RELATIONSHIP BETWEEN LAND COVER AND WATER QUALITY IN TSENG-WEN RESERVOIR WATERSHED, TAIWAN

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Abstract:
The relationship between land cover and water quality such as suspended solid (SS) is explored in Tseng-Wen Reservoir watershed. Fine resolution satellite imagery offers the opportunities for land cover monitoring and assessment. The multiple satellite images are collected from 2001 to 2010 covering study area and land cover conditions are evaluated by Normalized Difference Vegetation Index (NDVI). Results show that the temporal SS data can be explained by variation of average NDVI value. The study provides information for assessing the influences of land cover on variation of water quality.

INTRODUCTION

The changes in land use and land cover interact with anthropogenic and natural driving factors to affect the water quality of watersheds. Studies have used environmental data to examine relationships between land use and land cover changes and suspended sediment (Allan et al., 1997; Bolstad and Swank, 1997; Johnson et al., 1997; Ahearn et al., 2005). Their results indicated that water quality was significantly related to vegetated coverage. How particular land covers influence water quality within a watershed is a traditional issue. A key question here involves the extent that land covers hierarchically affect water quality at space-time scales. The most widely used land cover index in this context is NDVI, the normalized difference vegetation index, which is a function of red and near-infrared spectral bands (Stefanov and Netzband, 2005). On a regional scale, multi-temporal NDVI images are commonly used for monitoring vegetation dynamics. It has been reported that multi-temporal NDVI is useful for classifying land cover and detecting the dynamics of vegetation (Legendre and Legendre, 1998; Senay and Elliott, 2001). The typhoons and earthquakes induced landslides cause the major change of NDVI in Taiwan (Lin et al, 2009; Chu et al., 2009).

The study identified and delineated the relationships between temporal variations of NDVI and water quality in the study area, Taiwan. For the representation of the land use and land cover change, the NDVI evaluation at multiple spatial scales was determined. In this study, the NDVI data were derived from SPOT satellite images in the Tseng-Wen Reservoir Watershed of Taiwan, before and after the Typhoon Morakot as well as before and after several large typhoons during 2001 – 2010 (i.e. Mindulle 2004, Haitang 2005, Sepat 2007, Kalmaegi 2008, Fanapi 2010).

STUDY AREA AND MATERIAL

Tseng-Wen Reservoir Watershed

The Tseng-Wen Reservoir is a multipurpose reservoir designed for flood control, hydroelectric power generation, irrigation, water supply, recreation and flow augmentation. The Tseng-Wen Reservoir Basin is located in the upstream area of the Tseng-Wen River system in Chiayi county (Figure 1). The entire watershed area of this river basin is 1,176 square kilometres, in which the Tseng-Wen Reservoir watershed covers 481 square kilometres. Average rainfall in this watershed area is close to 3,000 mm per year. The average slope of this river basin is about 1/57. Rich soils in the watershed have motivated a fast growth of the total number of fruit farms and tea farms in recent years.

Satellite images

Multi-temporal SPOT (Système Pour l'Observation de la Terre) satellite images, acquired after typhoons in 2001, 2003, 2004, 2005, 2007, 2008, 2009 and 2010, were used to quantify land cover change in the study area. The acquisition dates of the SPOT images are listed in Table 1. The atmospheric correction is achieved by FLAASH (http://www.exelisvis.com/portals/0/pdfs/envi/Flaash_Module.pdf).

Water quality data

Seasonal time series water quality data (from 2001 to 2010) of the reservoir were obtained from Taiwanese EPA websites (http://taqm.epa.gov.tw/taqm/zh-tw/default.aspx). The sampling sites are shown in Fig. 1. The following variables, such as nitrate-nitrogen (NO_3-N), suspended sediment (SS), chemical oxygen demand (COD), dissolved oxygen (DO), total phosphorus (TP), and Turbidity were selected for analysis.

METHOD

The SPOT images are classified using supervised classification by the software package ERDAS IMAGINE. Land-use types were classified into the following six categories: forested land, built-up land, landslide, grassland, water, and bare land. The reference maps were the aerial photographs by the Aerial Survey Office, Forestry Bureau, Taiwan.

