CLIMATE CHANGE AND URBANIZATION IMPACT ASSESSMENT ON INUNDATION CHARACTERISTICS OF LAGUNA DE BAY BASIN

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ABSTRACT

Laguna de Bay is the largest lake in the Philippines located inside the Pasig-Laguna Basin. It acts as a flood retention lake to safeguard Metro Manila from extreme flooding. However, the threat of climate change and rapid urbanization affect the basin, which puts the lives of those residing within its hydrological boundary in danger. This study is a rapid assessment of the impact of climate change and urbanization on the lake level and shore inundation of the Laguna de Bay using the Rainfall-Runoff-Inundation Model. The simulation revealed that the lake level could increase by 2.54 m under future climate in the RCP8.5 scenario compared to the level during Typhoon Ulysses in 2020. Also, compared to the same event, the average highest lake level could be reached 2.8 months earlier in the seasonal cycle. In addition, the lake level could increase by 0.24 m in the 3rd quarter of the year if cropland is urbanized, and a 0.22-m increase in the peak lake level may be observed if forestland will become a built-up area. The simulated results also show that the maximum inundation depth will increase by 2.34 m and the extent will increase by 442.61 km^2 owing to climate change, especially in shoreline communities, exposing more barangays (villages) and more people to flood hazards.

Keywords: climate change, urbanization, inundation, RRI model

INTRODUCTION

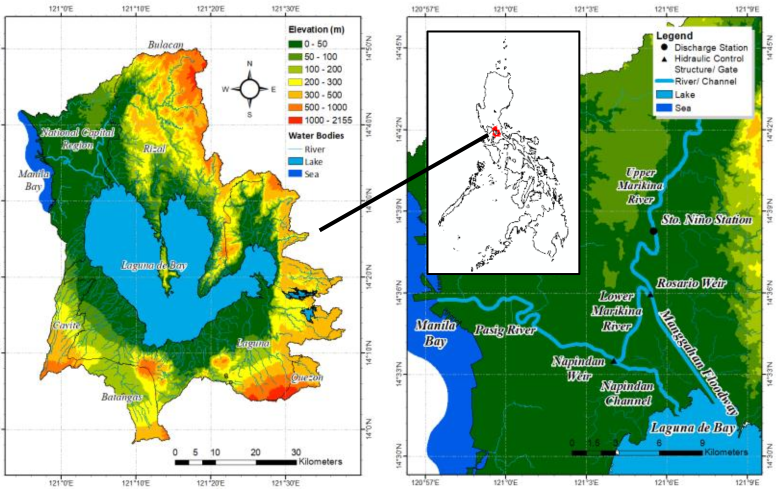

Figure 1. Pasig-Laguna River Basin and its Complex Hydrologic and Hydraulic Network

Laguna de Bay is the largest lake in the Philippines with a surface area of approximately 900 km^2 at an average height level of 12.50 m. It is a part of the Pasig-Laguna Basin, the seventh-largest (4,108.74 km^2) in the country, which has a complex hydrologic and hydraulic network, as shown in Figure 1.

In 1986, Laguna de Bay became a flood retention lake for the National Capital Region (NCR) when the Manggahan Floodway was constructed. A large portion of the flow from the Upper Marikina River is diverted to the lake through the floodway, which is controlled at the Rosario Weir based on the observed water level at Sto. Niño Station. The Pasig River is a tidal estuary and the only outlet of the lake to Manila Bay. The Napindan Channel is the portion of

