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Rainfall and Land Cover Changes Impact on the Hydrologic Responses of Santa Cruz Watershed, Laguna, Philippines

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ABSTRACT

Watershed provides a wide range of ecosystem services. Part of its provisioning services is the quantity, distribution, and timing of water supply. The state of water resources is affected, among others, by rainfall and land use and land cover (LULC) changes. With the Philippines consistently ranking very high in the World Risk Index reports in terms of disaster risks and land use intensification due to continuous growth in population and economic activities; it is crucial and timely to conduct research in relation to its hydrological impacts. This study aimed to detect and project the separate and combined impacts of these changes on the surface runoff responses of Santa Cruz Watershed during a typhoon event using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model. The study was able to identify, and bias-corrected five General Circulation Models (GCM) under Representative Concentration Pathways (RCP) 4.5 and 8.5 storylines to account for the future impact of change in rainfall. Meanwhile, LULC modeling was executed using the Markov chain method to project its 2040 state. Combined impacts revealed a certainty that peak discharge and total volume will increase, and the time of peak will be earlier than the baseline model for both RCP 4.5 and 8.5 scenarios. The output of the study can serve as a vital input in crafting evidence-based policy and decision-making in relation to watershed planning and management.

Keywords: *General Circulation Models (GCMs), Representative Concentration Pathways (RCPs), Land Use and Land Cover (LULC), HEC-HMS, surface runoff responses*

INTRODUCTION

Flood is considered one of the most destructive and widespread natural disasters (*Cabrera and Lee 2019; Danumah et al. 2016*). The Philippines is one of the most flood-prone countries in the world (*Badilla et al. 2014*) ranking third on the World Risk Index with a risk percentage of 27.98% due to the multitude of natural disasters that ravaged the country annually (*UNU-EHS 2015*). Climate change and land cover change, among others, are known to exacerbate the problems of flooding (*Talib and Randhir 2017*). Changes in both factors play important roles in the modification of flow regimes and the availability of water (*Yin et al. 2017*). Climate change is expected to bring varying weather and rainfall patterns at increasing frequency and intensity (*Arias 2016*) while land conversion alters the watershed's hydrological characteristics, among other impacts of urban development, with a significant impact on peak discharges, volume, and frequency of floods (*Ficklin et al. 2009; Franczyk and Chang 2009*).

Measurement of precipitation is listed as the most vital meteorological input for forcing and calibrating hydrological and ecological models (*Sun et al. 2018*). For this research, global climate models particularly the coordinated climate model experiments known as Coupled Model Intercomparison Project (CMIP5), were used to project the probable impact of change in rainfall in the watershed. CMIP5 developed a standard set of model simulations to evaluate the accuracy of the models in the past and provide estimates of future climate change, among others (*Taylor et al. 2011*). Moreover, its model simulations provided climate information and knowledge to international assessments of climate science (IPCC's AR5 and beyond). Change in global precipitation patterns alters the global water cycle which resulted in the temporal and spatial redistribution of water resources (*Yin et al. 2017; Murray et al. 2012; Milly et al. 2005*). In terms of extreme precipitation events, on the global scale, for each 1°C of global warming, there is high confidence that extreme daily precipitation events will intensify by about 7%, and the proportion and peak wind speed of intense tropical cyclones (Category 4–5) to increase (*IPCC 2021*). In the Philippines where precipitation extreme indices show distinct spatial variability, projected changes indicate a general drying trend with the occurrence of localized extreme rainfall wet spots. Moreover, in terms of maximum one-day rainfall, portions of Luzon are projected to increase by 15 mm and 30 mm under RCP 4.5 and RCP 8.5 early future scenarios (2020-2039), respectively, from its 180 mm upper limit baseline observation (*PAGASA 2021*). While excessive rainfall is considered the primary cause of flooding (*Kim and Kim 2014*), land use and land cover change can easily affect runoff through the alteration in soil properties and surface roughness (*Schilling et al. 2010*). Aside from runoff, LULC change affects water partitioning among hydrological pathways including interception, evapotranspiration, and infiltration (*Sterling et al. 2012*). Overall, there is a universal recognition that whether separated or combined, climate and LULC changes play significant roles in the alteration of the runoff process.

The threats of the adverse impacts of environmental changes led to various researches about the dynamics between hydrological systems and changes in both climate and land use and land cover. *Pan et al.* (*2017*) combined the SWAT model, Quantile Mapping (QM) method, and CA-Markov model to investigate runoff responses to climate and LULC changes in Beijing River Basin, China. *Li et al.* (*2018*) found that the combined effects of land use change and climate variability decreased runoff, soil water contents, and evapotranspiration in an agricultural catchment on the Loess Plateau of China using the SWAT model. *Chawla and Mujumdar* (*2015*) reported that runoff was influenced by climate change and was sensitive to change in urban areas in the upper Ganga Basin, based on the Variable Infiltration Capacity (VIC) model. *Karlsson et al.* (*2016*) compared three hydrological models (NAM, SWAT, and MIKE SHE) to evaluate the sensitivity of results to the choice of hydrological model as well as to determine the combined effects of land use and climate changes in the hydrology of a catchment in Denmark. In the Philippines, though hydrologic modeling studies are still limited, several have explored the relationship between rainfall and LULC with various hydrologic processes using various computer-based models (e.g., *Alibuyog et al. 2009; Combalicer and Im 2012; Principe 2012; Hernandez et al. 2012; Pati et al. 2014; Briones et al. 2016; and Boongaling et al. 2018*). The significant findings of these local studies emphasize the wealth of knowledge that can be harnessed through research even with the country's sparsely available hydro-meteorological historical database. It also entails hydrologic modeling as a powerful tool to simulate the effect of watershed processes on both soil and water resources (*Sajikumar and Remya 2014*).

Despite the growing number of research related to climate and LULC changes, a significant number of cases assumed that LULC is static between two time periods which could lead to bias in model parameters during calibration (*Talib and Randhir 2017*). Hence, this study attempted to link dynamic land use modeling and bias-corrected rainfall projections to derive insights into the sensitivity of the hydrologic responses of the already-developed hydrological rainfall-runoff model (HEC-HMS) published by the PHiL-LIDAR 1 Program in the Santa Cruz Watershed to future separate and combined changes in rainfall and LULC during a single storm event in the year 2040.

