



Modeling land use change impacts on hydrology and the use of landscape metrics as tools for watershed management: The case of an ungauged catchment in the Philippines



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ABSTRACT

The impacts of land use/land cover (LULC) change and the relationship between landscape pattern and hydrologic processes in the ungauged Calumpang watershed, Batangas, Philippines were studied. LULC change from 2003 to 2008 included an increase in built-up areas (69%) and a reduction of mixed vegetation including riparian vegetation (–10%), which have significant effects on hydrology. Using the Soil and Water Assessment Tool (SWAT), significant increases in surface runoff (5%) and sediment yield (6%) and a reduction in baseflow (–11%) were shown. Spatial and temporal variations of the impacts were observed: degraded sub-basins experienced increased streamflow (up to 31%) during stormy months and reduced baseflow (up to –26%) during dry months. In contrast, improved sub-basins decreased stormflow (up to –4%), and increased baseflow (up to 5%) during dry months. Nine landscape metrics known to affect hydrology were quantified using Fragstats and were correlated with surface runoff, baseflow and sediment yield using partial least square (PLS) regression. The results indicated that increasing patch density and largest patch index of agricultural and forested landscapes, respectively, leads to a decrease in surface runoff and sediment yield while increasing baseflow. In contrast, increasing cohesion and aggregation index of agricultural and forested landscapes, respectively, results to an increase in surface runoff and sediment yield as baseflow decreases. Although more observed data is needed for validation, the relationship model produced in this study can be applied to new data or used for scenario analysis. When coupled with economic, social and political assessments, the model serves as a useful tool in formulating comprehensive watershed management and land use policies.

1. Introduction

The impacts of land use/land cover (LULC) change on hydrological processes within the watershed have been the subject of many researches worldwide in the past decades (Baker and Miller, 2013; Chen et al., 2009; DeFries and Eshleman, 2004; Niehoff et al., 2002; Price, 2011; Zimmermann et al., 2006). This is because LULC together with precipitation, soil, and topography are among the most important factors that affect the rainfall-runoff and erosion processes (Miller et al., 2002). Unlike modifying topographic characteristics using land management practices (e.g. terracing, contour tillage) where the effect is small scale, changes in the type and distribution of LULC causes variation of hydrologic response at the watershed scale through time (Miller et al., 2002).

In the past, many studies on land use change impacts on run-off

were done using catchment experiments, which often produced variable and sometimes contradicting results (Hundecha and Bárdossy, 2004). In addition, such experiments are costly and time-consuming. Advances in computer hardware and software combined with more extensive hydrologic data monitoring efforts mostly in advanced countries, have led to the development and application of various hydrologic models that use digital computers to simulate watershed behavior (Bedient et al., 2008). A major advantage of simulation models is the cost-effective generation of hydrologic data that can be readily analyzed. A major limitation however is the inability to calibrate and verify model parameters in applications where data are lacking, especially in ungauged watersheds common in developing countries, such as the Philippines.

Calumpang watershed is an example of such ungauged catchment, which needs hydrologic information for local planning and

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development. Primarily an agricultural area that saw rapid urbanization during the past years, the impacts of LULC change on the hydrologic services in the area need to be assessed. With the occurrence extreme weather events in recent years and the continuous degradation of the river water quality, generating hydrologic information using cost-efficient models has become more important than ever in the rehabilitation and management of the watershed.

While the use of hydrologic modeling is still limited in the Philippines, a number of studies have explored the relationship of LULC with hydrologic processes through the use of computer models. These include the use of Brook 90 to simulate Molawin Creek in Mt. Makiling (Combalicer and Im, 2012), HEC-HMS and HEC-RAS to assess vulnerability of Mabitac, Laguna to flooding (Pati et al., 2014); SWAT to evaluate runoff, soil erosion and sedimentation in Manupali (Alibuyog et al., 2009) and Layawan (Palao et al., 2013) watersheds in Mindanao; and SedNet conceptual water quality model to evaluate the Pagsanjan-Lumban watershed (Hernandez et al., 2012).

Despite the richness of literature, previous studies have focused mainly on the composition (percentage) of LULC and its effect on hydrologic processes. This is true for runoff and baseflow studies (Nobert, 2012), soil erosion and sediment yield studies (Feng et al., 2010; Nie et al., 2011; Pelacani et al., 2008; Phippen and Wohl, 2003), and also for monitoring other pollutants such as nitrate and phosphate (Boyer et al., 2002; Casali et al., 2010). From a landscape ecology perspective, spatial configuration or pattern of LULC plays a critical role in determining hydrological connectivity processes, temporal storage of runoff and sediment delivery (Shi et al., 2013). Recent studies have investigated the effects of landscape configuration on streamflow (Roberts, 2016) and have found significant correlation between sediment yield and several indices used to measure landscape pattern (Li and Zhou, 2015).