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the Pasig River from the lake in which the flow is controlled by the Napindan Weir at its confluence with the Lower Marikina River (Sato and Nakasu, 2011; Japan International Cooperating Agency, 2018). The basin covers a small part of Region III-Central Luzon and a large portion of the two top lifetime migrant destination regions of the country, NCR and Region IV-A-Southern Tagalog (Philippine Statistics Authority, 2020). This suggests that urbanization continued inside the basin (Jamilla et. al, 2021). In 2020, 22 tropical cyclones entered the Philippine Area of Responsibility, seven of which occurred in only one month (PAGASA, 2020). During that year, Regions III and IV-A were the most frequently visited by tropical cyclones and received extreme impacts, such as flooding, especially from Typhoon Ulysses. Such events are proof of the threat caused by climate change (Santos, 2021). Consequently, communities around the lake shoreline were greatly affected by the inundation that lasted for months (UPLB Perspective, 2021). The increase in the lake level, river overflow, urban flooding, and unsustainable development are possible causes of flooding experienced in shoreline communities (Arlades, Jr. et. al, 2015). To better understand the situation, this study aims to perform a rapid assessment of the impact of climate change and urbanization on the inundation characteristics of Laguna de Bay Basin using the Rainfall-Runoff-Inundation (RRI) model.

THEORY AND METHODOLOGY

Five main parts comprise the methodology of this study as shown in Figure 2: (a) data gathering and preparation, (b) hydrologic modeling, (c) climate change analysis, (d) land cover change, and (e) climate change and urbanization impact assessment.

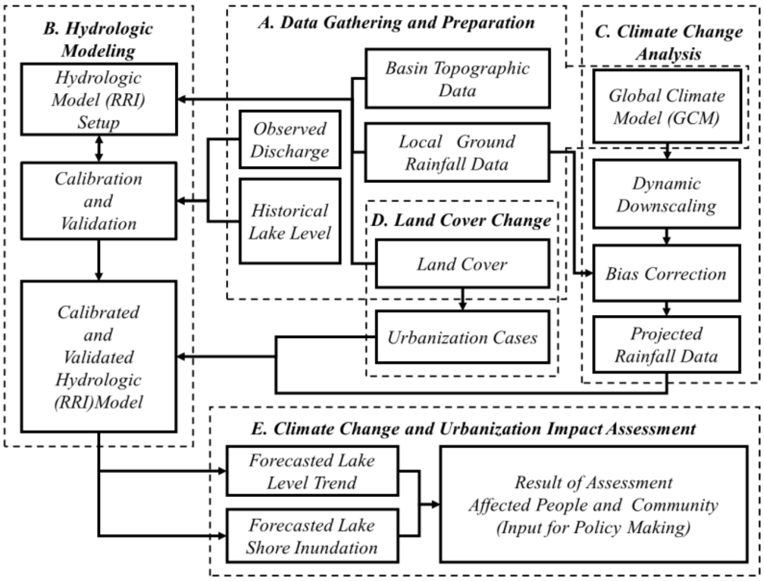


Figure 2. Research Methodology

A. Data Gathering and Preparation

Data were gathered from different agencies and online sources. Basin topographic data, local ground rainfall, and land cover data were collected and prepared to establish the hydrologic model. The observed river discharge and lake level data were also gathered for model calibration and validation. The global climate model and local rainfall data were utilized for climate change analysis. ArcGIS, a web-based map building software, was used to process and prepare the spatial data.

B. Hydrologic Modeling

The RRI model was used to simulate the hydrologic process in the basin using the gathered and prepared input data from step A. Figure 3 shows the schematic diagram of this model (Sayama, 2012). The model was calibrated and validated on the basis of the availability of reliable data. In 2005, the daily average discharge in Sto. Niño Station was used for calibration, and the observed daily average discharge at the same station in 2006 and 2007 was used for validation. In addition to river discharge, the observed and simulated lake levels for 2005, 2006, 2007, and 2020 were also compared. Model reliability was evaluated using Nash-Sutcliffe efficiency, coefficient of determination, and index of agreement.

