Recent Advances of Data Integration, Spatial Analysis and Modeling for Sustainable Development

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Abstract

Remote sensing is entering the third generation when high technologies such as high resolution satellite data with one meter ground resolution, SAR (synthetic aperture radar) interferometry, integrated sensor system with GPS (global positioning system) and INS (inertia navigation system) and so on will be implemented in actual applications. On the other hand, GIS (geographic information system) has emerged with a variety of applications, some of which remote sensing can be integrated as a latest data source to be input to GIS.

Remote sensing data with multi-function are now available for data integration, spatial analysis and modeling for sustainable development. In this paper, the authors summarize their observations and vision about the subject in relation to their own researches or knowledges in a quarter century.

Introduction

"Sustainable development" has become a key word since "Earth Summit" with agenda 21 held in Rio de Janero 1992. "Space technology applications for environmentally sound and sustainable development" has become another key word in Asia and Pacific since so called "Beijing Declaration" at Ministerial Conference was adopted with more than 30 ministers or subministers in Asia and Pacific in Beijing, China in 1994 (UN ESCAP 1994).

This is why many national projects with a title of sustainable development are now running in connection with remote sensing and GIS.

It should be noted that Asian remote sensing scientists have exchanged their experience and knowledges about how to solve environmental problem with remote sensing through Asian Conferences on Remote Sensing to be held annually since 1980 (Murai, 1992). Nowadays not only high technologies of remote sensing but also GIS are to be applicable to our final goal of sustainable development.

The objective of this paper is to review recent advances of data integration, spatial analysis and modeling particularly in view of sustainable development in Asia and Pacific.

Integration and analysis of multi-function remote sensing data

At the beginning stage of remote sensing in 1970's multi-spectral was a major concept of remote sensing. However, at present, we have many multi-function remote sensing data as follows.

- Multi-spectral/multi-frequency
- Multi-temporal
- Multi-resolution
- Multi-sensor
- Multi-source
- Multi-station
- Multi-polarization
- Multi-media

Data integration and analysis have been developed or proposed for these multi-function remote sensing data as follows (see Table 1).

a. **Multi-spectral/Multi-frequency**

One of the most exciting high technologies in remote sensing will be hyperspectral analysis with imaging spectrometer with 32~384 bands. It enables more precise classification of ocean colors, wetland vegetation, rock types etc. (Tong, 1997).

Multi-frequency of SAR data, for example L, C and X band, possibly in combination with multi-polarization of HH, HV and/or VV will provide users with more information about features of targets or objects on the surface or sub-surface (Shao et al. 1997).

Not only normal color composition but also principle component analysis or hyper-spectral analysis are often used.

b. **Multi-temporal**

Multi-temporal data are of remarkably importance in change detection and trend analysis of dynamic features such as agricultural field, land use change, urban sprawl, disaster monitoring and so on. In addition to multi-temporal capability, more and more real time monitoring and identification of serious phenomenon such as oil spill or disasters should be paid attention. Change detection has been implemented by many researchers with for example, principle component analysis and spectral signature similarity analysis (Yasuoka et al, 1994).

Multi-temporal data are also useful to improve land cover classification particularly vegetation cover.

c. **Multi-resolution**

It would be a good idea to integrate high resolution data with narrow coverage, and lower resolution data with wider coverage, because of limitation of data amount. The idea is to simulate a wide area with high resolution data using a relation of spectral features between high and low resolution data. For example, NOAA AVHRR data with a wide coverage can provide more reliable vegetation classification by using a relation with high resolution TM data as ground truth (Lertlum, Murai and Honda, 1997).

Pan sharpened color image with integration of one-meter panchromatic and three meter multi-spectral satellite data is being proposed to obtain a "pseudo high resolution color image".

d. **Multi-sensor**

Several sensors from different countries are now available. For example, American Landsat, French SPOT, Japanese JERS-1, Indian IRS, Canadian Radarsat, ESA ERS etc. are in operation with different sensors and resolution.

