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ORIGINAL ARTICLE

Land Use and Land Cover (LULC) Change Impact Assessment on Surface Runoff Responses of Santa Cruz Watershed, Philippines

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Abstract: LULC plays significant role in the alteration of partitioning among hydrological pathways including interception, evapotranspiration, infiltration and runoff. It is also one of the major drivers of increasing frequency of flooding worldwide. With Philippines being prone to hydro-meteorological hazards, continuous population increase and economic development leading to LULC conversion intensification; it is vital to conduct a research pertaining to its hydrological impact. This study aimed to detect and project the LULC change impact on surface runoff responses including total instantaneous volume, peak discharge, and time of peak of a single storm event using HEC-HMS in the ungauged Santa Cruz Watershed. To estimate runoff responses, LULC modeling was executed using Markov chain method in Terrset™ to project LULC 2040. Validation between observed and modeled map had 82.73% overall accuracy. Output of the projection permits the alteration of Curve Number in the model to account for LULC changes between 2010 and 2040. Results showed that increase between baseline and with LULC change for peak discharge is 61%, volume is 55%, and time of peak is 30 minutes earlier than baseline. Output of the study can serve as additional baseline information in the formulation of DRRM, water resources management, and watershed management plans.

***Keywords**:* land use and land cover (LULC) change, Markov chain, ungauged watershed, HEC-HMS, surface runoff

1. Introduction

Land cover is defined as the biophysical land surface while land use is related to the human-driven management activities that affects the land (Kleemann et al., 2017). It is considered as one of the fundamental subjects in the study of environmental change and sustainable development (Guan et al., 2011). LULC change affects water partitioning among hydrological pathways including interception,

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evapotranspiration, infiltration, and runoff (Sterling et al., 2012). These alterations caused by LULC change are known to exacerbate the problem of flooding (Talib & Randhir, 2017). And Philippines being dubbed by the United Nations Office for Disaster Risk Reduction as the top three most disaster-prone country in the world is being affected by this phenomenon.

One way of investigating the relationship between LULC changes and watershed responses is through modeling. Modeling studies gained popularity over the years primarily because of its ability to represent, through simulation, a system that is impossible or too costly to manipulate in reality (Combalicer & Im, 2012). One of its many uses is the detection and prediction of hydrologic responses to different phenomenon such land use and land cover (LULC) change. Its spatial nature makes it natural to be analyzed together with remote sensing and geographic information system (GIS) to understand patterns, detect and monitor changes, and model and simulate processes such as urban growth and land use change (Bhatta et al., 2010).

Hydrologic modeling using watershed models is considered as a powerful tool to simulate the effect of watershed processes on both soil and water resources (Sajikumar & Remya, 2014). Though hydrologic modeling is still limited in the Philippines, several studies have explored the relationship of LULC with various hydrologic processes using computer-based models. Alibuyog et al. (2009) used the SWAT model to predict the effects of land use change on runoff and sediment yield in Manupali river subwatersheds; integration of SWAT model, remote sensing and GIS by Principe (2012) to explore the effects climate change on watershed sediment yield and land cover-based mitigation measures in Cagayan River Basin; use of HEC-HMS and HEC-RAS to assess vulnerability of Mabitac, Laguna to flooding (Pati et al., 2014); hydrologic impact evaluation of LULC change in Palico Watershed, Batangas using the SWAT model (Briones et al., 2016); and the combination of SWAT model and Fragstat to model the land use change impacts on hydrology for watershed management in Calumpang watershed in Batangas (Boongaling et al., 2018) are some of them. Specific model useful for extreme (flood) event is an event-based model. An event-based model simulates a single storm event which duration may range from several hours to several days (USACE, 2001). This type of simulation reveals the watershed's response to an individual rainfall event in terms of quantity of surface runoff, peak, and time of concentration among others. One of the many uses of this fine scale event modeling is for flood estimation and forecasting.

1.1. Objectives

With Philippines being prone to hydro-meteorological hazards, continuous population increase and economic development leading to LULC conversion intensification; it is vital to conduct a research pertaining to its hydrological impact. This study aimed to detect and project the impact of LULC change in the surface runoff responses of one ungauged catchment that is Santa Cruz watershed. It specifically attempts to link land use modeling and projection to changes in total instantaneous volume, peak discharge and time of peak of a watershed to derive insights on the sensitivity of surface runoff responses to LULC changes using HEC-HMS. This research was conducted in line with the Rio Declaration Principle #15: Precautionary Principle and in part of the achievement of *Ambisyon Natin*

2040: The Philippine Long-Term Vision particularly the commitment to the achievement of a healthy and resilient community in the country (NEDA, 2015).

