A case study of spatial analysis for environmental monitoring

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Abstract: Spatial analysis is an effective technique for environmental monitoring. Since river systems, road networks and land use patterns are closely related, establishing the spatial distribution of these patterns is of fundamental importance as basic information for environmental monitoring. In recent years, development of road networks has been rapidly accelerated in developing countries and its impact to natural environment such as forests and river systems are strong. Currently, remote sensing data and GIS technique are improved and they have become a key tool for providing information for environmental monitoring.

The objective of this study is to determine spatial distribution of forests, river systems and road networks in 1989 and 2002 at the lowland watershed of Vam Co Dong river basin which flows from Cambodia to Vietnam. Digital Elevation Model (DEM) has recently become a powerful tool for detecting river systems at various scales because DEM enables direct detection of river systems. However, DEM analysis was not effective for flat plains and was considered difficult to apply in the past. In this research, river networks were successfully detected by pit-filling method with Shuttle Radar Topographic Mission (SRTM) DEM which is available with 90 m mesh for the whole world. Forests and road networks were delineated by using ASTER and LANDSAT. Observation of spatial distribution and forest cover changes between 1989 and 2002 indicate that natural forest decreased to 66%, while rubber plantation areas have increased twofold. Distances between natural forests or rubber plantation areas from river systems have not changed significantly. However, maximum distance of natural forest from road networks halved to 5 km in 2002. This drastic change may reflects rapid road networks development, while geographical locations of natural forest and rubber plantation areas are stable similar to the distance from river systems if catchment area is larger than 10km^2.

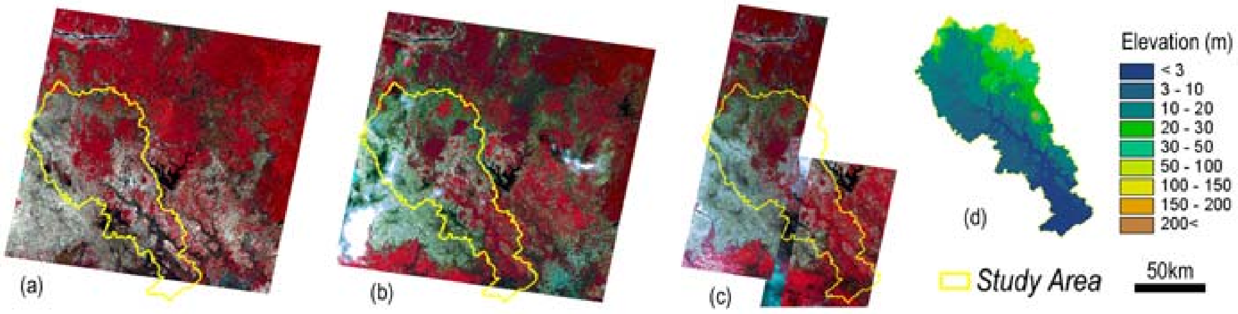
Keywords: spatial analysis, DEM, Vam Co Dong river

1. Introduction

Since the 1980s, spatial analysis technique has been developed with the objective of determining the spatial distribution of objects with GIS and remote sensing data. Spatial analysis deals with two of types of information, namely 1) the attributes of spatial objects, which include measuring area, rainfall, slope angle and other factors:. 2) positioning information of the spatial objects which are shown on geographical coordinate systems. Digital Elevation Model (DEM) has recently become a powerful tool for spatial analysis by providing spatial data of river systems because DEM enables direct detection of river systems by hydrological models. Remote sensing data , GIS and DEM are very important for environmental monitoring and they are now playing key roles for quantitative evaluation. In many developing countries, environmental changes occur widely and road networks have developed widely. As a result, its impact to natural environment is quite strong. Thus quantitative environmental monitoring has now become possible and is an essential tool for evaluation of environmental changes. .The objective of this study is to determine spatial distribution of forests and relationship between forests and river systems or road networks for the lowland watershed of Vam Co Dong (VCD) river basin.

