IMPROVEMENT OF FLOOD FORECASTING FOR STRENGTHENING FLOOD RESILIENCE IN THE AGNO RIVER BASIN

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ABSTRACT

The Agno River Basin Flood Forecasting and Warning Center of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) provides flood advisories and warnings to the basin, including its allied river basins, mainly using real-time monitoring of rainfall and water levels. This study analyzed the impact of climate change in the Agno River Basin (ARB) for the period of 2041-2060 using the Global Climate Model archived in the Data Integration and Analysis System of Japan considering the Representative Concentration Pathway 8.5 scenario. The results revealed an increase of 1m and 151 km^2 in the future flood depth and extent, respectively. To increase the resilience of the community to flood disasters, this study utilized the operational Weather Research and Forecasting (WRF) model, Domain1 (12km) and Domain2 (3km), used by PAGASA to increase the lead time. The results showed that both domains of WRF predicted the discharge at the Carmen Station for Tropical Cyclone (TC) Ompong (2018). WRF Domain2 showed good performance in predicting discharge during TC Jenny (2019), TC Josie (2018) and Southwest Monsoon (August & September 2019), however, WRF Domain1 exhibited a very poor performance in these cases. To warn the people in the ARB of the possible flood in the future, a longer lead time is required to prepare and minimize the risk of such hazards, thus Numerical Weather Prediction, like WRF can be advantageous.

Keywords: RRI Model, NWP, GCM, WRF, flood forecasting

INTRODUCTION

The Agno River Basin (ARB) is the fifth largest river basin in the Philippines and the third largest in Luzon, with a 5,952 km^2 basin area and 270 km river length that empties water from the mountains of Cordillera into the Lingayen Gulf. The Tarlac River is one of the major tributaries of the Agno River that originates from Mt. Pinatubo and meets the main river at Poponto Swamp, where floodwaters are temporarily retained during the wet season. ARB is classified as Climate Type I based on Modified Corona's Climate Classification, which has two pronounced seasons: dry season (November–April) and wet season (the remainder of the year), receiving average rainfall of between 2516mm (Dagupan Station) and 3824mm (Baguio Station) annually. During the wet season in ARB, the basin experiences flooding due to the tropical cyclones (TC) and southwest monsoons (SWM). Among the flood cases in the ARB, the number of affected individuals during TC Lando (2015) was reported to be 992,365 with crop damages worth ₱568,864,437, while TC Ompong (2018) reportedly affected 588,245 individuals and caused crop damages worth ₱929,747,134 in the Pangasinan Province alone (NDRRMC). Although it is uncertain whether the frequency and intensity of TC will increase or decrease in the Philippines in the future, annual variability is highly possible, in that, a high or low number and powerful or weak TCs can be expected (Gallo, F. et. al., 2019). Based on the *Philippine Climate Extremes Report 2020*, extreme

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rainfall (maximum 1-day total rainfall) was analyzed using the 12-member model ensemble considering RCP8.5 for the 2046–2065 period, and the results showed that extreme rainfall in the Benguet Province will slightly increase by 0.5 mm/day, while in the Pangasinan Province, rainfall will decrease by 5.9 mm/day. This indicates the spatial rainfall variability in the ARB. In addition to the real-time monitoring of rainfall and water levels in the basin, rainfall forecasts, are necessary for forecasting floods and issuance of warnings (World Meteorological Organization, 2011). Considering the changed in the future flood due to increased extreme rainfall in the ARB, this study aims to increase the lead time in flood forecasting to disseminate flood warnings to the concerned areas within the ARB. As rainfall plays an important role in any hydrological model to simulate the possible flood scenario for the concerned area, therefore, the Weather Research and Forecasting (WRF) rainfall forecast was used as an input rainfall combined with the observed ground rainfall data to the Rainfall–Runoff–Inundation (RRI) model to simulate several flood cases caused by TC and SW Monsoon during 2018 and 2019.