MATERIALS AND METHODS

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 within the Mount Banahaw-San Cristobal Protected Landscape (MBSCPL). Its hydrologic elements include 43 sub-basins, 43 reaches, and 22 junctions (*Paringit and Abucay 2017*). 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 2011*). The watershed is characterized by mostly 3-8% sloping. It has ten soil classes with Lipa loam being the most dominant. Based on the Modified Coronas Classification of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), it has a Type III climate that has no pronounced maximum rain period with a dry season lasting only from one to three months, either from December to February or March to May. According to Mines and Geoscience Bureau (MGB), the Santa Cruz River Basin is generally classified to be highly susceptible to flooding and has areas with both low and high susceptibility to landslide.

Bias Correction of Rainfall Data

To analyze the impact of change in rainfall, collectionand analysis of past and future rainfall data are

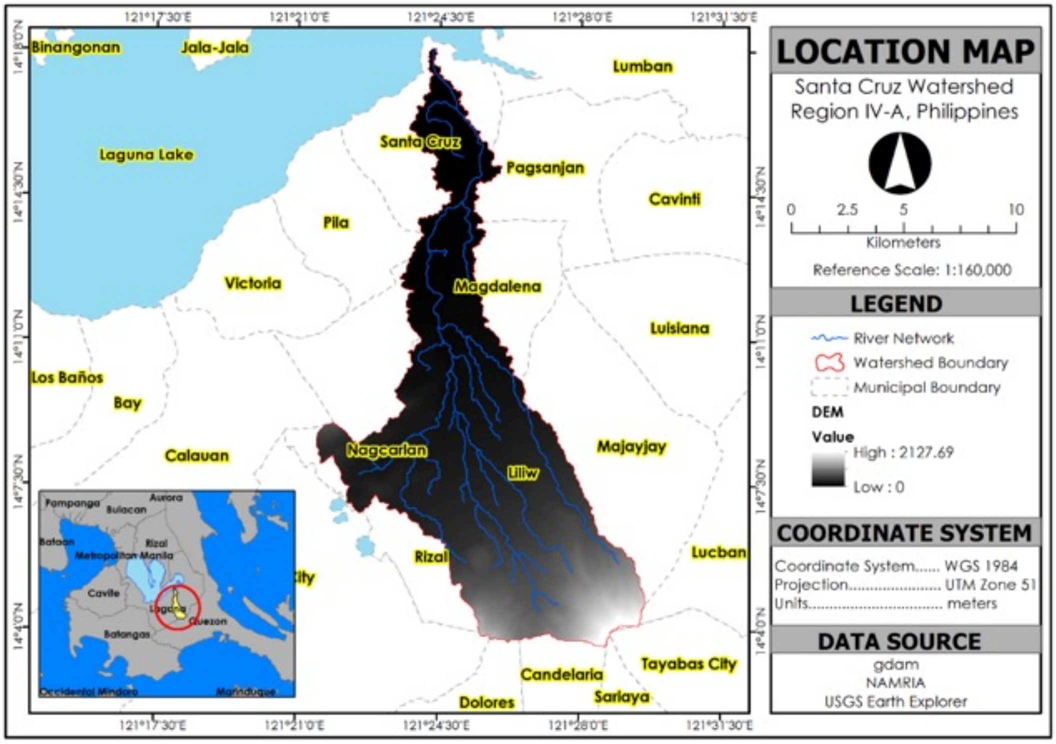

Figure 1. Location map of Santa Cruz Watershed, Philippines.

required. Primary climatological data that were used in the study were acquired from the Data Integration and Analysis System (DIAS) server which is developed by the Earth Observation Data Integration and Fusion Research Initiative (EDITORIA) of the University of Tokyo. Data collected from DIAS web-based database are Coupled Model Inter-comparison Project 5 (CMIP5) GCM gridded daily precipitation data wherein 1981-2000 is the defined control period and 2040-2059 as the projected period, under the RCP 4.5 and 8.5 emission scenarios. Available ensemble models were trimmed down by specifying the variables, experiment, and frequency, among other user-defined parameters, in the database.

After gathering and preprocessing the data, bias correction was executed. Basin-scale climate change impact studies mainly rely on general circulation models (GCMs) with various emission scenarios but bias in GCMs should be removed first before using it for regional or local scale circulation studies. This step is required to achieve a more realistic output. Realistic representation of precipitation fields in future projections from climate models is crucial for impact and vulnerability assessment.

Embedded in the DIAS online platform, upon setting several user-defined parameters, a feature for CMIP5 analysis involves automatically performing bias correction on selected files from the CMIP5 data viewer window. This capability was utilized to execute precipitation data bias correction in the study area. According to *Jaranilla-Sanchez et al.* (*2013*), bias correction of the precipitation data in the web-based platform was executed in three steps. The first step is the truncation of rain or no rain days using a cumulative ranking of the no rain days from observed data which is translated on the ranking; followed by the fitting of a monthly factor using observed climatological average and lastly, plotting position of the highest values for each year considered to correct extreme values. As noted in the output file, the detailed bias correction method was based on *Nyunt et al.* (*2013*). The output of the bias correction procedure particularly the difference between the control and projected rainfall data of the resultant model ensembles were compared with gridded APHRODITE data by root mean square error (RMSE) calculation to account for model ensembles' uncertainties. Models with complete datasets from historical to projected (RCP 4.5 and 8.5 GHG emission scenarios) were used in the study. Downloaded historical data were corrected by conducting linear regression of observed data from University of the Philippines Los Baños Agrometeorological Station in Los Baños, Laguna.

Land Use and Land Cover Change Detection

The research design of the land use and land cover change component of the study utilized the land cover change modeling process and output conducted by

Magpantay et al. (*2019*). As most of the research related to LULC change impacts assumed that land use is static between two time periods, which commonly leads to bias in model parameters during calibration (*Talib and Randhir 2017*), this research explored the incorporation of dynamic changes in LULC within the framework of the hydrologic model as recommended and implemented by several studies.

For change analysis, LULC data were sourced from the National Mapping and Resource Information Authority (NAMRIA). This is the government agency responsible for providing mapmaking services and related information for the public in the Philippines. Among the driver variables for LULC are DEM, slope and distance (**Table 1**). These factors are weighted equally important and are limited to open-sourced data only. The varying and often difficulty in identification and quantification of drivers of LULC change is said to be a manifestation of the complex and diverse interactions in the socio-ecological systems (*Ostrom 2009*). Since there is no generally recognized and established analytical framework of driving forces for LULC change *(Li et al. 2018*), holistic approach is necessary in the conduct of driver analysis with focus on its direct and indirect influences.

