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Forecasting Urban Expansion in the Seven Lakes Area in San Pablo City, Laguna, Philippines Using the Land Transformation Model

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Abstract

Managing urban growth is essential to the conservation of the Seven Lakes ecosystem in San Pablo City, Laguna province in the Philippines. This study simulates potential conversion of agricultural lands to built-up areas using the Land Transformation Model (LTM), which integrates Geographical Information Systems (GIS) and an Artificial Neural Network (ANN). Historical drivers of the expansion of built-up areas are identified and validated through the application of LTM to land cover maps from 1988 to 2015. Identified drivers include distance to roads, distance to trails, distance to the seven lakes, distance to existing built-up areas, slopes, and population density per barangay. Results from the percent correct matrix (PCM) were 79.88% for the 1988-2003 runs and 66.42% for the 2003-2015 runs while the Kappa statistic for both time periods was higher than 0.60, which indicates high levels of agreement. Forecasted scenarios were business-as-usual growth, doubled growth, and, strict law implementation protecting the vicinity around the seven lakes and other natural areas. In the business-as-usual scenario, urban expansion spread out along the road networks. The doubled growth scenario showed that further expansion will likely extend around the proximity of the lakes, which may adversely affect the livelihoods of the local fishing communities. As such, it was recommended that preventive measures, such as strict implementation of buffer zones coupled with regular monitoring, be taken to manage land use in the surrounding lake areas.

Key Words: Land Transformation Model, Land use and land cover change (LULCC), urbanization, GIS, neural network, San Pablo City

Introduction

Land use and land cover change (LULCC) has become a global issue with long-term impacts on the environment (Foley et al. 2005). This is most especially true with urbanization since established infrastructure is more costly to revert back to a natural state than an agricultural area. Rapid, unplanned urbanization can be especially problematic since it can lead to wildlife fragmentation, energy inefficiency, loss of farmland and increased temperatures among others (Bhatta, 2010). Cities themselves also tend to have adverse effects on the environment. For example, cities consume high amounts of energy and have high emissions and waste outputs making them dependent on external sources (Odum & Odum, 1980; Pickket et al.,1997 cited in Chen, Chen & Fath, 2014). Due to the difference of properties of soil and cement, urban areas tend to have higher radiation surface, increasing the ambient temperatures (Cengiz, 2013) and allow little percolation of rainwater to refill aquifers. Hence, understanding the trends of LULCC becomes more important for supported decision-making for urban planning.

In the Philippines, there have been pressures to urbanize, most especially during the 1900s and 1940s when real estate sales and construction activity were at their peak (Magno-Ballesteros, 2000). At present, The Philippines has a high urban growth rate of 3.75% and was already at 62.7% urbanized according to the National Urban Development and Housing Framework (NUDHF) (Housing and Development Coordinating Council (HUDCC), 2008-2010). A study (Liu, Iverson & Brown, 1993) compared land use maps of the country from 1934 and from 1988, and found that almost 78% of 21,000 km^2 of forests were lost within that time span. In the provinces of Cavite and Laguna, an estimate of 214 km^2 of agricultural land was lost to urban expansion from 1986 to 1994 (Cardenas, n.d.). Urban expansion into agricultural areas is an issue notably in the CALABARZON region, which consists of the provinces Cavite, Laguna, Batangas, Rizal and Quezon (NUDHF, 2008-2010).

This study focuses on the Seven Lakes area of San Pablo City in the province of Laguna, Philippines. The site is important for tourism, agriculture and aquaculture purposes, and has been undergoing urban expansion. The extent of LULCC can be affected by several factors, which vary depending on the bio-physical characteristics of an area, socio-economic and political trends, factors of accessibility and more. These are known as "drivers" of

LULCC. The factors which drive LULCC can vary from factors contributing to accessibility, such as proximity to an existing road network (Singh, 2003; Pijanowski, Long, Gage & Cooper, 1997), pressure to urbanize given proximity to an already built-up area (Pijanowski et al., 1997), as well as high-density areas (Pijanowski et al., 1997). Socio-economic opportunity also is a driver of land use change (Mulatu, 2014), which can be manifested from resource extraction from the lake areas, especially since aquaculture and fishing activities were observed.

The impact of potential LULCC drivers can be investigated using the Land Transformation Model (LTM). The LTM, which was developed by Pijanowski et. al (1997), is a tool that can be used to predict areas that are likely to undergo LULCC based on historical changes by combining geographical information systems (GIS) and artificial neural networks (ANN). GIS enables the model to conduct spatial analysis, and process the potential drivers of change for input into the ANN. The ANN, on the other hand, is used to read the historical patterns of change vis-à-vis the input drivers to train the neural networks to determine each input's 'weight' or influence on the land use change, and then generate a forecast of future areas of change while also checking the predictive capability of the model (Pijanowski, Brown, Shellito and Manik 2002). The advantages of ANN are that it is both tolerant of errors in data, which is often found in satellite imagery and, capable of finding non-linear solutions to fit input and output data (Skapura, 2996; Swingler, 1996 in Pijanowski, Hyndman & Shellito, 2001). The LTM is capable of integrating socio-economic, political, and environmental factors as its driver variables by 'learning' how each of these influenced previous land use conversions. The model had been previously applied in a number of studies such as those assessing agricultural expansion driven by demand for biofuels (Li, et al. 2012), urbanization surrounding a watershed (Oyebode 2007) and loss of high-quality farmland to urbanization (Song et al. 2015). Other studies have integrated the LTM with other models such as the L-THIA, in order to assess environmental impacts (Tang et al. 2005) and the SPARROW P fate and water transport watershed model to predict phosphorus loads (La Beau et al. 2014).

The study uses the LTM to investigate historical patterns and drivers of urbanization in order to forecast possible expansion of built-up areas. Given the potential environmental impacts of urbanization, policies need to be implemented to guide urban planners and developers on where and to what extent they can build an infrastructure without compromising the benefits gained from ecological services from the surrounding ecosystem. In the case of

San Pablo City, the quality of the ecosystem services provided by the lakes may become degraded by stressors from extensive urbanization. For example, the lakes in San Pablo City are used as fisheries but the lakes can undergo much stress and become less habitable for fish if there were further infrastructure development around the lakes without establishing proper waste management systems. In short, given the current rapid trend of urbanization, the natural state of the lake ecosystems may be threatened. Thus, the questions that this study aims to answer are the following: What is the extent of historical urban expansion in San Pablo City? What are the main drivers that are causing these changes? Where are these changes most likely to occur, given those drivers, and what are the potential implications for the surrounding ecosystem, particularly the seven lakes? The study identifies historical drivers of urban expansion through the application of the LTM, then uses the validated drivers to forecast areas prone to conversion to built-up land in the future. Potential implications on the seven lakes are discussed.

The Seven Lakes area of San Pablo, Laguna

The province of Laguna is home to approximately 2.7 million people (National Statistics Office [NSO], 2013). Located in the southernmost portion of Laguna, San Pablo City is 82 km away from Metro Manila. It covers an area of 197.56 km^2 and is roughly 1500 m above mean sea level. Roughly 9.2 % of Laguna's population resides in San Pablo City (National Statistics Office [NSO], 2013). Over the years, San Pablo City has developed economically and is mainly an urban-agricultural community. As a tourist destination, San Pablo City is one of the oldest cities in Luzon. It is most commonly known for its reputation as the "City of Seven Lakes". These seven lakes are Mojicap, Palakpakin, Yembo, Pandan, Calibato, Bunot and Sampaloc (DILG, n.d.).

Given that the seven lakes are central to San Pablo City's identity, the city's zoning ordinances were made to regulate city growth but also promote overall wellness among the inhabitants. In terms of implementation, City Ordinance No. 2012-40 states that violators of the Comprehensive Land Use Plan (CLUP) Zoning Ordinances can be fined starting from Php 500 at a minimum, for minor violations, to up to PhP 5,000 at maximum. Infrastructures and activities that do not conform with the zoning ordinances must be relocated as well. The Zoning Ordinance of San Pablo City also follows regulations of the Department of Environment and Natural Resources [DENR] and does not allow developments, such as residential, commercial or industrial, in forest areas unless a permit from the DENR is secured. A section in San Pablo City's Zoning Ordinance requires that there be an easement away from the lakes depending on the land use. In the case of an urban land use, the easement away from the lake is 30 m while it is 20 m for agricultural land and 40 m for natural areas. The five lakes north-east of the City center, namely, lakes Palakpakin, Mohicap, Yambo, Pandin and Kalibato, as well as the barangay areas adjacent to them, which are barangays San Buenaventura, Sta. Catalina, San Lorenzo and Sto. Angel, are classified as part of the Tourism Circuit/ Eco- Tourism Zone. The lake areas within the Tourism Circuit/ Eco-Tourism Zone are supposed to have an easement of approximately 100 m, which is reserved for parks, recreation and nature activities, such as tree planting and recognition of the lake ecosystem.