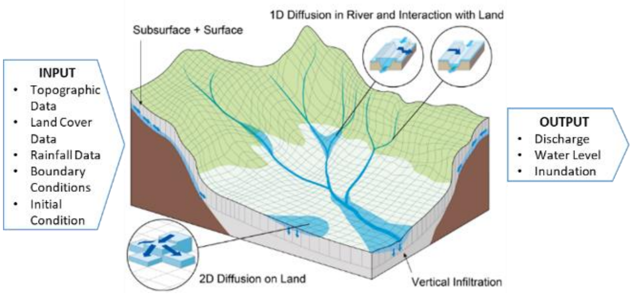


Figure 3. Schematic Diagram of RRI Model

C. Climate Change Analysis

Dynamic downscaling was performed using MRI-AGCM 3.2S with a resolution of 20 km. It is one of the highest resolution global climate models (GCMs) in the world. Bias correction was performed using historical local ground rainfall data for 25 years of past rainfall (1979–2003) and the RCP 8.5 scenario was utilized to project 25 years of future rainfall (2075–2099).

D. Land Cover Change

Four land cover files were processed and prepared in ArcGIS to represent the four urbanization cases for analysis. One of these is the current urbanization case, and the other three are created by hypothetically converting the forestland, grassland/brush/shrubs, and cropland into additional built-up areas. In all cases, the percentage of inland water remained the same.

E. Climate Change and Urbanization Impact Assessment

The impact of climate change and urbanization were assessed based on the difference between the simulated present conditions and projected future lake level trends, inundation depth and extent, and the number of affected barangays (villages) and people.

DATA

A. Basin Topographic Data

The Digital Elevation Model (DEM) from HydroSHEDS (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple scales) with a spatial resolution of 15 arcseconds was used. It was modified using the edit feature of the RRI model to correct the paths of some major rivers. The flow direction and flow accumulation files were extracted from the modified DEM using ArcGIS.

B. Local Ground Rainfall Data

Local ground rainfall data were obtained from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), the Metropolitan Manila Development Authority - Effective Flood Control Operation System (MMDA-EFCOS), and the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). 25 years of rainfall data (1979–2003) were used for climate change analysis. Daily rainfall data from 2005, 2006, 2007, and 2020 were used for the model calibration and validation.

C. GCM

The Meteorological Research Institute Atmospheric GCM version 3.2 Super-high Resolution (MRI-AGCM3.2S) with 20 km resolution was used for projecting past and future rainfall. The GCM was dynamically downscaled using the Weather Research and Forecasting model into a 5 km horizontal resolution.

D. Land Cover

The land cover data from GLCC-V2 (Global Land Cover Characterization) provided by the United States Geological Survey (USGS) was reclassified into five categories using ArcGIS: (1) forestland, (2) grassland, brush/shrubs, (3) cropland, (4) built-up, and (5) inland water.

E. Observed Discharge

The observed daily average discharge data for Sto. Niño Station from the Streamflow Management System of the Department of Public Works and Highways – Bureau of Design – Water Projects Division was used to calibrate and validate the RRI model.

F. Historical Lake Level

The observed lake-level data from the Angono Station of MMDA-EFCOS and the Laguna Lake Development Authority were used. The average daily lake level was calculated.

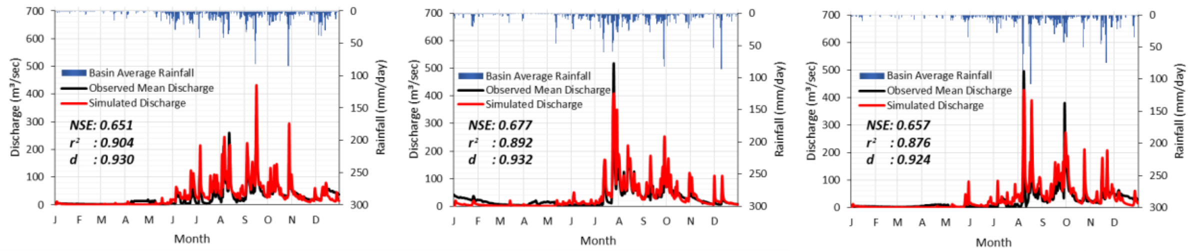
G. Population

The 2020 Census of Population and Housing (2020 CPH) from the Philippine Statistics Authority (PSA) was used in this study. The population count therein was declared official as of 01 May 2020 by the President of the Philippines. In this study, the population was distributed over the barangay's political boundaries.