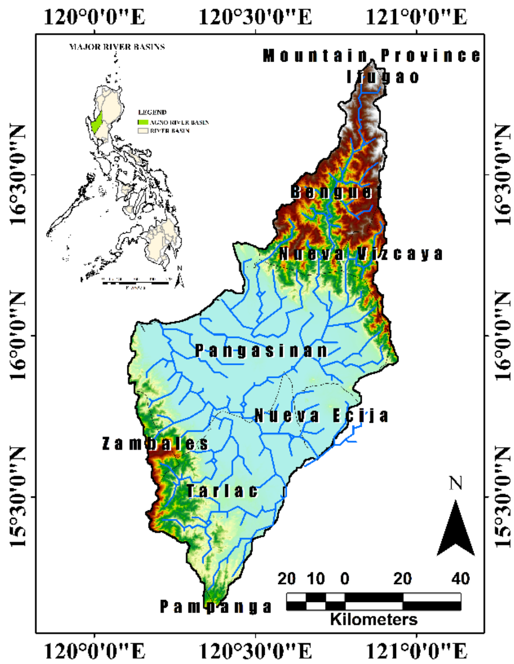


Figure 1. Location and Elevation of the Agno River Basin

THEORY AND METHODOLOGY

The methodology in this study is divided into 3 parts: (a) Development of Hydrologic Model, (b) Climate Change Analysis, (c) Numerical Weather Prediction Assessment, shown in Figure 2.

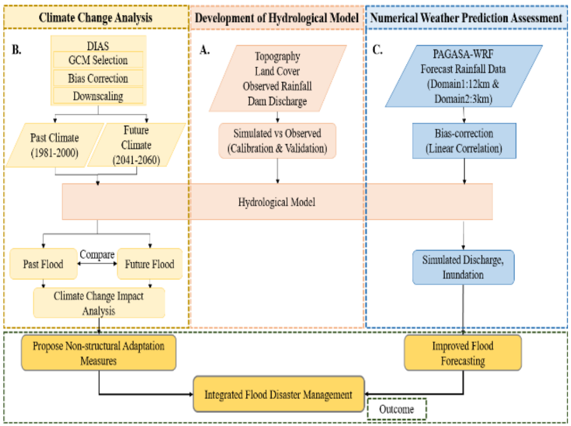


Figure 2. Methodology of the Study

A. Development of Hydrologic Model

This study used RRI Model to simulate the hydrologic cycle to analyze the flood scenario in the target area. TC Lando (2015) flood event was used to calibrate the model, while 4 flood events used for validation (TC Mario-2014, TC Ineng-2015, TC Lawin-2016 and TC Ompong-2018). RRI is a 2-D model that simulates the rainfall-runoff and flood inundation at the same time and treats the slope and river channel individually (Sayama T., 2021). Considering the available data, hourly rainfall data of 11 rain gauge stations of ARB and observed daily average discharge of San Roque Dam were used for the calibration and validation of the model and compared the simulated discharge at the Carmen Station. To evaluate the performance of the model, Nash-Sutcliffe Efficiency (NSE), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) was considered.

B. Climate Change Analysis

To compare the past and future flood, appropriate GCMs among 44 models archived in the DIAS were selected. There are 8 meteorological components used to evaluate the performance of GCMs in reproducing the climatology of the target area, such as Precipitation, Air Temperature, Outgoing Longwave Radiation, Sea Level Pressure, Zonal and Meridional Wind, Sea Surface Temperature and Geopotential Height and compared with the past global-scale observation and reanalysis data from 1981 to 2000. Selection of suitable GCMs was based on the grand total score of Spatial Correlation (S-corr) and Root Mean Square Error (RMSE), in which the selected GCMs in this study have a grand total score of 5 to 8, importantly with a good performance in representing the precipitation of the study area. Due to the coarse spatial resolution of GCMs, rainfall intensity and distribution for basin-scale might be incorrect. To reduce the biases to the rainfall output of GCM, bias-correction was carried out in the DIAS using the rainfall from 40 PAGASA Synoptic Stations (1981-2000). Extreme Rainfall, No Rain

Day and Normal Rainfall are corrected using the Generalized Pareto Distribution, Ranking Order Statistics and Gamma Distribution, respectively.

C. Numerical Weather Prediction Assessment

PAGASA started running WRF since 2010 and after configuration and sensitivity conducted for the next 2 years, it became operational for weather forecasting, also for research in 2012 providing up to 72-hour forecast, that time. 2 domains are available in WRF, one that covers the Philippine Area of Responsibility (PAR) (2.35º-25.09º Latitude,114.99º-135.01º Longitude) with 12km spatial resolution uses for weather forecasting due its longer forecast time, while the other domain with 3km spatial resolution that centered mainly the Philippine landmass (5.08º-21.03º Latitude, 117.06º-127.04º Longitude). WRF model updates yearly and in 2016 undergone many changes including the Land Surface using MODIS having higher resolution compared to previous version using USGS, changing the codes and numerical methods for Cloud Physics, WRF 6 Scheme for Micro-physics and increase in Vertical Levels from 30 to 36 levels (R.A.A.Flores, 2019). The current PAGASA-WRF is either over-forecasted or under-forecasted, therefore simple bias correction using linear correlation equation is applied to correct the forecast rainfall before using as an input to RRI. Flood events not older than year 2018 are used considering the recent update of WRF Model. Simulated discharge at the Carmen Station of the validated hydrologic model using ground gauge rainfall was compared to the simulated discharge at the same station using corrected WRF Model forecast rainfall with every 3-hr initialization.