2. Study area

Vam Co Dong river basin which flows from Cambodia to Vietnam was selected for the study. Because in this basin, environmental changes have been underway and natural ecosystem has been threatened through cutting of natural forest areas for rubber plantations, crop lands, settlements, etc. Fig.1 (a)-(c) show the images of the study area taken in 1989 and 2002. Forest coverage in the central part of study area on those images show significant changes. Topography of the study area shows no significant relief and elevation is mostly less than 200m without a steep hill which is located at eastern part of the study area (Fig.1 (d). Since elevation of riverside of Vam Co Dong river is almost under 3 meters, it is submerged by flooding water in every rainy season. While, in dry season water supply is not sufficient because dams and irrigation network systems are still short for supplying agricultural products and other human activities. Thus environmental change in this study area should be evaluated comprehensively to use remote sensing data and GIS for spatial analysis technique.



(a) Landsat/TM (16Jan.1989), (b) Landsat/ETM (13Feb.2002), (c) Terra/ASRER (4 and 13 Feb., 28 Nov. 2002), (d) SRTM DEM

Fig.1 False color images and SRTM DEM of study area

3. Data used

Satellite data sets used in this study are SRTM DEM, LANDSATand ASTER data laid out in Table 1. False color composites images and SRTM DEM are shown in Fig.1. DEM was generated by Shuttle Radar Topographic Mission (SRTM) which is a joint project between the National Geospatial Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA). Data was acquired by radar interferometry technique which enables generation of digital elevation data by two radar data which are taken at a distance. Data were acquired in February, 2000 and accordingly processing began in April, 2002. Currently 1 arc-second-spacing data are available for United States and 3 arc seconds spacing data for other countries.

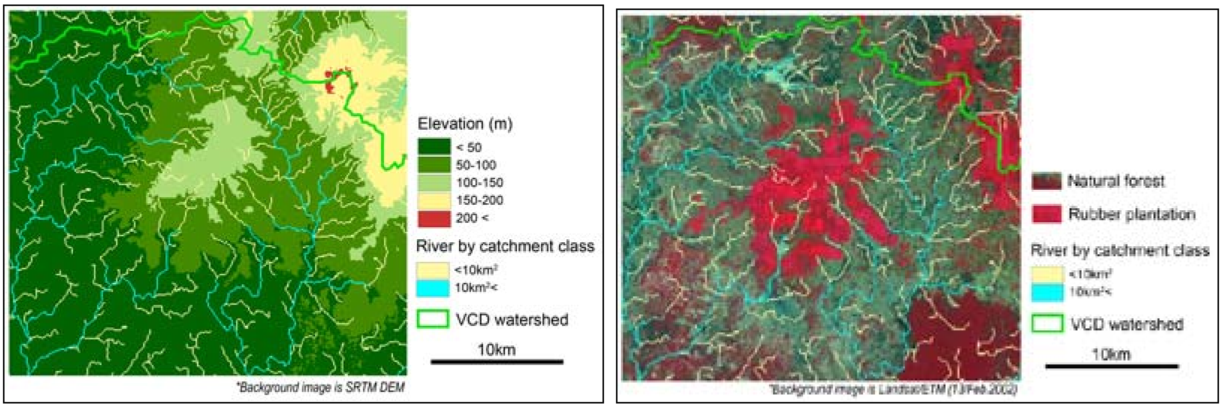
Table 1. Data used in this study

Satellite/Sensor	Acquisition Date
SRTM DEM	February, 2000
Landsat/TM	16th January, 1989
Landsat/ETM	13th February, 2002
Terra/ASTER	4th, 13th February, 2002
	28th November, 2002

4. Method and results

There are three steps to carry out spatial analysis for environmental changes in the study area. Firstly, river networks was delineated by flow-path method developed by using DEM. Secondly, natural forest, rubber plantation area and road networks were delineated by using Landsat and Terra/ASTER. And then, distance from road and river to natural forest and rubber plantation area were calculated on ESRI ArcView to evaluate spatial distribution.

