USING GIS AND REMOTE SENSING TO MONITOR THE NATURAL RECOVERY OF LANDSLIDE AREAS IN THAILAND

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KEY WORDS: GIS, RS, LANDSAT, NDVI, Greenness, Landslide, Landslide scars.

ABSTRACT:

The worst landslide causing massive destruction occurred in 1988 after being triggered by heavy rainstorms and many more have occurred since. Many researchers have focused their attention to the issue and urgently tried to find ways to prevent the lost of lives and properties if such phenomenon repeats itself. The objective of this study was to monitor the recovery of landslide areas after 20 years (1988-2008). The eight time-series data of LANDSAT imagery dated 1990, 1993, 1994, 1996, 1999, 2002, 2006, and 2007 were used. The Geographic Information System (GIS) and remote sensing (RS) technology were selected as the analytical tools. The changes of the NDVI and Greenness between the satellite images, representing the change of vegetation or land cover, were analyzed. Visual interpretation showed the improvement of the landslide areas. In addition, the quantitative analysis of land cover was calculated.

1. INTRODUCTION

Landslides, result in great loss of life and property, are normally triggered by events such as earthquakes, heavy snow, or rainfall that can induce unstable conditions on otherwise stable slopes, and accelerate mass movement, especially in mountainous areas of the world. Landslides can be triggered by both natural and man-induced changes in the environment. Changes in slope result from terracing for agriculture, cut-and-fill construction for highways, the construction of buildings and railroads, and mining operation (Wold and Jachim, 1989). Mass movement have been controlled by climate, rock types, tectonic conditions, intensity of settlement, and changes in land use and land cover (Saddle et. al., 1985). Tropical areas, which have high rainfall, such as Thailand, tend to be susceptible to landslides, particularly on steeply sloping terrain. These landslides usually occur when natural forests have been cleared for other purposes, such as agriculture or urban development.

Thailand's worst natural disaster took place in November 1988 when thousands of landslides occurred after extremely heavy rainfall in the provinces of the southern region. These landslides and the accompanying outwash of debris and downstream flooding claimed some 370 lives and caused damage of at least 7 billion baht (about $ US 280 million). The landslide disaster was widespread all over Thailand since then.

Geographic Information System (GIS) is recognized as a powerful tool for environmental studies and is used for analyzing environmental change by providing the capabilities for modifying physical properties in a spatial context (Woodcock et.al., 1990). GIS can also be used as a tool for predicting the occurrence and behavior of natural events (Wadge, 1988). It is possible and feasible to integrate sophisticated models in a GIS (Shasko and Keller, 1991). Landslides can be triggered by the types of landforms and/or land use/land cover types. For example, steeper slopes generally result in a greater potential for erosion (ESRI, 1992a).

Remote sensing is used extensively in the acquisition of forest resource data and for updating any changes in land use. Landsat (Thematic Mapper) images are comparatively cheaper than other airborne sources such as aerial photography. In addition, GIS and ERDAS remote sensing data could be integrated. The digital data from Landsat are available in digital format, i.e. ready for processing by GIS and can increase productivity and reduce time for processing.

The Landsat TM band1 (0.45-0.52 μm), band2 (0.52-0.60 μm), band3 (0.63-0.69 μm), band4 (0.76-0.90 μm), band5 (1.55-1.75 μm), and band7 (2.08-2.35 μm) including their derivatives, are typically used to study land use/land cover (Lauver and Whistler, 1993; and Townshend, 1984). However, the thermal band 6 was not employed because of its low spatial resolution (Lauver and Whistler, 1993). The spectral reflectance properties of a leaf in the 0.4 to 2.5 μm region are function of pigments, primarily chlorophyll, the leaf cell morphology, internal reflective index discontinuities, and water content (Raines and Canney, 1980). The pigments of the chlorophyll group are primary control from 0.4 to 0.7 μm, cell morphology and internal reflective index discontinuities are the primary control from 0.7 to 1.3 μm, and water content is the major controlling factor in the 1.3 to 2.5 μm region. The longer-infrared TM bands have been suggested to be most sensitive to both soil moisture (Stoner and Baumgardner, 1980) and plant moisture (Tucker, 1980).

