BASIN-WIDE FLOOD FORECASTING WITH NWP MODELS' RAINFALL FORECASTS FOR THE INTERACTION OF TROPICAL CYCLONE-MONSOON EVENTS IN THE BICOL RIVER BASIN

Allen B. Orogo* **Supervisor: Prof. USHIYAMA Tomoki****
MEE22723 **Assoc. Prof. MIYAMOTO Mamoru *****
Prof. HIBINO Naohiko****

ABSTRACT

There have been increasing cases of major flooding in the Bicol River Basin (BRB) that are not caused by tropical cyclone (TC) alone. Understanding the nature of these events requires thorough simulation of the reciprocal relationship between rainfall and flooding. Initially, this study evaluated the performance of numerical weather prediction (NWP) models in forecasting rainfall from the interaction of TC-monsoon. The research focused on the analysis of deterministic vs. ensemble forecasts. Given the primary goal of developing a flood-forecasting tool for such occurrences, these rainfall forecasts were simulated within the Rainfall-Run-off-Inundation (RRI) Model to assess how rainfall influences discharge outcomes. The simulation between rainfall and discharge forecasts was aimed at generating essential information, such as the time to flood/peak, and the duration of flood. During the course of study there appeared to be difficulties in predicting the rainfall amount brought by the interaction between TC Usman and monsoon in the BRB using deterministic forecasts. The results show that there is a probability that this rainfall amount can be predicted within a high-resolution ensemble forecast. A total of 20 forecasts were executed, downscaled from the NCEP ensemble model, and the findings exhibited three forecasts that demonstrated the closest alignment with the observed rainfall data. Subsequently, the results indicated good agreement between the forecast discharge and observed discharge using these three ensemble members. The closest rainfall forecast was then utilized in the RRI model to establish more information such as when the flood (at knee-depth) will arrive at a certain municipality and how long will the flood last. These are crucial data in the context of operational flood forecasting because they serve as the basis for the issuance of flood warnings. The generation of these datasets will make the forecasting process simpler and easier to understand, initiating more cooperation and awareness on the part of the affected communities. This forecast information can serve as an essential tool for the Bicol River Basin Flood Forecasting and Warning System of the Philippine Atmospheric, Geophysical and Astronomical Services Administration to deliver its functions to the BRB community.

Keywords: Numerical Weather Prediction (NWP), Deterministic and Ensemble Forecasts, RRI Model

INTRODUCTION

Living in a tropical country, the notion of rainfall holds immense significance for our population. For some people, rainfall means abundance and good fortune. It signifies a fundamental requirement for nature to sustain itself. But for most of the people dwelling in the vulnerable areas, the concept of rainfall translates to disasters, leading to extensive floods that results in property losses, damage to structures and, even more gravely, casualties. Understanding these rainfall events and establishing an effective lead time is critical in mitigating these negative impacts.

*Weather Specialist I, Philippine Atmospheric Geophysical and Astronomical Services Administration – Department of Science and Technology (PAGASA-DOST), Philippines.
** Adjunct Professor, National Graduate Institute for Policy Studies (GRIPS) / Senior Researcher, International Centre for Water Hazard and Risk Management (ICHARM), Japan
***Adjunct Associate Professor, National Graduate Institute for Policy Studies (GRIPS) / Senior Researcher, International Centre for Water Hazard and Risk Management (ICHARM), Japan
****Professor, National Graduate Institute for Policy Studies (GRIPS)

By highlighting the significance of rainfall as a critical factor in triggering disasters, society has prioritized the development and refinement of forecasting capabilities. In line with this, there are two fundamental issues underlying the development of this research:

1. Numerical Weather Prediction Models' (NWP) capacity to provide future rainfall data.
2. The reciprocal relationship between NWP with the generation of flood forecasts.

Accurate rainfall forecasts enable the authorities to issue timely warnings and take appropriate measures to mitigate the risks associated with flooding. The coupling of hydrological models with high-resolution rainfall forecasts enhances the ability to make informed decisions and take prompt actions in response to imminent flood threats.

The repeated occurrence of flooding in the Bicol River Basin (BRB) has resulted in a sense of resignation among the BRB local population. However, the massive flooding in December 2018 brought by the interaction of tropical cyclone (which then dissipated into a low- pressure area) and the Northeast Monsoon was an exception. While the community initially attributed the heavy rainfall to Tropical Depression Usman, its dissipation brought about a sense of relief among the people However, they were caught off guard when the rainfall persisted for an additional three days, caused by the interaction, leaving them unprepared and vulnerable. Figure 1 shows the total precipitation from December 28 to January 1, 2019. This event serves as a single example of the immense devastations that occurred in the basin.