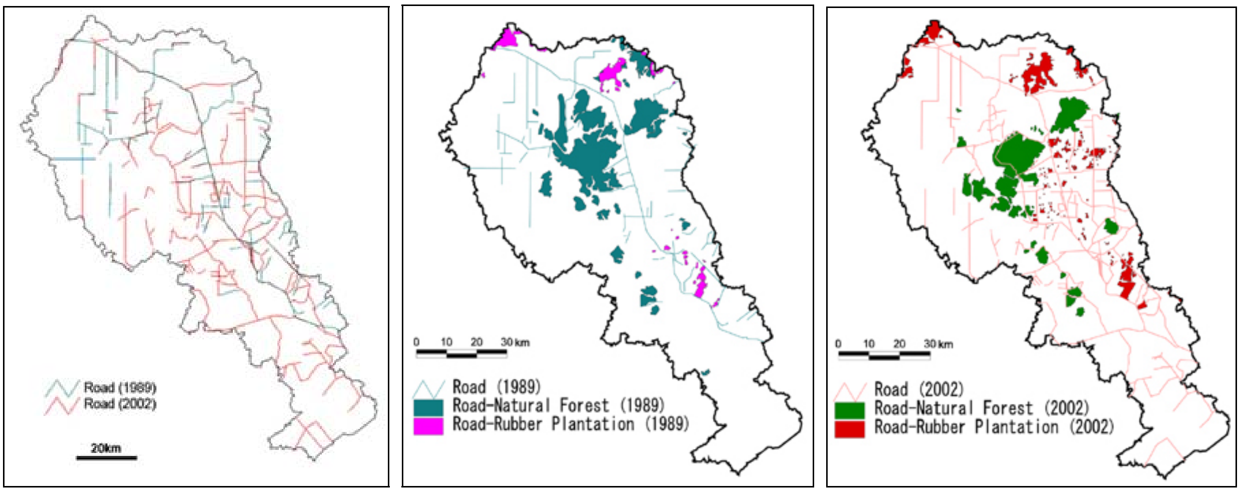
In the first step, flow path direction was estimated in considering with elevation values on DEM. Deterministic 8 (D8) algorithm developed by O'Callaghan and Mark (1984) is a basic method to assign one flow path direction from each grid cell in considering with the elevation values of its eight neighbors [1]. It has been widely used for hydrological models. However, since DEM data include noises such as pits and dams caused by DEM processing procedure, D8 algorithm sometimes has difficulty to estimate possible flow path in flat areas. Because heights of pits and dams in flat areas are sometimes bigger than elevation values in the surrounding areas. It makes flow-path algorithm difficult and some flow paths can not be connected with the adjoining grid cells. As a result, discontinuities of flow path networks are generated. In order to solve this problem, pit-filling algorithm was proposed to make it possible to find flow paths in flat areas (Marks et al., 1984 [2]). Pit-filling algorithm is basically used to increase elevations of depressions to the lowest elevations in the surrounding pixels and it is used in this study. Flow path was created in connecting with lowest elevations of outflow points. However, in some areas, two or more directions of flow paths can be found. For this problem, random numbers are generated to select one flow path direction. Consequently, depth of water at outflow point in the edge of depression was replaced in order to delineate ideal flow path and to maintain natural conditions. As a result, flow paths are generated. This method was applied for this study and water networks were delineated as shown in Fig.2. In this study, river networks are defined as connected rivers which are larger than 10km^2 in catchment area (blue line in Fig.2). Fig2 shows river networks on SRTM DEM (a) and LANDSAT/ETM false color image (b).



(a) (b)

Fig.2 Water network in the study area with SRTM DEM (a) and Landsat/ETM false color image (b)

In second step, natural forest, rubber plantation area and road networks were delineated by using Landsat, ASTER and SRTM DEM and ASTER DEM. Spectral variations of Band1 to Band 9 of ASTER were considered. Slope angle of DEMs of SRTM and ASTER were used to separate natural forest and rubber plantation. Because distribution pattern of height of tree show different at the edge of each forest. Natural forest has broad change and rubber plantation has rapid change derived from uniformity of tree age. This different pattern can be expressed in DEM and it was confirmed by field verification which was carried out in November 2004. As a result, each spatial distribution is shown in Fig.3. Observation of spatial distribution and forest cover changes between 1989 and 2002 indicate that area of natural forest decreased to 66%, while area of rubber plantation forest has increased twofold. Particularly natural forest in central part of the study area shows strong changes and rubber plantation in northern part of the study area was increased. At the same time, newly constructed roads were widely observed as shown in Fig.3(a). Thus it appears that construction of roads have profound affect on changes of areas of natural forest and rubber plantation. On the other hands, river networks are likely to have some relation to distance from natural forest and rubber plantation. Because those forest areas are good habitat for animals and birds and they need water to live.



