SPATIAL ANALYSIS OF LAND COVER CONFIGURATION FOR SUSTAINABLE WATER QUALITY MANAGEMENT IN THE SILANG-SANTA ROSA RIVER BASIN, LAGUNA, PHILIPPINES

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ABSTRACT: How land use/cover changes, which result from and spatially reflect anthropogenic activities, affects water quality has been discussed directly or indirectly since the 1970s. Proper land cover configuration and water management can improve water quality in rivers and lakes and have been a high priority concern for land use planners, local residents, and land developers. However, the main priority of developing countries is, in many cases, economic development, which is often associated with disordered land cover configuration.

Recently, rapid urbanization and drastic changes in land cover have occurred in the Silang-Santa Rosa River basin, which is located south of Metro Manila, Philippines, where disordered land cover exists and residents are facing water quality deterioration. This river basin has experienced encroachment of urban land uses, which affects the residents' livelihood as well as water quality in the river.

The objective of this study was to determine feasible solutions for land use planners, residents, and developers, taking urban development trends, residents' livelihood, and land cover configuration in the Silang-Santa Rosa River basin into consideration. This study clarified the current land cover situation and characteristics of the changes in such spatially by using local indicators of spatial autocorrelation. In addition, the current situation was confirmed spatially through a field survey to help understand the estimated effects of land cover changes on water quality.

In conclusion, 1) fields of pineapple have increased extensively in number in the upstream sites of the river basin and have affected water quality; 2) the "Built-up" area has not increased in the downstream sites of the basin, as no significant spatial clusters were detected; and 3) new developments of residential areas called "gated communities" were observed distinctly in one characteristic cluster during the field survey, which carries a high risk of affecting water quality in the future.

1. INTRODUCTION

In recent years, studies of land cover changes have been conducted for many regions in numerous countries, and the main objectives of these studies were to understand the impacts of land cover changes on their corresponding regions, economic activities, and environmental circumstances, as well as to construct sustainable developmental strategies (Meneses et al., 2015). Some of these studies have focused on the quality of water resources in particular to understand the cause-effect relationship of these land cover changes on the reduction in water quality and their implications on hydrological processes (Erol and Randhir, 2013; Seeboonruang, 2012; Warburton et al., 2012; Zhang et al., 2014).

The existence of the relationship between land cover and water resources has been well confirmed and is broadly known in the academic fields that use such information (Gyawali et al., 2013). Land cover types in a certain area and the intensity of land cover type in that area influence water quality because surface water quality is highly correlated with inadequate anthropogenic practices such as swidden cultivation or the degradation of vegetation covers (Casalí et al., 2010; Smith *et al.*, 2013; Wang, 2001). On the other hand, waterbody distribution reflects these land cover changes, especially when a reduction in water quality resources is found, in many cases due to population growth, industrial expansion, and land management policies (Ahearn et al., 2005; Mouri et al., 2011; Valle Junior et al., 2015). The current land cover situation reflects several anthropogenic practices, such as agriculture, logging of natural vegetation, animal husbandry, residential development, transport infrastructure construction, etc., and the changes in them. Regarding this, population growth is an obvious major cause of the increasingly frequent conflicts over land cover, which are occurring globally (Saizen et al., 2006). In many regions, agricultural activities including animal husbandry, paddy fields, row crops, and particular cash crops occupy vast land areas (Seeboonruang, 2012). Whereas numerous aspects of land cover change can be found worldwide, the outskirts of mega cities are areas in particular for which land use planners, governments, and researchers are struggling to manage sustainably developed land cover, although many issues can be still found here and there. These areas are experiencing residential development in accordance with population growth. Flat lands are encroached by urban development. These areas were formed downstream in the watershed so that, in most situations, water quality in the entire watershed should be discussed when land cover problems are found.

In the Philippines, the regions surrounding Metro Manila have been facing issues related to land cover as well as water quality challenges. For the upstream sites in these regions, the risk is from soil degradation coupled with inefficient farm production systems that can cause low productivity in agriculture. For the downstream sites, households might face poverty-related issues such as food insecurity and low income by declines in the residents' livelihood in coastal and lakeshore areas. In addition, pollution from both upstream and downstream sites threatens the residents' livelihoods and increases the incidence of water-borne diseases (Rañola et al., 2014). Furthermore, services provided by these ecosystems are being threatened increasingly by land cover changes in watershed systems. There is still an urgent need to explore the linkage between land cover and water quality in watersheds in more detail (Erol and Randhir, 2013).