After land change analysis, transition potential modeling was executed using the Land Change Modeler (LCM) feature of the Terrset™ software. Multi-layer perceptron neural network (MLPNN) was utilized as a transition modeling method to integrate the causal factors to determine the pixels that are more likely to transform from one land use to any other classification. The MLPNN method's ability to integrate the explanatory variables of land change into one sub-model without much human intervention lessens the possible error due to human interference with the process (*Eastman 2016*). For future projection, Markov Chain analysis was implemented. This is a predictive change modeling technique that can model future changes based on past changes by computing the probability that a pixel will change from one LULC type to another within a specified period (*Eastman 2016*). Thegenerated output of the process includes soft and hard prediction maps of the possible future LULC of the watershed based on the same transition rate between LULC 2010 to 2015 together with the identified explanatory variables. Lastly, the confusion matrix and kappa index were computed to assess the accuracy of the classification and ensure the validity of the future LULC map projection.

Mapping was executed using ArcGIS software. ArcGIS® is a geographical information system (GIS) software developed by ESRI built on industry standards that provides exceptional and user-friendly capabilities (*ESRI 2003*).

Hydrologic Modeling using HEC-HMS

Hydrologic Engineering Center-Hydrological Modeling System or HEC-HMS, a public domain program developed by the US Army Corps of Hydrologic Engineers' research and development program and produced by the Hydrologic Engineering Center (HEC), is the physically based and semi-distributed model used in this study. It is designed to simulate precipitation-runoff processes of dendritic watershed systems and is applicable in a wide range of geographic areas for solving an equally large array of problems (*USACE 2013*).

The data and its respective sources utilized to simulate the projected separate and combined impacts of rainfall and LULC changes to the calibrated flood model of the UPLB Phil-LIDAR 1 is part of the Phil-LiDAR 1 or Hazard Mapping of the Philippines using LiDAR Program (**Table 2**). The detailed output of the program was published by *Paringit and Abucay* (*2017*). The model served as the baseline condition in the investigation of the separate and combined impact of rainfall and LULC changes on runoff responses in the Santa Cruz Watershed. The spot measurement was conducted on December 14, 2015, at the Pagsawitan Bridge in the municipality of Santa Cruz. Other major inputs are divided into static and dynamic data. Dynamic data includes the bias-corrected rainfall data and modeled land use and land cover data of 2040.

Table 1. Driver Variables for LULC Modeling of Santa Cruz Watershed, Philippines.

Category	Driver	Unit	Source
Topography	DEM	meters (m)	Earth explorer, USGS
	Slope	percent (%)	Derived from DEM
	Distance from built-up	meters (m)	Openstreetmap (OSM)
Spatial Context	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

Table 2. Data requirements for hydrological modeling of Santa Cruz Watershed, Philippines.

Category	Data	Source
Static Data	Soil Data	FAO, BSWM
	SAR DEM	NAMRIA
Dynamic Data	Rainfall	DIAS
	LULC 2010	NAMRIA
	LULC 2040	generated using LCM
Calibrated Model	Flood model	*Paringit and Abucay (2017)*

The LULC change was incorporated in the hydrological model via alteration of the Curve Number which represents the change in the loss of the model in HEC-HMS. Curve Number was used because it is a simple, predictable, and stable method for estimating precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture using tables (TR-55) published by SCS-USDA (*USACE 2000*). The Generate CN grid tool, 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.

RESULTS AND DISCUSSIONS

Rainfall Pattern Change

Bias correction of past and future CMIP5 GCMs was initially executed to investigate the hydrological impact of rainfall pattern change in the hydrology of the Santa Cruz watershed. CMIP5 was used because according to the IPCC AR5 report, it is the most recommended GCM that has become available to the scientific community (*Brands et al. 2013*). For future precipitation projection, RCP 4.5 & 8.5 GHG emission scenarios were utilized in line with the latest PAGASA's local climate projection study in 2018. In addition, RCP 4.5 and 8.5 were considered because the scenarios exemplify moderate level of GHG emissions and high level of GHG emissions or urbanizing scenarios, respectively. In the end, in terms of rainfall change trend analysis in relation to watershed hydrology, the study attempts to harmonize the global dataset with local conditions and scenarios (i.e., RCP GHG emissions scenarios) set by the government so that it can be useful or be smoothly integrated with local or watershed level plans.

Bias Correction. Data downloaded from DIAS web-based database includes CMIP5 model ensembles for daily precipitation for 1980-2000 (historical/ control period) and RCP 4.5 and 8.5 future GHG emissions scenarios (2040-2059). Specifically, 19 CMIP5 model ensembles for daily precipitation for 1980-2000 (historical/ control period) and 11 model ensembles for RCP 4.5 and 8.5 future GHG emissions scenarios (2040-2059) with similar specifications were downloaded and clipped to the area of interest. Data downloaded includes both pre- and post-bias correction datasets of all the available model ensembles for the area chosen.

Root mean square error (RMSE) which calculates the standardized size of error was computed for APHRODITE (observed/reference) and outputs of each model ensemble. Results show that MIROC5@r3i1p1 (9.89) and MIROC5@r1i1p1(14.9) have the smallest RMSE values which means that these two outputs, in terms of RMSE only, exhibit the closest rainfall estimate in the region of interest. This information is vital because it exhibits the ability of a specific model ensemble to represent the real and observed past data, therefore higher confidence that it can also provide a more realistic estimate of future precipitation projection.

The historical model ensembles have both RCP 4.5 and RCP 8.5 counterparts together with their corresponding RMSE (**Table 3**). The climate model ensembles used in this study are primarily divided into three models namely MRI-CGCM3, NorESM-1M, and three different MIROC5 experiments.

MRI-CGCM3 is developed by the Meteorological Research Institute (MRI) as the model upgrade of the institute's former climate model MRI-CGCM2 series and a subset of MRI's earth system model MRI-ESM1(*Yukimoto et al. 2012*). Meanwhile, NorESM1-M is the core version of the Norwegian Climate Center's Earth System Model. The model is largely based on the Community Climate System Model version 4 (CCSM4) of the University Corporation for Atmospheric Research (*Bentsen et al. 2013*). And last, MIROC5 is the newest version of the atmosphere-ocean general circulation

Table 3. Model ensembles with a complete dataset for Santa Cruz Watershed, Philippines (Historical, RCP 4.5, and RCP 8.5).