DATA

A. Rainfall Data

Ground rainfall data used in the hydrologic model is an hourly rainfall data of 11 rain gauge stations collected from the ARBFFWC-PAGASA. Additionally, WRF Model forecast rainfall data for Doamin1 & Domain2 with 144hr and 48hr hourly forecast data, respectively, with 3-hr initialization were collected from the Numerical Model Section of the same agency. Ground rainfall data used for the bias-correction of GCM is a daily rainfall data of 40 Synoptic Stations of PAGASA from 1981-2000.

B. Discharge Data

Daily average discharge data used for the calibration and validation of the hydrologic model was obtained from the National Power Corporation (NPC), includes discharge of San Roque, Binga and Ambuklao Dam. Discharge simulated by RRI at Carmen Station in each events was use to compare with the simulated discharge simulated using WRF rainfall forecast.

C. Topographic and Land Cover Data

The Digital Elevation Model (DEM) and Land Cover used in the development of hydrologic model was collected from the National Mapping and Resource Information Authority (NAMRIA), Philippines. DEM is used to generate the flow direction (DIR) and flow accumulation (ACC). Originally, obtained DEM is a 5m resolution and up-scaled into 300m resolution considering the size of the target area to be able to run the RRI model. Land Cover is a 2km resolution and downscaled into 300m resolution, same with the DEM. There are 11 identified land cover type in the target area, namely Annual Crop, Brush/Shurbs, Built-up, Closed Forest, Fishpond, Grassland, Inland Water, Mangrove Forest, Open Forest, Open/Barren and Perennial Crop. From the original number of land cover type it is reclassified into 3 types as (1) built-up, (2) crop-land, and (3) forest land for the development of RRI model.

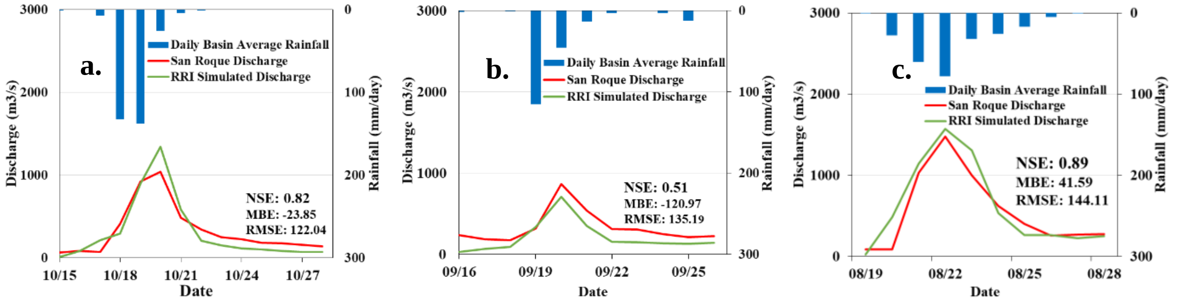
D. Global Climate Models (GCMs)

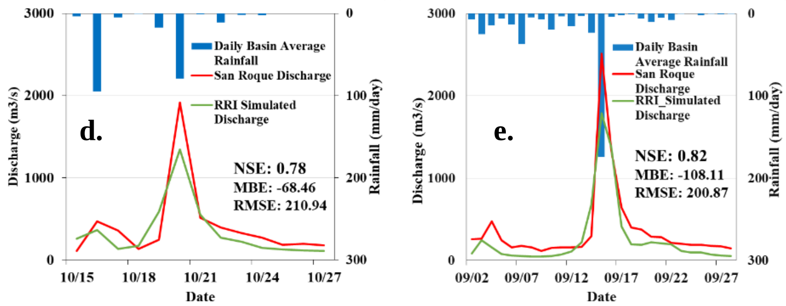
To analyze the past and future climate, climate models like GCMs are helpful tool to understand and visualize the climate system. The selected GCMs archived in the DIAS were used for the analysis of past flood (1981-2000) and projected future flood (2041-2060) considering the RCP8.5 scenario. There are 5 GCMs selected from the 44 GCMs in the World Climate Research Programme's (WCRP') Coupled Model Intercomparison Project phase 5 (CMIP5) based on its performance in reproducing the key meteorological elements in the target area.

