SPATIO-TEMPORAL WATER QUALITY CHANGES AS REFLECTIONS OF LAND COVER CHANGE IN LAGUNA DE BAY, PHILIPPINES

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ABSTRACT

Lake environments provide numerous ecosystems services that range from provisioning to regulating. In some cases, the number and variety of functions these environments serve also lead to conflicts between uses and users. Water quality monitoring provides a measure for understanding how a lake and its rivers are faring relative to both natural and anthropogenic activities within the watershed. Laguna de Bay in the Philippines is a lake of interest in this regard. It is a good example of a multi-use resource that continues to experience significant changes due to expansive urbanization, continued agricultural activities, aquaculture, power generation, rapid land use changes, and climate change, among others. Impacts from these activities are initially reflected in the watershed's rivers prior to being reflected in the lake environment itself. In the 2005 Millennium Ecosystem Assessment's Sub-Global Assessment of the Laguna de Bay and its environments, most of the rivers that drain into this basin were considered in very poor conditions, based on various physicochemical parameters. In fact, most of the major rivers in the basin were declared as "virtually dead." This study reviews the results of the sub-global assessment and compares them with more recent data for three of the lake's rivers: San Cristobal, San Juan, and the Molawin-Dampalit Rivers. Variations in basic parameters, such as dissolved oxygen (DO), pH, and temperature were analyzed from the years after the assessment report up to the present. Initial observations indicate that, despite measures put in place through legislation by the national government, key parameters indicate that the rivers have not improved at all, and that in some respects, the rivers' health levels have continued to decline. These figures are examined relative to how changes in land cover within the sub watersheds, have potentially influenced these observed continued environmental degradations.

Keywords: *Land Cover Change; River Water Quality; Spatial and Temporal Watershed Analysis; Spatial Analysis; Remote Sensing and GIS*

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INTRODUCTION

The land cover within a watershed greatly affects the quality of the water bodies within it [1-6]. Areas formerly covered by forests that have been converted to agricultural and/or built-up lands have significantly decreased infiltration capacities; thus, have experienced increased runoffs that, in turn, intensify the erosion of top soil [7] and the likelihood of flood occurrences. This surge in eroded materials significantly increase the turbidity and nutrient content of the receiving water bodies, sometimes leading to eutrophication [8, 9]. In the Philippines, one of such water bodies greatly affected by land cover changes is Laguna de Bay. This lake is located in southern Luzon and is adjacent to Metro Manila, the country's National Capital Region and the most highly urbanized region. Various anthropogenic activities and the rapid, poorly planned urban sprawl are often blamed for the lake's continuously deteriorating water quality too [10, 11]. A number of its tributaries are also considered as "virtually dead" [12].

This study looks into the water quality trends of three rivers that have been potentially affected by land use changes as deduced from historical Landsat satellite images. Recently, the use of remote sensing and satellite images have greatly improved the monitoring of land cover changes through various temporal spans [13, 14]. Furthermore, the development of GIS and other software that utilize built-in algorithms for determining spectral signatures (*e.g.*, ENVI and ERDAS) have made the technology of land cover classification more accessible to academics and professionals. These and various studies that correlate changes in land covers within a watershed and water quality [15-18] are the bases for this study.

The three rivers chosen for this study are San Cristobal, San Juan and Molawin-Dampalit. They represent three watersheds that drain into the south bay of the Laguna de Bay. These sites were chosen for the following reasons: (1) each of the three rivers originate in areas with various dominating land uses (San Cristobal watershed is characterized the presence of industrial plants and factories; San Juan watershed is mostly covered by residential/urban area; and Molawin-Dampalit watershed is characterized by a protected forest reserve with developing human settlements at its downstream); and, (2) most researches on the water quality of Laguna de Bay focus on the western and north-western portion of the lake, where NCR is located; hence, there is a dearth of studies on the southern portio

To assess the general state of the three rivers, three major physicochemical parameters were measured and analyzed in this study: (1) dissolved oxygen (DO); (2) pH levels; and (3) temperature. Dissolved oxygen (DO) is the concentration of oxygen dissolved in water, expressed as the milligram of oxygen in a liter of water, or as mg/L. It is useful in determining the degree of pollution of streams and lakes at any time; hence, it can be used in determining the purification capacities of bodies of waters receiving organic wastes, and can also be an indicator of amount of nutrients, for higher DO concentrations means a high plant activity [19].