Model Ensembles	RMSE
MIROC5@r3i1p1	9.89
MIROC5@r1i1p1	14.99
MRI-CGCM3@r1i1p1	18.77
MIROC5@r2i1p1	20.73
NorESM1-M@r1i1p1	25.54

model, known as the Model for Interdisciplinary Research on Climate (MIROC), produced by the Japanese research community with a standard resolution of the T85 atmosphere and 18 ocean models (*Watanabe et al. 2010*). The difference among r3i1p1, r2i1p1, and r1i1p1 is that the realized scenarios of the different simulation run of the same GCM.

In the end, the study was limited to model ensembles with a complete historical and future dataset. This is because the study attempts to analyze both the spatial and temporal impact of climate change which would only be possible if both past and future data is available.

LULC Change

As it is considered a dynamic variable, change prediction involving two time-period (2010 and 2015) LULC data and aided by several explanatory variables was executed to model the year 2040.

To test the fit of change analysis and the identified explanatory variables with actual ground data, a validation map of the near future (2018), with reference to the input LULC, was created first. Based on the error matrix of the observed (google earth) and modeled map of 2018, the overall accuracy is at 82.73% and a kappa coefficient of 73.11% (**Table 4**). The rating is considered an acceptable accuracy rating hence the permission to use the model for the 2040 target future LULC map projection.

Findings revealed that between 2010 and 2040, a 30-year period difference, two LULC categories are expected to increase massively while the rest will be reduced due to the projected land reallocation (**Figure 2**). Built-up areas will have an annual increase rate of 8.45% while closed forests will expand by 1.42% yearly. Consequently, open forest (-8.42%), brushland or shrubland (-7.64%), annual cropland (-0.76%), and perennial cropland (-0.27%) were anticipated to exhibit these annual declines.

As the population is expected to grow in the future, massive land conversion to urban uses (built-up areas) is generally expected. However, it is also a subject of concern considering that land conversion to impervious surfaces affects watershed hydrology. Lessening the mentioned concern is the positive increase in closed forest cover. Efforts within and around the protection and management of the MBSCPL play a pivotal role in the maintenance of the upstream portion of the watershed. However, despite these efforts, forest loss is still evident within the watershed as exemplified by the likely decrease in open forests in the future. Forest loss coupled with unregulated land-use conversion often leads to water source stress or if remained unchecked, watershed degradation. Forest loss, among others, leads to increased stream discharges and surface runoff (*Guzha 2018*) while watershed degradation has a high probability of leading to an inevitable water crisis in the future (*Farokhzadeh et al. 2018*).

Separate and Combined Impacts to Run-off Responses of Santa Cruz Watershed

Four scenarios including business-as-usual (BAU),

Table 4. Error matrix of land use/land cover classification in Santa Cruz Watershed, Philippines, 2018.

Land Cover	Annual Crop	Built-up	Brushland	Perennial Crop	Open Forest	Closed Forest	Total	CE	UA
Annual Crop	29	3	0	2	0	1	35	15	82.86
Built-up	4	18	0	5	0	0	27	22.5	66.67
Brush-land	1	0	7	2	0	0	10	7.5	70.00
Perennial Crop	12	3	0	123	5	2	145	55	84.83
Open Forest	0	0	0	0	8	2	10	5	80.00
Closed Forest	0	0	1	0	0	21	22	2.5	95.45
Total	46	24	8	132	13	26	249		
OE	36.96	25.00	12.50	6.82	38.46	19.23		**OA**	82.73
PA	63.04	75.00	87.50	93.18	61.54	80.77		**CK**	73.11

* CE -Commission Error; UA – User's Accuracy; OA- Overall Accuracy; CK- Cohen's Kappa; OE- Omission Error; PA – Producer's Accuracy