Landsat data, which are large and complex data sets, may cause processing problems in terms of storage, analysis, and data display. If this occurs, the transformation of data to a single variable, such as Normalized Difference Vegetation Index (NDVI) or TM tasseled Cap Transformations is appropriate (Rouse et al., 1974; and Chirst and Cicone, 1984a). Tassel Cap Transformation was primarily developed for condensing the four bands of MSS data (Kauth and Thomas, 1976). After that equations have been developed for TM data (Chirst 1983;

Chirst and Cicone, 1984b, c). TM Tasseled Cap Transformations captured approximately 95 percent of total variability in scenes dominated by vegetation and soils (Chirst and Cicone, 1984b), and condensed this invariability into three features; namely brightness, greenness, and wetness. The brightness, greenness, and wetness features represent the soil, vegetation, and soil moisture characteristics respectively (Chirst and Cicone, 1984b).

The greenness feature responds to the combination of high absorption in the visible bands (due to plant pigments particularly chlorophyll) and high reflectance in the near infrared (due to internal leaf structure and the resultant scattering of near-infrared radiation), which is characteristic of green vegetation. Greenness has been shown to be moderately to well correlate with canopy closure percentage, leaf area index, and fresh biomass (Bauer et al., 1980). By the result, the Greenness was selected for this study.

The NDVI is an index for measuring how plants absorb or reflect sunlight (http://svs.gsfc.nasa.gov/stories/drought/index.html, 2007). The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected (http://earthobservatory.nasa.gov/Library/MeasuringVegetation/measureing_vegetation_2.html,2007).
This method can be used to determine the density of green on a patch of land. Satellite remote sensors can quantify what fraction of the photo synthetically active radiation is absorbed by vegetation. In the late 1970s, scientists found that net photosynthesis is directly related to the amount of photo synthetically active radiation that plants absorb. The more a plant is absorbing visible sunlight (during the growing season), the more it is photosynthesizing and the more it is being productive. Either scenario results in an NDVI value that, over time, can be averaged to establish the "normal" growing conditions for the vegetation in a given region for a given time of the year. Increasing positive NDVI values, shown in increasing shades of green on the images, indicate increasing amounts of green vegetation. NDVI values near zero and decreasing negative values indicate non-vegetated features such as barren surfaces (rock and soil) and water, snow, ice, and clouds.

The objective of this study was to monitor the natural recovery of the landslide areas in southern Thailand. The natural recovery means the natural self healing of the landslide areas by the natural vegetation which is gradually and slowly increased by time after the landslide disaster.

2. MATERIALS AND METHODS

2.1 Description of study area

Nakhon Si Thammarat province located in southern Thailand. It is about 610 km from Bangkok (Capital of Thailand) on the east coast of the Malay Peninsula. The climate is classified as tropical Monsoon (Am) by Köppen's classification (Department of Land Development, 1988). The rains are influence by the northeast monsoon wind during the period between October and January and the southwest monsoon between May and September. Consequently, the southern part of Thailand receives high rainfall throughout the year and totals about 2,212 mm (Meteorological Department, 1989).

Phipun watershed, located on the Nakhon Si Thammarat Mountain range, was selected as study area (Figure.1). Phipun was suffered from the landslide in November, 1988. The area is located between the 08º 35´ N to 08º 43´ N and 99º 28´ E to 99º 37´ E covering an area of about 94 km^2. The area covers Amphoe Phipun and the highest mountain peaks including Khao Phai Kathun (1,911 m), Khao Krabiat (1,262 m), Khao Chang Lom Tai (1,123 m), Khao Plai Khong Phuan (775 m), and Khao Kathun (772 m). Surrounding the mountains are low lying hills, terraces, and floodplains of small stream (Pantanahiran, 1994). Most of the area is composed of granitic rock. Silurian-Carboniferous shale, sandstone, quartzite, mudstone and shale are also found in small areas in the southern portions of the watershed (Geological Survey Division, 1985). Natural forest is still found in the study area; however, Para rubber is the main land use (Pantanahiran, 1994, 2001).

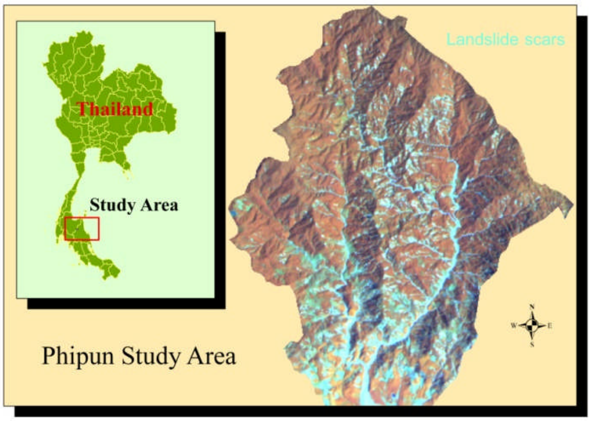

Figure 1. The location of study area

The primary factors that controlled the landslides in the area were (1) fractured limestone and granitic bedrock in the mountain; (2) steep slope (over 30%); (4) high rainfall earlier in November as well as a particular storm in November; (5) the pathway of the storm; (6) reduction in natural forest cover; (7) planting of shallow-root trees and crops; (8) recentness of clearing and replanting (Zinke, 1989; Thiradilok et. al., 1990; and Tantiwanit, 1991).