2. Materials and Methods

2.1 Study Area

Santa Cruz River Basin is a 131.658 km^2 watershed (Figure 1). It covers portions of the municipalities of Calauan, Liliw, Lumban, Magdalena, Majayjay, Nagcarlan, Pagsanjan, Pila, Rizal, San Pablo City and Santa Cruz in Laguna; and, Candelaria, Dolores, Lucban, Sariaya and Tayabas in Quezon. The headwater of the watershed is in the Mt. Banahaw-San Cristobal Protected landscape (DENR Region 4-A). Its hydrologic elements include 44 sub-basins, 22 reaches and 22 junctions. It is one of the 21 major rivers draining into the Laguna de Bay, the largest living lake in Southeast Asia, and accounts for about 15% of the total water in the lake (LLDA, n.d.). The watershed is characterized with mostly 3-8% sloping. It has ten soil classes with Lipa loam being the most dominant. There are also six major LULC types including perennial cropland, annual cropland, built-up, brushland, open forest and closed forest.

Based on the Modified Coronas Classification of PAGASA, it has a Type III climate which has no pronounced maximum rain period with a dry season lasting only from one to three months, either during the period of December to February or March to May. According to Mines and Geoscience Bureau, the Santa Cruz River Basin is generally classified to be highly susceptible to flooding and have areas with both low and high susceptibility to landslide.

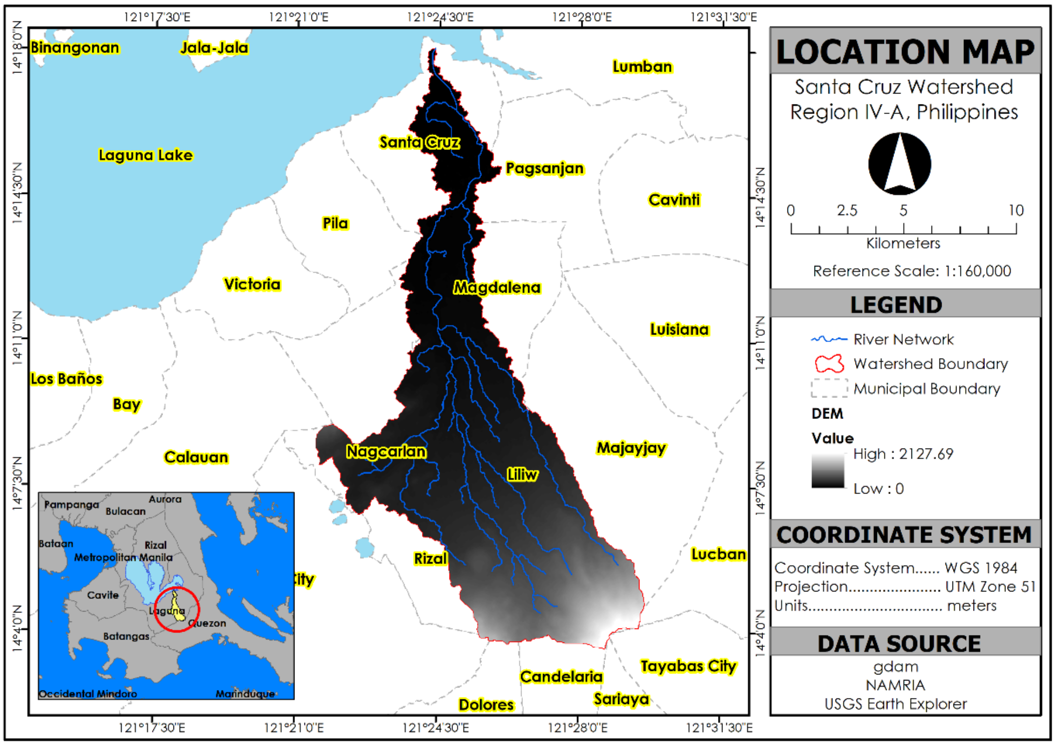

Figure 1. Location Map of Santa Cruz Watershed.

2.2 LULC Change Modeling

The generalized workflow of the LULC change prediction modeling is exhibited in Figure 2. The final output is projected 2040 map which was the map used in simulating the future impact of surface runoff responses of Santa Cruz Watershed.