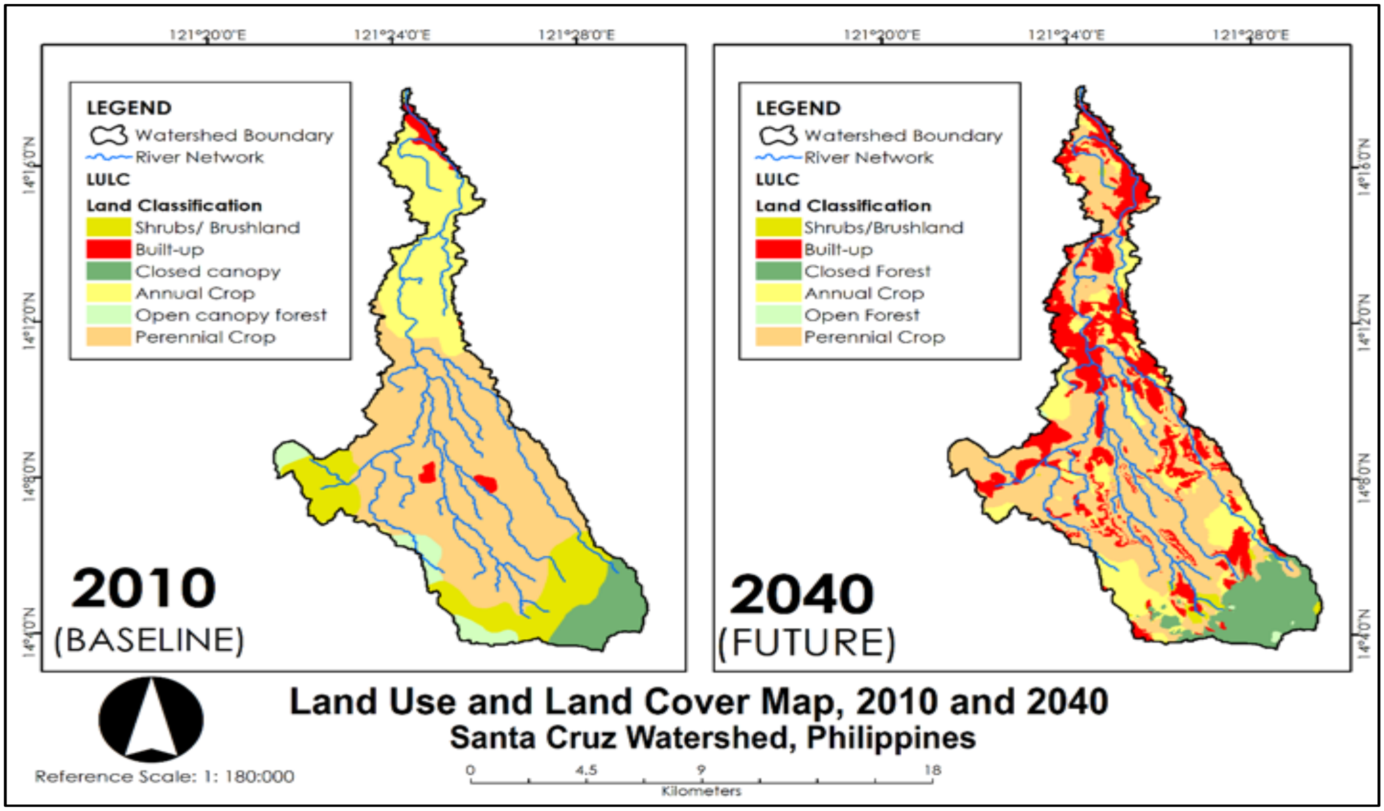

Figure 2. Land use/land cover 2010 (baseline) and 2040 (future) of Santa Cruz Watershed, Philippines.

change in rainfall pattern only, change in LULC only, and combined rainfall and LULC changes were investigated to determine its future (2040) separate and combined impacts to the run-off responses of Santa Cruz Watershed during a single storm event.

Calibrated Model (BAU). Observed flow, gathered from spot measurement, generated 634.5 (‘000 m^3) volume, peak discharge of 18.2 m^3 s^{-1}, and time of peak at 11:25 PM. On the other hand, simulated flow yield 633.9 (‘000 m^3) volume, peak discharge of 19.3 m^3 s^{-1}, and time of peak discharge at 11:40 PM (**Figure 3**). Through visual inspection, a good fit between the simulated and the observed can be inferred. This is supported by the numerical figures produced by the two hydrographs. The simulated and observed flow had 0.6 (‘000 m^3) residual volume, 6% (1.1 m^3 s^{-1}) difference in peak discharge, and a 15-minute gap in time of peak. The minimal difference in measured parameters of observed and simulated flow are considered uncertainties. Upon validation of goodness of fit, with a Root Mean Square Error (RMSE) of 3.103 and Nash-Sutcliffe (E) value of 0.631, the model produced statistically sound and acceptable results (*Paringit and Abucay 2017*). The full report regarding the calibrated model of Santa Cruz Watershed is published by *Paringit and Abucay* (*2017*) under the PHiL-LiDAR 1 program.

Impact of Rainfall Pattern Change. Under the RCP 4.5 GHG emissions scenario (**Figure 4**), two models (MIROC5@r1i1p1 and MIROC5@r2i1p1) displayed lower peak discharge, less total volume, and later time of peak for the former and same with the baseline time of peak, for the later model. On the contrary, the three remaining models exhibit higher peaks, more total volume, and earlier time of peak. Among the 5 models, MIROC5@r3i1p1 demonstrated the biggest change with 89% and 81% increase in peak discharge and total volume, respectively. On the other hand, MIROC5@r2i1p1 shows the least change from the baseline with identical time of peak and 1% change in both peak discharge and total volume.

Under the RCP 8.5 GHG emission scenario (**Figure 5**), only one model (MIROC5@r2i1p1) exhibited a very minimal negative difference with baseline mirroring all its resultant values from under RCP 4.5 scenario. The rest of the models display an increase in peak discharge volume and total volume which corresponds to earlier time of peak. The models from both scenarios that show a decrease in peak discharge volume and total volume leading to a later time of peak means that in the future, less rainfall volume can be expected during rainfall events (typhoon event or habagat), which consequently means that the probability of recurrence would increase or be more frequent. On the contrary, more models exhibit an increase in peak discharge volume, total volume and earlier time of peak which means that more intense typhoons leading to more

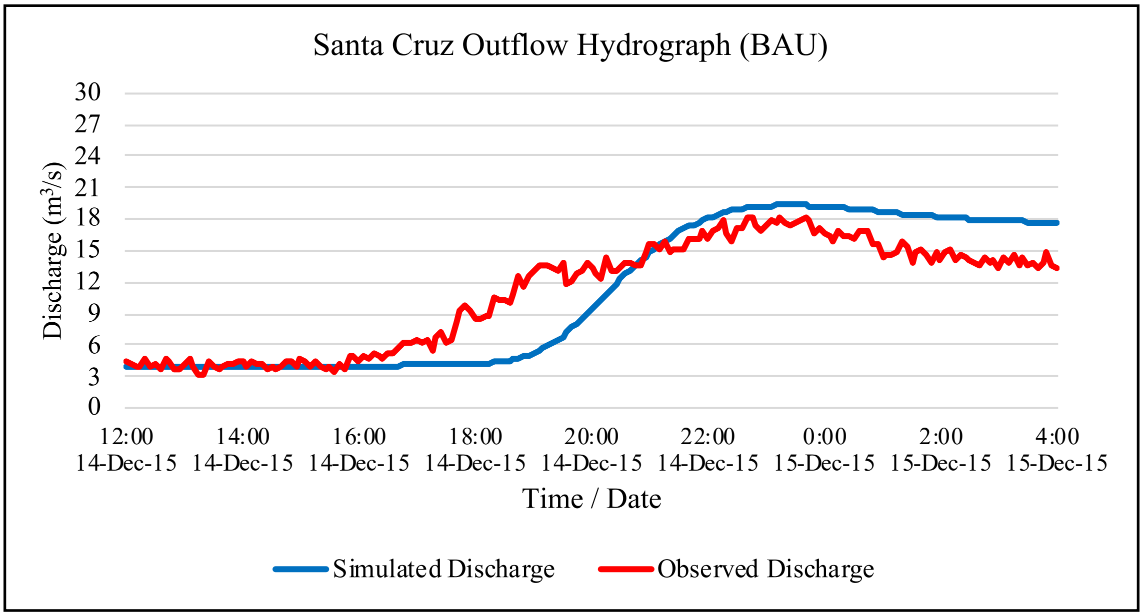

Figure 3. Outflow hydrograph for simulated and observed discharges of Santa Cruz Watershed, Philippines.d