Water samples are acquired after typhoons in fourth season and acquire annual value each year. We ran a series of statistical models to examine the correlations between land-cover and the water quality variables. Cases with missing data were excluded. Statistical analyses were done using SPSS 10.0.

Result and discussion

Temporal change of land use change

Fig. 2 shows that land use classification in 2001, 2004, 2007 and 2010. The forested land, grassland, build-up, bare land and landslide accounted for 77.61%, 11.72%, 2.55%, and 0.42% (excluding water) of the watershed's total area in 2001, respectively. During 2004 - 2007, forest has decreased 2.73%, grassland has increased 2.02%, bare land has increased 0.14 % and landslide has increased 0.57%. During 2007- 2010, forest has decreased 3.7%, grassland has increased 1.25%, bare land has increased 0.84 % and landslide has increased 1.58% (Fig. 3). Typhoon Moarkot caused dramatic increase of landslide and bare land during this period . Fig. 4 shows that the temporal change of landslide and bare land and the NDVI. From 2004 to 2010, the total area decreases with increasing NDVI.

Temporal change of NDVI and water quality

Table 1 demonstrates the statistics of NDVI images after each typhoon events during 2001–2010. Results demonstrate the lowest mean NDVI values occurred in 2009, after Typhoon Morakot, and the second lowest NDVI values occurred in 2010.The standard deviations of NDVI values were largest after typhoon Fanapi. Results match the previous study (Borghuis et al. (2007)) that showed many landslides in the Tseng-Wen reservoir watershed induced by typhoons. Land cover changes induced by disturbances are shown in multiple NDVI images (Chu et al., 2009).

Table 2 lists descriptive statistics of three-monthly measurement of SS data at three water quality monitoring sites in 2001–2010 (Fig. 5). The average concentrations of SS for sites 1, 2 and 3 are in the ranges of 0.8–13.5 [ppm], 1.1-12.6 [ppm], and 1.0-9.8 [ppm], respectively. The average SS values are 4.51, 4.85, and 4.52 [ppm] for these three sites. Fig. 5 shows that the SS concentrations are affected by typhoon visits as are coincident to the observation by Galewsky et al. (2006).

Relationship between SS concentration and land cover change

Table 3 shows the correlation coefficients between the averaged NDVI of the watershed and average water quality parameters for the whole year and for the fourth season, respectively. Result shows that the averaged NDVI is highly correlated to SS for the fourth season during 2001-2010. However, SS are impacted negatively by average NDVI in the watershed, suggesting that typhoon impacts land cover change in the watershed. For example, typhoons cause landslides and landslides product the sediments in the watershed. The average NDVI in the watershed, adversely impacting the water quality and therefore increasing sediments associated with water quality. The average NDVI in whole watershed becomes a key factor influencing the SS concentration. The typhoons events are major natural disturbances to NDVI change and cause serious landslides (Fig 2, 3 and 4).

CONCLUSIONS

This study has revealed that the NDVI data from 2001 to 2010 based on SPOT image data. The imagery reveals that the land cover changes in the study vary with the influences of typhoons and human activities. SS data showed a little rise in the acreage of vegetation cover implying increased landslide and decreased forest land on the vegetation resources. Land use and cover change had a significant influence on suspended solid loading. Understanding the relationship between land cover change and water quality provides a useful approach for watershed management. Further study could use regression model to represent the relationships between land use change and water quality in the watershed.

REFERENCES

Allan, J.D., Erickson, D.L., Fay, J., 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37 (1), 149–161.

Bolstad, P.V., Swank, W.T., 1997. Cumulative impacts of landuse on water quality in a southern Appalachian watershed. Journal of the American Water Resources Association 33 (3), 519–533.

Borghuis A.M., Chang, K., and Lee, H. Y. 2007 Comparison between automated and manual mapping of typhoon-triggered landslides from SPOT-5 imagery. International Journal of Remote Sensing: 28: 1843-1856.