In this study, we focused on land cover changes in the basin located south of Metro Manila from 2010–2015. In this study, spatial distribution and its trends of spatial clusters of land cover were discussed and a method for sustainable development in the basin was suggested, based on the results of the spatial analysis conducted.

2. METHODOLOGY

2.1 Study area

In this study, the Silang-Santa Rosa River basin and some of the surrounding administrative regions were chosen as the study area (Figure 1). The Silang-Santa Rosa River empties into Laguna Lake, which is located southeast of Metro Manila, and land cover changes in the Laguna Lake basin consist of unique urban-rural features, created when the rural landscape was transformed into a busy center of anthropogenic activities in the 1980s. A continuous need to attract foreign investments, create more employment opportunities, and decongest the population in Metro Manila has been a driving factor in the landscape changes there, which has caused deterioration to the local environment (Engay-Gutierrez, 2015). The western sections of the lake region, which are in close proximity to Metro Manila, have been extensively industrialized, whereas areas in the southern and eastern sections are utilized primarily for agricultural purposes. Hence, rural-to-urban conversions are often found in the lakeshore municipalities adjacent to the lake's west coast.

The Silang-Santa Rosa River basin is located administratively in the municipalities of Biñan, Cabuyao, and Santa Rosa in the Laguna province and the municipalities of Silang and Tagaytay in the province of Cavite. One finds historical land use types in the midstream and downstream areas of the basin such as lowland rice, corn, sugarcane, orchard, legumes, plantation crops, root crops, tree perennials, upland rice, coconut, vegetables, and plantation crops (Engay-Gutierrez, 2015). The lowland areas of the basin used to be major suppliers of food to Metro Manila. In 1946, approximately 96% of Santa Rosa City's land area was utilized for agriculture, which was maintained until the late 1970s. From the 1940s to the late 1980s, agricultural lands in the basin were utilized for rice farming and other crops, such as vegetables, high value commercial crops, fruit crops, corn, and coconut, covering more than 5,000 ha previously designated as special agriculture and fisheries development zones by the government because of the large need for food supplies for Metro Manila (Engay-Gutierrez, 2015). Major changes, however, happened from the 1980s to the early 1990s, when the municipality started to shift from an

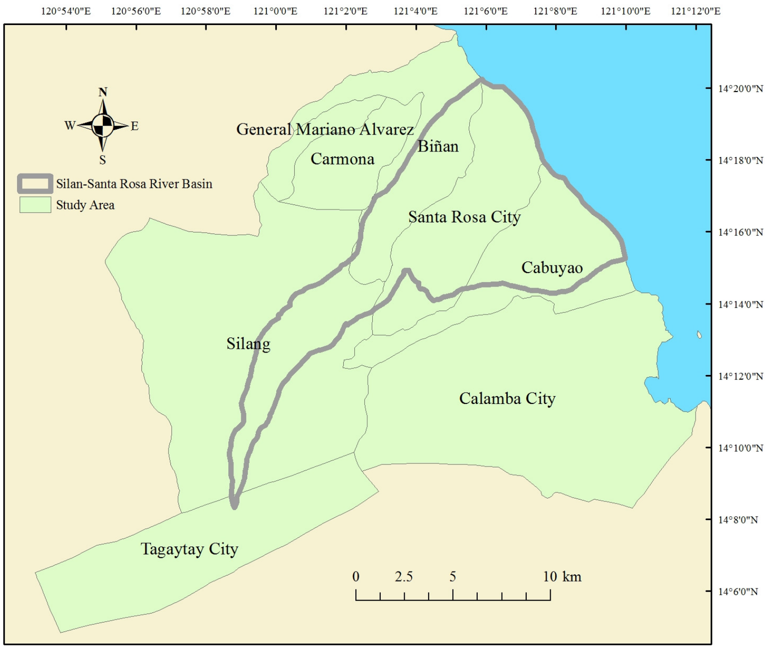


Figure 1. Map of the study area, with the Silang-Santa Rosa River basin boundary defined

agriculture-based to an industry-based economy, and accordingly small multinational companies were established in the area as the government provided incentives to companies relocating not less than 40 kilometers away from Manila. Thus, this area became popular for its industrial parks, manufacturing plants, and at present, housing developments (Engay-Gutierrez, 2015).