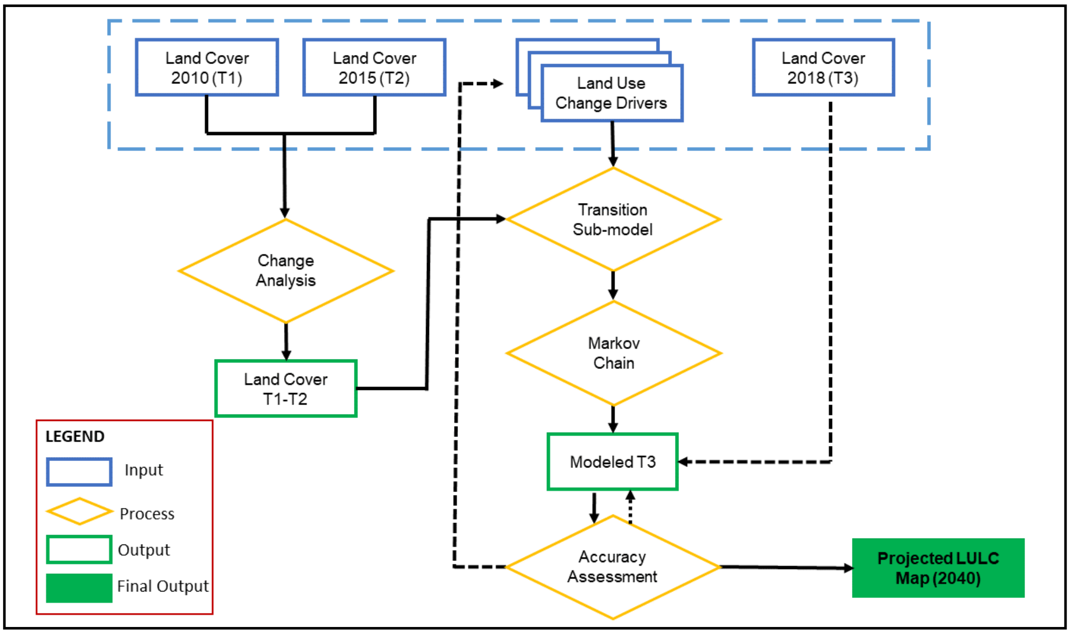

Figure 2. Land use and land cover (LULC) change Modeling Workflow

Land use and land cover (LULC) maps for the years 2010 and 2015 were secondary data gathered from NAMRIA served as the input LULC in the study specifically in the change analysis. Collected and used driver variables are listed in Table 1. The varying, often difficulty in identification and quantification, drivers of land use and land cover (LULC) change proved the complexity and diversity of interactions in socio-ecological systems (Ostrom, 2009). According to Li et al. (2018), there is no generally recognized and established analytical framework of driving forces for LULC change. Driving factors in this study were considered equally important and only includes open source data.

Table 1.Driver Variables for Land Use Modeling

Category	Driver	Unit	Source
Topography	DEM	meters (m)	Earth explorer, USGS
	Slope	percent (%)	Derived from DEM
Spatial Context	Distance from built-up	meters (m)	Openstreetmap (OSM)
	Distance from river	meters (m)	NAMRIA (topographic map)
	Distance from road	meters (m)	OSM
	Distance from critical facilities	meters (m)	OSM
	Distance from Protected Area	meters (m)	PhilGIS

Result of the change analysis, the transitions that occur between the two inputted LULC, and the collected driver variables are the elements necessary in the conduct of transition potential modelling. Transition potential modeling was implemented using the Land Change Modeler (LCM) feature of the

Terrset™ software. The causal factors were integrated to determine the pixels that are more likely to transform from one land use to any other classification. Multi-layer perceptron neural network (MLPNN) was utilized as transition modeling methods due to its ability to integrate the explanatory variables of land change into one sub-model. MLPNN has been extensively enhanced that it operates in an automatic mode that requires no user intervention (Eastman, 2016), thus, lessening the possible error due to human interference with the process. Output of the process are soft and hard prediction maps of the possible future LULC configuration of the watershed.

The probability of changes occurring in different years in the future was calculated using Markov Chain analysis, a technique for predictive change modeling that can model future changes based on past changes. Based on the observed data between two past LULC and defined explanatory variables, the Markov Chain computes the probability that a pixel will change from one LULC type to another within a specified period (Eastman, 2016).

