-basin, the vegetation had been damaged due to 1993 eruption. This has occurred below the lava flow exposing the surface for more erosion.
5) Migration of Maninila, Tumpa, and Quirangay river channels towards east was observed when compared with 1949 aerial photographs with 1994 satellite data. In some areas, the shift is more than 200 meters.
6) New stream has been formed starting just below the 1993 lava flow draining into Pawa Burabod.
7) Extensive lahar discharge was observed in the lower plane of Padang river extending its riverbed.
8) It was observed that activity of lava is in steep slops, and generally flow up to areas where the slope is around 10º.
9) Sediment production is within the medium slope areas (7-10º), where much of the land area is grass or bush lands. These areas are tend to affect during volcanic eruptions.
10) River migration, and meandering is taking place in the gentle slope areas, 4-6º.

During the study, it was found that the Mayon eruption and related activities are changing with time. Some of the changes are due to eruption itself, and others are due to lahar or mudflow. Further, the geomorphology as well as the topography has been changed and there is a need to produce new maps showing these changes for future monitoring and disaster management works. Finally, there is a need to increase the public awareness on the disastrous events where satellite data could be very useful in presenting the information for general public. In view of these factors, future works related to geoinformatics could be suggested below:

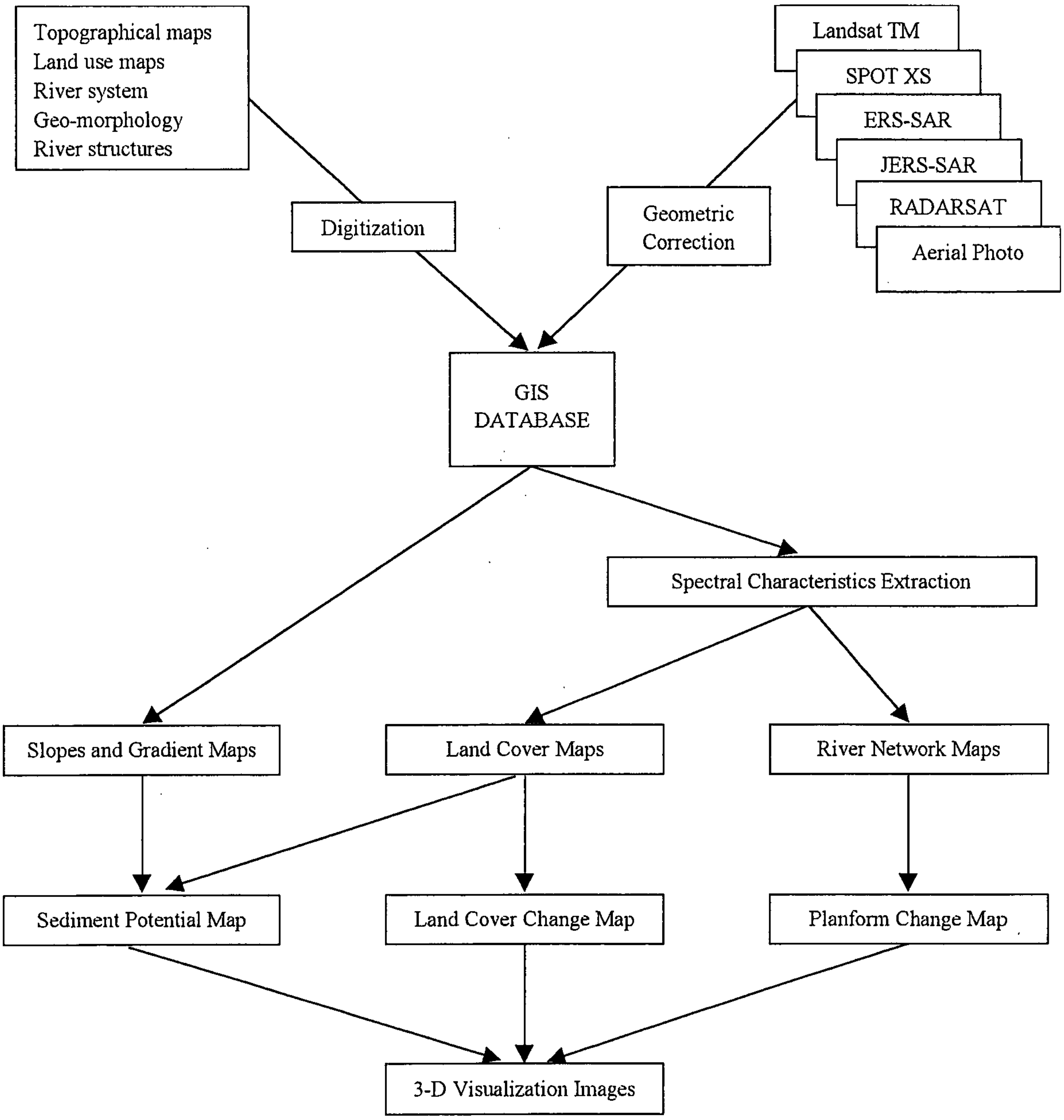
1) Continuous observation of the area using high resolution future satellite systems with the collaboration space agencies
2) Create a digital elevation model using 1999 aerial photographs to use in erosion potentials and generate present river system that have been changes during past eruptions.