2.2 Spatial autocorrelation for detection of land cover distribution

This study employed a spatial autocorrelation analysis method to determine land cover configuration in the study area. The coincidence of value similarity and locational similarity is the definition of spatial autocorrelation (Premo, 2004); so that positive spatial autocorrelation occurs when high or low values of a random variable tend to be spatially clustered, whereas negative spatial autocorrelation occurs when areal units tend to be surrounded by neighbors with very dissimilar values (Saizen et al., 2010). Analyzing the geographical dimension of the spatial patterns of land cover should help us understand the characteristics of its distribution and transition and enable us to derive meaningful information for managing urban development as well as natural conservation in the study area. Hence, techniques of exploratory spatial data analysis were applied. These techniques serve to describe spatial distribution (clusters or dispersions) in terms of spatial association patterns such as global spatial association and local spatial association (Goovaerts and Jacquez, 2004). Moran's I statistic is a representative measure of global spatial autocorrelation (Anselin, 1988; Moran, 1948). Moran's I is useful as a global test that may suggest randomness or nonrandomness in the overall spatial pattern of land cover in the target years but does not indicate where clusters in a specific type of land cover are located or what type of spatial autocorrelation is occurring spatially. Therefore, the local indicators of spatial autocorrelation (LISA) were applied as indicators of local spatial association. The LISA, the so-called Local Moran Index, was developed based on Moran's I and was applied in multiple fields (Andresen, 2009; Hare and Barcus, 2007). These patterns are associated with a spatial weight matrix, where each unit is connected to a set of neighboring units. In other words, spatial connectivity is incorporated by means of a spatial weight matrix (Anselin, 1995). In this study, a matrix of one of contiguity of each barangay, which is an administrative minimum unit like a village, was used to model the relationships between spatial units. In this analysis, a Monte Carlo permutation approach was applied to verify the significance of the LISA. This permutation approach assumed that data are likely to be observed at any location equally. The observed values were shuffled randomly over all locations, and the LISA was recalculated for each permutation. Then, the significance of the LISA was determined by generating a reference distribution by using 999 random permutations. Finally, we created a LISA significance map by incorporating information about the significance of the local spatial patterns. Specifically, the LISA map shows the types of spatial relationships between a unit of place and its neighboring units, which allows us to visualize five types of local spatial associations between the observed units and their neighbors, each being located in a quadrant of the scatter plot. Thus, in the present analysis, each neighborhood was characterized by one of the following associations: (1) high-high (HH), indicating a clustering of a high target land cover density in a barangay (positive spatial autocorrelation); (2) high-low (HL), indicating that low values were adjacent to high values of land cover density in a barangay (negative association); (3) low-low (LL), indicating clustering of low values of land cover density in a barangay (positive association); (4) low-high (LH), indicating that high values were adjacent to low values of land cover density in an barangay (negative association); and (5) not significant (NS), indicating no spatial autocorrelation was detected by the LISA statistics.

The LISA was defined by Anselin (1995) and is determined using equation (1);