An idea is why not integrate different sensor data to supplement each other, for example to avoid cloud cover problems as well as to identify different features with different sensors.

Data fusion of optical and SAR data is a successful data integration. For example, SAR can monitor flood in rainy season even with dense cloud cover, while optical data will provide better land use classification (Honda et al, 1997). Vegetation index obtained from NOAA AVHRR can be overlaid onto Defense Meteorological Satellite data with night light and fires that identify urban and deforestation areas, respectively.

e. **Multi-sources**

Remote sensing data can be successfully integrated with other data obtained from other sources such as maps, statistics, GIS database etc. DEM (digital elevation model) can be simply overlaid onto geo-coded satellite imagery to produce 3D bird's eye view or animation of flight simulation.

Remote sensing data have been integrated with GIS data in many GIS applications and modeling (Murai, 1991). Remote sensing can also combined with GPS data for field investigation or ground truth survey.

f. **Multi-station**

Introduction of concept of stereo vision has been well recognized in the history of aerial photogrammetry to obtain three dimensional information such as contour lines, DEM or ortho-image. Stereo or even triplet models are now possible for very high satellite imagery with submeter ground resolution, which is equivalent to capability to produce 1:10,000 to 1:25,000 topographic maps with 5 to 10 meter contour interval (Sinclair 1997).

SAR interferometry is also based on multi-station with a short base length in the requirement of interferometric condition (Tokunaga, 1997). SAR interferometry is now being proposed to generate global DEM at one second interval or about 30 meter grid on the land with Space Shuttle. SAR interferometry is also applicable to detect subtle deformation of ground height due to earth quake, volcanic eruption, glacier meeting, sedimentation or soil erosion, etc. It will be very useful for environmental problems in Asia and Pacific.

g. **Multi-polarization**

For combinations of two options, horizontal (H) or vertical (V) for transmission polarization by two options, H or V for reception polarization for SAR, that is HH, HV, VH and VV will provide different feature signals because SAR data depends on polarization in its return signals.

Integration of Multi-frequency (L, C, X band) and multi-polarization (HH, HV, VH, VV) will be a powerful SAR system for better land type classification (Shao et al, 1997).

h. **Multi-media**

Not only different types of media such as hard copies and soft copies (CCT, CD ROM, video types etc.) but also many types of visualization such as animation and virtual reality are now available. More attentions are being paid to create beautiful products called "virtual reality map" as proposed by the first author in consideration of human sensibility. (Tanaka, Ono and Murai, 1997).

Some examples of modeling for sustainable development:

Modeling is to obtain estimated or simulated solutions by adopting parameters or data to a model or equation, while analysis is to determine unknown parameters of a model. As it would be difficult for the authors to review all of the modelings that have been proposed or applied for sustainable development, the author tries to introduce several interesting models and their findings in relation to the author's research works on sustainable development.

a. **Regression Model on Relation between Population Density and Forest Loss**

Regression model is a typical and most popular model to correlate two variables. Pahari and Murai (1997) found a very good regression model to correlate population density and forest loss continent by continent, as shown in Figure 1. The forest loss is defined as forest loss between current forest cover and potential natural forest cover to be estimated only from temperature and rainfall on Martonne's model.

From this regression model, it would be possible to predict future forest loss due to population increase in 2025 and 2050 as shown in Table 2 (Pahari and Murai, 1997).

b. **Global Soil Loss Prediction Model**

Pahari and murai (1997) modified the existing universal soil loss equation (USLE) for a global model to predict soil loss, that enables the prediction of soil loss region by region with possible forest loss due to population increase as shown in Table 3 (Pahari and Murai, 1997).

c. Simulation Model for Prediction of Regreening at Deforestated Area due to Copper Mine