And last, to assess the validity of the model, before modeling the future LULC of the study site, the simulated present LULC was compared with the actual present LULC of the research locale. Validation of the simulated map using confusion matrix and kappa index were executed to assess the accuracy of the classification.

2.3 Hydrological Modeling using HEC-HMS

2.3.1 Model Calibration

The study used GeoHMS, an ArcGIS extension tool, to create the basin model and the HEC-HMS model to implement the actual hydrological modeling process. Software definition and stepwise processes are based from the user's manual guide of HEC-GeoHMS (USACE, 2013) and HEC-HMS (USACE, 2000) provided upon downloading the public domain software online.

Table 2. Instruments and Stations used in data collection details

Station Name	Coordinates		Unit	Time Interval
	Latitude	Longitude		
		Automatic Rain Gauge (rainfall)		
1. Brgy. Bubukal	14.251435°N	121.402060°E	Millimeters (mm)	15 minutes
2. Cavinti	14.246850°N	121.500390°E		
3. Majayjay	14.115120°N	121.503550°E		
4. Rizal	14.111040°N	121.391240°E		
		Portable Rain Gauge (rainfall)		
1. Magdalena	14.80002°N	121.4464006°E	Millimeters (mm)	5 minutes
		ADCP (flow rate)		
Pagsawitan Bridge	14.266760° N	121.423031° E	Cubic meter per second m^3/s	5 minutes
		Portable Depth Gauge (water level)		
Pagsawitan Bridge	14.266760° N	121.423031° E	Pascal (Pa)	5 minutes

Source: UPLB Phil-LiDAR 1

The calibrated event-based model that was utilized in the study came from the Phil-LiDAR 1 Program particularly from the UPLB Phil-LiDAR 1 project. Nationwide Hazard Mapping using LiDAR or Phil-LiDAR 1 was a research program launched by the University of the Philippines Training Center for

Applied Geodesy and Photogrammetry (UP-TCAGP) and supported by the Department of Science and Technology (DOST) Grant-in-Aid (GiA) Program. The model served as baseline condition in the investigation of the impact of LULC change to runoff responses. Table 2 lists the data collection instruments used and its corresponding installation locations. Discharge data collection was executed in December 14-15, 2015 with 5 minutes flow measurement interval which coincides with *Typhoon Nona (Melor)* wherein Laguna was classified signal number 2.

Runoff calculation utilized to develop the calibrated model of the basin is in Table 3. Among these methods, only curve number was altered to account for the impact of LULC change in the runoff response of the watershed.

Table 3. Methods for runoff components calculation

Hydrological Element	**Calculation Type**	**Method**
Subbasin	Loss	SCS Curve Number (SCS-CN)
	Base flow	Exponential Recession
	Direct runoff	Clark's Unit Hydrograph
Reach	Routing	Muskingum-cunge

2.4 Generation of Curve Number Grid

LULC change were incorporated in the hydrological model via alteration of the Curve Number of the basin model in HEC-HMS. The CN of a watershed can be estimated as a function of land use, soil type, and antecedent moisture condition and using TR-55 tables published by the SCS-USDA. For a watershed that consists of several soil types and land uses, a composite CN is calculated as:

$$CN_{composite} = \frac{\sum(A \times CNi)}{\sum Ai}$$

where,

CNcomposite = the composite CN used for runoff volume computations

i = an index of watersheds subdivisions of uniform land use and soil type

CNi = Curve number for subdivision i and

Ai = the drainage area of subdivision i

The Generate CN grid, part of the Utilities in Geo-HMS toolbar, requires CN composite in shapefile and lookup table to produce a CN grid which can be inputted in the Input Initial Loss Grid option of Subbasin Parameters from Raster tool under the Parameters toolset.

3. Results and Discussion

3.1 Land Use and Land Cover (LULC) Change

The input LULC maps, sourced from the official LULC maps of NAMRIA, utilized in the study were secondary data, thus, validation was not executed as the assumption is that the gathered maps represent the actual ground data. Validation was only implemented to assess the accuracy of the modeled map in comparison with actual ground data. Validation is performed by creating an error matrix of the observed (google earth) and modelled map of 2018 with an overall accuracy of 82.73% and kappa coefficient of 73.11%. The acceptable accuracy rating of the validated map permits modeling of the target 2040 map.