Multivariate regression techniques have commonly been used to determine the relationship between hydrologic processes and watershed characteristics including land use. However, landscape metrics derived from land use are highly collinear and are not independent predictors. Multicollinearity can result in redundancy and lack of independence can confuse correlative analyses and produce potentially misleading results (Shi et al., 2014; Fang et al., 2015). To overcome the inherent limitations of traditional multivariate approaches in handling multicollinear and noisy data, partial least squares (PLS) regression, a technique that combines features of principal component analysis and multiple linear regression, can be used (Woldet al., 2001; Shi et al., 2014).

This study aimed to establish the relationship between the landscape pattern and hydrologic processes by building a hydrological model of Calumpang watershed using available physical, meteorological and remotely sensed data. In particular, we: (1) determined temporal and spatial changes in the landscape pattern using remote sensing and GIS; (2) obtained a reliable estimate of run-off, baseflow and sediment yield using SWAT; and (3) established the relationship between chosen landscape metrics (i.e. area/density/edge, shape, diversity, connectivity) and run-off and sediment yield processes. Improved understanding of such relationship should assist the decision-making, planning and management processes in the watershed.

2. Study area

Calumpang river is a major watershed in the Batangas province that drains into Batangas Bay (Fig. 1). It has a catchment area of approximately 354 km² covering six municipalities (Ibaan, San Jose, Taysan, Rosario, Cuenca, Padre Garcia) and two cities (Lipa, Batangas). It is a 6th order drainage basin with a dendritic pattern. Altitude range from 0 m along the coast up to 867 m above sea level (msl) in parts of Mt. Makulot in Cuenca and Mt. Banoi in Batangas City. Slope ranges from 0 to 3% or flat (63%); 3–6% or rolling (27%); 6–15% or hilly (7%); 15–30% or steep (2%) and > 30% or very steep (1%). Based on the

World Reference Base for Soil Resources (WRB), the soil in the area are dominated by Cambisols (99%), while Gleysols (1%) are observed near the main outlet towards Batangas Bay (Carating et al., 2014). Agriculture is the principal land use type in the watershed. Major crops include sugarcane, rice, coconut and coffee (National Economic Development Authority, 2010).

Based on the Modified Coronas Classification System (Coronas, 1920; Kintanar, 1984), Calumpang has two types of climate: Type 2 for the north-western part which exhibits a dry season from November to April, while the rest of the year is wet; and Type 3 for the south-eastern part which, unlike Type 2, the two seasons are not very pronounced. Based on the nearest weather station of the Philippine Atmospheric Geophysical Astronomical Services Administration (PAGASA), average annual rainfall in the area from 1985 to 2015 is 1821 mm. This highly varies from year to year and is significantly lower than the national average of 2400 mm. The highest rainfall occurs in July and August while driest period is on February and March. Lowest mean daily temperature ranges from 22 °C to 26 °C during December to January, while the highest mean daily temperature occurs in May from 30 °C to 36 °C.

3. Materials and methods

3.1. LULC change detection using remote sensing

Satellite Pour l' Observation de la Terre (SPOT) 5 imagery with a resolution of 10 m and a panchromatic band resolution of 2.5 m were acquired from the National Mapping and Resources Information Authority (NAMRIA) for the years 2003 and 2008. ENVI classification software was used to extract the land cover from SPOT5. In particular, a supervised classification using maximum likelihood (ML) method, which is based on Bayes theorem, was used. ML makes use of a discriminant function to assign the pixel to the class with the highest likelihood of it being a member. Class mean vector and covariance matrix are key inputs to the function which can be estimated from the training pixels of a particular class. This means that training sites of known land cover in the area are identified to begin with and inputted into the software.

Prior to delineation of training sites, unsupervised classification using the Iterative Self-Organizing Data Analysis Technique (ISODATA), which is an algorithm that splits or merges classes based on user-defined thresholds (e.g. minimum number of pixels), was used to provide an idea on the kind of clustering present in the area. Analysis of histograms determined which clusters share the same characteristics and can be combined to produce a single class. As a result 5 classes were pre-determined namely: agriculture (AGRL), built-up (URBN), forest (FRST), mixed vegetation (MXDF), and water (WATR). MXDF are combination of forest trees, shrubs and grass such as bamboo. A total of 30 training sites for each class were delineated based on the researcher's knowledge on the area and Google Earth imagery. After running the supervised maximum likelihood classification tool, the produced classification was overlaid with the original image for visual validation. In cases of poor classification, the training sites and other parameters were adjusted until majority of the classification are satisfactorily done. The resulting classification was validated on the ground. A confusion matrix was employed to assess the accuracy of the classification. The matrix shows in rows and columns the number of sample units (e.g. pixels, polygons) that were correctly and incorrectly classified relative to actual classes verified on the ground.

3.2. Hydrologic modeling using SWAT

SWAT was developed to predict the effects of land management practices on water, sediment and agrochemical yields in large ungauged basins (Arnold et al., 1998). It is a physically based model that uses readily available information on weather, soil properties, topography,

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