San Pablo City's seven lakes are mainly used for fisheries and as venues for tourism. It was observed from site visits, that Lakes Mojicap, Yambo and Kalibato offer recreational activities for tourists while Lakes Palakpakin and Sampaloc have several aquaculture set-ups. Lakes have additional ecological value by providing ecosystem services, such as providing habitat for fishes, both wild and farmed. As a water resource, lakes can serve as a back-up source of drinking water, given that the water is treated and disinfected from harmful pollutants and bacteria such as E. coli. Finally, lakes have recreational and cultural value (Bolund & Hunhammar, 1999), which can contribute to tourism and contentedness of the residents. These benefits and functions that freshwater systems and watersheds offer can be lost if the ecosystem is under too much stress. Among the seven lakes, this applies most heavily on San Pablo's largest crater lake, Lake Sampaloc which is surrounded by built-up spaces and housing areas. In the past years, the lake has been used for drinking and domestic uses (Roque, 2005) and, along with the other lakes, may undergo more stress as the development within its vicinity increases.

The scope of this study extends to the north-eastern portion of San Pablo City which includes the immediate surroundings of the seven lakes. As can be seen in Figures 1 to 3, built up areas have been steadily increasing from 1988 to 2010, as can be seen by the land cover maps of 1988, 2003 and 2010. The 2010 map was updated to 2015 via ground-truthing and the use of an aerial image[1] covering the area of Lake Mohicap and Lake Palakpakin. Ground-truthing involved traversing the site to verify land cover in certain areas, such as around the seven lakes, while recording the location with a Global Positioning System (GPS). Six (6) visits were made to San Pablo City to gather more than 300 points. The aerial imagery acquired through the use of unmanned aerial vehicles was overlaid on the 2010 land use map to supplement the ground-truthing. Areas on the aerial map that displayed the roofs houses or buildings that did not match the 2010 map were edited to indicate built-up instead.

<Insert Figure 1, Figure 2 and Figure 3 here>

Historical Drivers of Urban Expansion

To better analyze and manage urban expansion in the Seven Lakes area, the drivers of conversion to built-up areas must be identified, validated and used to forecast future conversion. Potential drivers were identified by referencing previous literature, conducting interviews with key informants, specifically, the City Environment and Natural Resources Officer and City Planning and Development Officer of San Pablo City, both experts in their respective field as well as attending a workshop for the CLUP of San Pablo City. These interviews and related literature highlighted the following drivers of urbanization: distance to roads, distance to trails, or foot-paths, distance to the Seven Lakes, distance to existing built-up areas, population density, and, slope. These hypothesized drivers were then validated by applying the LTM to historical data then checking for acceptable values using the percent correct metric (PCM) and Kappa Statistic, which are already built into the model.

<Insert Table 1 here>

Land cover data from 1988, 2003 and 2010 were processed from maps provided by the National Mapping and Information Resource Agency (NAMRIA) (Figures 1-3). Land cover classes are generalized into agriculture (which includes coconut plantations), natural (which includes grasslands and forest areas), built-up (which consists of all buildings and concrete areas, regardless of residential, commercial, etc.), and water features. The raster map calculator, was used to determine how many cells, hence, the equivalent land area, underwent conversion to built-up between the 1988 map and 2003 map, as well as between the 2003 map and 2015 map (previously updated from the 2010 map). Driver maps were prepared using the program ArcMap. Topographical shapefiles for creating the driver maps were provided by the National Mapping and Resource Authority. The drivers reliant on proximity were processed using the Spatial Analyst extension of ArcGIS. The slope classification map, which was downloaded from the Philippine GIS Data Clearinghouse (PhilGIS), was reclassified into raster file, using the same extension. The population density driver maps were made with data provided by the Philippine Statistics Authority (PSA) from years 2000 and 2010, and were created to reflect the number of people per barangay, or subdivision, area. The complete list and rationale for the driver inputs can be found in Table 2. It also specifies the original format of each of the outsourced data. Driver maps can be found in Figures 4 and 5

<Insert Table 2 here>

<Insert Figures 4 and 5>

Details on the use of the LTM, including preparation of input files and analysis of output files, can be found online at < http://ltm.agriculture.purdue.edu/default_ltm.htm>. Input map layers are prepared in a GIS platform, then, the neural net is set up and trained so it can then be used to generate a forecast of areas likely to undergo a particular land cover conversion, based on the identified drivers. Each of the prepared input files was in raster format and set to have a 10 x 10 m cell resolution. The output is an ASCII file was reconverted in GIS into a forecast map. This process is first done using historical data so that the forecast map can be checked against actual map by using the statistical tools. Thus, for the training and driver verification phase, the model required raster maps of historical land use at different years. Using the maps shown in Figures 1-3, two tests were conducted for 'training' the model and verifying suitability of selected drivers: a first test investigating urbanization from 1988 to 2003, and a second from 2003 to 2015. Drivers were then further evaluated in terms of the quantity of their influence on the urban expansion or 'weight' by running the 2003-2015 tests again while removing one at a time then obtaining the difference in the PCM of the run with all the drivers and the run in which one was removed. The number of cells that underwent change from the most recent time period, hence, between 2003 and 2015, were used as a reference for both training and forecasting simulations. The complete methodological flowchart is illustrated in Figure 6.

<Insert Figure 6>

The forecasts made by the LTM were compared to actual land cover change (Figure 7). Areas labeled as "True Positive" were those cells that were forecasted by the model to change and indeed underwent that change. Similarly, "True Negative" areas were those correctly forecasted not to change. "False Positives" are those forecasted to change but did not, while "False Negatives" are those not forecasted to change but did. The forecasts were also evaluated for accuracy by use of the Percent Correct Metric (PCM) and the Kappa Statistic, which are both intrinsic to the model and used in previous studies. The Kappa Statistic is used to calculate for the model's percentage of success relative to the percentage of chance (Pijanowski, Pithadia, Alexadridis & Shellito, 2005). The Percent Correct Matrix compares the forecasted change to the actual land use change (HEMA, n.d.). Table 3 shows the acceptable and ideal ranges for both methods of validation.

<Insert Figure 7>

<Insert Table 3 here>

In the testing phase for 1988 – 2003, the model obtained a score of 79.88% for the Percent Correct Metric, which is good and even almost excellent, while obtaining a Kappa Statistic of 0.78, which indicates a strong agreement. During this time span of 15 years, urban expansion in San Pablo City was amounted to an estimated 4.89 km^2, an average of about 0.33 km^2/year. For the 2003 – 2015 test runs, the model was able to get 66.42% in the Percent Correct Metric, which is considered good, and had a Kappa Statistic value of 0.618086, which indicates a strong agreement. Within this time span of 12 years, urban expansion increased to 14.59 sq.km, an average of about 1.22 km^2/year. Comparing the results from the 1988-2003 and 2003-2015 test runs indicates an increased rate of urban expansion. The total change in the latter 12 years is 9.7 km^2 more than in the previous 15 years – almost double the total change from 1988 to 2003. The estimated annual rate of change is 3.7 times higher during 2003-2015 than in 1988-2003.

Evaluation of the individual drivers (Tables 4 and 5) showed that from 1988-2003, the most influential drivers were the distance to the lakes (particularly Lake Sampaloc), and distance to existing built-up areas, today considered as the city proper. Removing the distance to existing built-up areas as an input to the LTM decreased the PCM by 6.73%. Removing the distance to the lakes decreased the PCM by 7.22%. These results indicate the relative weights of the said drivers, and explain why the expansion is more centralized during this period, as seen in Figures 1 and 2. The most influential driver of conversion to built-up areas during the time span of 2003 until 2015 was the road network. During this period, the road driver proved to be the most influential in determining land use change, causing the PCM of decrease by 26.05% when removed as an input. Expansion during this period is more spread out along the roads and trail networks.