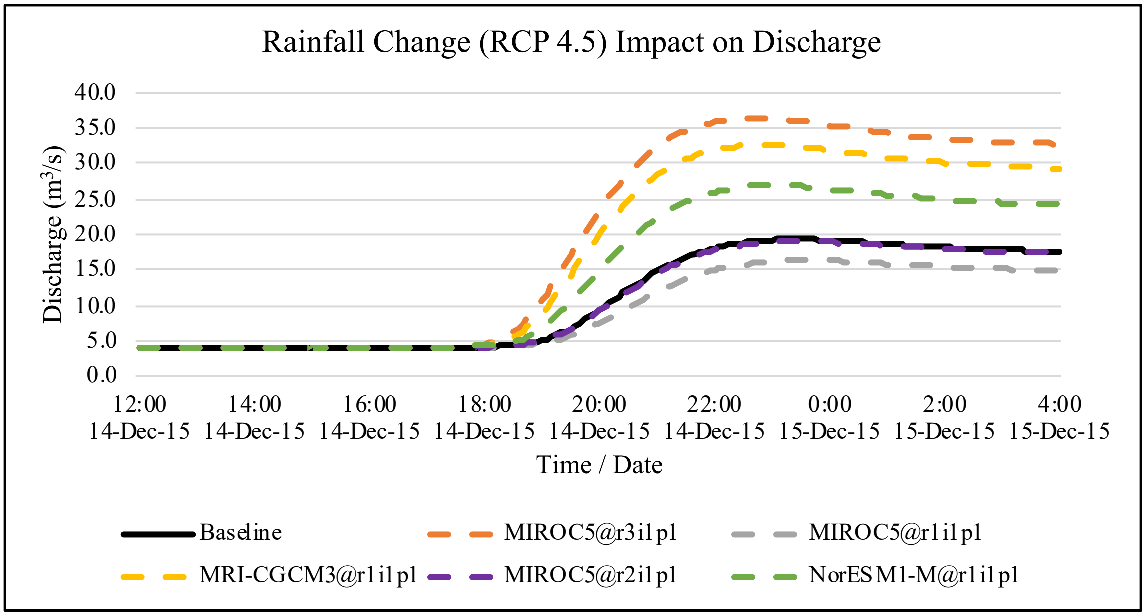

Figure 4. Rainfall change under RCP 4.5 scenario impact on discharge of Santa Cruz Watershed, Philippines.

flood occurrences can be expected in the future. And since rainfall is the only variable changed, earlier time of peak can be attributed to more rainfall volume (more discharge volume) which will consequently overflow the riverbanks and inundate the floodplains at a faster rate. Faster increase in the hydrograph could indicate flash floods or a sudden increase in the volume of water which can put affected communities in danger if not warned and if no appropriate actions are implemented.

Impact of LULC Change. For the separate impact of LULC change to run-off responses of Santa Cruz Watershed, the Curve Number (CN) value of baseline year (2010) and projected future (2040) were generated and compared. CN value is directly proportional to rainfall-run-off volume. Higher runoff (CN value) can be expected from built-up areas (lighter gray shade) which represent impervious areas (**Figure 6**). Moreover, it is noticeable in the map that almost the entire watershed will experience higher run-off in the future based solely on altering the LULC component of the CN formula.

Projected LULC 2040 data exhibited 61% higher peak discharge, 55% more volume, and 30 minutes earlier

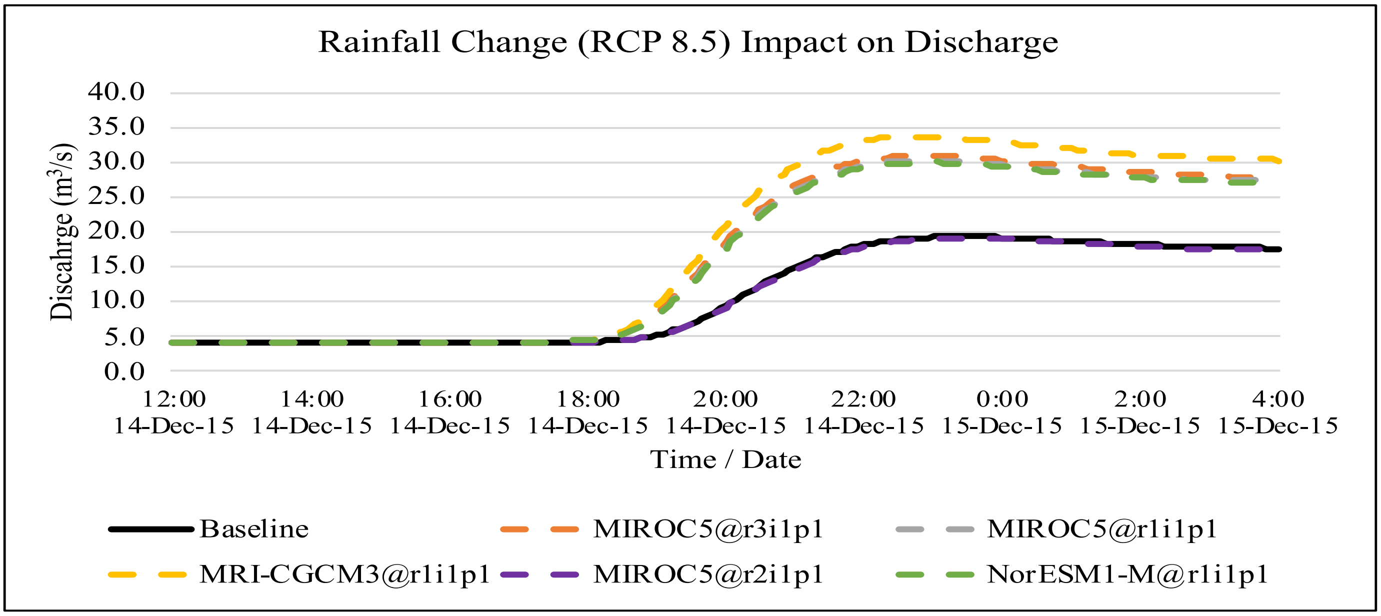

Figure 5. Rainfall change under RCP 8.5 scenario impact on discharge of Santa Cruz Watershed, Philippines.