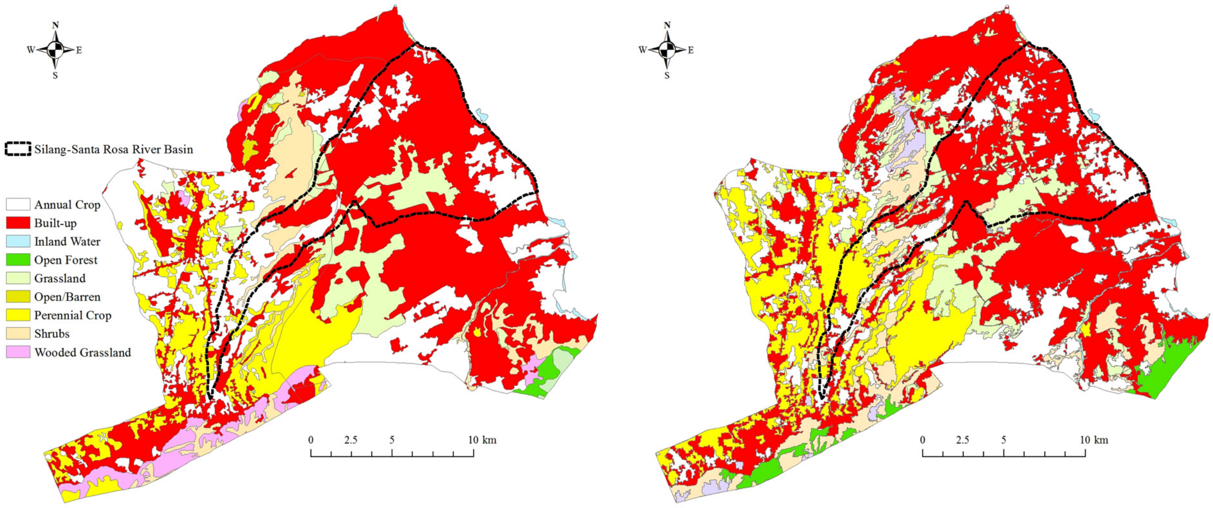
$$I_i = \frac{x_i - \bar{x}}{\sum_i^n (x_i - \bar{x})(x_i - \bar{x})^2} \sum_j^n w_{ij}(x_j - \bar{x}) \tag{1}$$

where *n* equals the number of observed barangays; w_{ij} denotes the weight between locations *i* and *j*; x_i and x_j are the values at locations i and j, respectively; and $\bar{x}$ is the average over all locations of the variables. The analyses were conducted using GeoDa (Anselin et al., 2006), a stand-alone software package that provides exploratory spatial data analysis techniques for areal data. GeoDa has been applied and proven to be an efficient method in multiple fields such as epidemiology, biology, geography, and so forth (Charreire and Combier, 2009; Goldberg and Waits, 2009; Lincaru et al., 2016; Scarborough et al., 2009).

3. RESULTS

3.1 Land cover distribution and changes in such in the study area

Land cover maps for the study area in 2010 and 2015, which were provided by the Environmental Remote Sensing and Geo-Information Laboratory, University of the Philippines, Los Baños, are shown in Figure 2. “Built-up” areas are distributed in particular over the northeast section of the area along Laguna Lake in both 2010 and 2015; however, the area did not seem to expand drastically during this period. In the southwest section of the area, “Perennial Crop” drastically increased and spread in accordance with the conversion of annual crop to perennial crop. The areas of each land cover type and the changes in such are listed in Table 1. The land cover type that increased the most was “Perennial Crop,” with an areal increase of 19.9 km^2, followed by “Shrubs” with an increase of 10.9 km^2. On the other hand, the land cover type that decreased the most was “Annual Crop” with a decrease in area of 22.7 km^2, followed by “Built-up,” which had a 13.1 km^2 decrease.



2010

2015

Figure 2. Map of land cover type distributions in 2010 and 2015.

Table 1. Areas of land cover type in 2010 and 2015 and the changes in such between 2010 and 2015.

Land cover type	Area in 2010 (km^2)	Area in 2015 (km^2)	Area of change (km^2)	Change rate (%)
Annual crop	121.5	98.9	-22.7	-18.6
Built-up	231.5	218.4	-13.1	-5.7
Inland water	2.1	2.3	0.2	8.7
Open forest	4.9	12.1	7.2	145.7
Grassland	39.1	47.5	8.4	21.4
Open/barren	1.2	0.0	-1.1	-98.7
Perennial crop	62.9	82.8	19.9	31.5
Shrubs	35.0	45.9	10.9	31.2
Wooded grassland	16.9	7.1	-9.8	-58.0

3.2 Spatial clusters of land cover

Considering the extensive changes in land cover types described in section 3.1, the LISA statistic was calculated for the “Built-up” and “Perennial Crop” changes between 2010 and 2015. The resulting LISA cluster maps are shown in Figures 3 and 4. In the study area, HH clusters were not observed within the Silang-Santa Rosa River basin whereas some HH clusters were found outside the basin. LL clusters were found in the “Built-up” dominated area in the basin. These results indicate that this area had been developed as a whole already and the development intensity was less compared to the surrounding areas. One barangay named Santo Domingo, which is located at the midstream sites, had an HL cluster; that is, this barangay was developed more than the surrounding areas were. In total, any extensive and discriminative features in the clusters were not detected by the results of the LISA statistics for the "Built-up" category.