3) Possibilities of securing old aerial photographs (1949, 1952, 1982 etc.) with camera information and others required to generate ortho-photos would be very important to identify the river migration phenomenon.
4) Organize necessary training courses on geoinformatics that includes remote sensing, GIS, GPS and Cartography to local agencies.
5) Establish a GIS system with GIS data generated during the project within a local disaster-monitoring agency for further and future analysis.
6) Develop Real Time Differential GPS system to make investigation to be more systematic.
7) Develop tools within a GIS environment for produce maps providing timely and useful information to increase awareness among inhabitants.
8) Develop multimedia contents to facilitate education of inhabitants.



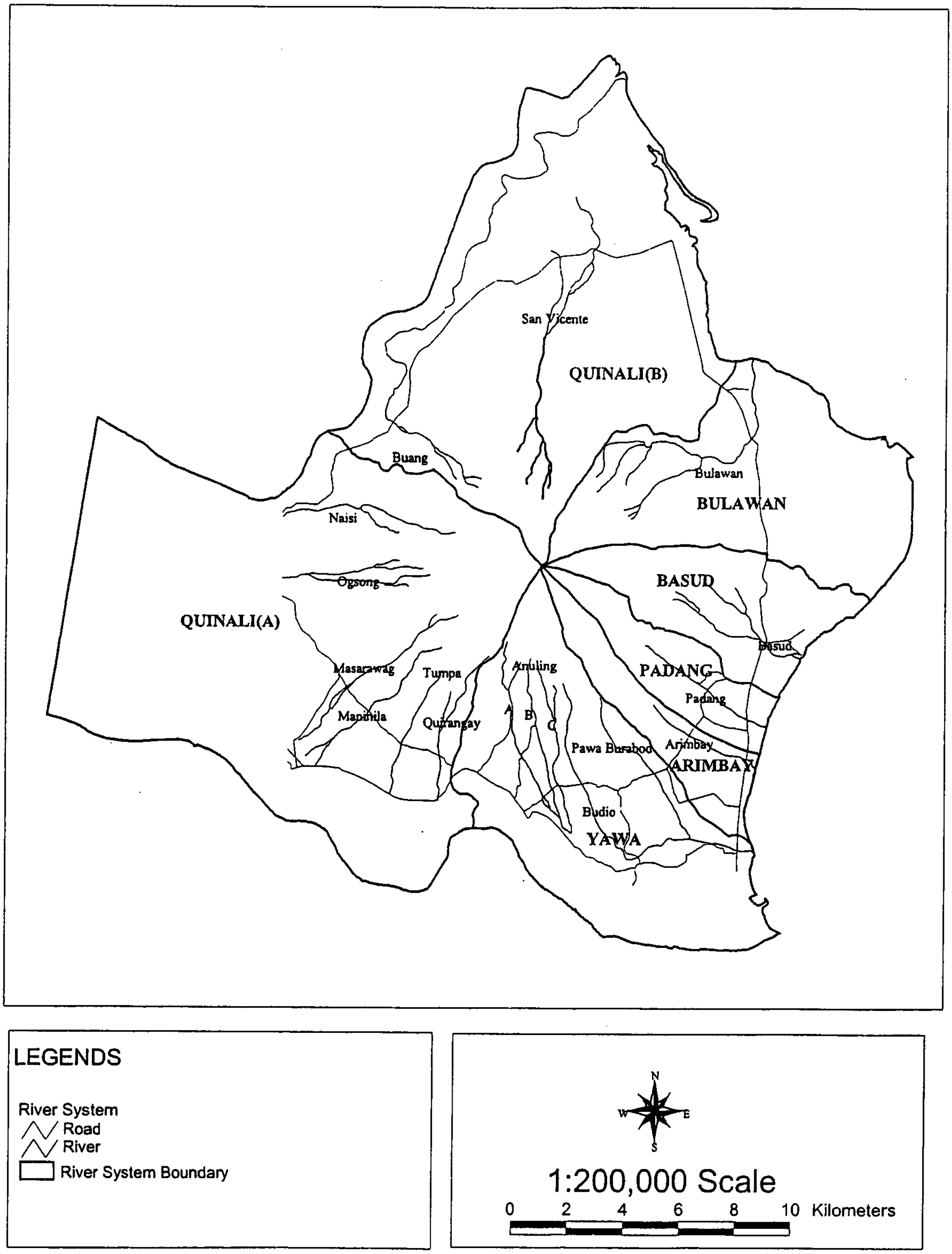