As seen in Figure 3, results of the map projection illustrated that between 2010 and 2040 only two LULC will increase, built-up areas will have the largest increase of 1,042% while closed forest areas will increase by 52.5%. On the contrary, the rest of the other classifications are projected to decrease including open forest (-92.85%), brushland or shrubland (-90.77%), annual cropland (-20.34%), and perennial cropland (-7.9%). It can be inferred that most of the reducti converted into the massive increase in built-up areas. Moreover, the closed forest can also be credited to the watershed environmental protection cooperation in the management of Mount Banahaw which is a protected area in the Philippines. However, if the changes in open and closed forest areas is to be lumped, -2% of the total cover is still expected despite conservation effort of the protected area and the national greening program (NGP). In relation to its hydrological impact, forest cover loss is accompanied by increased stream discharges and surface runoff (Guzha, 2018). Aside from more runoff due to less infiltration, all these changes can lead to degradation of the watershed. Watershed degradation threatens, among many other ecosystem services, the quantity, distribution, and timing of water supply which is vital for human survival and completion of various ecological processes. Its continuous degradation, if remained unchecked, can result to an inevitable water h, & Nouri, 2018)

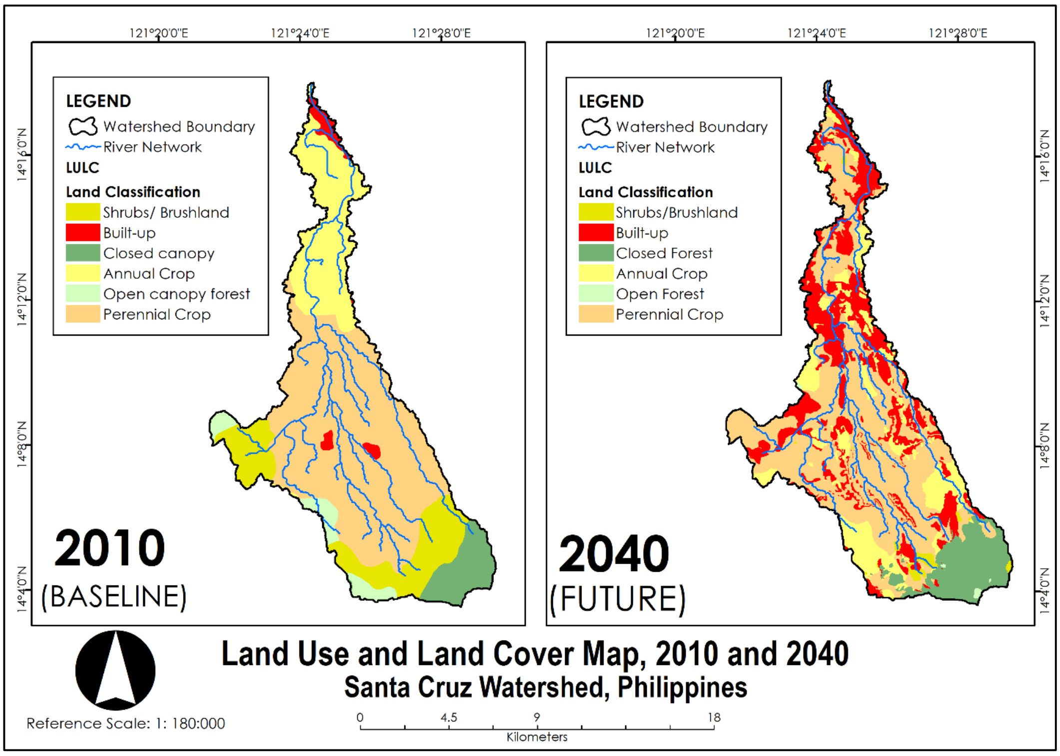

Figure 3. LULC 2010 and 2040 of Santa Cruz Watershed, Philippines

3.1 Hydrological Modeling

3.1.1 Calibrated Model (BAU)

As implemented on the ground, the model was calibrated using a solitary point (tributary) to estimate the runoff volume, peak discharge, and time of concentration of the watershed (BAU) thus, in determining the impact of LULC change similar assumption was made. From this point, where river flow and cross section were measured, it is assumed that the rest of the basin behave similarly or uniformly. For Santa Cruz Watershed, the relative location of the point is before the bridge facing downstream of the Pagsawitan Bridge in the municipality of Santa Cruz.