PH is the acidity or alkalinity of the water. Natural waters range between pH 5.0 and pH 10.0 but seawater is near pH 8.3. The pH is interdependent with other water quality parameters, such as carbon dioxide, alkalinity, and hardness. It can be toxic in itself at a certain level, and also known to influence the toxicity as well of hydrogen sulfide, cyanides, heavy metals, and ammonia [20].

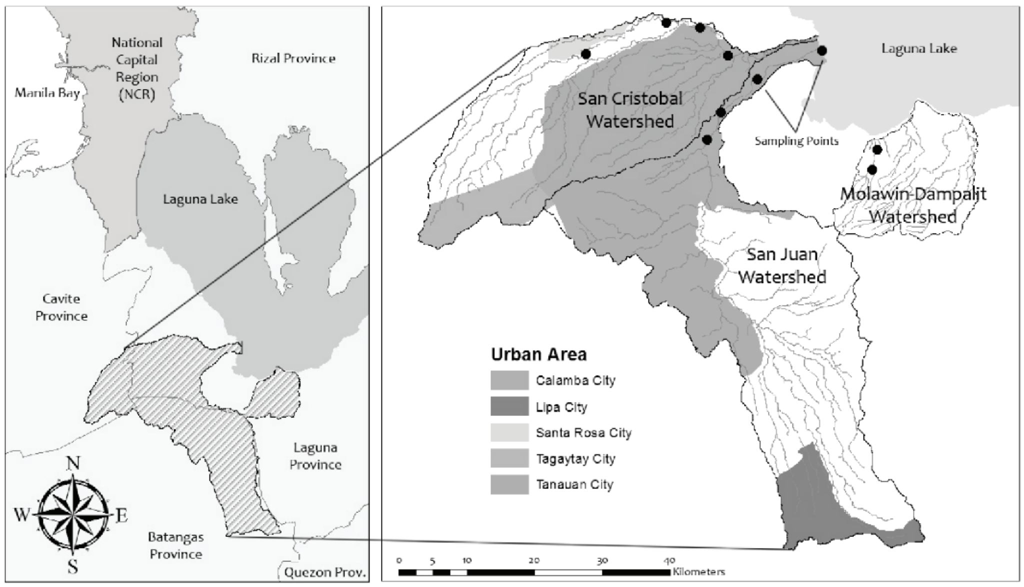
Temperature (T) refers to the amount of heat of the stream transferred by solar radiation, atmospheric radiation, and other cooling processes. In rivers and moving waters, many natural and human-made factors can affect the temperature. The increasing amount of shade within the area of the water decreases the maximum temperature of moving water [21]. Thermal pollution, which is the deteriorating effect of any process that affects the ambient temperature of the water, is one of the major anthropogenic alterations of river water temperature [22].

MATERIALS AND METHODS

Study Area

Three watersheds draining into Laguna de Bay were chosen for the study: San Cristobal Watershed (125.91 km^2), San Juan Watershed (195.4 km^2), and Molawin-Dampalit Watershed (51.66 km km^2) (Figure 1). These watersheds encompass three provinces (Laguna, Batangas, and Cavite) and include five cities (Tagaytay at the eastern part, Lipa at the southern part, Tanauan at the central-southern part, Calamba at the northeastern part, and Sta. Rosa at the north). The area is characterized by a tropical climate of Type I (pronounced wet and dry seasons) and Type III (not very pronounced wet and dry seasons) based on the classification by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA). Because of its proximity to the National Capital Region, as well as the presence of five rapidly expanding cities, urban sprawl has led to extensive land conversions of forested and agricultural lands. Various perennial and intermittent streams and rivers within the three watersheds mainly come from three elevated areas: Taal Highlands for San Cristobal Watershed; Malepunyo Mountain Ranges for San Juan Watershed; and Mount Makiling for San Juan ang Molawin-Dampalit Watersheds.