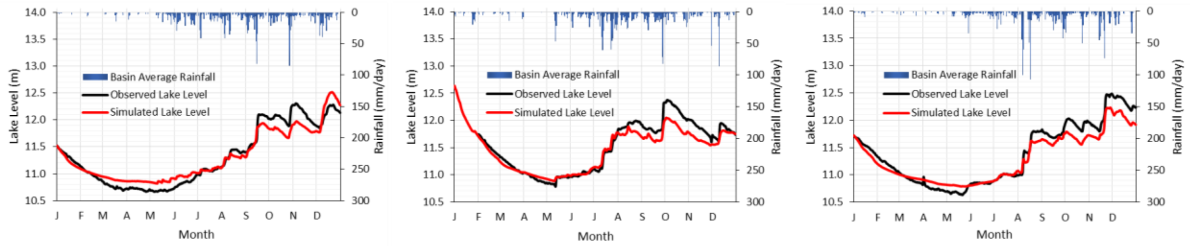
RESULTS AND DISCUSSION

A. Model Set-up, Validation, and Calibration

Figure 4(a) shows model calibration using the 2005 discharge hydrograph at Sto. Niño Station. The parameters used in the calibration were also used to simulate the hydrographs for 2006 and 2007, as shown in Figures 4(b) and 4(c), respectively, to validate the model. All models achieved acceptable model efficiency values. Furthermore, the simulated lake levels for 2005, 2006, and 2007 had the same trend as the observed lake levels at Angono Station, as shown in Figures 4(d), 4(e), and 4(f), respectively.



(a) 2005 Hydrograph at Sto. Niño Station *(b) 2006 Hydrograph at Sto. Niño Station* *(c)2007 Hydrograph at Sto. Niño Station*



(d)2005 Lake Level *(e) 2006 Lake Level* *(f) 2007 Lake Level*

Figure 4. Model Calibration and Validation

B. Climate Change Analysis

The frequency analysis of the annual maximum 1-day rainfall in the basin from the dynamic downscaling and bias-corrected results of MRI-AGCM3.2S is shown in Figure 5. It was found that the rainfall intensity will increase in the future. Table 1 presents the factors corresponding to 50-, 100-, 150-, and 200-year return periods. The derived factors have almost the same value, suggesting very little difference among the four return periods. The 2020 rainfall event, shown in Figure 6, which has a recent maximum 1-day basin average intensity of 210 mm/day, is multiplied by these factors to predict future rainfall.

Table 1. Future Rainfall Factor

Return Period	Future Rainfall Factor
50-Year	1.784
100-Year	1.815
150-Year	1.829
200-Year	1.832

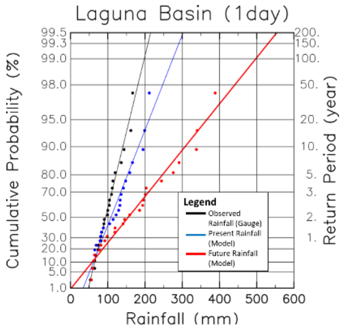


Figure 5. Frequency Analysis

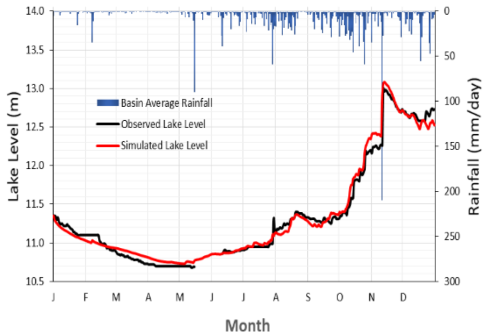


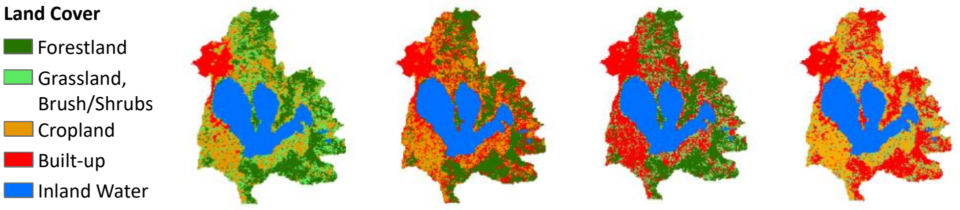
Figure 6. 2020 Basin Average Rainfall and Lake Level

C. Land Cover Change

Figure 7 presents the four urbanization cases created by hypothetically converting other land cover into a built-up area. The corresponding percentages of new land cover for each case are presented in Table 2.