2.2 Data input and analysis

The Geographic Information System (GIS) and remote sensing technology were selected as the analytical tools to deal with the problem of landslides. The ArcGIS software version 9.2 and ERDAS version 8.7 running on PC under Windows XP operating system, were used as analytical tools. The GRID modules of the ArcGIS software were used for terrain modeling and analysis. The Universal Transverse Mercator (UTM) coordinate system and the WGS 1984 spheroid were used as a standard coordinate system. The DEM (Digital Elevation

Model), with a spatial resolution of 30x30 m, of the study area was used to manipulate the slope. The derivatives of TM data including Greenness and NDVI were used as index to evaluate the recovery of landslide scars in the area.

The GRID or Raster module, which is a component of the ArcGIS software, was used in this study. GRID is a raster-based or cell-based geo-processing system. GRID provides the tools for both simple and complex grid-cell analyses and provides a powerful environment in which to explore spatial problems (ESRI, 1991a). Its strengths include the reduction of database size, the support of both continuous and discrete data, and the ability to use map-algebra concepts. In addition, it is a powerful tool for the manipulation of data and modeling, and directly supports image processing such as ERDAS.

2.2.1 The landslide scar detection

The eight time-series data of LANDSAT TM-5 images dated 1990-03-04, 1993-09-23, 1994-03-03, 1996-01-16, 1999-01-01, 2002-06-01, 2006-04-01, and 2007-03-03 were used. The images were converted into GRID data format under ArcGIS software. Then, Landsat TM band 1-7 were separated as GRID data format with a spatial resolution of 30x30 m.

A modified supervised classification technique was used. This procedure was conducted on screen by visualization technique. The digital number (DN) was used for landslide classification. The Landsat-5 TM band 5 in 1990 was used to delineate landslide scars from other features. It was found that DN between 90 and 245 was assigned as landslides, and all other pixels were assigned as vegetation or land cover. In addition, the relationship between landslide occurrence and the elevation, the slope as well as the stream channel were found (Pantanahiran, 1994). Then, the landslide pixels having the slope less than six degrees, the elevation less than 250 m and the pixels in stream channel were eliminated from the assigned landslide areas**.** It was found that the Landsat-5 images in 1993, 1994, 1999, 2002 and 2006 were covered with clouds and shadows. Then, the landslide pixels inside those clouds and shadows were eliminated by using a modified supervised classification technique as mention.

Then, combination of multiple grids on a cell-by-cell basis among the landslide grid and the Landsat-5 band 5 in 1990, 1993, 1994, 1996, 1999, 2002, 2006 and 2007 were done by the combine command under ArcGIS software. The data of DN between 90 and 245 were compared and calculated the DN change and the landslide recovery.

2.2.2 The Greenness Index development

The Greenness Index is the difference between (TM1, 2, 3 and 7) and (TM4, 5) Then, Greenness was calculated by equation:

$$\begin{aligned} Greenness = {} & (-0.2848TM1) + (-0.2435TM2) \\ & + (-0.5436TM3) + (-0.1800TM7) \\ & - (0.7243TM4 + 0.0840TM5) \end{aligned} \tag{1}$$

Where $TM1\text{-}7$ = Landsat TM-5 band1-7.

Then, the combine command under ArcGIS software was used to combine multiple grids on a cell-by-cell basis among the landslide grid. The Landslide scars from 2.2.1 were used as the mask grid. The Greenness from 1990, 1993, 1994, 1996, 1999, 2002, 2006 and 2007 were calculated and compared the Greenness change and the landslide recovery.

2.2.3 The NDVI development

The eight time-series data of Landsat TM-5 dated 1990, 1993, 1994, 1996, 1999, 2002, 2006, and 2007 were used to develop the NDVI in this study. Landsat TM-5 band 3 and 4 were used. The Indices were calculated by equation:

$$NDVI = (RIR-R) / (RIR+R) \tag{2}$$

where $NDVI$ = Normalized Difference Vegetation Index
R = the visible red band (TM band 3)
RIR = the near-infrared band (TM band 4).