Figure 1. Location Map of the Study Areas and the Cities Within Them



Land Cover Classification

Two Level 1 – Tier 1 Landsat images (Path/Row: 116/50) with 30m resolution obtained from the USGS Landsat Archives were utilized in the study: (1) a Landsat 5 image dated September 13, 2006; and (2) a Landsat 8 image dated February 13, 2016. The images were pre-processed in ENVI 5.1 for supervised classification (radiometric calibration, dark subtraction, and loaded in Color-Infrared (CIR) band combination for a better view of vegetation). As the images downloaded are Level 1 – Tier 1 data, orthorectification was no longer applied. Maximum Likelihood Classification Algorithm was applied to the images using six (6) classifications: (1) Water; (2) Cropland or Agricultural Lands; (3) Built-up and Impervious Lands; (4) Forests; (5) Bare lands; and (6) Cloud Cover. The accuracy of the resulting map was determined by generating random points and verification was performed by going through Google Earth's historical images (dated within the same month and year).

The number of minimum points were computed by using the equation:

$$N = \frac{Z^2(p)(q)}{E^2}$$

where N is the minimum number of points, Z is equal to 2 (from the standard normal deviate of 1.96 for the 95% two-sided confidence level), p is the expected percent accuracy, q is 100 – p, and E is the allowable error. Using 80% as the desired accuracy and 10% as the allowable error, the minimum number of points needed to verify the classification was 64.

However, for a better view of the accuracy, the author decided to increase the sample points to 100. The overall and individual accuracies were determined using the individual accuracy matrix while Kappa Coefficient of Agreement was determined using the equation:

$$\widehat{K} = \frac{M\sum_{i=j=1}^{r} n_{ij} - \sum_{i=j=1}^{r} n_i n_j}{\sum_{i=j-1}^{r} n_i n_j}$$

where M is the total number of sample points, n_{ij} are the points correctly identified, and n_i & n_j are the total number of points within a class as determined by ENVI 5.1, and Google Earth respectively.

River Water Quality

Historical pH, temperature, and DO data were obtained from the Laguna Lake Development Authority (LLDA) for the years 2006, 2009, 2012, and 2015. Primary data were collected by using an in-situ multi-parameter meter at 11 sites and were averaged to represent the year 2016.

RESULTS AND DISCUSSION

Land Cover Classification

The results of the supervised land cover classification show considerable changes within the three watersheds in the last ten years. The San Juan and the San Cristobal watersheds demonstrate significant increases in the built-up areas (>10% increase) coupled by consistent decrease in their forest covers (>10% decrease). This can be attributed to the large numbers of human settlements and cities scattered around the two watersheds.

On the other hand, the Molawin-Dampalit Watershed, which has no city within it, underwent minor land cover changes (<5% change).

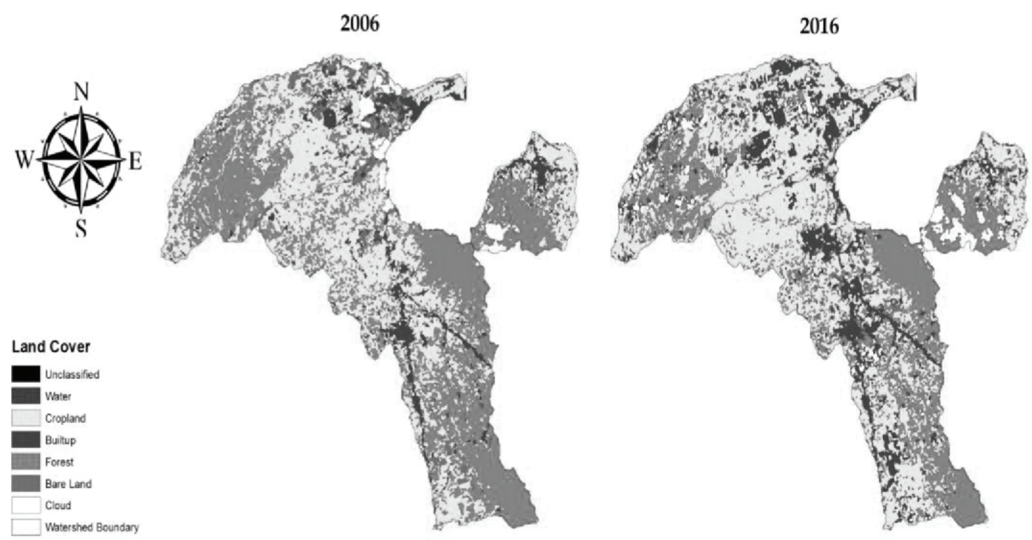
However, these numbers for the Molawin-Dampalit are being refined to consider potential misclassification due to the relatively high cloud cover of the 2016 image (16%) in contrast to that of 2006 (5%). Cloud covers for the San Juan and the San Cristobal watersheds are less than 5%.