For the changes in the LISA statistics for "Perennial Crop," significant HH cluster distribution was detected. HH clusters were distributed mainly in the western section of the study area and occupied the upstream sites of the river basin. Land cover changes for upstream sites often affect water quality in rivers, so it was necessary to identify the changes in detail through a field site visit. No clusters occurred along the lakeshore.

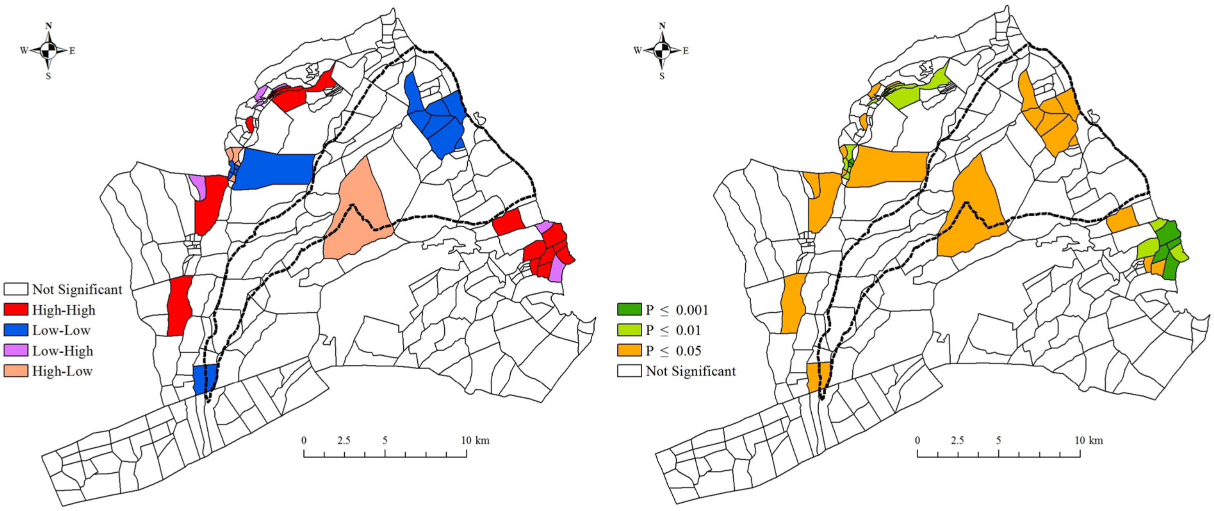


Figure 3. LISA cluster and p-value distribution maps for the changes in the "Built-up" land cover category from 2010 to 2015.