Normalized Difference Vegetation Index (NDVI) was calculated for all images in the ERDAS Modeler using the algorithm: *(NIR-IR)/(NIR+IR)* for Landsat TM-5 bands 3 and 4 are used: (b4-b3)/(b4+b3).

As mention, the combination of multiple grids was done. The Landslide scars from 2.2.1 were used as the mask grid. The NDVI from 1990, 1993, 1994, 1996, 1999, 2002, 2006 and 2007 were calculated and compared the change of NDVI and the landslide recovery.

2.2.4 The change of Index and the landslide recovery

The change of DN, Greenness and NDVI in 1990, 1993, 1994, 1996, 1999, 2002, 2006 and 2007 were calculated. The records of 1990 indicated the landslide scars and were treated as the base of data change in 1993, 1994, 1996, 1999, 2002, 2006 and 2007. Firstly, *the base of data* was assigned as 100 percentages, indicating the maximum reflectance. When the natural recovery or the natural vegetation were gradually found, the reflectance were decreased. Secondly, *the change of data* was calculated as *Change was (100 – Y)/X*. *Change* was the change of Indices (%); *Y* was The data in 1993 to 2007; *X* was the data in 1990. Thirdly, *the landslide recovery* were calculated by 100 (%) minus Change (%). Finally, *the rate of landslide recovery* was calculated by dividing the landslide recovery by the number of years.

3. RESULTS AND DISCUSSIONS

3.1 Characteristic of landslide Scars

By GIS calculation, it was found that the areas of the study areas were approximately 93 km^2. The landslide scars or sample were 4,003 pixels or 3.6 km^2 (3.87%).

It was found that the Digital Number (DN) decreased (Table 1) from 158 (1990) to 104 (1993), 97 (1994), 79 (1996), 90 (1999), 101 (2002), 104 (2006), and 98 (2007), respectively. The NDVI increased (Table 1) from 0.2702 (1990) to 0.4901 (1993), 0.6271 (1994) 0.5632 (1996), 0.552 (1999), 0.4455

(2002), 0.6497 (2006), and 0.6085 (2007), respectively. The Greenness increased (Table 1) from -168.40 (1990) to -133.38 (1993), -130.98 (1994), -102.67 (1996), -118.28 (1999), -139.74 (2002), -137.59 (2006), and -116.68 (2007), respectively.

Year	DN	NDVI	Greenness
1990	158	0.2702	-168.40
1993	104	0.4901	-133.38
1994	97	0.6271	-130.98
1996	79	0.5632	-102.67
1999	90	0.5520	-118.28
2002	101	0.4455	-139.74
2006	104	0.6497	-137.59
2007	98	0.6085	-116.68

Table 1. The change of indices between 1990-2007

The results indicated that reflectance of the landslide areas decreased. It showed that the natural vegetation in the landslide areas has been increasing during the period 20 years. In addition, the results showed the variation of the healing of the areas during 1994 to 2002.

3.2 The recovery of landslide scars

Using DN as the index to estimate the percentage of recovery of landslide scars, it was found that the results showed the increasing of the recovery (Table 2, Figure 2) from 0 (1990) to 33.93 (1993), 38.33 (1994), 50.23 (1996), 43.26 (1999), 35.93 (2002), 33.94 (2006), and 38.12 (2007), respectively.

Year	DN	NDVI	Greenness
1990	0.00	0.00	0.00
1993	33.93	30.13	28.8
1994	38.33	48.90	22.33
1996	50.23	40.15	39.03
1999	43.26	38.61	29.76
2002	35.93	24.02	17.02
2006	33.94	52.00	18.30
2007	38.12	46.35	30.71

Table 2. The percentage of recovery of landslide scars based on the index

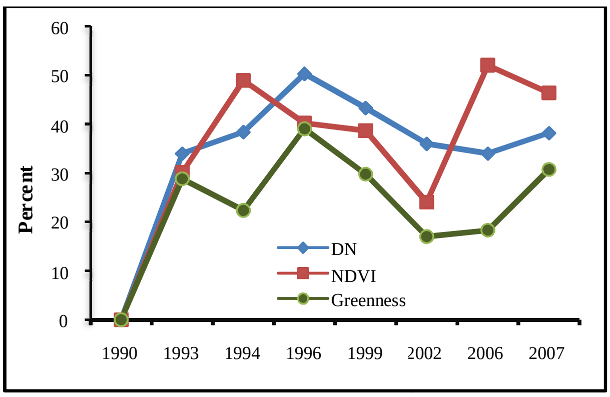

Figure 2. The landslide recovery using selected indices (%)