Table 1. Land Cover Changes of San Cristobal, San Juan, and Molawin-Dampalit Watersheds within the years 2006-2016

Watershed	Year	Land Cover (%)				
		Cropland	Bare Land	Built-up	Forest	Water
Molawin-	2006	33.21	3.84	9.90	47.45	0.21

Dampalit	2016	29.27	1.41	9.98	42.32	0.14
	Difference	-3.95	-2.44	+0.08	-5.12	-0.06
San Juan	2006	41.08	3.30	7.92	46.46	0.06
	2016	47.04	3.83	15.10	32.92	0.08
	Difference	+5.96	+0.53	+7.18	-13.54	+0.02
San Cristobal	2006	43.09	8.98	6.33	38.00	0.00
	2016	50.40	1.91	20.22	23.62	0.00
	Difference	+7.31	-7.08	+13.89	-14.38	0.00

Figure 2: Land Cover Maps of the Study Areas for 2006 and 2016.



The resulting land cover classifications were found to have an overall accuracy of 81% and 76% for the years 2006 and 2016, respectively. The 2006 image falls above the desired accuracy of 80% while the 2016 image falls 4% below.

However, since land cover classifications rarely reach the 80% threshold, both the generated land cover maps can give a sound approximation of the actual land cover. Individual accuracies ranged from 71% to 100% with the exception of the 2016 bare land, which has an accuracy of only 50%. The computed kappa coefficient of agreement was 0.70 (2006) and 0.63 (2016) which means that there are 70% and 63% better agreement than by chance alone [23]. Due to its extremely low percent cover, there were no points generated that fall within the Water classification.

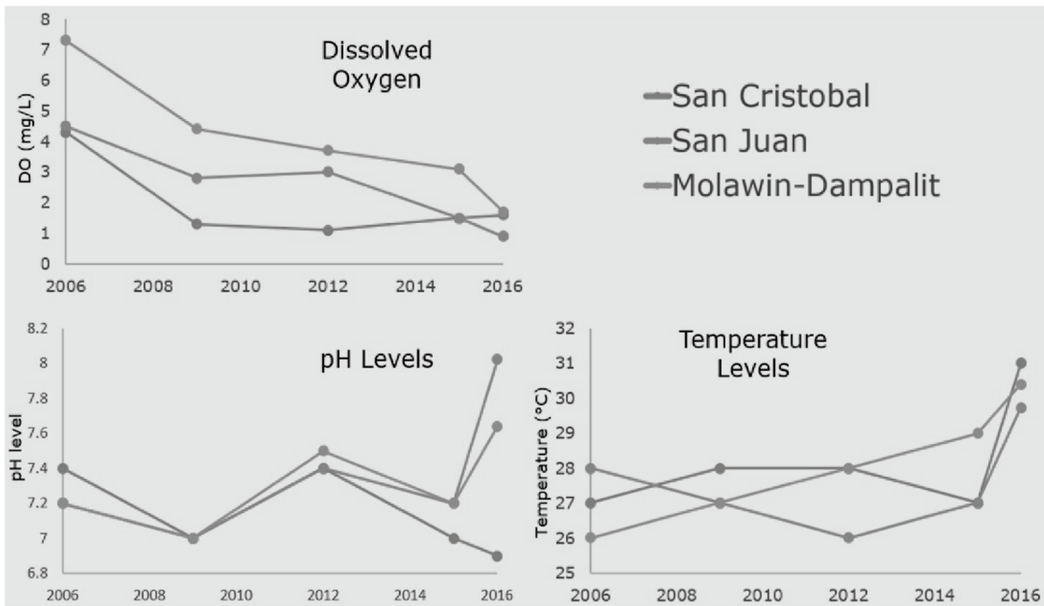
Table 2. Individual Accuracy Assessment Matrix of the Generated Land Cover Maps for the years 2006 and 2016.