Honda, Murai and Shibasaki (1993) applied so called "Logical Curve" developed by Mischerlich (1919) to predict and simulate regreening process from the damaged area at Ashio Copper Mine in Japan. Many phenomena are anticipated to follow the logical curve as defined as follows with respect to time change.

$$Y(t) = a(1-\exp(-kt))$$

This logical curve shows a slow start at the beginning, rapid change in the middle stage and slowing down at the saturated stage as shown in Figure 2.

d. Simulation Model for Prediction of Human Carrying Capacity

Asakura et al (1991) developed a model to predict human carrying capacity in terms of how many population can be supported, with use of GVI (Global Vegetation Index) from NOAA AVHRR Data to predict potential agricultural productivity of nine major crops. In this study, it was predicted that 7.7 billion population can be supported if we will eat as we eat now in each country (see Table 4).

e. Prioritization Model for Forest Conservation

Shibasaki et al (1995) developed a GIS model with use of NOAA AVHRR data and other GIS data to prioritize the forest conservation at global level using overlay with weights as shown in Figure 3.

The model was in consideration of carbon storage conservation, erodability and ease of forest.

f. Simulation Model for flood due to Deforestation

Ochi and Murai (1989) developed a simulations model with use of DEM and vegetation index at the damaged area of land slide in Nakhon Sri Thammarat, in Thailand. The model was to predict the speed up of the peak time and the increase of run off of flood in case of deforestation by using the relation that run off ratio will increase if vegetation index decreases due to deforestation.

Figure 4(a) shows the three cases of flood simulation for dense, sparse and non-vegetation.

Figure 4(b) shows the analysis of landslide occurrence with respect to land covers; bare soil, sparse vegetation, rubber and tropical forest. It is clear that less vegetation will cause more landslide as well as flood.

g. Deforestation Speed Model

Sah, Honda and Murai (1997) have developed a model for establishing a relation between watershed land degradation over time and socio-economic status of people living over there in Trijuga Watershed, Nepal. Degradation was represented by soil loss from Universal Soil Loss Equation (USLE). In this study, three indices of DSI (degradation speed index), SI (sensitivity index), and SSI (socio-economic status index) were found to have strong relationship in a multiple regression model as follows.

$$DSI = 0.6\ SI - 0.27\ SSI + 3.92$$

Where

DSI : a linear combination of forest change (%), rate of soil loss change

(t/ha/yr) and contribution to soil loss change (%)

SI : soil loss increment (t/ha/yr)/forest loss (%)

SSI: sum of ratio of locational value divided by total value

This regression model was found very useful to integrate social-economic factor and physical factor such as soil loss in three different ecological zones of valley, mainland and hill in a severely affected area by soil erosion in Nepal as shown in Table 5.

h. **Visualization for Digital Terrain Model**

Tanaka, Ono and Murai (1997) have developed various visualization models to represent digital terrain model (DTM) in consideration of human sensibility. These models are called "virtual reality map" by the first author, because several virtual reality conditions are added to DEM to create more beautiful and also more understandable DTM. Virtual reality will be generated with additional illumination, atmospheric effect, seasonal changes, color space conversion, map projection etc.

The concept of virtual reality map is shown in Figure 5.

CONCLUSIONS

a. It was demonstrated that recent advances of multi-function remote sensing data have a lot of potential of data integration and analysis for applications.

2. Several examples of modeling for sustainable development were introduced to show how remote sensing and GIS can be applicable to the solution of global and local environment problems.