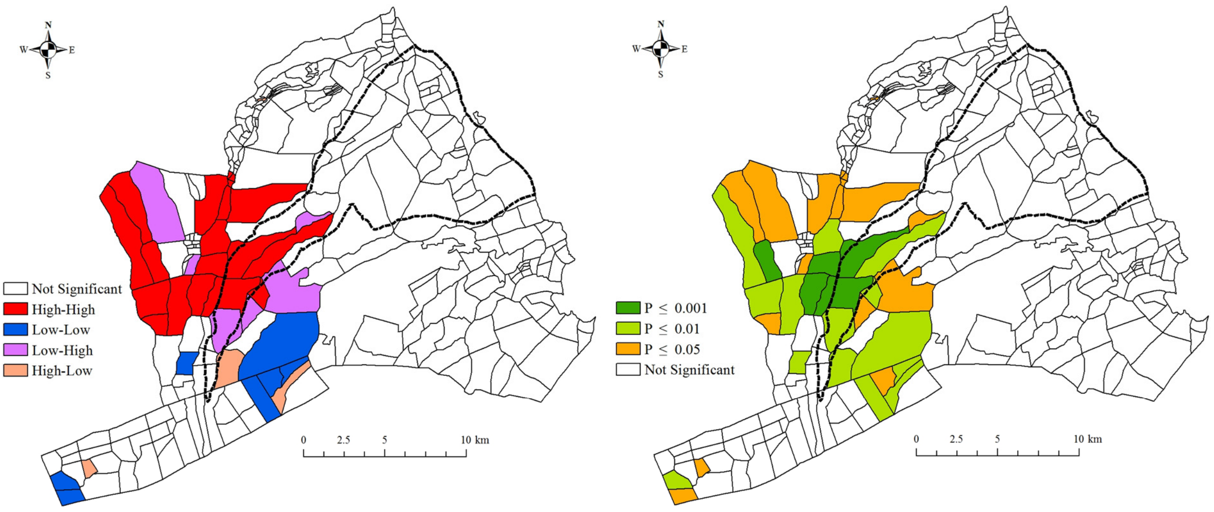


Figure 4. LISA cluster and p-value distribution maps for the changes in the "Perennial Crop" land cover type from 2010 to 2015.

3.3 Field survey in the areas where extensive clusters were detected in the basin

A field survey was conducted in the Silang-Santa Rosa River basin in July 2016. For the upstream sites, many areas were covered with pineapple fields (Figure 5). Household residents cultivate the pineapples, which is becoming an important means of earning income. Engay-Gutierrez (2015) conducted land cover change analysis for the Silang-Santa Rosa River subwatershed and found that the "Built-up" areas rapidly increased and the areas for perennials and corn decreased at the midstream and upstream sites between 1993 and 2008. The current study revealed that this trend has changed, with pineapple fields now expanding.

Figure 5. A typical pineapple field, which are dominating the upstream sites of the Silang-Santa Rosa River basin (Photo taken by Saizen in July 2016).

Figure 6. A typical, new residential development area called a "gated community" near the midstream sites of the Silang-Santa Rosa River basin (Photo taken by Saizen in July 2016).

For the midstream sites, many aggregated residential developments called “gated communities” were groundtruthed through the field survey (Figure 6). The area of one plot of gated community was not very wide; however, the gated community residents used local ground water and proper treatment of the residential sewage was not conducted. Thus, these community constructions affected water quality in this basin.

4. CONCLUSION

Annual crops, such as corn, wheat, rice, soy, etc., are normally recognized as less environmentally friendly compared to perennial crops, such as banana, olive, cacao, coffee, and pigeon pea, because perennials live for years once planted, producing many consecutive harvests and reducing the needs for soil tillage and practices which often cause soil erosion and chemical run-off. However, pineapple, although a perennial crop, has other aspects such as intensive production that make it less environmentally friendly.

Excessive pesticide use has had serious consequences for natural ecosystems, such that pesticide residues from pineapple plantations have been discussed globally and have been found in surface waters on several occasions, leading to fish kills (Echeverría-Sáenz et al., 2012) and water quality problems in or near conservation areas (Castillo et al., 2006). In Costa Rica, pineapple cultivated lands have expanded tremendously. The intensive production of pineapple involves the use of large quantities of fertilizers and pesticides. Furthermore, some pineapple fields, located near rivers and forests, do not keep safety vegetation margins, which makes agricultural impacts on ecosystems even greater (Echeverría-Sáenz et al., 2012).

The existence of environmental effects by consecutively cultivating pineapple is still a controversial issue and changes depending on the soil and climate situations, therefore this phenomenon in the study area should be monitored over time. If this cultivation causes water quality deterioration, a feasible solution should be determined, with the local government and residents participating as stakeholders.

Although specific clusters of “Built-up” changes were not detected, only one HL cluster was found in a barangay named Santo Domingo, in which commercial zones, industrial parks, and residential lots are situated (Engay-Gutierrez, 2015). Thus, the HL “Built-up” cluster was detected by the LISA statistics whereas no other distinctive clusters appeared. This result indicates that the LISA statistics evaluated and explored the features of the land cover changes appropriately in this study.

In conclusion, 1) pineapple, a perennial crop, increased extensively in the upstream sites of the river basin and affected water quality; 2) the “Built-up” area in the river basin did not increase in the downstream sites of the basin nor were significant spatial clusters of such detected; and 3) new developments of residential areas called “gated communities,” which have a high risk for affecting water quality in the future, were distinctly observed in one characteristic cluster during the field survey. Further studies should be conducted, such as an analysis of the relationships between land cover configuration and water quality spatially over the Silang-Santa Rosa River basin.

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