Table 4. Summary of the Efficiency Test of Sta. Cruz HMS Model

Statistical Validation	**Values**
Root Mean Square Error (RMSE)	3.103
Pearson Correlation Coefficient (R^2)	0.899
Nash-Sutcliffe (E)	0.631
Percent Bias (PBIAS)	-0.206
Observation Standard Deviation Ratio (RSR)	0.608

Figure 4 exhibits the outflow hydrograph of both the observed and simulated discharges. It can be noticed that the simulated hydrograph produced a good fit in comparison with the observed hydrograph. In term of volume, close measurements were gathered with 633.9 (‘000 m^3) and 634.5 (‘000 m^3) for simulated and observed instantaneous flow, respectively with only 0.6 (‘000 m^3) residual. In terms of peak discharge, 19.3 m^3/s and 18.2 m^3/s for simulated and observed can be seen which corresponds to 6% difference only. And last, for time and date of peak discharge, there is a 15 minutes gap between the two with simulated peaking at 11:40 PM and observed at 11:25 PM both on December 14, 2015. The resulting difference between the two hydrographs are considered uncertainties. Nevertheless, statistical efficiency tests or validation of the goodness of fit between the two hydrographs show acceptable results (Table 4).

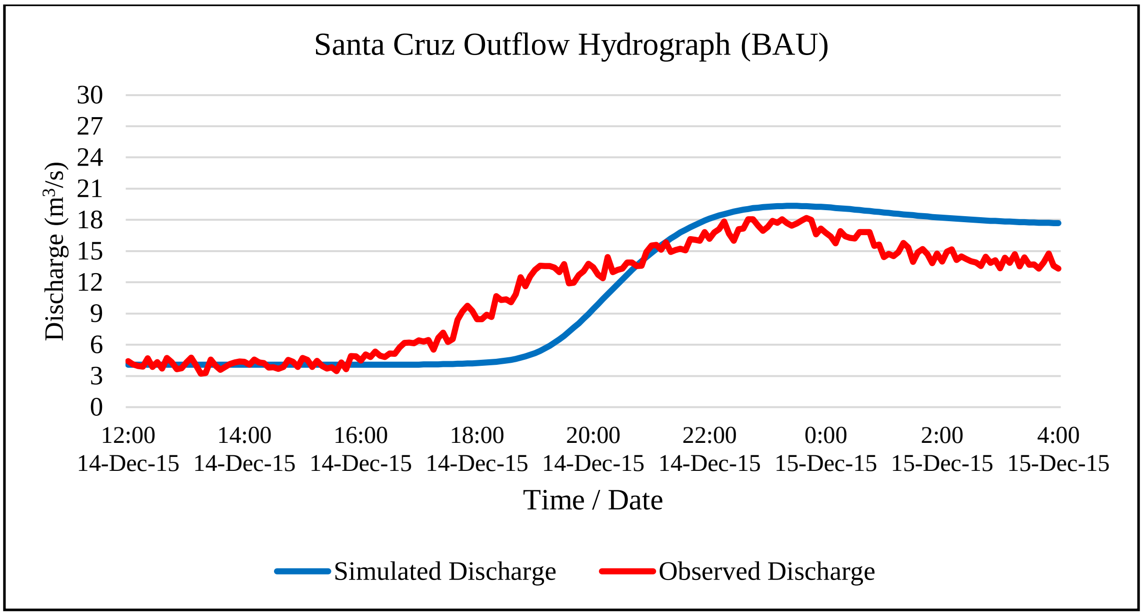

Figure 4. Santa Cruz Outflow Hydrograph for Simulated and Observed Discharges

3.1.2 Impact of LULC Change

The assessment and projection of runoff responses as affected by LULC change were performed by changing the Curve Number (CN) value of the input CN grid (raster file). As shown in the CN Grid Map (Figure 5), the lighter the shade, the higher the Curve Number. This means that higher runoff can be expected from these areas and the likes of built-up areas are commonly situated on them. Between 2010 and 2040, areas with lighter shade gained the highest increase in CN grid which if translated into land classification is the built-up area in the watershed.