Table 2. Urbanization Case Land Cover

Land Cover	Case 1	Case 2	Case 3	Case 4
Forestland	27.81 %	27.81 %	27.81 %	0
Grassland Brush/Shrubs	18.09 %	0	18.09 %	18.09 %
Cropland	24.78 %	24.78 %	0	24.78 %
Built-up	6.95 %	25.04 %	31.73 %	34.76 %
Inland Water	22.37 %	22.37 %	22.37 %	22.37



Case 1 **Case 2** **Case 3** **Case 4**

Figure 7. Urbanization Cases

D. Climate Change and Urbanization Impact Assessment

Based on the RRI model simulation, the lake levels due to future rainfall (50,100,150, and 200 years return period) are not significantly different from each other. However, the lake is predicted to have an increase of 2.52 m in maximum level compared to that of 2020 and will reach the average highest level of 2.8 months earlier in the seasonal cycle. Figure 8 shows the results of lake-level simulations under climate change.

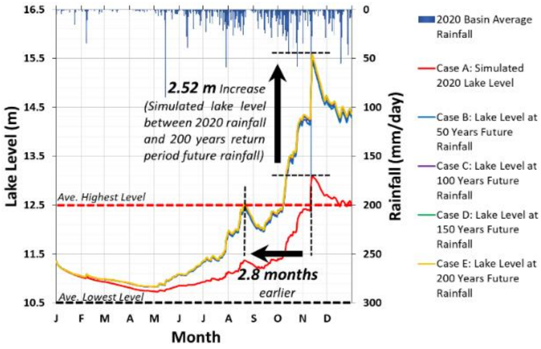


Figure 8. Simulated Lake Level under Climate Change

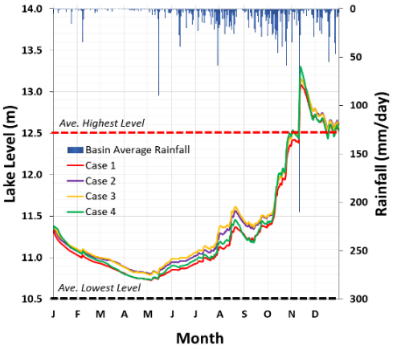
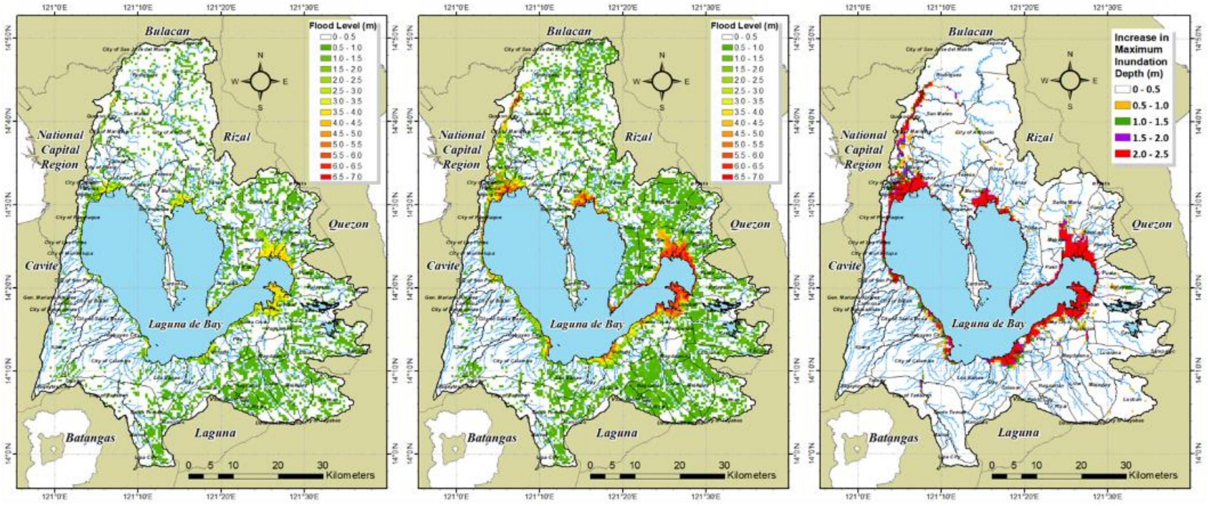