<Insert Table 4>

<Insert Table 5>

Forecasts of Urban Expansion

Upon verification of the suitability of the selected drivers for forecasting expansion of built-up areas, forecasts of potential future trends were simulated to determine which additional areas may be susceptible to urban expansion. For this study, three different kinds of scenarios were considered:

1. Business-as-Usual (BAU) Urban Expansion: This simulation is used to determine which areas would most likely undergo change based on the number of cells, and the equivalent area, that underwent conversion between 2003 and 2015. The results of this simulation could represent a scenario over the next 12 years, to the year 2027, assuming the same rate of change as in 2003-2015.This scenario implicitly assumes a preference for urban sprawl as development growth type instead of building upward.
2. Doubled Urban Expansion: In this case, the number of cells that converted to built-up was double the number of cells that changed during the period of 2003-2015. This simulation follows the assumption that the rate of urban expansion might increase, as was the case historically. The results of this simulation could also represent a scenario over the next 12 years, to the year 2027, but assuming a doubled rate of expansion. (This scenario is even a conservative one given that the 2003-2015 estimate annual rate of change is 3.7 times higher than the 1988-2003 rate.)

3. Enforcement of Buffers: Strong enforcement of buffer zones over ecologically valuable areas is assumed. These areas are the vicinity directly surrounding the lakes as well as the remaining forested areas up north and east. A buffer will cover two-hundred-meters (200 m) away from the edges of the seven lakes. This policy recommendation is currently being considered by San Pablo City's local government as part of their CLUP. This scenario will simulate where urban expansion would spread if the lakes were protected by buffer zones. This was done for both the business-as-usual scenario and the doubled urban expansion.

In the Business-as-usual simulations (refer to Figure 8) the built-up areas will expand towards, but not completely engulf, lakes Bunot, Palakpakin, Mohicap and, Kalibato. All four of these lakes are a part of San Pablo City's Eco-Tourism zone. The LTM also forecasted that there will be a little encroachment on the forest areas north-west of Lake Mohicap.

<Insert Figure 8 here>

In Figure 9, the map displays the results of a forecast run that selects 29.1 km^2 to change into built-up. This value is equivalent to double the number of cells that represent the areas that had undergone conversion to built-up areas in the past twelve years. The forecast is for more urbanization most especially in areas around all the seven lakes, except Lake Yambo.

<Insert Figure 9>

Figure 8 and Figure 9 show urban encroachment in the forests near Lake Mohicap as well as the said lake itself without the protective measures. The only lake that seems to not be at risk to urban expansion is Lake Yambo – likely because of its distance from the roads and the city center. In the scenario that effectively prevents built-up development within 200 m of the lakes (Figure 10), it can be seen that most of the built-up areas will, instead, disperse along the roads towards the southern areas of the city. Potential urban encroachment surrounding the lakes could reach up to 2.81 km^2 without the 200 m buffer.

<Insert Figure 10>

A full environmental impact assessment is needed for the areas projected to change to determine specific impacts but already we may identify possible implications. Based on literature, there may be potential impacts on nutrient levels and fish kill incidents in the lakes, and biodiversity in forested areas. Should the forecasted urban expansion occur around the seven lakes, there may potentially be increased run off and nitrogen levels (Tang, 2004), most especially since the current residences around the lake proper sewage and waste management facilities. This may increase the likelihood of fish kills in the lake (Ragas, 2016). Such fish kills have already been observed and were studied by Ragas (2016). This would be greatly detrimental to the community as fishing and aquaculture are among the main sources of livelihood. As for the forest area, such urban expansion could possibly result in a loss of biodiversity. Trees that may be lost to urban expansion will result to decreased carbon sequestration in the atmosphere and less capacity for filtering the air (Bolund, P. & Hunmammar, S., 1999) leading to poorer air quality (Bhatta, 2010). Both ecosystems will likely lose their viability as pristine tourism areas as there would be less woodland for recreational outdoor activities (Metzeger et al., 2006) and the watershed areas may become more susceptible to pollution (Acevado, 1999), including phosphorus (LaBeau, 2014) and nitrogen loading (Tong & Chen, 2002), at the same time leading to a decrease infiltration (Getachew & Melesse, 2012).

Conclusions and Recommendations

The rate of urban expansion in San Pablo City in between 2003-2015 has increased to approximately 3.7 times more than rate of change from 1988 to 2003. The selected drivers that account for majority of historical conversion to built-up areas are distance to roads, distance to trails, distance to the seven lakes, slope elevation, and, population density per barangay. In between the years 1988 and 2003, among the six drivers, the most prominent drivers were the distance to existing built-up and to the lakes, with the weights 6.73% and 7.22%, respectively. This could be the reason as to why the expansion is much more centralized. As for years 2003 to 2015, it was the road driver that proved to be the most influential in determining land use change with a weight of 26.05% based on the PCM of the LTM tests; hence, the expansion is much more spread out.

Assuming that the six identified drivers will continue to influence conversion to built-up areas, the LTM forecasted that urban expansion will eventually extend towards the seven lakes, particularly lakes Palakpakin, Mohicap, Pandin, and, Kalibato, unless reinforced by protective policies. Urban expansion engulfing the lakes may likely put stress on the lake ecosystem to an extent that would compromise the livelihoods of fishermen and fish pen owners and, potentially, reduce aesthetic quality which would affect the tourism industry of San Pablo City. As San Pablo City undergoes further infrastructural development, built-up expansion would begin to congest the area surrounding the northern lakes and encroach on some forested area near lake Mohicap. The potential loss in forest cover would lead to loss in biodiversity (Bhatta, 2010) and the capacity for carbon sequestration (Bolund, P. & Hunmammar, S., 1999).

Thus, one concrete protective policy under consideration is the use of ecological buffer zones. In order for San Pablo City to preserve the integrity of its natural ecosystems in the long term, it is recommended to further explore the 200 m buffer for lakes currently proposed by consulting firms to the local government unit, in tandem with protection of forested areas. Data-gathering measures, such regularly capturing aerial images, can be put in place to monitor LULCC surrounding the lake. A comprehensive environmental impact assessment can also evaluate whether implementing the 200 m buffer is enough.

However, it should be noted that forecast maps show where it is likely for built-up area to expand, given the identified drivers and specified amount of change, but are not prescriptive in nature. They do not indicate where built-up development should be allocated (the remaining area outside the buffer zones will need to be allocated appropriately across the housing, education, medical services and commercial sectors) nor what can be done to alleviate possible impacts. This is why contextual knowledge of the area must be integrated with the presented results to identify potential impacts on the environment needing further study, regular monitoring, and more careful regulation.

Additionally, forecasts for urbanization need to integrate infrastructure development that would affect mobility and accessibility to the area. Specifically, an extension of a major expressway is planned for construction south of the Seven Lakes area. This may have implications on population inflows. Given that population density is a validated driver of conversion to built-up areas, the LTM would likely be improved if it could be integrated with a population flow model to account for the influx of tourists and patterns of migration.

Further LULCC studies that utilize GIS would benefit from the availability of more detailed maps that include the different sub-types of built-up areas (e.g. residential, commercial, industrial), in order to better assess more probable and definite environmental impacts, as well as those that also include the urban density. Follow-up land cover studies on the area should compare actual LULCC in the coming years with the previously forecasted results. The comparison of the forecast to the actual land cover or land use can be utilized as input for gauging if changes in land use policies, if such have been implemented, were effective in either mitigating or redirecting LULCC. In a situation where there was no policy change within the estimated time frame in which the change could occur, a comparison of the forecast and the actual change could illustrate how accurate the forecasting tool can be, and whether there are other factors, such as a change of or among drivers, that may have greater influence on LULCC in the area.