Table 5. Runoff Responses as affected by LULC change in Santa Cruz Watershed

LULC	Peak Discharge	Date/Time of Peak Discharge	Volume
LULC 2040	31.0 m^3/s	14Dec2015 / 22:55 (10:55 PM)	982,300 m^3

In comparison with the baseline, under LULC 2040 scenario, both peak discharge and volume increase while time of peak arrives earlier (Table 5). The overall behavior and shape of the two hydrographs are almost similar. However, from the rising limb to peak and potentially to recession, LULC 2040 maintained higher flow discharge compared with that of LULC 2010. The percent increase between baseline and with LULC change for peak discharge is at 61% while for volume is at 55% both parameters. For time of peak, LULC 2040 peaks earlier with 30 minutes differential. Results mean that a higher water level, thus possibly a wider flood extent, and an earlier water level rise or flood event can be expected under the LULC 2040 scenario. This is consistent with the study by Kim et al., (2013) which stated that urban growth intensifies flooding, and by Farokhzadeh, Choobeh, & Nouri (2018) that impervious areas interrupt the natural water balance and decrease infiltration which leads to increase in runoff thus, higher flood peaks.

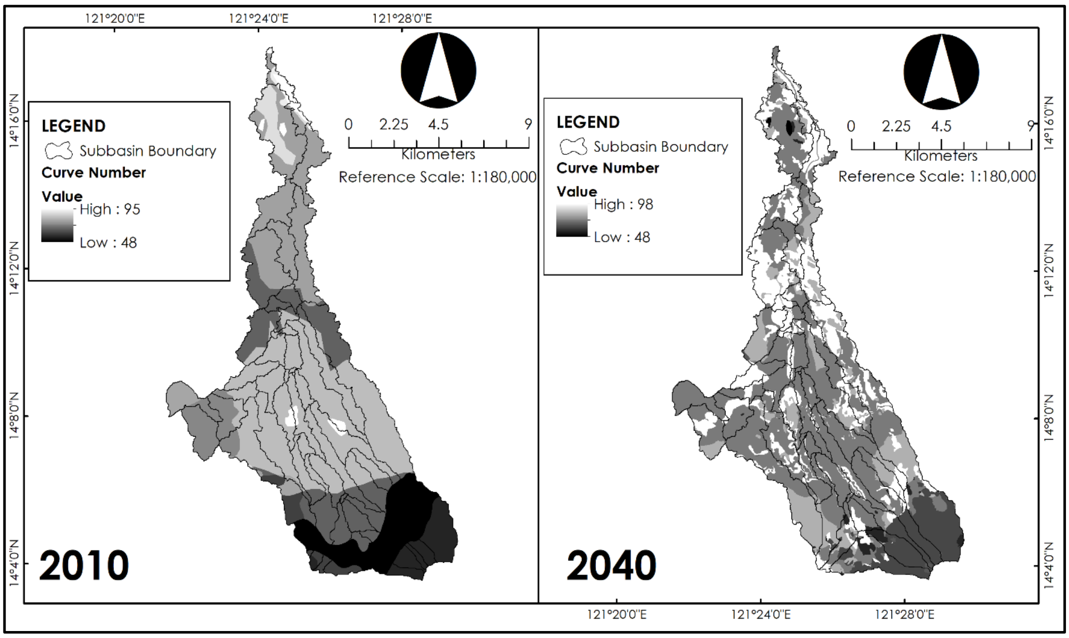

Figure 5. LULC 2010 and 2040 Curve Number Grid Map

4. Conclusion and Recommendation

The decrease in forest cover and the subsequent increase in built-up and agriculture area can affect the timing and quantity of runoff from upstream to downstream. Less forest cover coupled with more impervious areas would mean less interception and infiltration, respectively. This occurrence contributes substantially to higher peak discharge, total instantaneous volume and earlier time of peak. One physical advantage of the watershed is its elongated shape which delays the movement of water from headwater to outlet minimizing the possibility of flashfloods. However, its flat and low elevation downstream prevents the water from receding faster which is manifested by long term flood occurrences downstream of the watershed during typhoon events (i.e. Ondoy).

Result of the study shows that by altering and projecting the LULC in 2040, flooding will be more extreme in the future. Thus, preventive and mitigating measures need to be taken to minimize damage to properties and achieve zero casualty. One way that can contribute to preparedness is through early warning systems. This study took the Phil-Lidar 1 program's calibrated HEC-HMS model (baseline) and extended it by projecting the future LULC condition (LULC 2040) of the Santa Cruz. Output of the study can provide indicative trend with reference to the baseline hazard maps. Moreover, it can also serve as additional baseline information in the formulation of DRRM, water resources management and watershed management plans. Way forward is the creation of flood extent map to identify the communities that will be affected by the possible more extreme future flooding events.

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