The percentage of recovery of landslide scars using NDVI showed the increasing recovery of the scars (Table 2, Figure 2). The landslide recovery increased from 0.00 (1990) to 30.13 (1993), 48.90 (1994), 40.15 (1996), 38.61 (1999), 24.02 (2002), 52.00 (2006), and 46.35 (2007), respectively. The percentage of recovery of landslide scars using Greenness showed the increasing trend of the scars (Table 2). The landslide recovery increased from 0 (1990) to 28.8 (1993), 22.33 (1994), 39.03 (1996), 29.76 (1999), 17.02 (2002), 18.30 (2006), and 30.71 (2007), respectively.

The results indicated that the landslide recovery increased. Those indices showed the same trend at the first stage of recovery but the later stage of recovery the indices showed the variation of recovery.

3.2 The rate of landslide recovery

It was found that the rate of landslide recovery decreased. The DN indicator changed (Table 3, Figure 3) from 11.31 (1993), 9.59 (1994), 8.37 (1996), 4.81 (1999), 2.99 (2002), 2.12 (2006), and 2.24 (2007), respectively. When using the NDVI as an indicator, the rate of landslide decreased from 10.04 (1993) to 12.23 (1994), 6.69 (1996), 4.29 (1999), 2.00 (2002), 3.25 (2006), and 2.73 (2007), respectively. In addition, the rate of landslide recovery from the Greenness showed the same trend as DN and NDVI indicators. The rate of recovery decreased from 6.93 (1993), 5.56 (1994), 6.51 (1996), 3.31 (1999), 1.42 (2002), 1.14 (2006), and 1.81 (2007), respectively.

Year	DN	NDVI	Greenness
1990	0.00	0.00	0.00
1993	11.31	10.04	6.93
1994	9.59	12.23	5.56
1996	8.37	6.69	6.51
1999	4.81	4.29	3.31
2002	2.99	2.00	1,42
2006	2.12	3.25	1.14
2007	2.24	2.73	1.81

Table 3. The recovery rate of selected parameter based on the selected index (percentage per year)

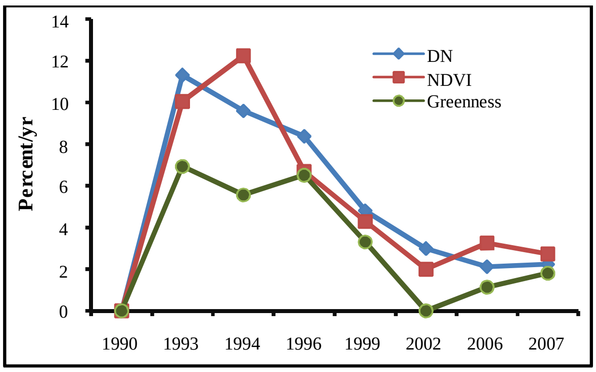

Figure 3. The landslide recovery rate

The results indicated that the rate of landslide recovery decreased by time. The indices to monitor the rate of landslide recovery showed the same trend.

4. CONCLUSIONS

This study could be concluded that firstly, the results showed that the natural vegetation in the landslide areas has been increased during the period 20 years. It showed that the natural recovery in the landslide areas started rapidly after 2-3 years. All of the indices show the same trend of natural recovery. Secondly, the quantities of land recovery were approximately 30-50%. Thirdly, the rate of landslide recovery was increasing at the first stage of recovering and then the rate was decelerating. It might be the ecological completion among type of vegetation.

REFERENCES

Bauer, M.E., L.L. Biehl, and B.F. Robinson. 1980. Final report volume I: Field research on the spectral properties of crop and soils. NASA. Rep. SR-PO-04022, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, IN.

Crist, E.P. 1983. The thematic mapper tasseled cap - a preliminary formulation. 9th Intl. Symp. On Machine of Remote Sensed Data Symposium, LARS, Produe University, West Lafayette, pp. 357-386.

Crist, E.P., and R.C. Cicone. 1984. Application of the Tasseled Cap concept to simulated Thematic Mapper data. Photogrammetric Engineering and Remote Sensing 50(3), pp. 343-352.