Chu HJ, Lin YP, Huang YL, Wang YC.2009 Detecting the Land-Cover Changes Induced by Large-Physical Disturbances Using Landscape Metrics, Spatial Sampling, Simulation and Spatial Analysis. Sensors *9*, 6670-6700.

Galewsky J., Stark C. P., Dadson S., Wu, C. C, Sobel, A. H., Horng, M. J., 2006. Tropical cyclone triggering of sediment discharge in Taiwan, Journal of Geophysical Research*,* Earth Surface, 111, F3, F03014.

Johnson, L.B., Richards, C., Host, G.E., Arthur, J.W., 1997. Landscape influences on water chemistry in midwestern stream ecosystems. Freshwater Biology 37 (1), 193–208.

Legendre P, Legendre L. Numerical Ecology; Elsevier: Amsterdam, The Netherlands.

Lin YP, Chu HJ, Wang CL, Yu HH, Wang YC. Remote Sensing Data with the Conditional Latin Hypercube Sampling and Geostatistical Approach to Delineate Landscape Changes Induced by Large Chronological Physical Disturbances. Sensors 2009; *9*, 148-174.

Stefanov WL, Netzband M. Assessment of ASTER land cover and MODIS NDVI data at multiple scales for ecological characterization of an arid urban center. Remote Sens. Environ. 2005; *99*, 31–43.

Table 1 Mean and standard deviation of NDVI during 2001- 2010

Year	Date	Mean	Standard deviation
2001	2001/10/22	0.585	0.205
2003	2003/12/30	0.704	0.163
2004	2004/12/29	0.600	0.171
2005	2005/11/05	0.663	0.191
2007	2008/01/05	0.563	0.209
2008	2008/11/12	0.686	0.171
2009	2009/11/01	0.437	0.218
2010	2010/12/27	0.494	0.221

Table 2 Descriptive statistics of SS data in three water quality monitoring stations during 2001- 2010.

		Mean	Standard deviation	Q25	Q75	Min	Max
SS(ppm)	Site1	4.51	2.47	2.90	5.70	0.80	13.50
	Site2	4.85	2.61	3.10	6.05	1.10	12.60
	Site3	4.52	2.14	2.90	5.78	1.00	9.80

Table 3 Correlation coefficients of average NDVI and water quality for whole year and fourth season

	NO_3-N (ppm)	SS (ppm)	COD (ppm)	DO (ppm)	TP (ppm)	Turbidity (NTU)
Whole year	0.687	-0.577	0.277	-0.498	0.313	0.086
After typhoons (the forth season)	0.529	-0.621	0.604	-0.060	0.364	-0.384