RESULTS AND DISCUSSION

A. Development of Hydrologic Model –- Calibration & Validation

RRI Model was calibrated using TC Lando flood event in 2015 by comparing the observed and simulated discharge in San Roque Dam and evaluated based on the acceptable value of 3 model efficiency criteria, NSE, MBE and RMSE. Parameters used in calibration was use in other flood events such as TC Mario in 2014, TC Ineng in 2015, TC Lawin in 2016 and TC Ompong in 2018 to be validated with acceptable value of the said model efficiency criteria. Figure **3** shows the hydrograph for each flood events and the model parameters used. Model has NSE value of 0.82 in calibration while NSE value of 0.51, 0.89, 0.78 and 0.82 in validation. Ranging from 122.04 to 210.94 for RMSE and between -120.97 to 41.59 for MBE.





f.

Parameters			
ns_river	4.00E-02		
ns_slope	1.50E-01	5.00E-01	5.00E-01
soil depth	1.00E+00	2.00E+00	1.00E+00
porosity	4.71E-01	4.37E-01	4.63E-01
ksv	0.00E+00	6.54E-05	3.67E-06
sf	2.73E-01	4.95E-02	8.89E-02

Figure 3. Observed and Simulated Discharge for Calibration (a) TC Lando (2015), Validation (b) TC Mario (2014), (c) TC Ineng (2015), (d) TC Lawin (2016), (e) TC Ompong (2018) and (f) values of model parameters

B. Climate Change Analysis

Five GCMs were selected for the climate change analysis in this study and evaluated on how well they replicated the occurrence of past extremes from 1981 to 2000 of the 2 synoptic stations, Dagupan Synoptic Station with relatively low elevation at the western part of the basin and Baguio Synoptic Station at the mountainous part of the northern portion of the basin, only BCC-CSM1.1 was able to represents it; therefore, this GCM was used for further analysis. The maximum inundation depth and inundation area in the ARB were analyzed by evaluating the top five extreme events in the past and the top five extreme events in the future by selecting the highest daily basin average rainfall from the BCC-CSM1.1 datasets obtained from the DIAS. Figure 4 shows the inundation area for each extreme event of the past and future climate, in which, the maximum inundation area in the future will increase by 151 km^2. Furthermore, Figure 5 shows the flood depth categorized into three: (a) shallow flood, (b) deep flood, and (c) maximum flood depth. The maximum flood depth in the future increase by 1m.

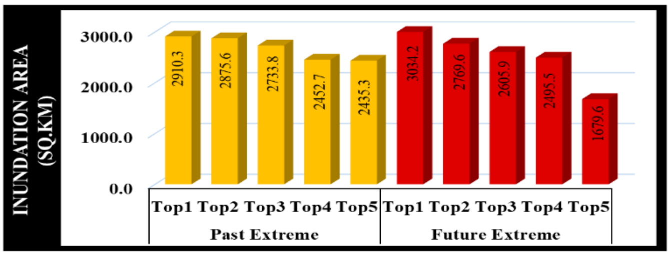


Figure 4. Inundation Area of the Top 5 Past and Future Extreme Rainfall in the Agnao River Basin