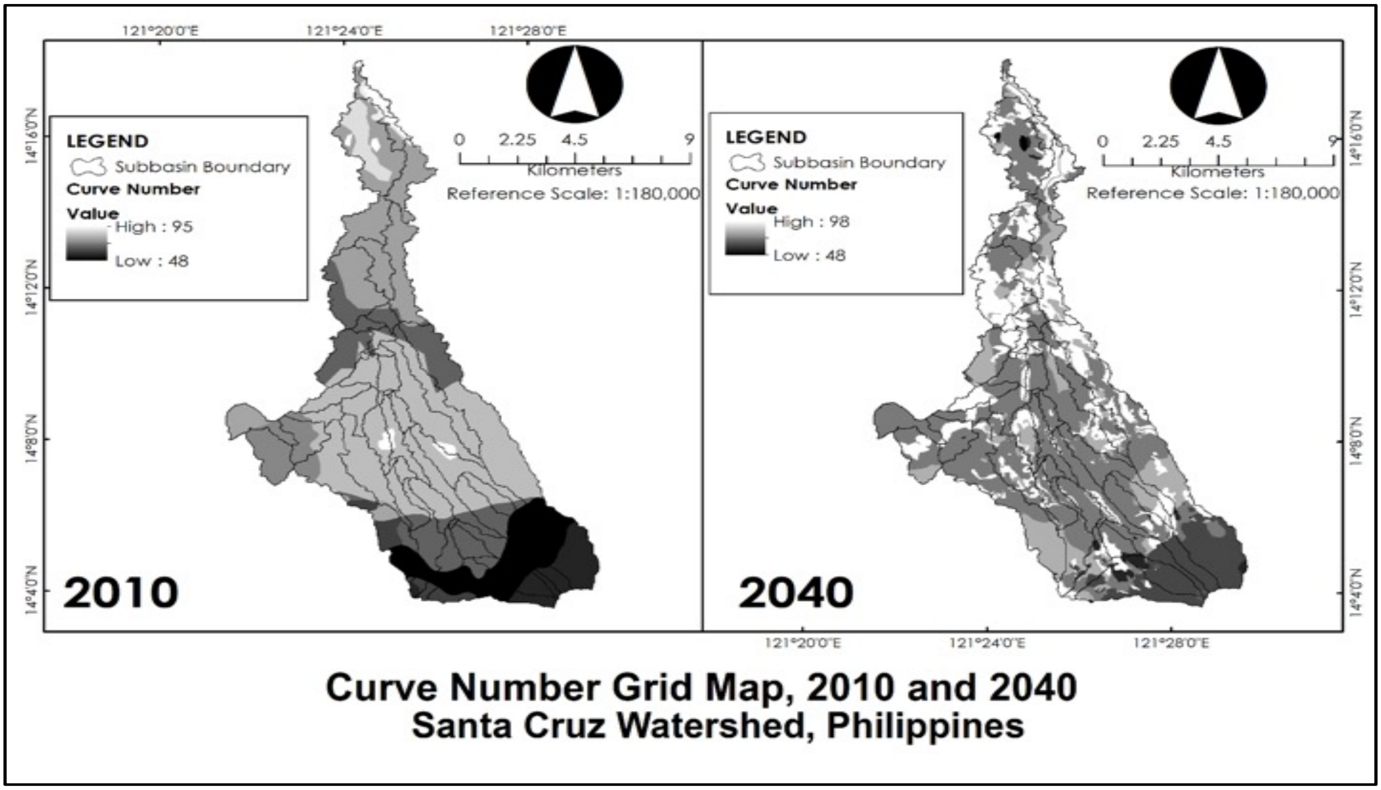

Figure 6. Land use/land cover 2010 and 2040 Curve Number Grid Map of Santa Cruz Watershed, Philippines.

time of peak as compared to LULC 2010 (**Table 5**). From this result, it can be inferred that the behavior of the two hydrographs are relatively similar in the beginning but deviates in the middle (peak) towards the end (recession) wherein LULC 2040 yields higher discharge than LULC 2010. Under the LULC 2040 scenario, higher flood peak with the potential of wider extent can be expected at a faster time gap from the beginning of a storm event. The LULC conversion to urban uses predicted to occur in

Table 5. Comparison of Runoff Responses as affected by Land use/land cover change in Santa Cruz Watershed, Philippines.

LULC	Peak Discharge	Date/Time of Peak Discharge	Volume
LULC 2010	19.3 m^3 s^{-1}	14Dec2015 / 23:25 (11:25 PM)	634,500 m^3
LULC 2040	31.0 m^3 s^{-1}	14Dec2015 / 22:55 (10:55 PM)	982,300 m^3

the watershed plays significant role in these hydrological changes. It was mentioned in literatures that alterations of watershed's hydrological characteristics, among other impacts of urban development, significantly impact peak discharges, volume, and frequency of floods (*Ficklin et al. 2009; Franczyk and Chang 2009*).

Combined Impacts of Rainfall and LULC changes. Rainfall and LULC change, though are equally important to be viewed in a separate perspective, have an intertwined relationship that change in one variable has a high chance of affecting the other. Strictly by just using the five models as reference, there is a 100% certainty that peak discharge and total volume will increase, and the time of peak will be earlier in comparison with the baseline model ffor both scenarios: RCP 4.5 (**Figure 7**) and RCP 8.5 (**Figure 8**).

Under RCP 4.5 scenario, MIROC5@r3i1p1 exhibits the highest increase with 141% and 130% in peak discharge and total volume, respectively. Consequently, it has the earliest time of peak (10:30 PM) which means that under this model's storyline, it will only take 6 hours and 5 minutes for the hydrograph to peak as compared