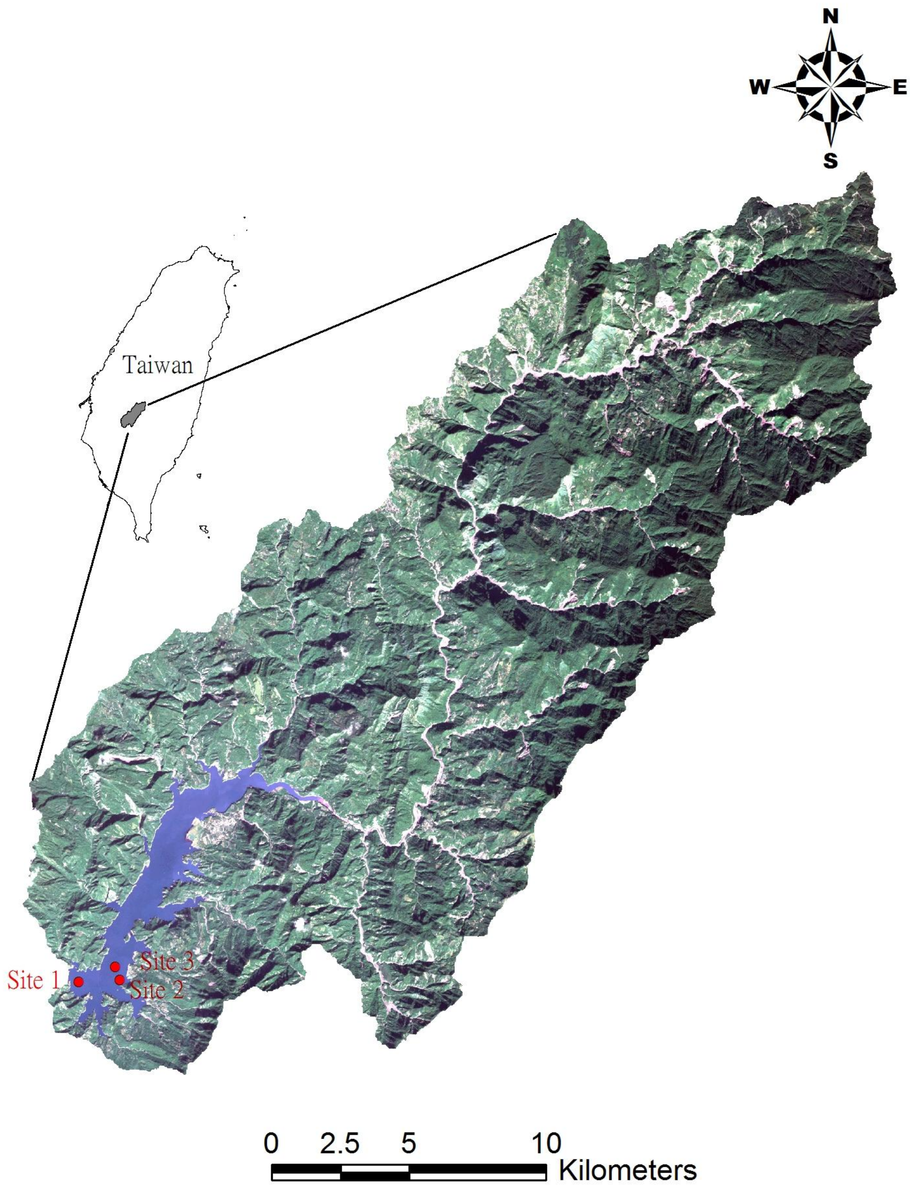

Figure 1 Location of Tseng-Wen Reservoir watershed and water quality sampling stations