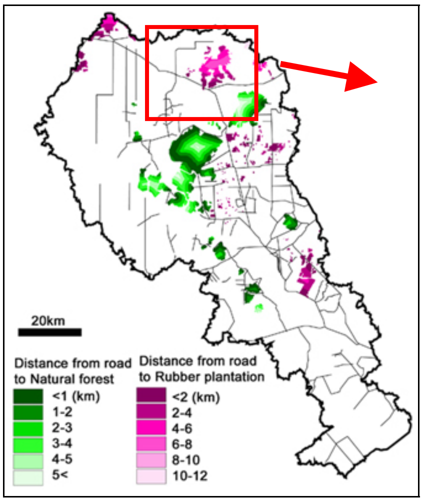
(a) (b) (c)

Fig.3 Road networks (a), natural forest, and rubber plantation in January of 1989 (b) and February of 2002 (c)

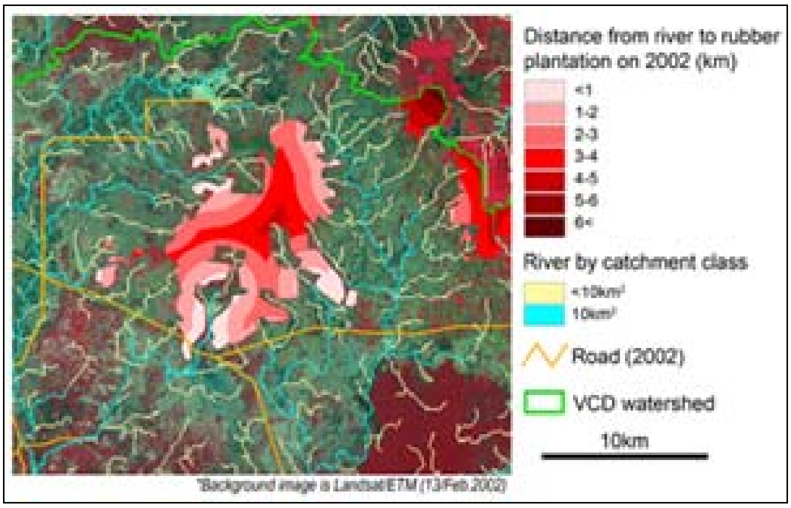
Finally, equidistance map was generated to calculate distance between river or roads and natural forest or rubber plantation area in Jan. 1989 and Feb. 2002 by ArcView for each 30m grid. From those point of views, distance from river or road to natural forest or rubber plantation area were determined in the next section.

5. Discussion

In the previous section, distances from roads and rivers to the forests and the spatial distribution of forests were delineated separately. In order to determine the distance from river/road to forests, each grid of distance of river/road area was overlain on areas which were delineated as natural forests and rubber plantation areas. As a result, the distances from rivers or roads to natural forests or rubber plantation were obtained. Fig.4 (a) shows the distances from roads to natural forests and rubber plantations in 2002. Fig.4 (b) is a larger scale of the same.



(a)



(b)

Fig.4 Distance from road to natural forest and rubber plantation (b) and distance from river to rubber plantation on 2002

Consequently, the total spatial distribution was calculated and summarized as shown in Fig. 5 and Fig. 6. Distances between natural forests or rubber plantation areas from river systems have not changed significantly as shown in Fig.5. However, maximum distance of natural forest from road networks halved to around 5 km from 10km in 2002 as shown in Fig. 6 (a). On the other hands, rubber plantation was developed at short distance from road. These drastic changes reflect rapid road networks development, while geographical locations of natural forest and rubber plantation forest are stable similar to the distance from river systems if catchment area is larger than $10km^2$.