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Conflict of Interest: None

Endnotes

[1] The aerial imagery was obtained through the project *Nutrient dynamics and spatial modeling in Lake Palakpakin* (specifically, through the permission of Dr. Teresita Perez and the Ateneo Innovation Center) funded by the University Research Council of the Ateneo de Manila University

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FIGURES

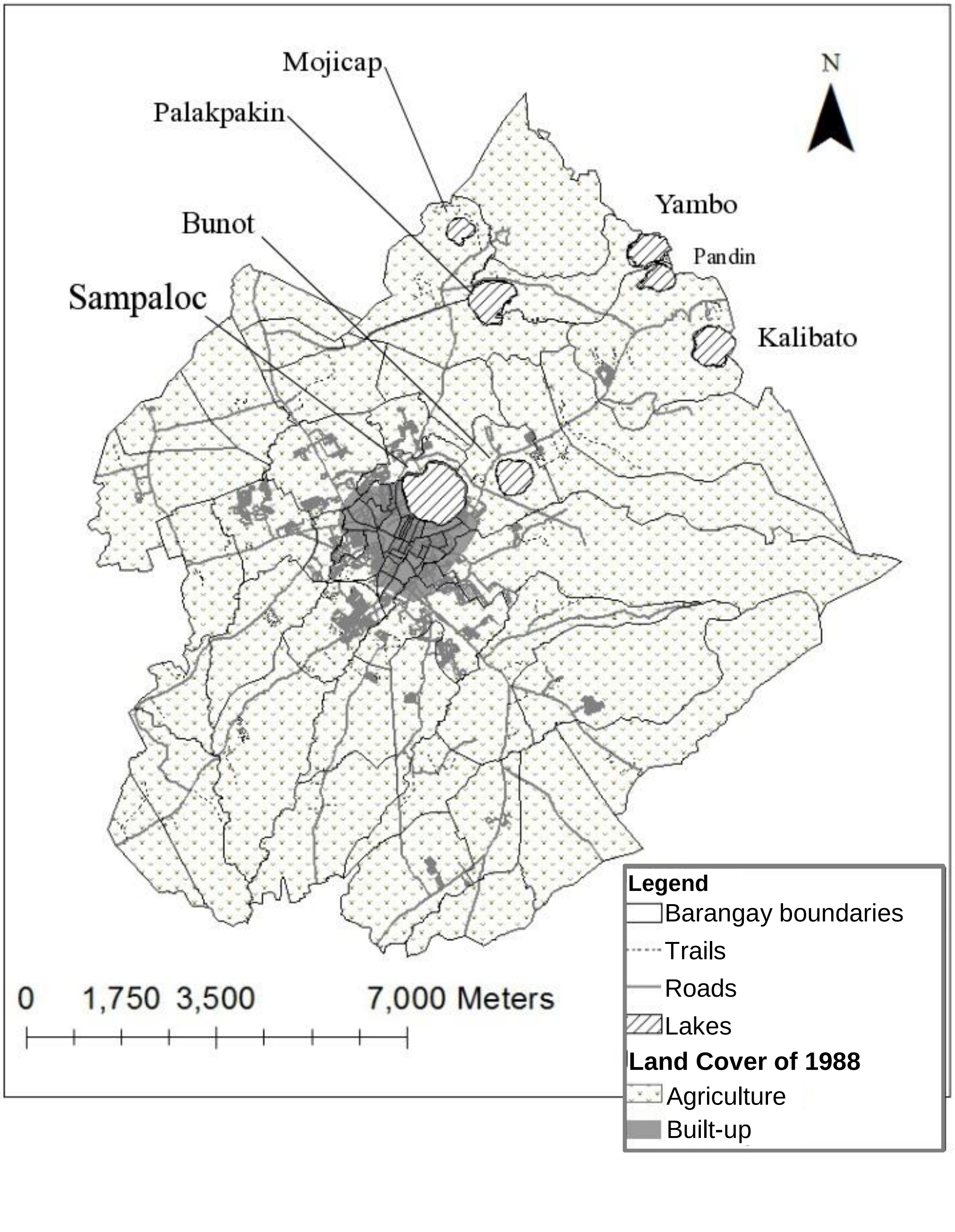

Figure 1. San Pablo City Land Cover Map as of 1988 (processed from Land Cover Map provided by National Mapping and Resource Information Agency)

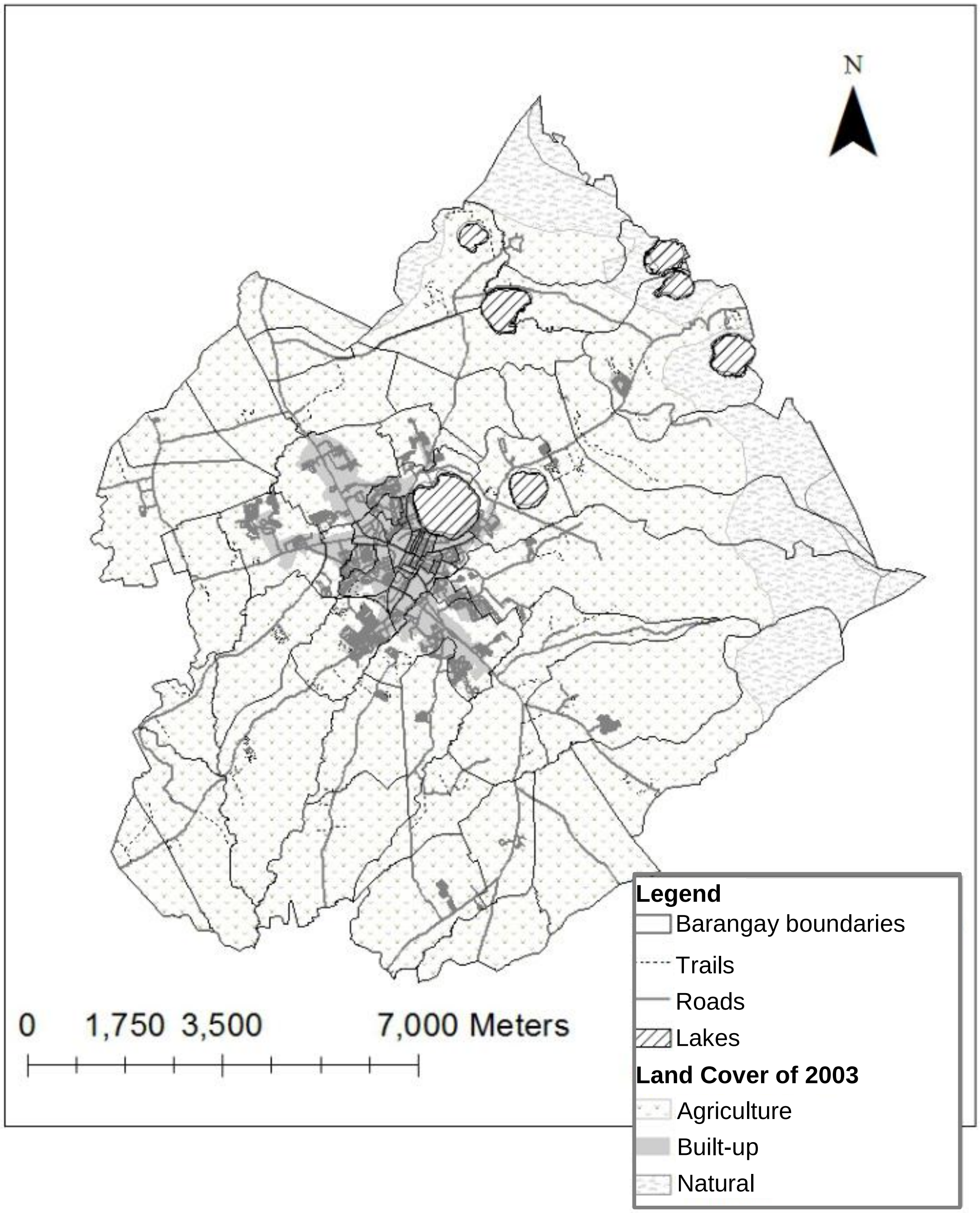

Figure 2. San Pablo City Land Cover Map as of 2003 (processed from Land Cover Map provided by National Mapping and Resource Information Agency)