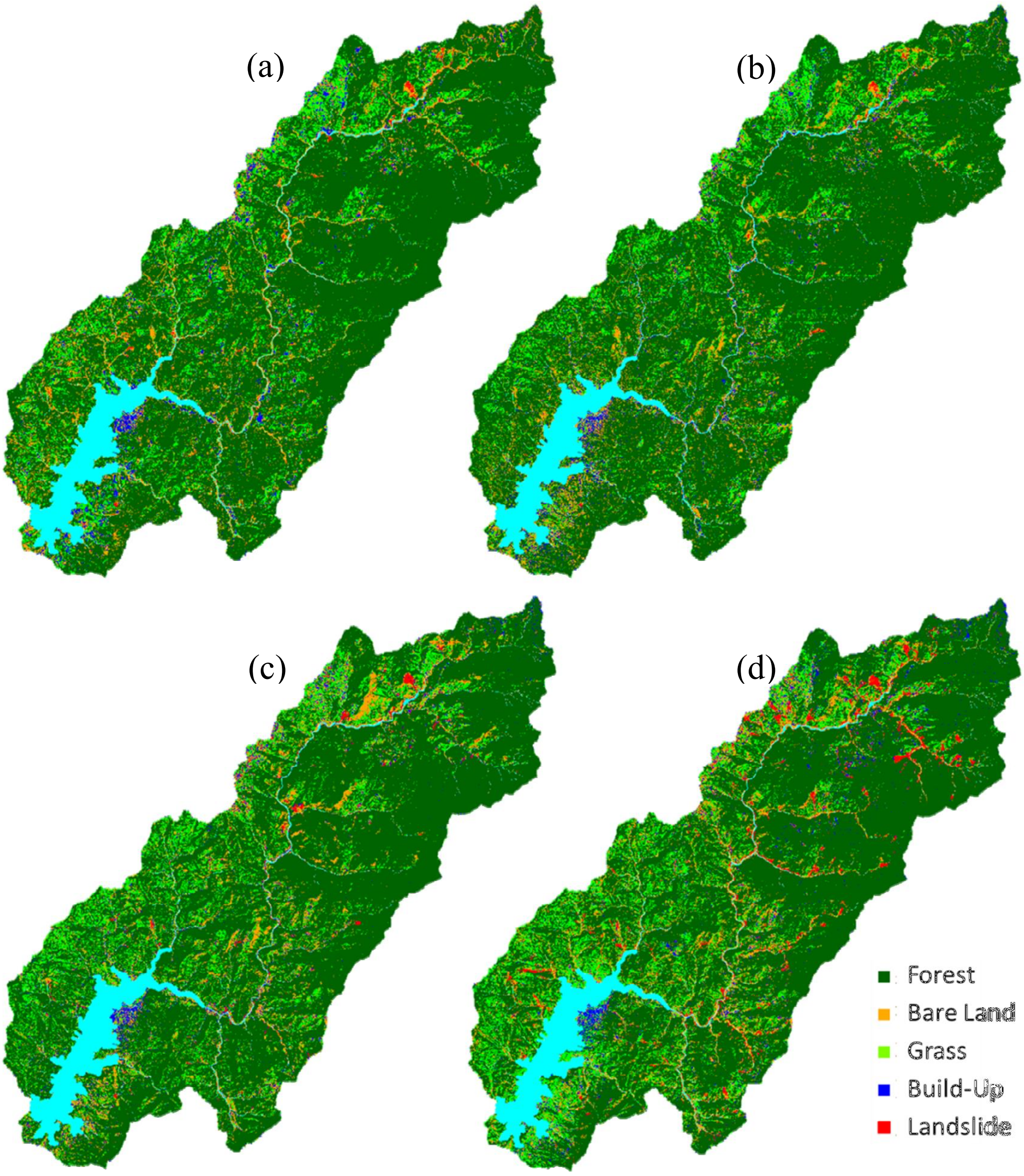

Figure 2 Land use classification in (a)2001, (b)2004, (c)2007 and (d)2010

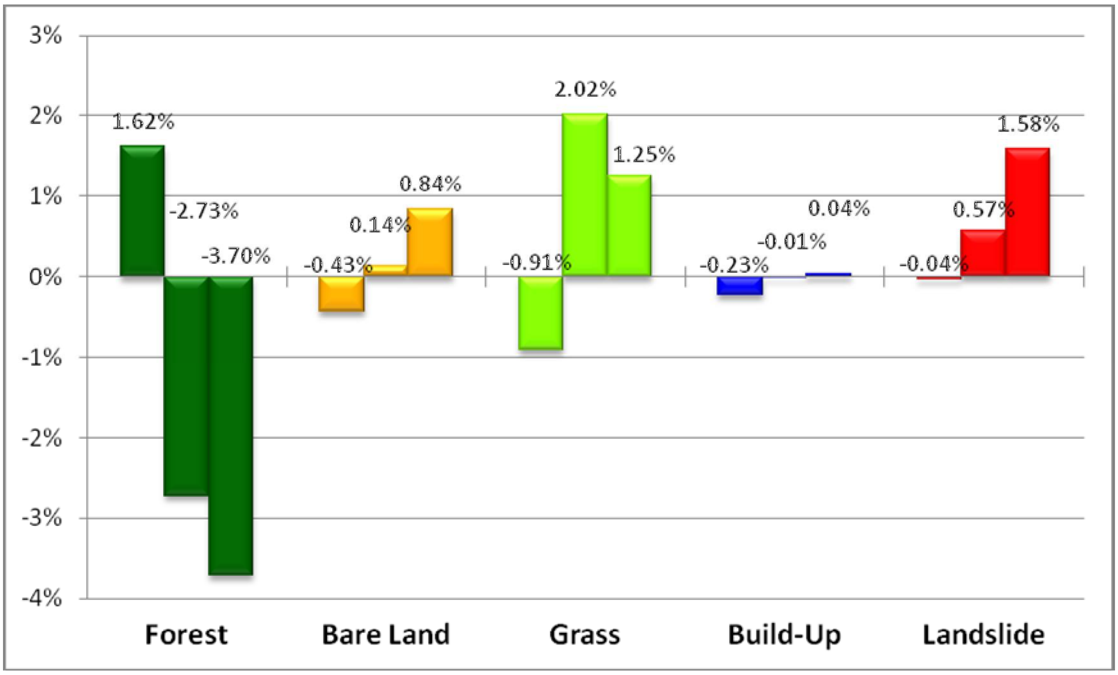

Figure 3 Percentage of land use change