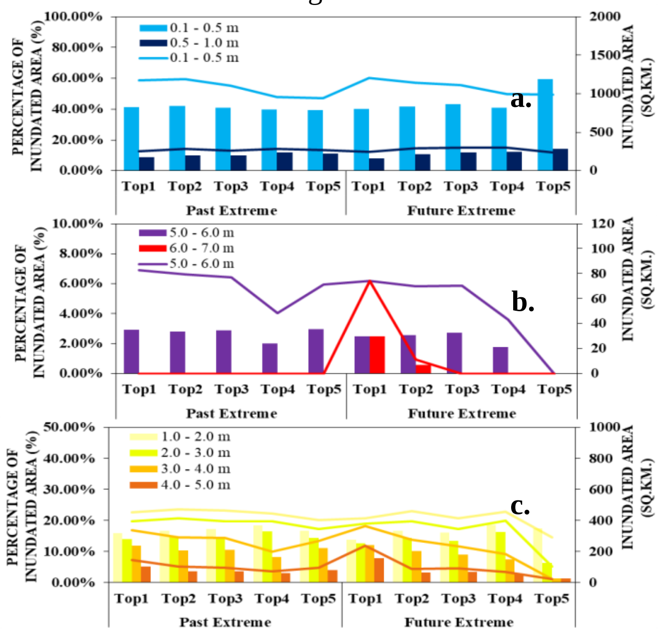


Figure 5. Inundated Area (% & km^2) of (a) shallow flood (1.0m – 5.0m), (b) deep flood, and (c) maximum flood depth of the top 5 past and future extremes

C. Numerical Weather Prediction (NWP) — Weather Research and Forecast (WRF) Model

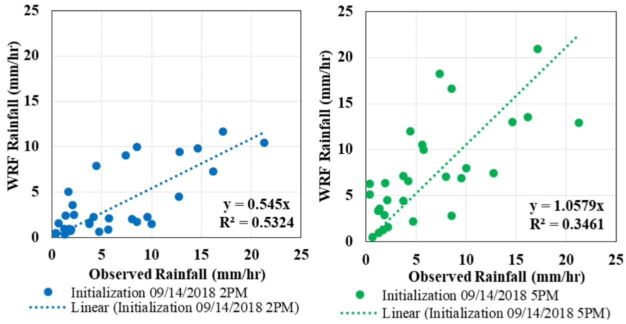


Figure 6. Linear Correlation of Observed Ground Rainfall and Forecast Rainfall of Domain1 (blue) and Domain2 (green)

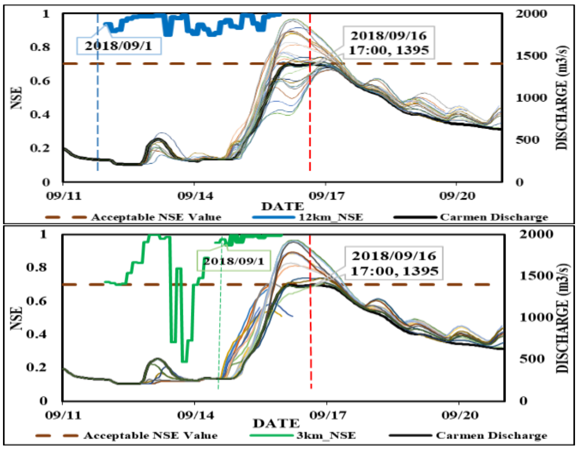
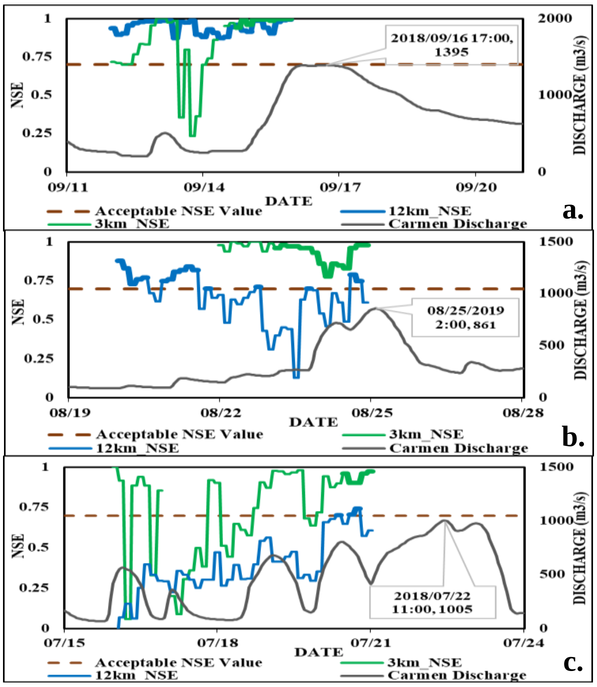


Figure 7. NSE Value and hydrograph of each initialization of Domain1 (top) and Domain2 (bottom)