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Table 1 Integration and Analysis of Multi-function Remote Sensing Data

Multi-function	Data Integration and Analysis
Multi-spectral Multi-frequency	Color Composition Principal Component Analysis (PCA) Hyperspectral Analysis
Multi-temporal	Change Detection (PCA etc.) Trend Analysis Multi-temporal Classification
Multi-resolution	Simulated high Resolution Image Pan-sharpening
Multi-sensor	Data Fusion (optical + SAR)
Multi-source	Integration with DEM, GIS, GPS etc.
Multi-station	Stereo-matching for DEM/Contour Maps Ortho-image SAR Interferometry
Multi-polarization	Classification with HH, HV, VH and/or VV
Multi-media	Hand Copy/Soft Copy Animation Virtual Reality

Table 2 Forest Cover by Region: Scenario until 2050

Region	Forest cover as percentage of land area			
	Without H.I.	Current (1990)	2025	2050
Tropical Asia	84.08	34.81	27.41	24.88
Tropical Africa	91.68	36.94	25.42	21.80
Sahelian Africa	31.31	13.52	9.52	8.54
Tropical Latin America	97.07	59.32	50.14	47.53
Central America	64.72	31.58	25.10	22.78
Europe	50.20	36.21	36.11	36.11

Remark: H.I. = Human Impacts,
Values for 2025 and 2050 are predicted values

Table 3 Comparison of Soil Erosion: Before the Human Impact, Current and Predicted (2025)

Erosion rate	Percentage of total land area		
	Without H.I.	Current (1990)	2025(predicted)
0 - 2 t/ha/yr	57.9	53.4	51.7
2 - 5 t/ha/yr	18.1	15.1	14.6
5 - 10 t/ha/yr	8.3	8.0	8.3
10 - 15 t/ha/yr	4.3	4.0	4.3
15 - 20 t/ha/yr	2.7	2.8	3.0
20 - 50 t/ha/yr	6.0	7.8	8.7
> 50 t/ha/yr	2.7	8.9	9.4

Remark: H.I. = Human Impacts

Table 4 **Prediction of Population Carrying Capacity based on Crop Production (Asakurat et al)**

a) Potential Arable Land (10^3 square kilometers)

	Present Area	Potential Area	Increase
North American	2,671	4,604	1,933
South American	1,163	1,446	283
Europe & Asia	7,752	8,832	1,080
Oceania	478	1,812	1,334
Africa	1,688	4,681	2,993
Total	**13,732**	**21,375**	**7,643**

b) Potential Population Carrying Capacity

Case	Condition	Estimated Population Capacity
Case 1	Each country's consumption	7.7 billion
Case 2	World average	9.0 billion
Case 3	American standard	4.0 billion

Table 5 **Relation between Degradation Speed Index (DSI), Sensitivity Index (SI) and Socio-econimic Status Index (SSI) in Trijuga Watershed, Nepal**

Location	DSI	SI	SSI
Valley	3.33	0.25	2.69
Midland	2.46	0.42	6.23
Hill	4.95	2.63	2.01