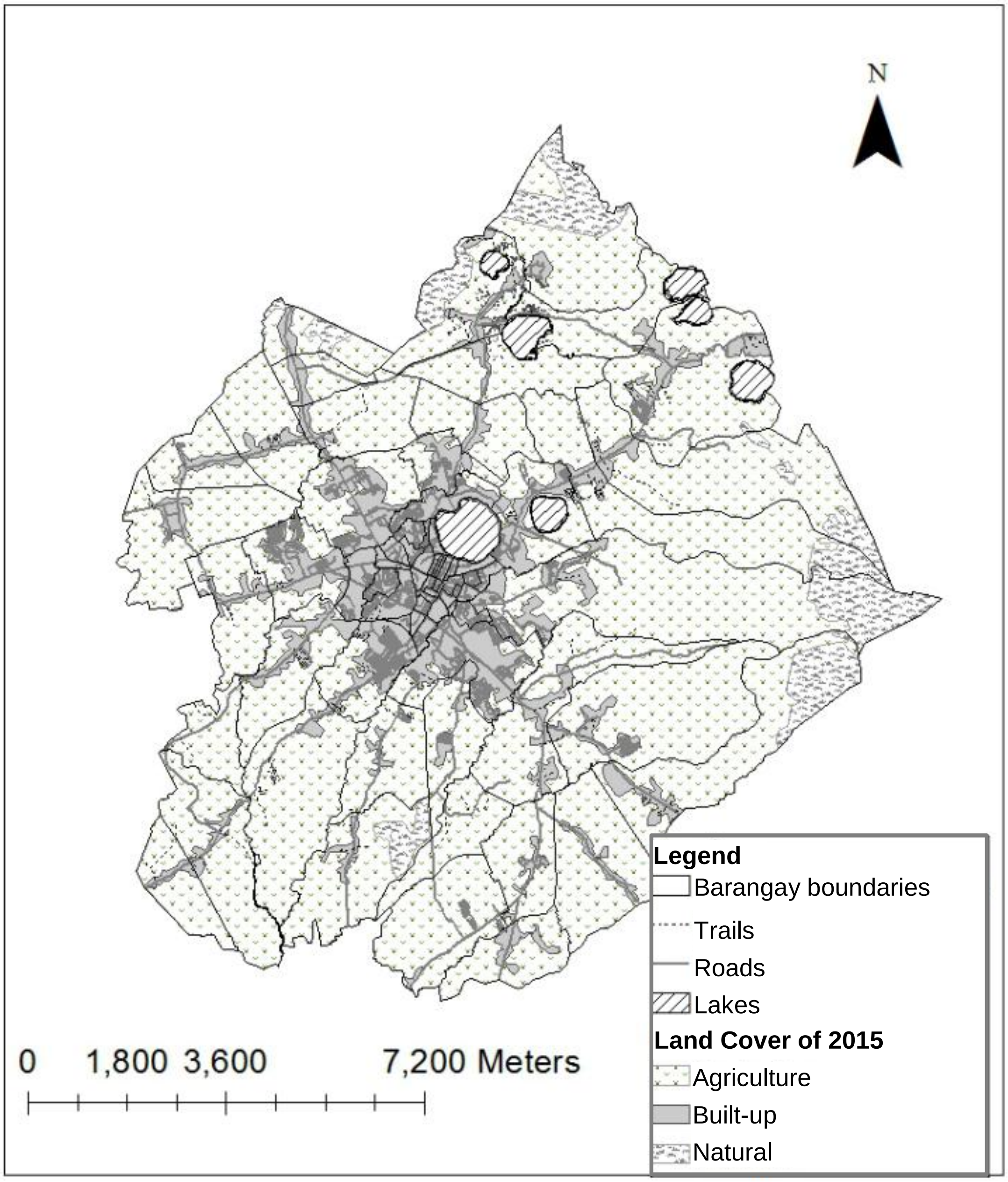

Figure 3. San Pablo City Land Cover Map as of 2015 (processed and updated from the 2010 Land Cover Map provided by National Mapping and Resource Information Agency)

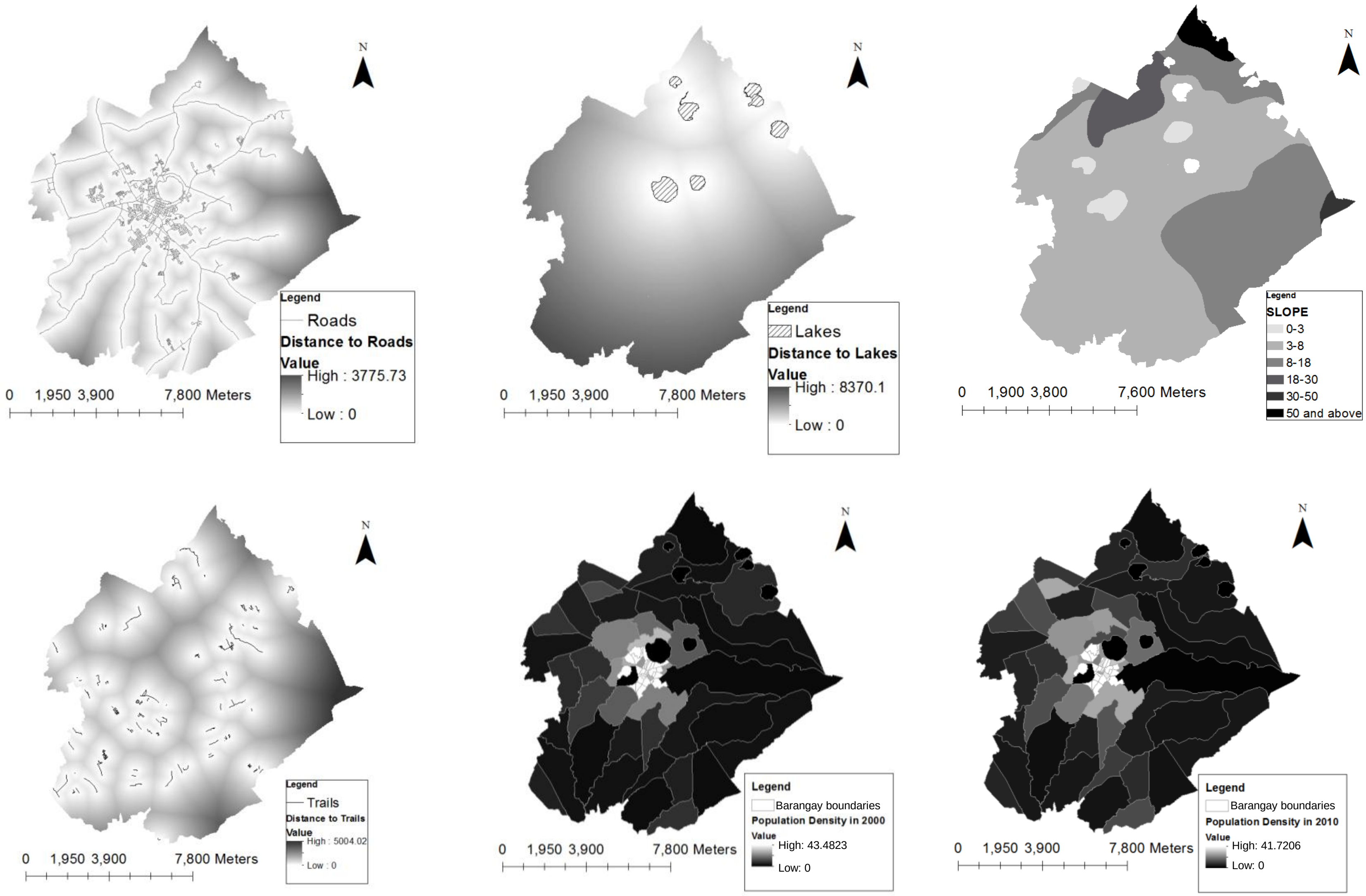

Figure 4. (From left to right, top row) Driver Maps of Distance to Road Network, Distance to Lakes, and Slope; (From left to right, bottom row) Driver Maps of Distance to Trails, Population Density Map from 1988, Population Density Map for 2003 (Original basemaps from National Mapping and Resource Information Authority; Population data and barangay shapefiles from Philippine Statistics Authority)