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure V 1.1** **Location of the Rivers Studied**
JAPAN INTERNATIONAL COOPERATION AGENCY	



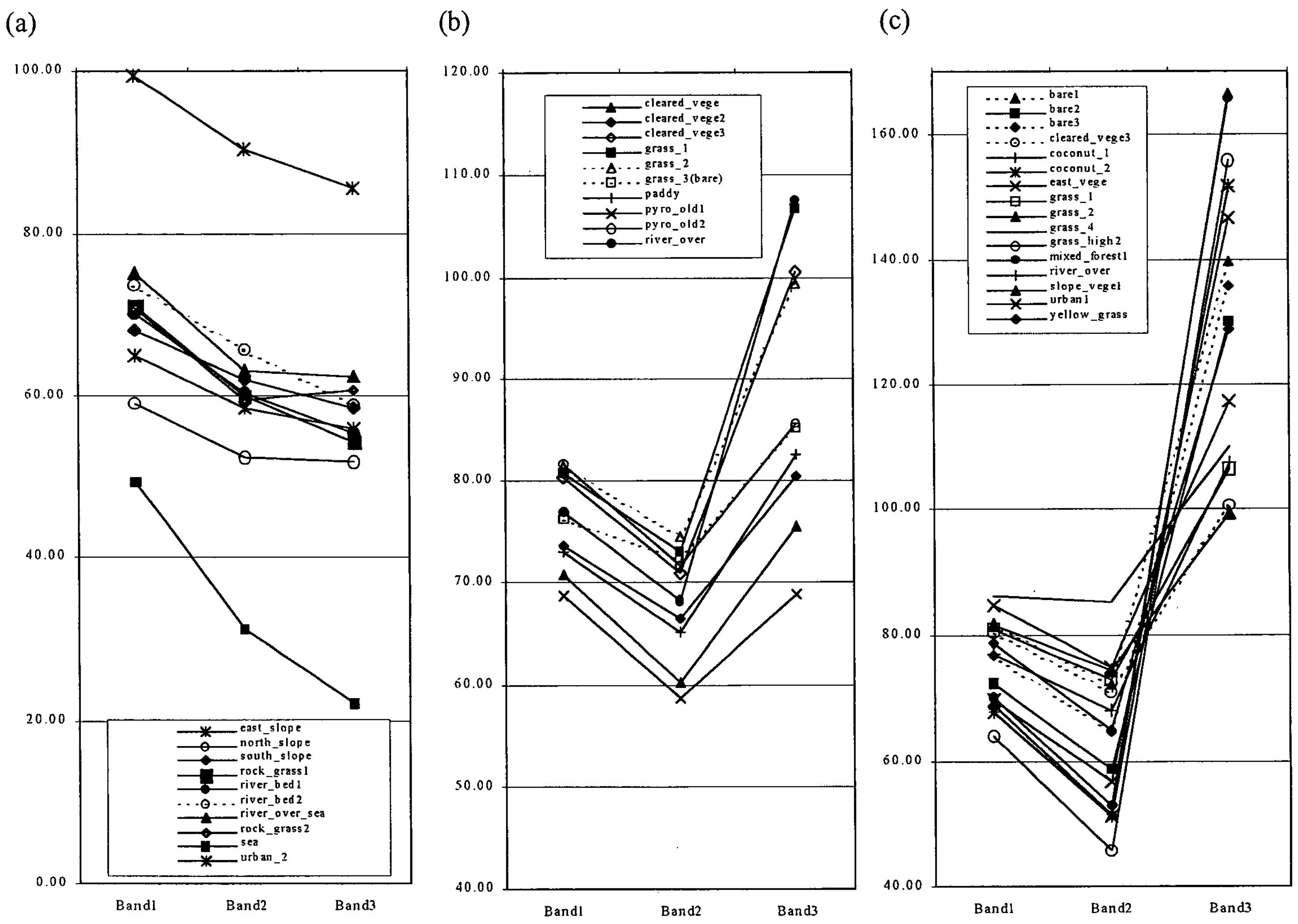
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure V 2.1** Area Covered by Aerial Photographs
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure V 4.1** **Database Creation and Method of Analysis**