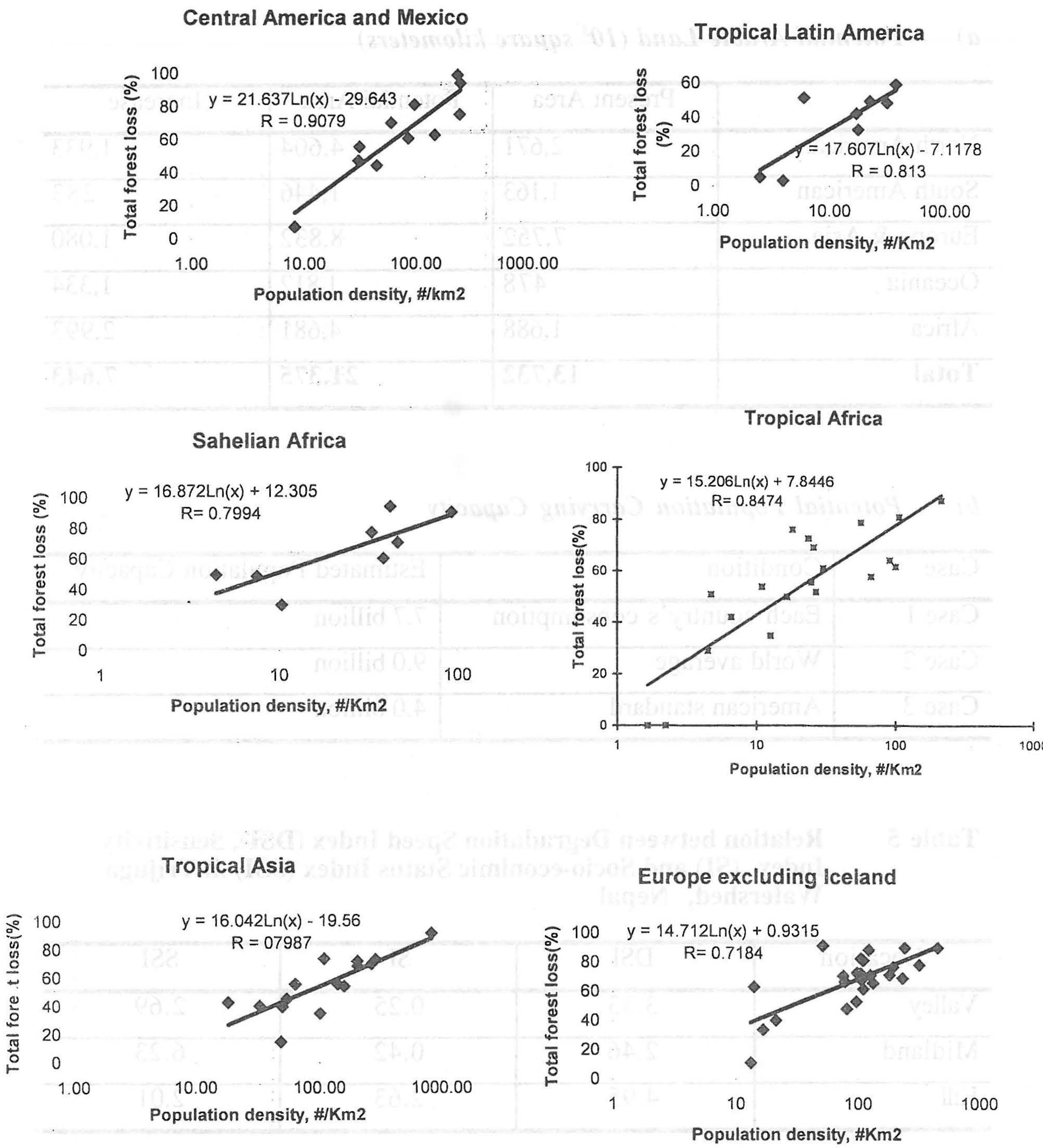


Figure 1: Correlation Diagram between Population Density (logarithmic) and Cumulative Forest Loss