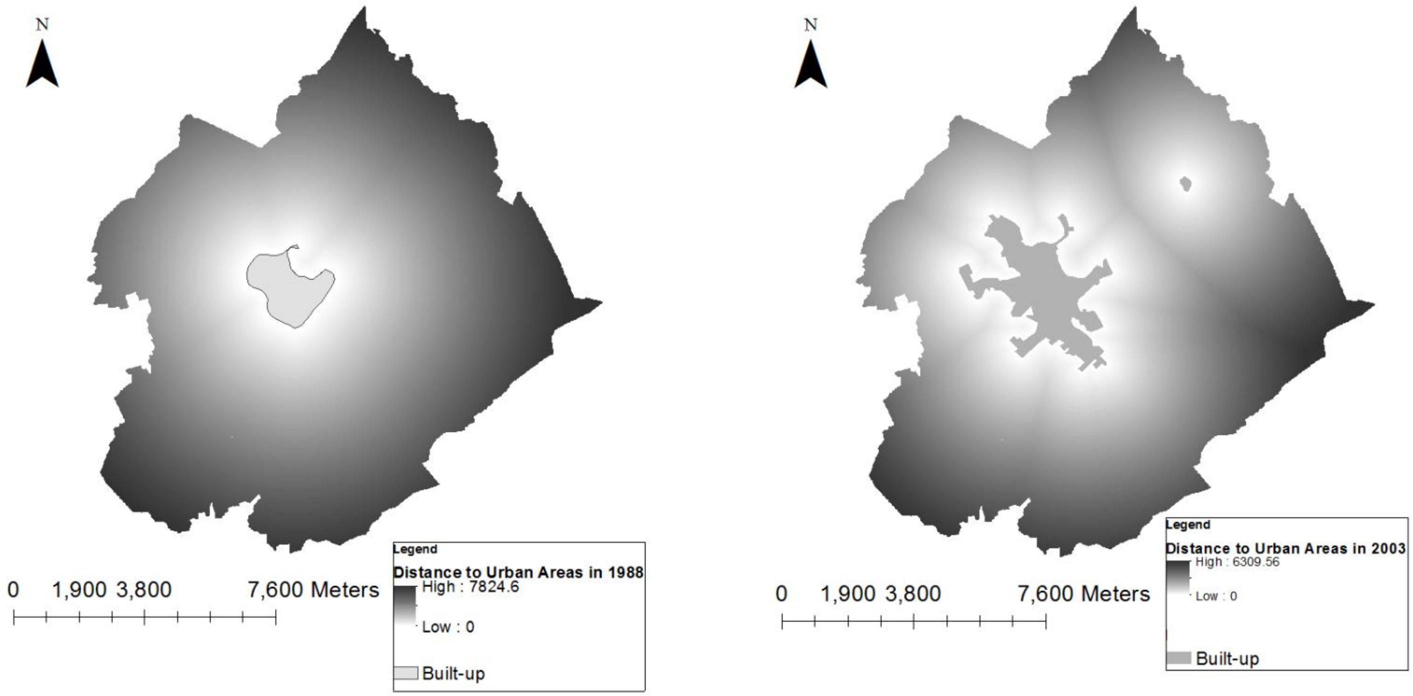

Figure 5. Driver Maps of Distance to Existing Urban Areas (left) 1988 (right) 2003 (Original basemaps from National Mapping and Resource Information Authority)