Thus trend of changed areas were estimated in the past between 1989 and 2002. And possible areas for cutting natural forests were estimated. It is said that distance of natural forests at 4 to 10 km from road could have been cut down. As a result, since remaining forests are mostly located less than 5km from road, natural forests at shorter distance say 2 to 3km could be affected by cutting if tree felling is not regulated.

This study focused on the distances between river systems/road networks and natural forest/rubber plantation areas. However, important factors or effective influence for environmental changes can be provided by further determination such as distribution of villages, population of villages, agricultural products by items, irrigation networks and so on.

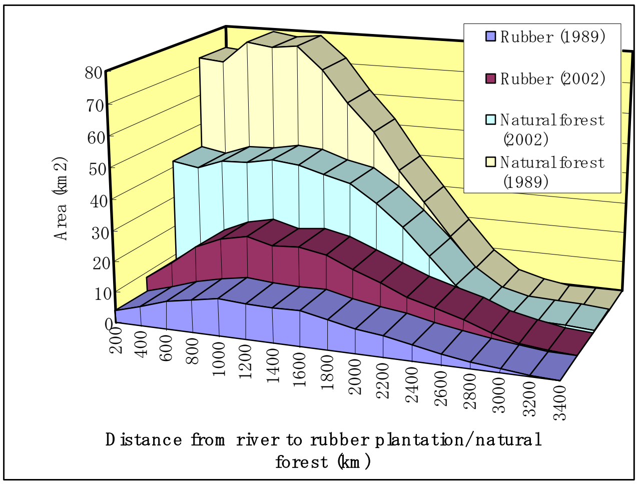
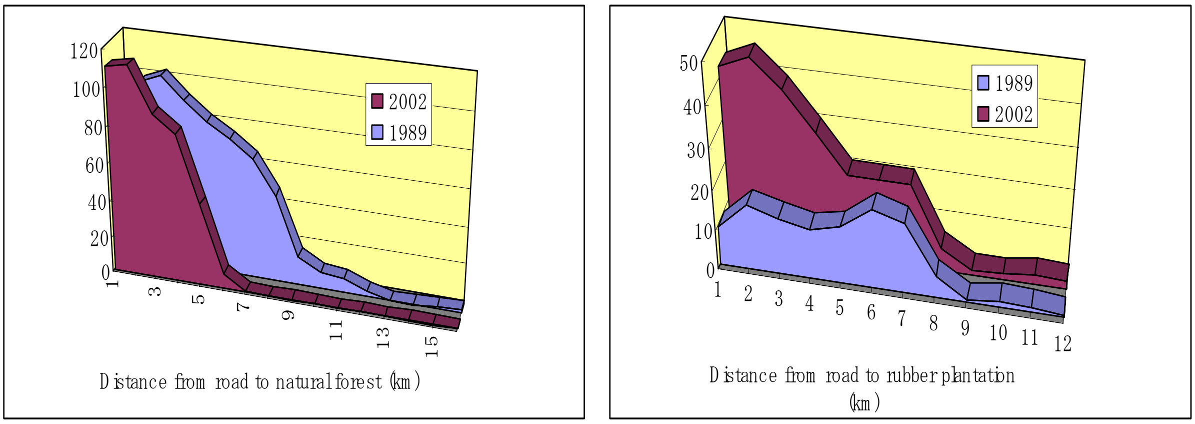


Fig.5 Distance from river to rubber plantation/natural forest



(a) **(b)**

Fig.6 Distance from road to natural forest (a) rand distance from road to rubber plantation (b),

6. Conclusions

In this study, spatial analysis was presented to determine spatial distribution of natural forest and rubber plantation areas in terms of distances from river systems or road networks by using SRTM DEM, Landsat and ASTER. And pit-filling method was applied for detecting river systems in flat areas such as the study area. Although the result needs to be revised and improved, trends of change area was estimated in the past between 1989 and 2002 as well as estimation of possible areas for cutting natural forest. This result encourages us to further study for evaluating spatial distribution for environmental monitoring and management in many countries which are suffering from severe environmental problems.

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