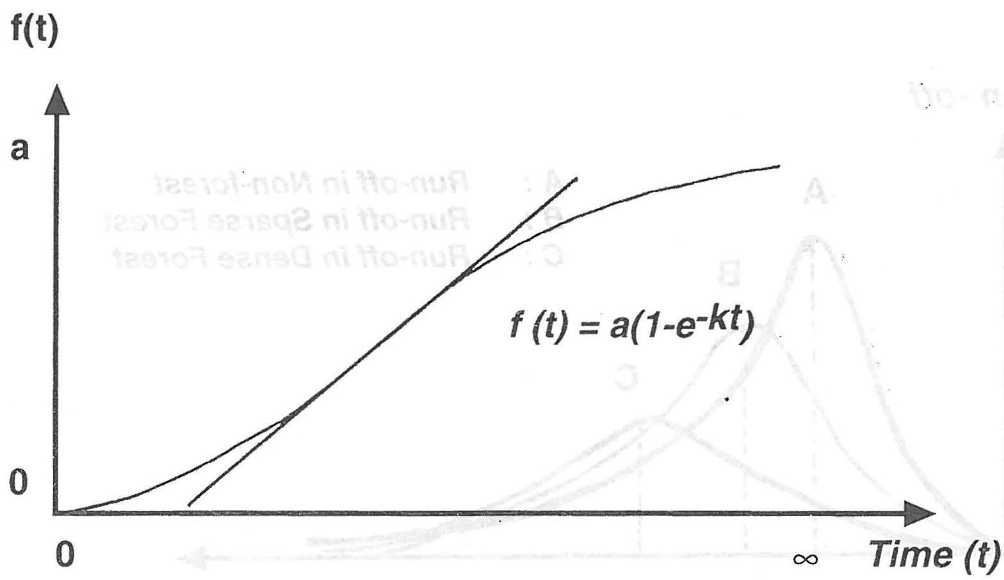


Figure 2 *Logical Curve for a Prediction Model with respect to Time*