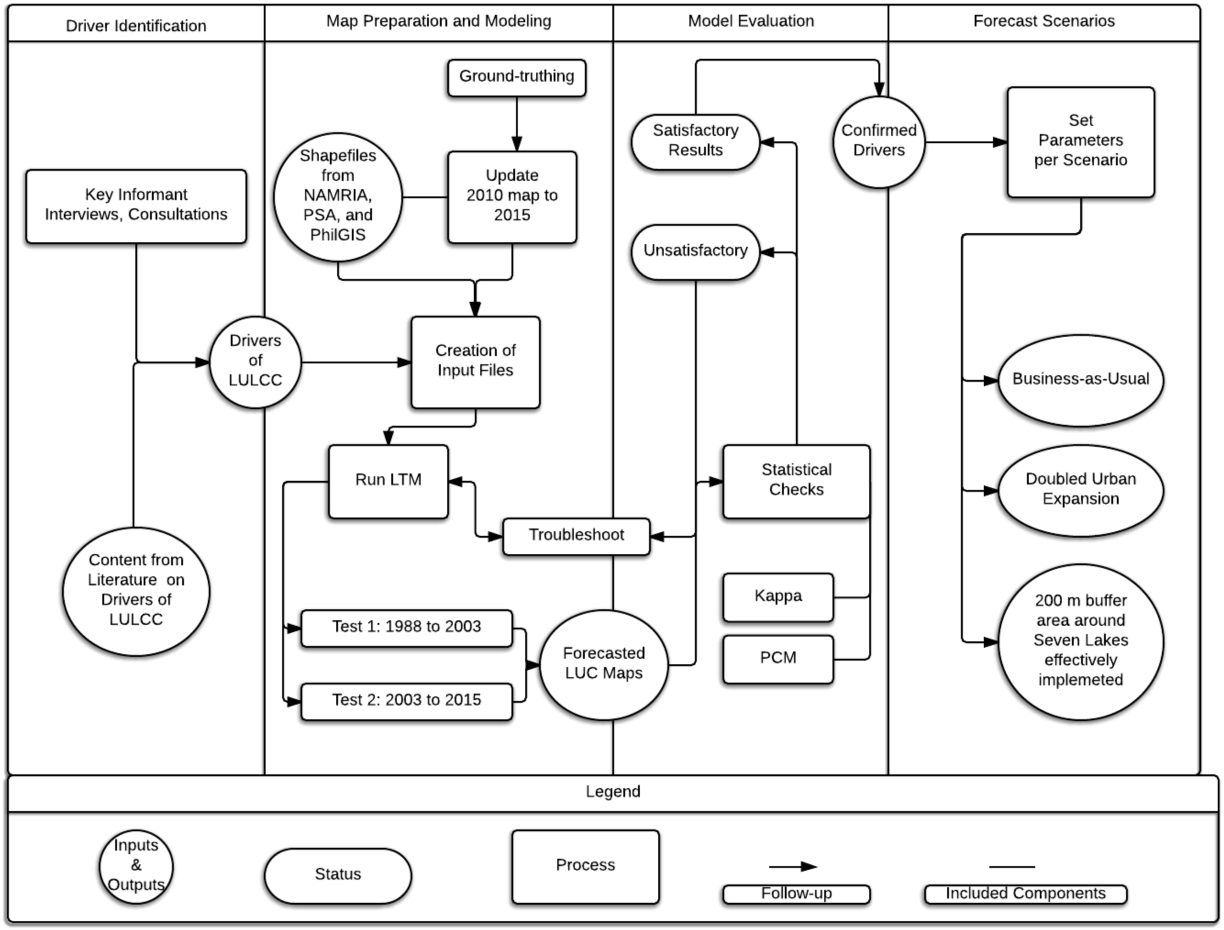

Figure 6. Methodological Flowchart

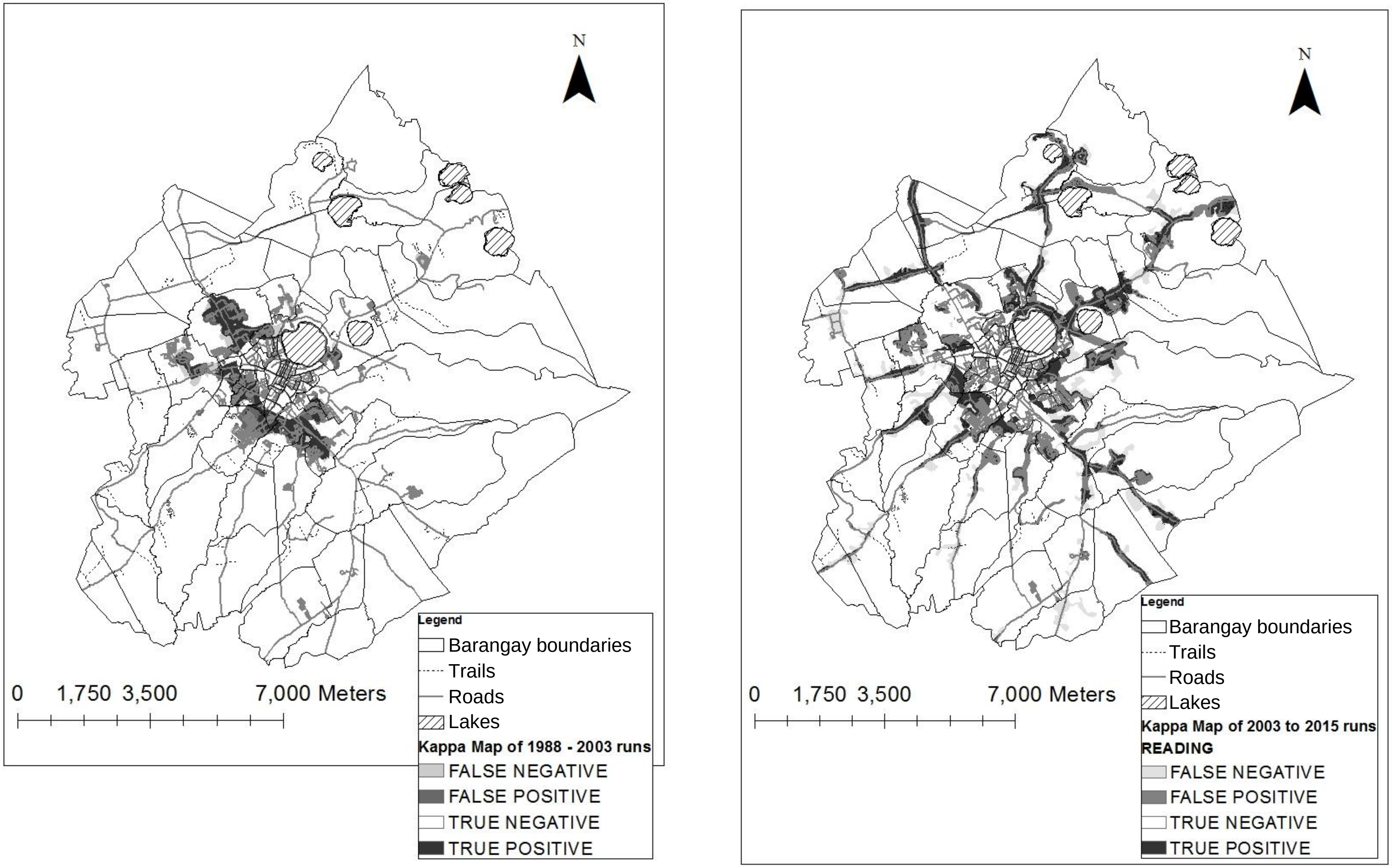

Figure 7. Maps Comparing LTM Predictions with Actual Historical Land Use Change; (left) Test Run Results from 1988 to 2003 and ,(right) Test Run Results from 2003 to 2015 (Original Basemaps from National Mapping and Resource Information Authority, Barangay Shapefile from Philippine Statistics Association)

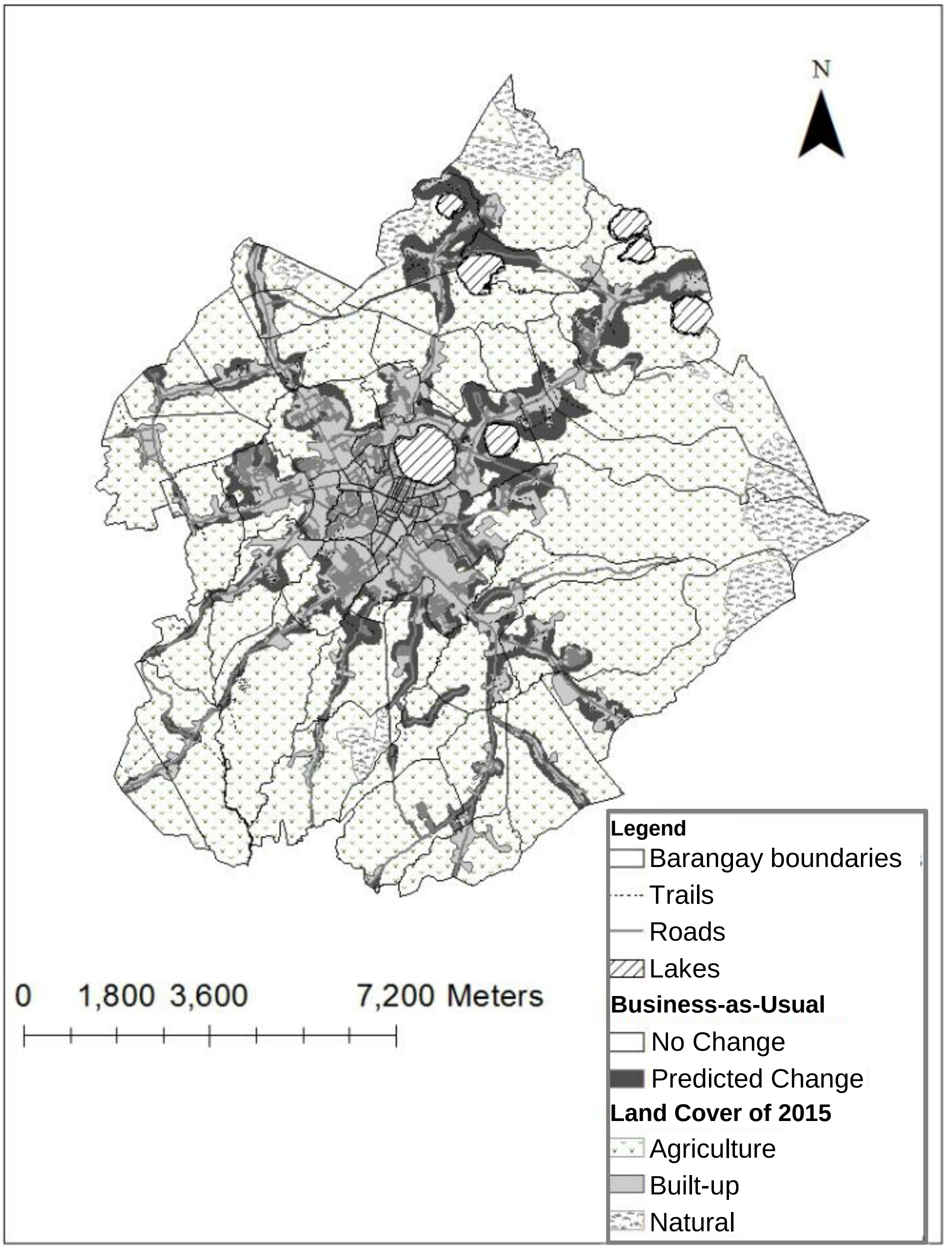

Figure 8. Forecast Results: Business-as-Usual (Original Shapefile Basemaps from National Mapping and Resource Information Authority; Barangay Shapefile from Philippine Statistics Authority)

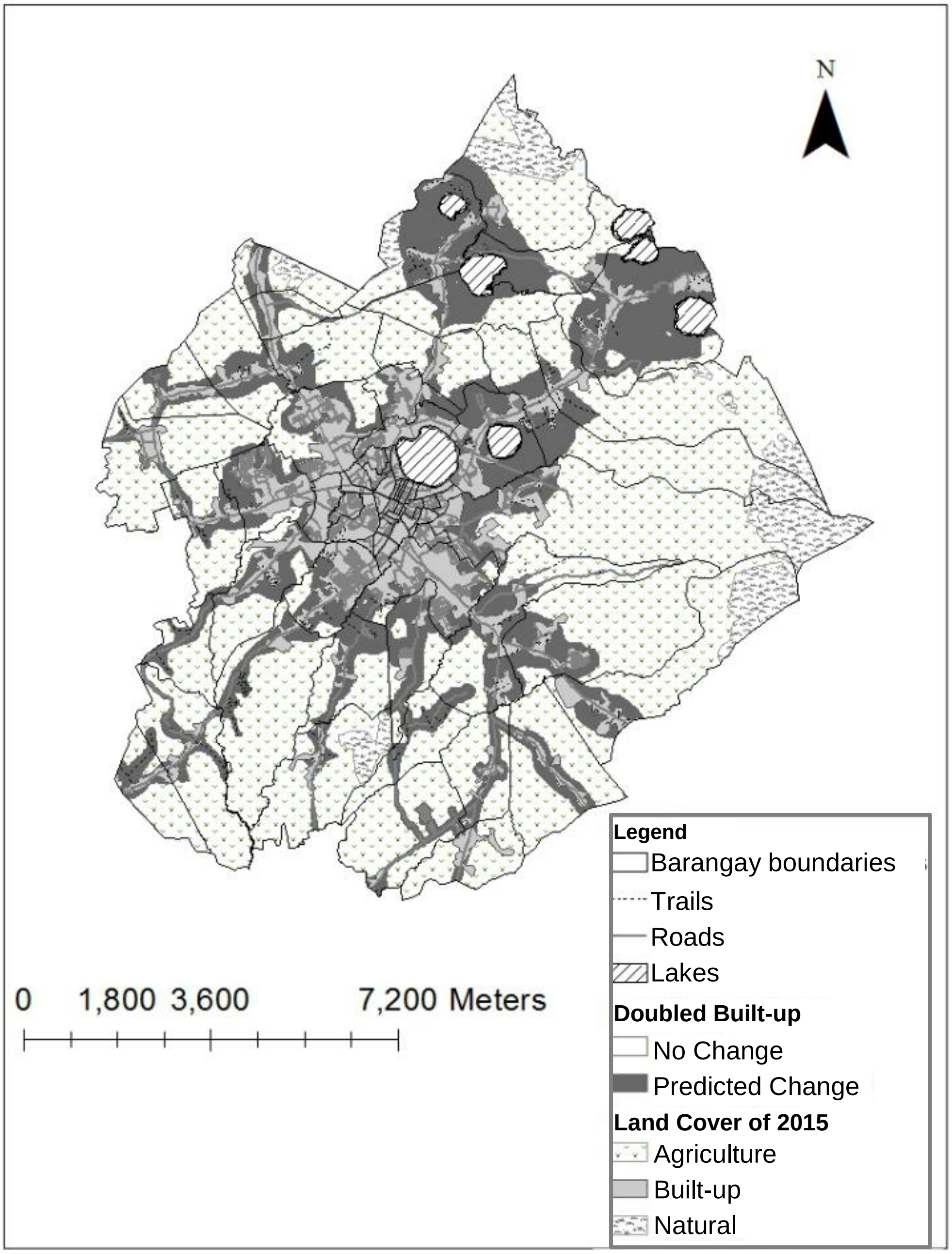

Figure 9. Forecast Results: Doubled Growth Simulation (Original Shapefile Basemaps from National Mapping and Resource Information Authority; Barangay Shapefile from Philippine Statistics Authority)