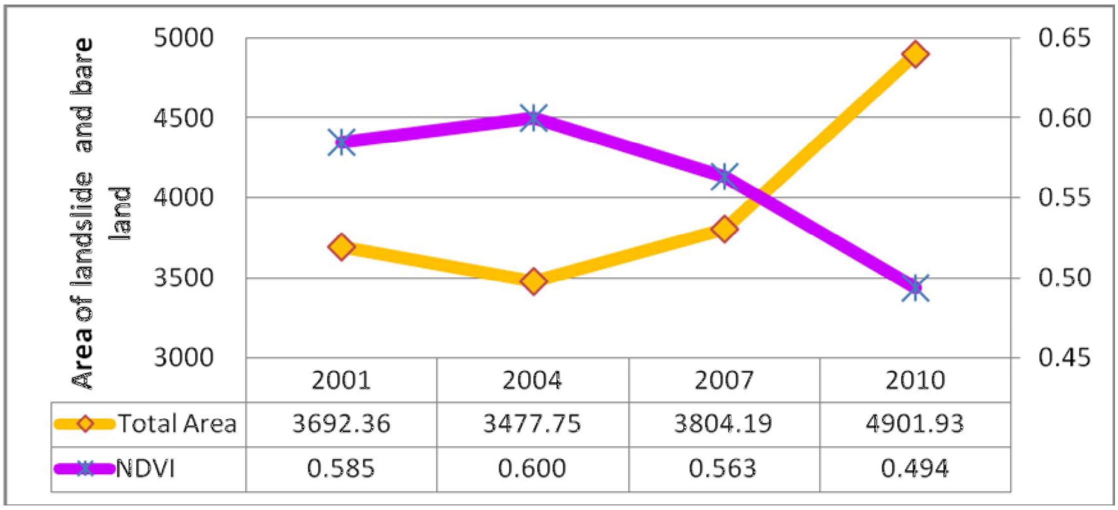

Figure 4 The temporal change of landslide and bare land area and the NDVI

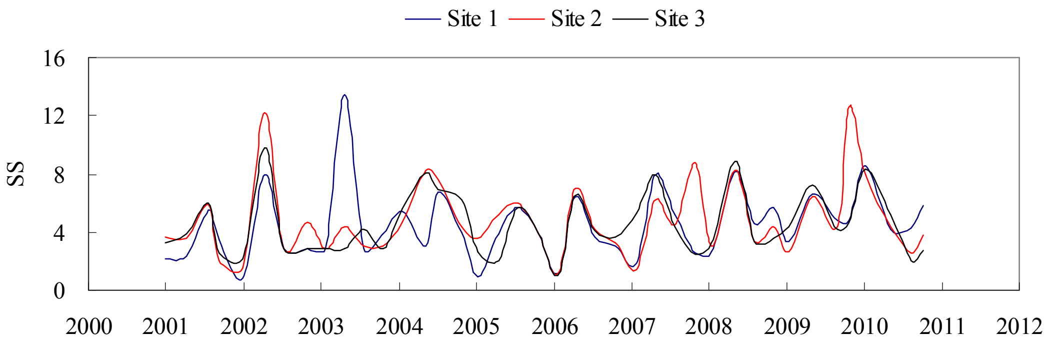

Figure 5 Temporal variation of SS during 2001 and 2010 (unit: ppm)