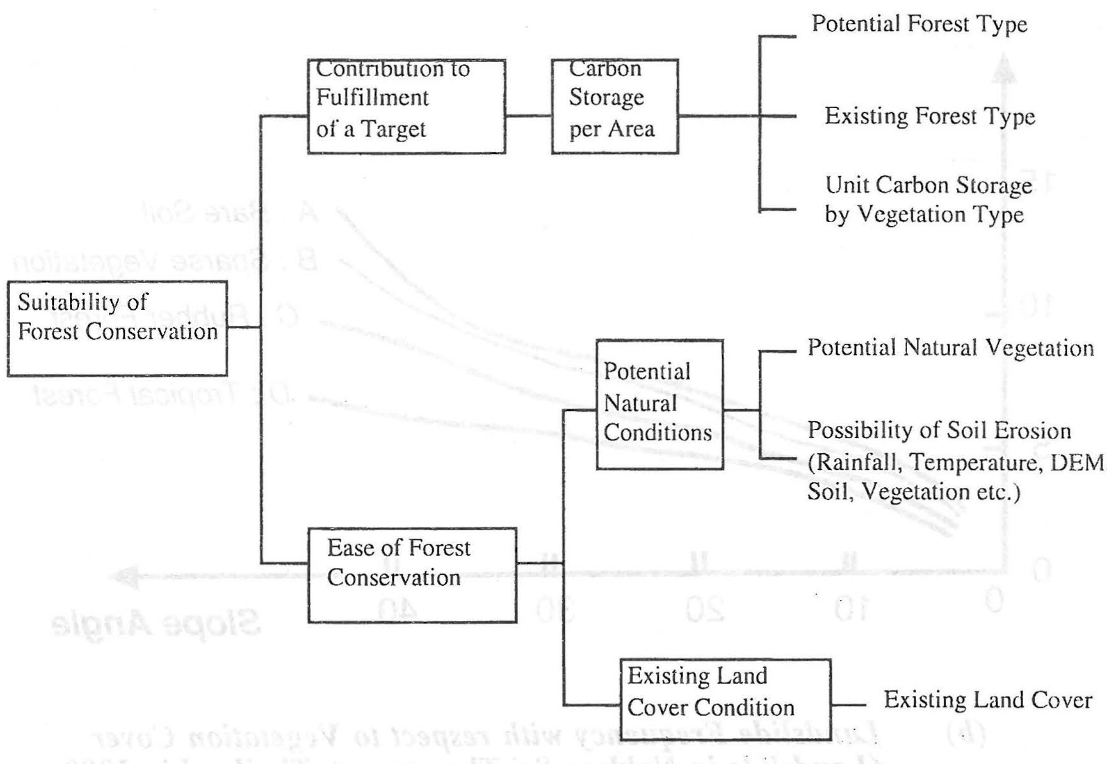
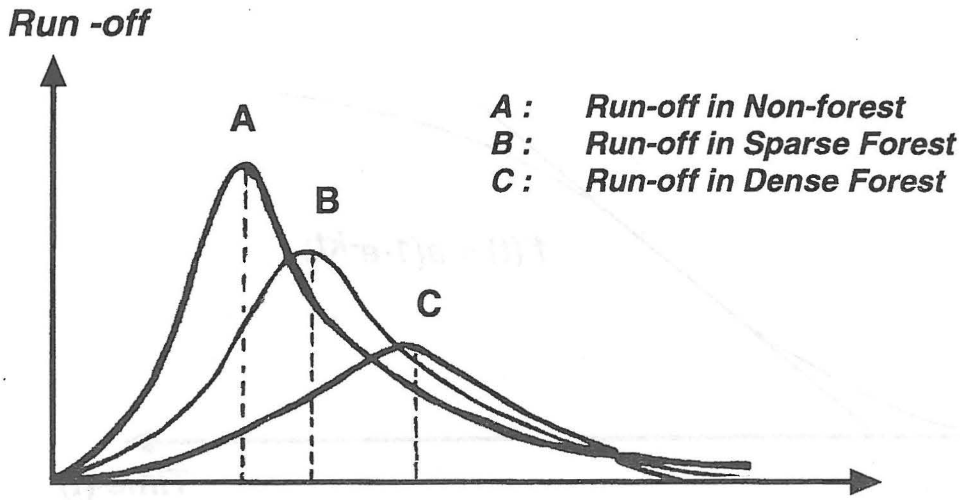
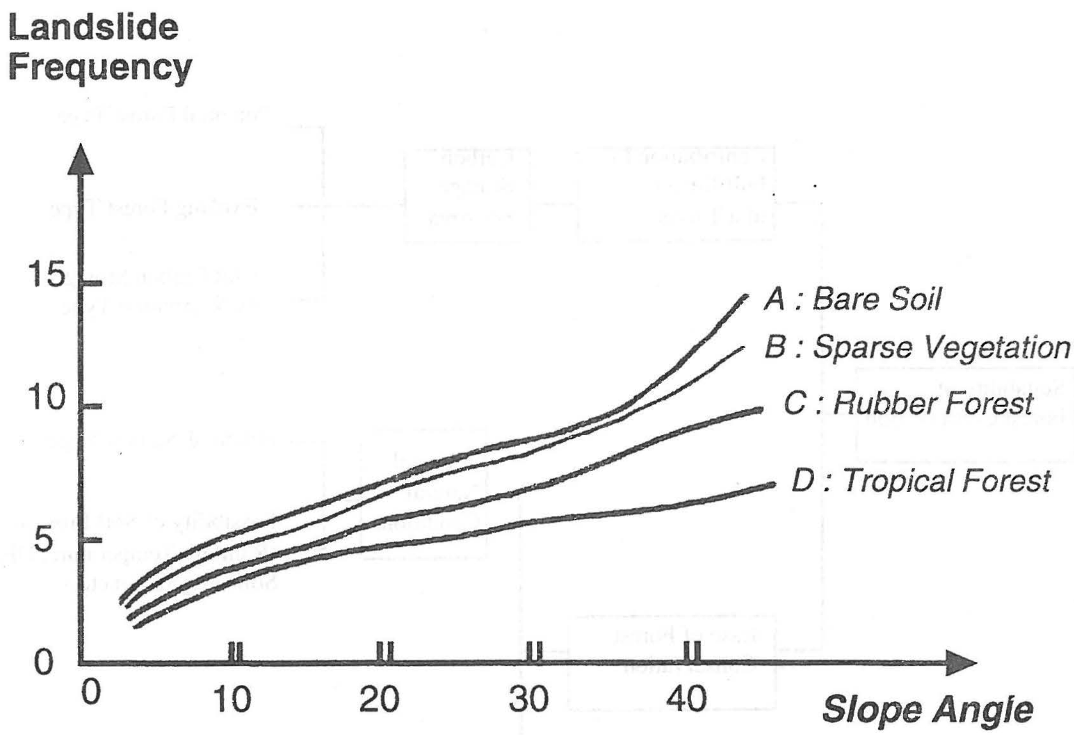