The WRF model used by PAGASA comes from National Centers for Environmental Prediction – Global Forecast System (NCEP-GFS) with 0.25° spatial resolution. It has two domains, Domain1 (12 km) with a 144-h forecast and Domain2 (3 km) with a 48-h forecast. Both domains have hourly temporal resolutions and are initialized every 3 h. WRF Domain1 and Domain2 were corrected using the factor obtained from a simple linear correlation equation using data from TC Ompong (2018). The correction factor for Domain1 was found to be 1.83—the inverse of the linear equation, as the rainfall forecast was underestimated—and 1.0579 for Domain2. Figure 6 shows the correlation between the WRF rainfall forecast and the observed rainfall for Ompong in September 2018. The datasets used were the WRF initialized at 2PM and 5PM on September 9, 2018, for Domain1 and Domain2, respectively, compared with the 31-h observed rainfall. The obtained correction factor for Domain1 and Domain2 were used to correct the rainfall forecast for TC Jenny (August 2019), TC Josie combined with SWM (July 2018), and two SWM events (August and September 2019).

The performance of both WRF domains were evaluated using the NSE value for each event, as shown in **Figure 7** and Figure 8. The WRF domain performs well if the NSE value is equal to or higher than the acceptable NSE value of 0.70, i.e., WRF can simulate the peak discharge; otherwise, the accuracy is insufficient to be used operationally for flood forecasting. The WRF rainfall forecast was simulated and combined with the observed ground rainfall data for every initialization. In **Figure 7** shows the NSE value and hydrograph for each initialization during TC Ompong (2018). The thicker line indicates that the peak discharge is covered by each initialization with acceptable NSE. In Figure 8, Domain2 showed



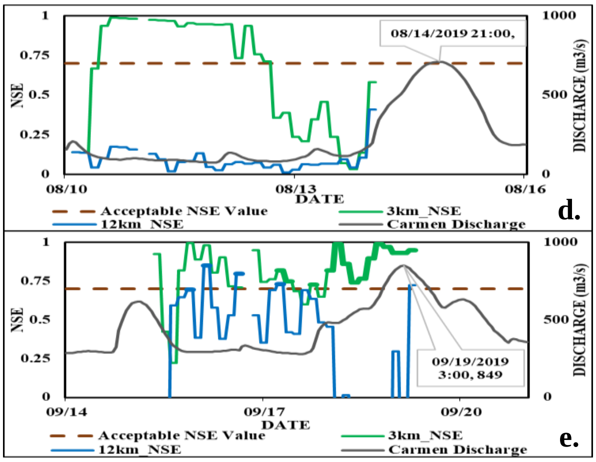


Figure 8. Observed Hydrograph and NSE Value of Domain1 (blue) and Domain2 (green) during (a) TC Ompong (2018), (b) TC Jenny (2019), (c) TC Josie (2018), (d) SWM (August2019), and (e) SWM (September2019)

a better performance than Domain1, except for SWM in August 2018 [Figure 8**(d)**], where both domains failed to simulate the discharge. Based on the different simulated events, the forecast time with good NSE for Domain1 is from 9–123 h, while maximum 48-h forecast is above the acceptable value for Domain2.

CONCLUSION AND RECOMMENDATION

The RRI model was successfully calibrated, validated, and used in this study to simulate the discharge during each flood events. The data used in calibration and validation are 300m resolution topographic data, hourly rainfall of ARB stations, and the daily average discharge of the San Roque Dam. Impact of climate change on future flood (2041-2060) using BCC-CSM1.1 showed a 1m and 151 km^2 increase in maximum flood depth and extent, respectively, indicating a significant risk to people living in the ARB. Our study also found that the WRF Domain2 can be use operationally for both TC and SWM events, compared to Domain1. The rating curve for the Carmen Station to convert the water level into a discharge was not used in the study, as it is outdated, and therefore, the reliability of the curve is questionable and an update is recommended. In addition, reliable input datasets are important in developing hydrological models; otherwise, the model will provide incorrect results and become difficult to calibrate and validate. To use the rainfall forecast of the WRF model, it is suggested that the rainfall forecast at the rain gauge stations of the basin be extracted, which will be helpful as an input data for any hydrological model for flood forecasting, such as the RRI. Moreover, further investigation of WRF is recommended, including bias correction, and its applicability in TC and SWM using the latest flood events with updated hydrological models using finer resolution. Detailed records of flood events, such as inundation depth, must indicate the basic unit and not be indicated as gutter depth, knee depth, or any other estimation. This will be useful for the future calibration and validation of hydrological models. GCMs provide a coarser climate system; thus, they must undergo downscaling and bias correction. To conduct the bias correction correctly, historical datasets for the target area are important, especially for the ground rainfall data, to compensate for the local rainfall pattern.

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