		2006							
		Verified						Overall Accuracy	$\hat{K}$
		Crop	Built	Forest	Bare	Sum	Accuracy		
Classified	Crop	33	5	3	5	46	72%	81%	0.70
	Built	0	5	0	0	5	100%		
	Forest	3	1	40	2	46	87%		
	Bare	0	0	0	3	3	100%		
	Sum	36	11	43	10	100	90% mean		
		2016							
		Verified						Overall Accuracy	$\hat{K}$
		Crop	Built	Forest	Bare	Sum	Accuracy		
Classified	Crop	37	5	7	3	52	71%	76%	0.63
	Built	1	11	0	1	13	85%		
	Forest	3	2	27	1	33	82%		
	Bare	1	0	0	1	2	50%		
	Sum	42	18	34	6	100	72% mean		

River Water Quality

A total of eleven (11) sampling points were selected for water quality sampling (6 for San Cristobal, 4 for San Juan, and 2 for Molawin-Dampalit). The sites chosen are all located near the mouth of the river and/or within industrial/urban sites to glimpse a better view of the overall quality of the river systems that drain into the lake. All the values within a river were then averaged for comparison with historical data. Consistent general trends were observed on all watersheds for all the water quality parameters. Dissolved oxygen levels significantly decreased for all the watersheds (-63% for San Cristobal, -80% for San Juan, and -77% for Molawin-Dampalit). The measured values for all the rivers fell below the lowest classification standard of the country's water classification legislation, DAO 2016-08 [24]. In terms of pH levels, there were no strong patterns observed in the trends of the rivers. San Cristobal's pH levels decreased by 7% only; those of the San Juan and the Molawin-Dampalit increased by a small percentage (11% and 6%, respectively). Moreover, the time series graph of pH levels indicates fluctuating values within the years; this denotes that the small changes are attributed to the variations of many other factors affecting pH, such as carbon dioxide levels, agricultural runoff, and waste discharge, among others [25]. All pH levels fall within the acceptable range of 6.5 to 8.5, in accordance with DAO 2016-08. In contrast, considerable increases were observed in temperature levels of the three rivers within a decade (15% for San Cristobal, 6% for San Juan, and 17% for Molawin-Dampalit).

Figure 3. Trends of DO, pH, and temperature levels within the study areas from 2006 to 2016.



Relationship between Land Cover and Water Quality

The results of the study show significant changes in the DO and temperature levels through the analyzed time intervals. There are also significant changes in the sizes of areas covered by built-up developments and by forests for two of the three watersheds. Dissolved oxygen levels in these rivers decreased significantly (63% to 80% decrease) and can be potentially linked to the increase in impervious surfaces (7.18% for San Juan and 13.89% for San Cristobal) and the conversion of forested areas (-13.54% for San Juan and -14.38% for San Cristobal) [26]. Such land conversions increase runoff, which lead to more materials being eroded into the rivers that can decrease their ability to hold oxygen [26]. For Molawin-Dampalit, there is only a small increase in built-up areas (0.08%) but a considerable decrease in forested areas (-5.12%). However, this might be attributed to the thick cloud cover within the forested area, which renders the lack of spectral data reflected by the land cover. In terms of temperature levels, it is recognized that numerous factors may have contributed to this considerable difference, and may include changing climatic conditions. However, it is also likely that the increases in temperature may be a reflection of the increase in the coverage of impervious surfaces. Surface waters that run across impervious surface usually absorb considerable amounts of heat which it transfers to the water bodies that they drain into, thus elevating the temperature [22]. Moreover, industrial effluents which usually have higher temperature, increase the temperature of the water [22]. The removal of trees and tall vegetation within riparian areas exposes previously shaded water to direct sunlight, thus increasing its temperature [21]. There were no significant patterns and/or changes that can be surmised from this study to prove the relationship between land cover change and pH levels.

CONCLUSIONS

Changes in the land cover of three watersheds were assessed using satellite images from 2006 to 2016 and were analyzed vis-à-vis the trends in three water quality parameters within the same time period. Results show a consistent increase in built-up areas that result from the continuous conversion of forested areas in all the watersheds investigated, albeit at different rates. Analyses of the trends in water quality also show a continued deterioration of the rivers in terms of DO and temperature levels. Considering what little is available in terms of historical water quality information on the lake and its rivers, it is recommended that water quality parameters for monitoring be expanded and that base lining work be done without further delay. Additionally, the relationship between water quality and land cover changes be quantified in order to statistically prove the association of the two set of measurements.

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