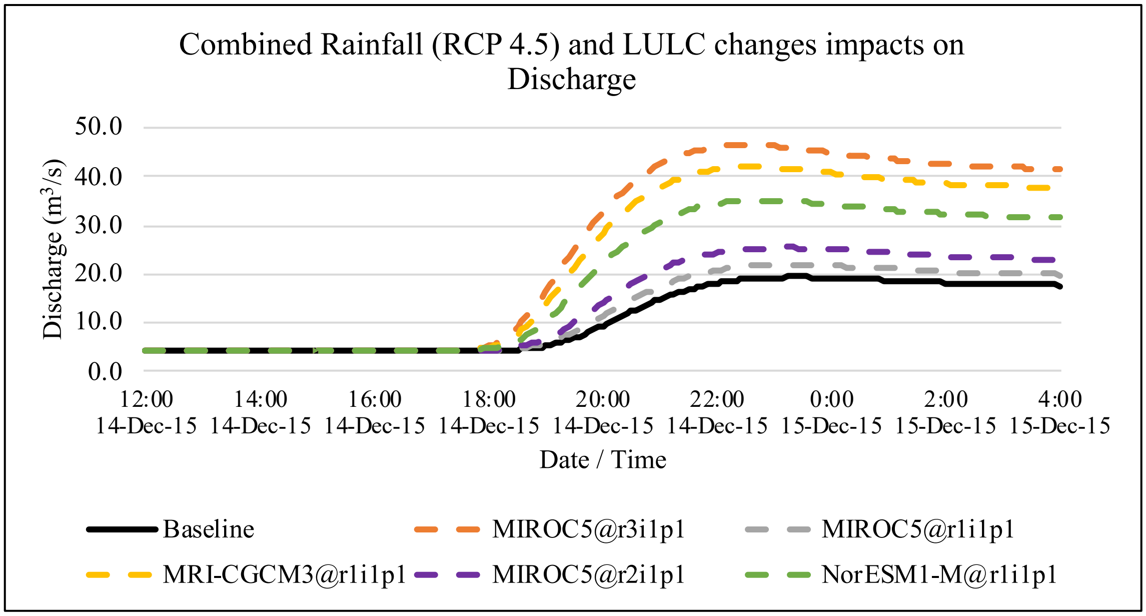

Figure 7. Combined impacts of rainfall (RCP 4.5) and land use/land cover changes on discharge of Santa Cruz Watershed, Philippines.

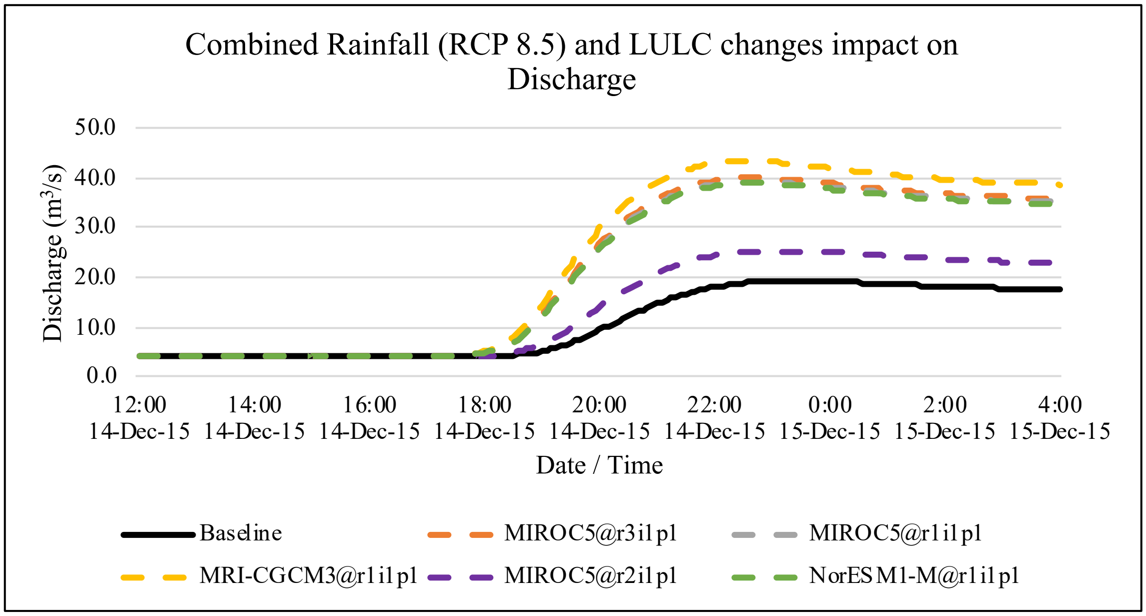

Figure 8. Combined impacts of rainfall (RCP 8.5) and land use/land cover changes on discharge of Santa Cruz Watershed, Philippines.

to the baseline which peaks after 6 hours and 55 minutes of an event. Under RCP 8.5 scenario, MRI-CGCM3@r1i1p1 has the highest increase in peak discharge and total volume with 124% and 114%, correspondingly. Subsequently, it has the earliest time of concentration (peak) among the models under the scenario at 10:35 PM which is 50 minutes earlier than the baseline condition.

The increase in volume and earlier time of peak, as compared with the baseline as well as the separate impact of rainfall and LULC changes, can be attributed to their cumulative impacts. The combination either increase the magnitude of impact through more pronounced change or neutralized the impacts because the impacts were acting in the opposite direction. Examples of this are MIROC5@r1i1p1 and MIROC5@r2i1p1 rainfall change model scenarios which when analyzed under rainfall change impact only exhibit a decreasing trend in all parameters measured but reversed to an increasing trend when coupled with the future LULC condition. This means that although, in some models, there is a decrease in total discharge primarily caused by decrease in total rainfall volume, when combined with a future LULC with increased impervious areas, it will still yield more runoff than the baseline. The LULC change (towards more impervious areas) negates the decline in total rainfall. This highlights the fact that increased socio-economic activities in the land or development, if not properly managed, gravely impact the runoff volume and increase possible occurrence of flash floods. Likewise, it emphasized the huge contribution of LULC changes in the hydrological responses of the watershed, especially during an extreme rainfall event. Nonetheless, change in the hydrological responses brought by rainfall and LULC changes, though can contribute significantly, are not the only determinants of disasters brought by strong rainfall events. Communities' exposure, vulnerability, and adaptive capacity are all accounted in disaster risk assessment and management. This information is also vital as it contributes to early warning strategies improving communities' adaptive capacity thus, increasing affected communities' resiliency.

CONCLUSIONS AND RECOMMENDATIONS

In anticipation of the threats and changes brought by climate and land use/land cover changes which will ultimately affect the ability of the local communities to adapt and respond to extreme rainfall events, the study was able to detect and project the separate and combined impacts of rainfall and LULC changes on the quantity, distribution, and timing of its discharge in the Santa Cruz Watershed. Findings indicated that flooding in the watershed will be more extreme in the future. It is projected that the total volume of rainfall will increase and that impervious surfaces will increase while the vegetation cover will decrease due to population growth and development in the area. These will affect infiltration and interception capabilities of the watershed, thereby shortening the time to reach its peak discharge. The possible threats of a single-factor change can be multiplied when combined. Since the probability of a flash flood is likely when the two factors interact, it is vital to plan appropriate pre-emptive measures and invest in early warning systems to minimize devastating damages. While validation and improvement of the developed models are advised to increase the robustness and reliability of the results, the output of the study can serve as a vital input in crafting evidence-based policy and decision-making as well as additional scientific baseline information in relation to watershed planning and management, with a precaution that the simulated values are indicative trends or pattern only rather than absolute figures. The current and projected scenario-based HEC-HMS models need further research using 2D unsteady flow hydraulic modeling to produce accurate flood hazard information and thus develop realistic flood risk maps of the study area.

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