____. 1984. A physically-based transformation of thematic mapper data. IEEE Transaction on Geoscience and Remote Sensing 22(3), pp. 256-263.

____. 1984. Vegetation and soils information contained in transformated thematic mapper data. Proceeding of IGARSS' 86 Symposium pp. 1465-1470.

Department of Land Development, 1988. Land use planning in southern part. (In Thai) Ministry of Agriculture and Cooperative, Bangkok, Thailand.

ESRI, 1991. Cell-based modeling with GRID: Analysis, display and management. Environmental Systems Research Institute, Inc. CA. USA.

Geological Survey Department. 1985. Geological map: scale 1:250000 Changwat Nakhon Si Thammarat sheet. Department of Mineral Resources, Bangkok, Thailand.

Lauver, C.L., and J.L. Whistler. 1993. A Hierarchical classification of Landsat TM imagery to identify natural grassland areas and rare species habitat. Photogrammetric Engineering and Remote Sensing 59(5), pp. 627-634.

Pantanahiran, W. 1994. The use of Landsat Imagery and Digital Terrain Models to Assess and Predict Landslide Activity in Tropical Areas. Ph.D. diss. Univ. of Rhode Island, Rhode Island.

Pantanahiran, W. 2001. Thai-German Technical Cooperation Project Environmental Geology for Regional Planning Technical Report No.33: Assessment of Landslide Hazard and Landslide Risk in the Surat Thani Province. Dept. of Mineral Resources, Bangkok, Thailand.

Raines, G.L. and F.C. Canney. 1980. Vegetation and geology. p. 365-380. In B. Seigal and A.R. Gillespie (ed.) Remote sensing in geology. John Wiley & Sons. New York, NY.

Rouse, J.W., R.H. Haas, J.A. Schell, and Deering. 1974. Monitoring vegetation system in Great Plains with ERTS. Third ERTS Symposium, NASA Sp-351, A, pp. 309-318.

Saddle, R.C., A.J. Pearce and C.L. O'Loughlin. 1985. Water resources monographs series 11: Hill stability and land use. American Geophysical Union. Washington, D.C.

Shasko, M.J., and C.P. Keller. 1991. Assessing large scale slope stability and failure within a geographic information system. P. 267-275. In M. Heit and A. Shorteid (ed.) GIS application in natural resources. GIS World, Inc. Fort Collins, CO.

Stoner, E.R. and M.F. Baumgardner. 1980. Physicochemical, site, and bidirectional reflectance factor characteristics of uniformly moist soils. LAR Technical Report. 111679, Laboratory for Remote Sensing, Purdue University, West Lafayette, IN.

Tantiwanit, W. 1991. A study of landslide disaster in Kathun area, southern Thailand. (In Thai.) Geological survey division, Bangkok, Thailand.

Theradilok, P., C. Hinthong, and W. Tantiwanit. 1990. The Preliminary report of the geology in flooding area of the south. (In Thai.) Geological survey division, Bangkok, Thailand.

Townshend, J.R.G. 1984. Agricultural land-cover discrimination using thematic mapper spectral bands. International Journal of Remote Sensing 5(4), pp. 681-689.

Tucker, C.J. 1980. Remote sensing of leaf water content in the near infrared. Remote Sensing Environment (10), pp. 23-32.

Woodcocks, C.E., C.H. Sham, and B. Shaw. 1990. Comments on selecting a geographic information system for environmental management. Environmental Management 14(3), pp. 307-315.

Wold, R. L., and C. L. Jochim. 1989. Landslide loss Reduction: A guide for state and local government planning. Federal Emergency Management Agency.

Zinke, P. 1989. Forest Influence on the floods of 2531 and flood hazard mitigation. In: National Operation Center, National Economic and Social Development Board, and United State Agency for International Development. Safeguarding the future: Restoration and sustainable development in south of Thailand. Jiramedha Advertising and Printing, Bangkok, Thailand.

http://earthobservatory.nasa.gov/Library/MeasuringVegetation/measureing_vegetation_2.html (accessed 14 May. 2007)

http://svs.gsfc.nasa.gov/stories/drought/index. html (accessed 14 May. 2007)

ACKNOWLEDGEMENTS

This project was carried out using the grant from Thai government budget for fiscal year 2009. The author is grateful to the **GISTDA** for supporting data. The author also would like to extend appreciation to the Faculty of Social Science, Srinakharinwirot University for support and encouragement.