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure V 4.2** River Basins of the Study Area
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES

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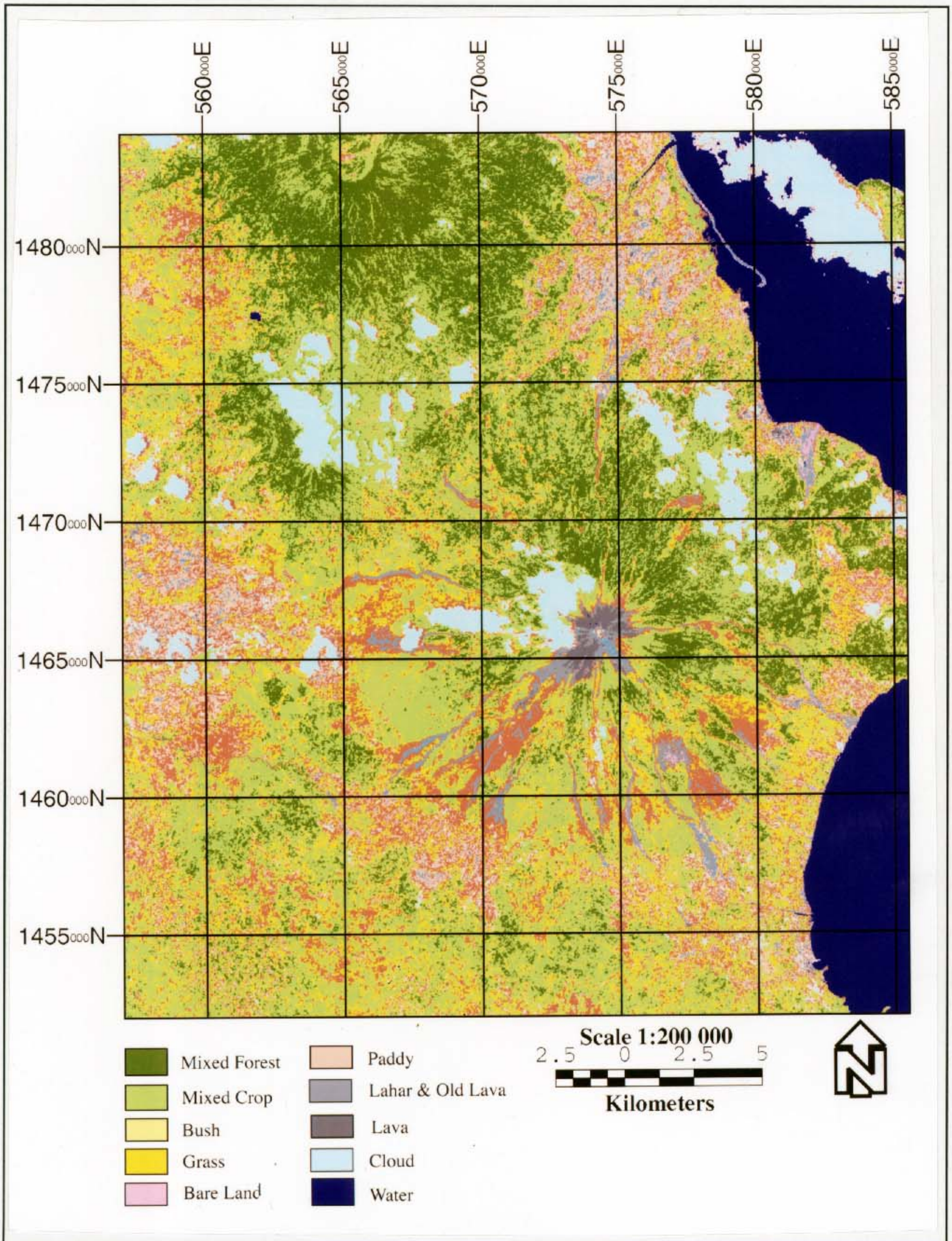
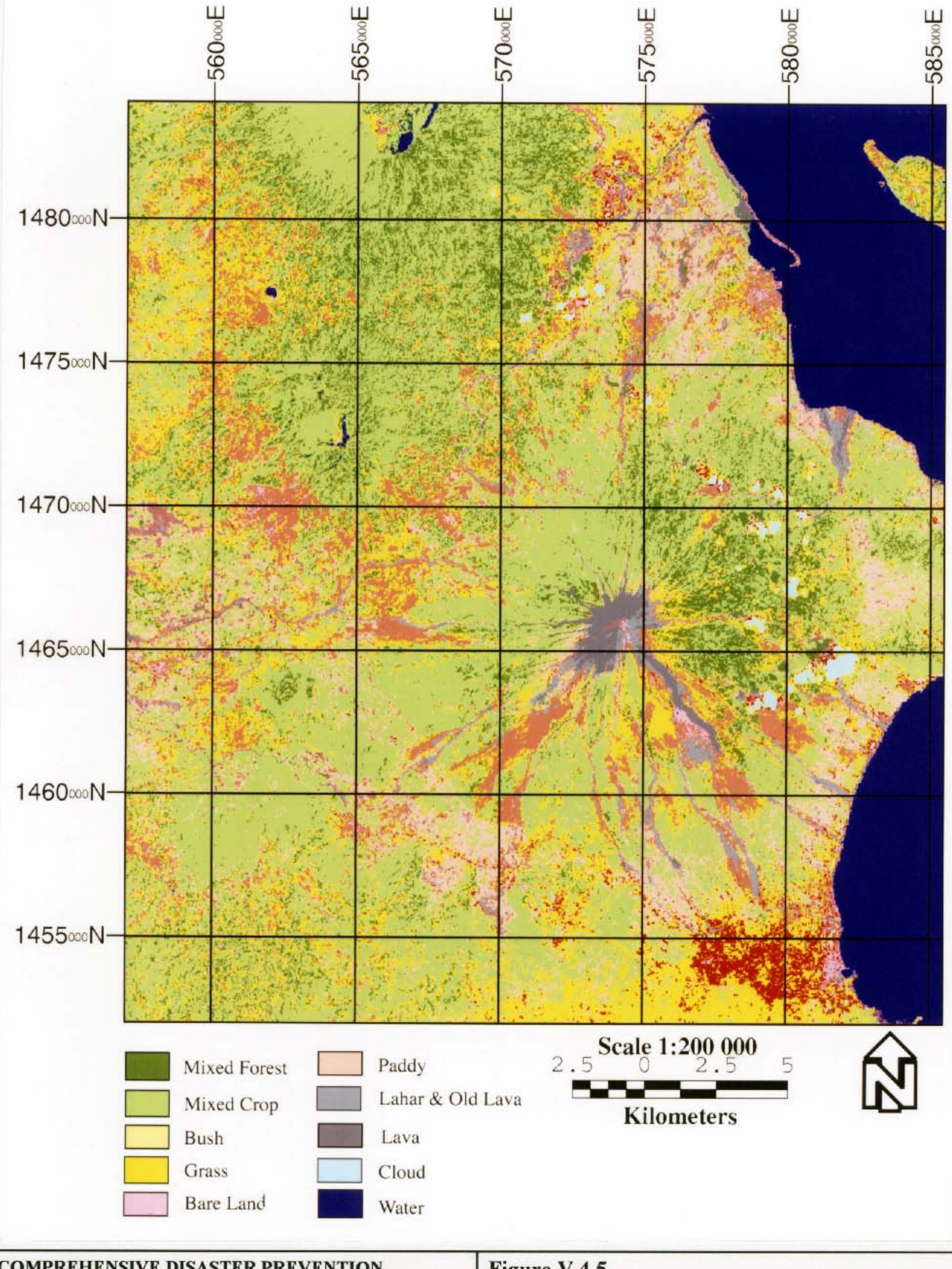
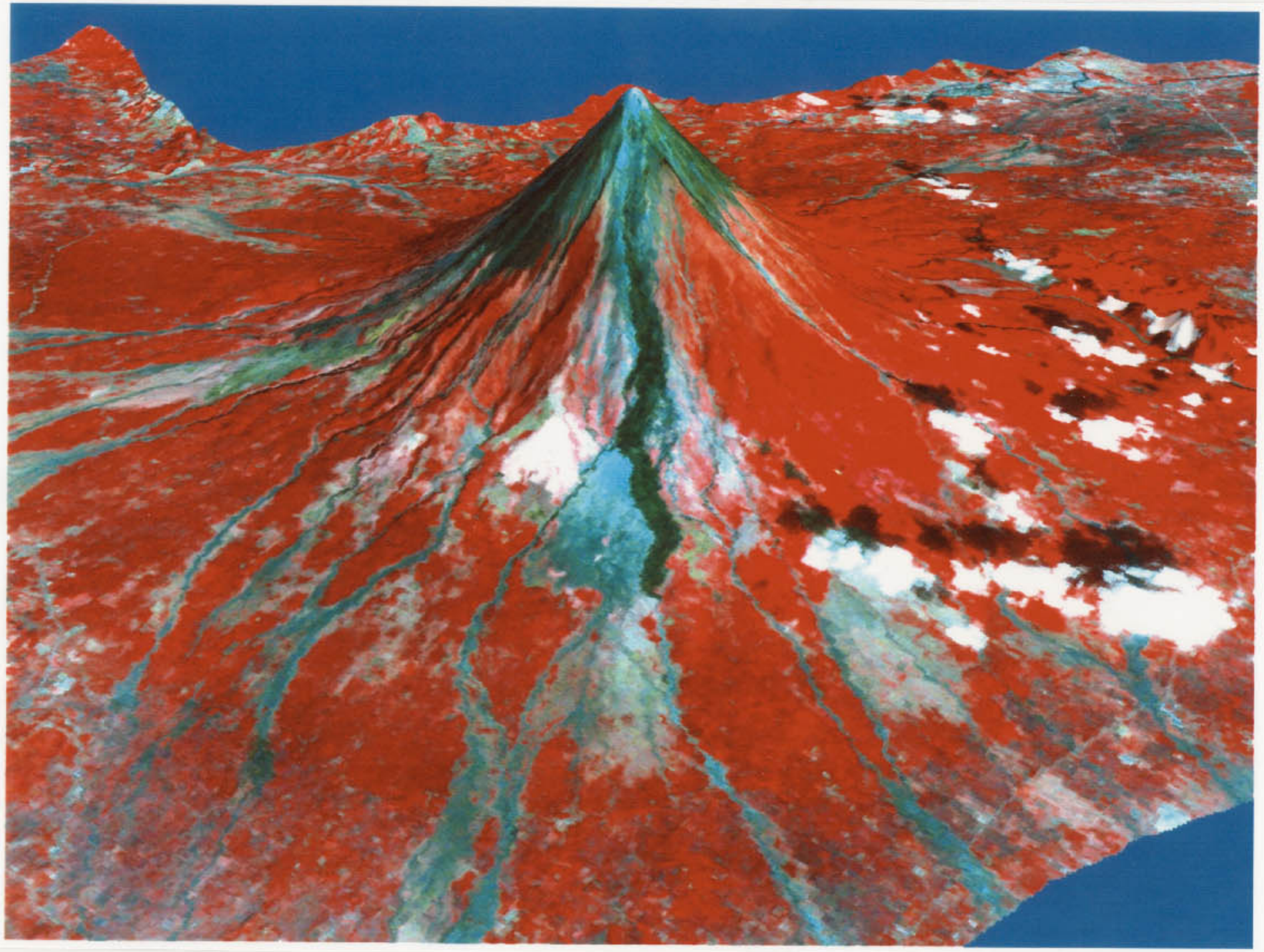
Figure V 4.3
Distribution of Digital Counts for Reference Samples of SPOT



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure V 4.4
JAPAN INTERNATIONAL COOPERATION AGENCY	Land Cover Map Generated using SPOT-XS 1992 Data



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure V 4.5 Land Cover Map Generated using Landsat-TM 1994 Data
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure V 4.6 3-D Image of View 1 using False Color Image 1994 Landsat-TM
JAPAN INTERNATIONAL COOPERATION AGENCY	