Figure 3 *Suitability Model for Forest conservation*

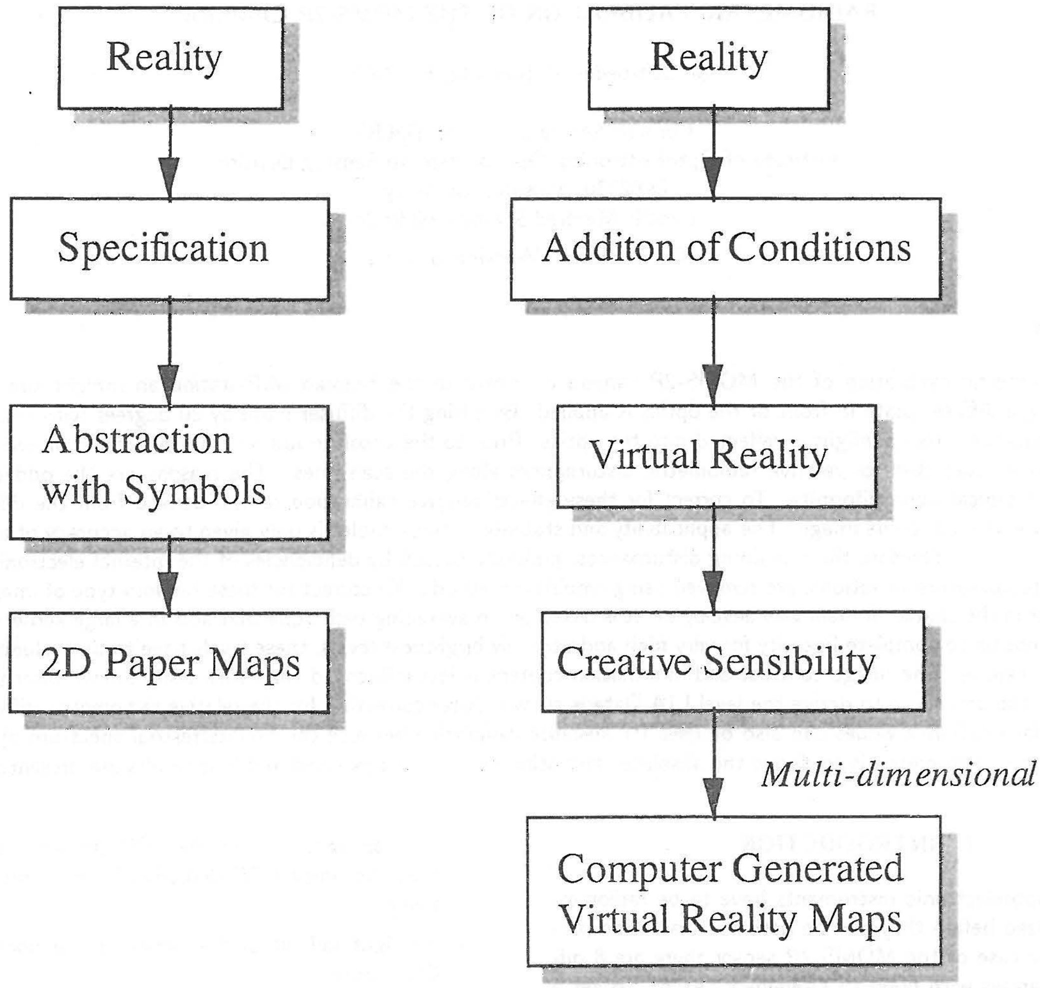


(a) Flood Peak and Run-off with respect to forest Cover



(b) Landslide Frequency with respect to Vegetation Cover (Landslide in Nakhon Sri Thammarat, Thailand in 1988

Figure 4 Impact of Deforestation to Flood and Landslide



(a) Existing Concept of 2 D Paper Map

(b) New Concept of Visrtual Reality Map

Figure 5 Comparison of Existing and New Concept for Map Production