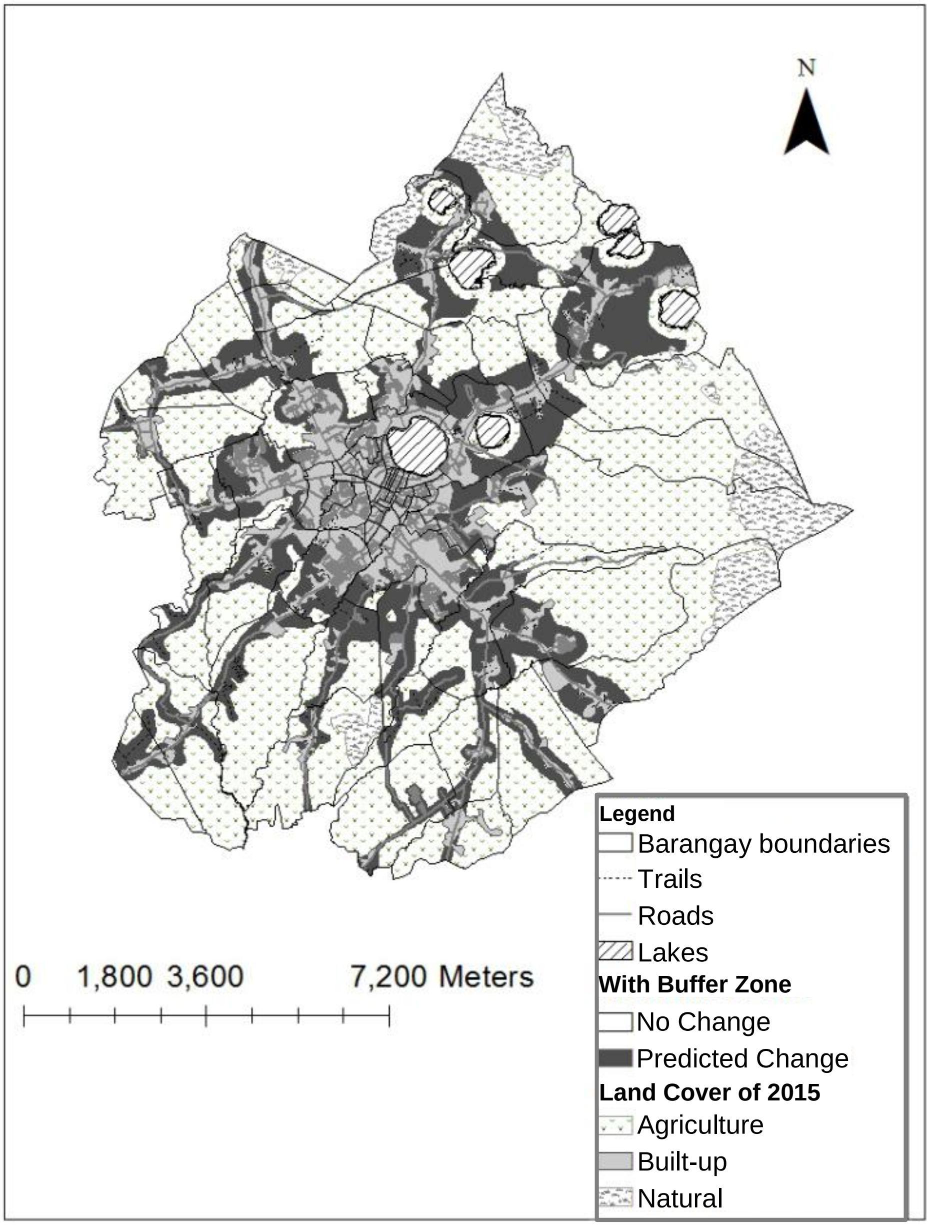

Figure 10. Forecast Results: Doubled Growth Simulation with Buffer area surrounding lakes (Original Shapefile Basemaps from National Mapping and Resource Information Authority; Barangay Shapefile from Philippine Statistics Authority)

TABLES

Table 1 Summary for Rationale behind Selected Drivers

Drivers	Rationale
Distance to Roads	Increases accessibility to an area Singh, 2003; Pijanowski, Long, Gage & Cooper, 1997; Liu et al., 1993
Distance to Trails	Functions similarly to roads by increasing accessibility to an area; Observed that some built-up areas deviate from the roads.
Distance to Lakes	Lakes provide sources of livelihood, food and water for various uses.
Distance to Existing Built-Up	Built-up areas tend to expand within their proximity Singh, 2003; Pijanowski, Long, Gage & Cooper, 1997
Population Density	Highly populated areas are more prone to conversion Mulata, 2014; Pijanowski et al., 1997
Slope	Area may be prone to change if not near a an urban center simply due to flat terrain Singh, 2003; Less slope also minimizes landscaping costs Tayyebi et al., 2011

Table 2 List of Key Data Inputs

Inputs	**Data Source**	**Original Format**	**Spatial Coverage**	**Temporal Coverage**	**Data Role**
Historical Land Use Maps	NAMRIA	Shapefile (.shp)	Northern area of San Pablo City, including a section of Laguna de Bay	1988, 2003 and 2010	Base Map
Road Networks	NAMRIA	Shapefile (.shp)	Northern area of San Pablo City, including a section of Laguna de Bay	2000	Driver Input
Lakes	NAMRIA	Shapefile (.shp)	Northern area of San Pablo City, including a section of Laguna de Bay	2000	Driver Input
Trails	NAMRIA	Shapefile (.shp)	Northern area of San Pablo City, including a section of Laguna de Bay	2000	Driver Input
Political Boundaries	PSA	Shapefile (.shp)	Entire San Pablo City	1999	Base Map
Population Data	PSA	Table; Hard copy	San Pablo City	2000 and 2010	Driver Input
Slope	PhilGIS	Shapefile (.shp)	Nationwide	1997	Driver Input

Table 3. Indicators for ranges of the Kappa Statistic (Sousa et al., 2002 as cited in Pijanowski et al, 2005) and PCM (*HEMA*, 2008)

Range of Kappa	**Agreement**	**Range of PCM**	**Ranking**
0.0 – 0.2	Very Poor	Below 40%	Unacceptable
0.2 – 0.4	Poor	40% - 60%	Acceptable
0.4 – 0.6	Acceptable	60% - 80%	Good
0.6 – 0.8	Great	80% and above	Exceptional

Table 4. Quantified Influence per Driver based on Test Runs from 1988 to 2003

Driver Removed	PCM	Weight of Removed Driver	Kappa	Difference
(All present)	79.881891	N/A	0.784469	N/A
Roads	78.835957	1.31%	0.773693	0.010776
Existing Built-up area	74.50664	6.73%	0.729087	0.055382
Lakes	74.117818	7.22%	0.725080	0.059389
Population Density	77.831611	2.57%	0.763353	0.021116
Trails	79.694745	0.23%	0.782549	0.00192
Slopes	76.791915	3.87%	0.752644	0.031825

Table 5. Quantified Influence per Driver based on Test Runs from 2003 to 2015

Driver Removed	PCM	Weight of Removed Driver	Kappa	Difference
(All present)	66.423635	N/A	0.618088	0
Roads	49.118866	26.05%	0.423935	0.194154
Existing Built-up area	63.824464	3.91%	0.588806	0.029283
Lakes	63.729786	4.06%	0.584828	0.033261
Population Density	63.814098	3.93%	0.588690	0.029399
Slope	64.027828	3.61%	0.591242	0.026847
Trails	63.729786	4.06%	0.587740	0.030349