Figure 9. Simulated Lake Level under Urbanization



Simulated 2020 Maximum Inundation Level

Simulated Future Inundation Level (200 Years Return Period)

Increase in Inundation Depth in the Future Scenario

Figure 10. Simulated Laguna Lake Shore Inundation

On the other hand, the simulation of the lake level under urbanization, shown in Figure 9, shows that if cropland is converted to a built-up area, the lake level will increase by about 0.24 m in the 3rd quarter of the year. If the forestland is converted into a built-up area instead, the lake level will increase by 0.22 m at its highest peak. Climate change also has a significant impact on basin inundation, specifically on the lake shore. It can be seen in Figure 10 the comparison of the extent of the simulated inundation between the present and the future rainfall condition. The results show that the maximum inundation depth will increase by 2.34 m and the extent will increase by 442.61 km^2. Additionally, the number of affected populations and barangays per inundation depth based on the model simulation are presented in Figures 11 and 12, respectively.

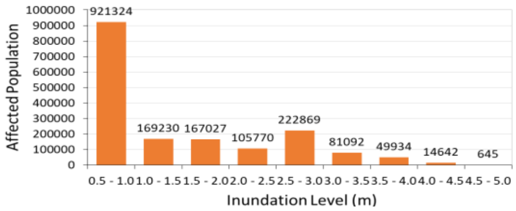


Figure 11. Number of Flood affected Population in 2020 based on Model Simulation

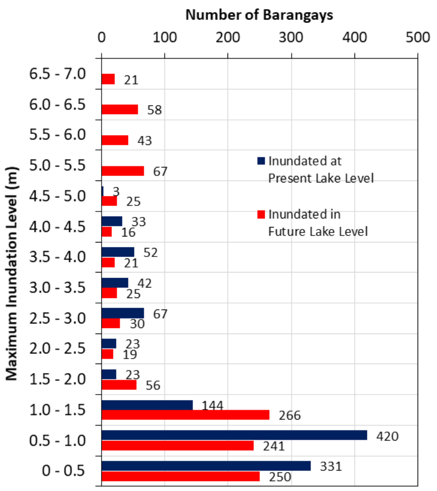


Figure 12. Number of Flood affected Barangay based on Model Simulation

CONCLUSION AND RECOMMENDATION

The assessment shows that higher-intensity rainfall is expected to occur in the Laguna de Bay basin in the future owing to climate change. This will result in a significant increase in the lake level and the extent of shore inundation. Based on the simulation, urbanization also results in higher maximum lake levels, although it has a relatively low impact compared with that of climate change. More barangays will experience higher inundation levels compared with that in the present. If lifetime migration into the basin continues, along with urbanization and worsening climate, more people will be at risk of flood disasters.

To improve the assessment, it is recommended that a finer-resolution DEM be used to set up the model. In a wide lake, a small difference in elevation has a significant effect on flood volume and flow. High-resolution layers are also required to identify a more accurate flood-affected area. In addition, correct and complete meteorological data are required to properly simulate the rainfall events being analyzed. The accuracy of the simulation results depends on the input data, setup, calibration, and validation.

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