To prevent the recurrence of the impact of such catastrophic flooding, it is imperative to conduct a thorough simulation of NWP model rainfall forecasts coupled with a hydrological model, particularly those that can accurately simulate the flooding caused by TC-monsoon interactions in the basin. The main objective of this research is to develop a flood forecasting tool for these events aided with a viable

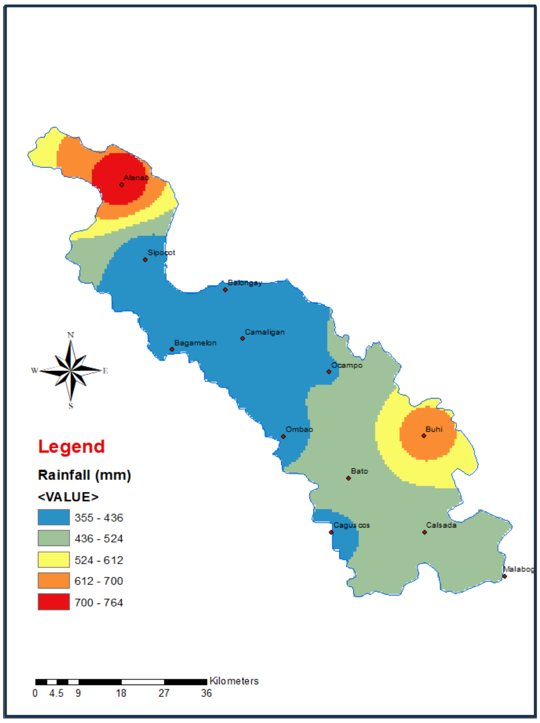

Figure 1. Total observed rainfall from December 28, 2018 to January 1, 2019 for the Tropical Depression Usman – Northeast Monsoon event. (Source: PAGASA)

THEORY AND METHODOLOGY

A simulation approach was adapted in this study which can be explained in three stages. The first stage encompasses the processing of rainfall forecast data, the evaluation of global circulation models (GCM), downscaling and ensemble forecasting. The second stage involves hydrological modelling using the rainfall forecast outputs. The third stage is the exploration of other significant information that can be derived from the hydrological modelling. The tools used for this purpose included the applications of Fortran, GRADS, GIS software and the implementation of these methods such as RRI hydrological modelling.

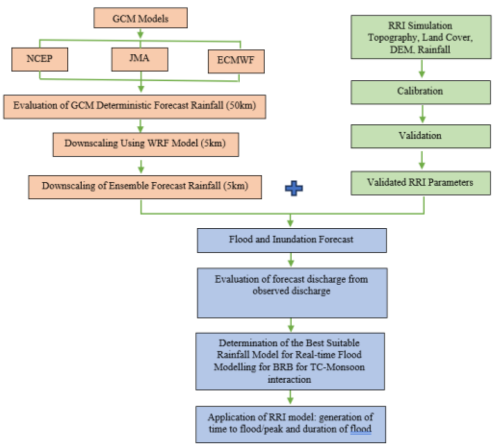

Figure 2. Methodology of the Study

DATA

A. Rainfall Forecast from original GCMs, Downscaling and Ensemble Forecasting

To conduct comprehensive analysis, accumulative precipitation forecasts from three NWP models namely NCEP-GFS, JMA-GSM, and ECMWF-IFS were obtained and downscaled using the weather research and forecasting (WRF) model at 5km single domain. A sample downscaled ensemble forecast from the NCEP model was also utilized for analysis. The event simulated occurred from December 28 to January 1, 2019, an event caused by the interaction of TC Usman (Local Name) and the Northeast Monsoon. The author examined the rainfall forecast 24hrs. and 12 hrs. prior to the significant rainfall onset and 5 days before the peak discharge.

B. RRI Model Input Data and Calibration

To capture the complex processes of rainfall-runoff-inundation in the basin, the RRI model was used. Table 1 provides a summary of the type, details, and sources used as inputs for RRI Modelling while Figure 3 shows the RRI calibrated hydrograph.

Table 1. Summary of the type, details, and sources used as inputs for RRI Modelling

Data	Features	Source
Digital Elevation Model (IFSAR)	Depicts the elevation or height values of the Bicol River Basin area and analyzes various aspects of the terrain including topography, slope, and drainage patterns.	NAMRIA
Land Cover	Classification of the BRB area surface into distinct categories such as cropland, built-up, forest and water bodies.	NAMRIA
Rainfall data	Depicts the amount, spatial distribution, and time period of precipitation, over the 12 BRB rainfall gauging stations.	PAGASA
Water level data	Depicts the height of the water surface over a specific period at the output location (discharge data were derived from these water level values using rating curve parameters)	PAGASA

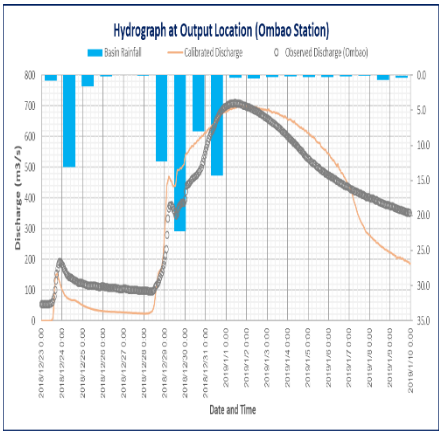

Figure 3. Hydrograph showing the observed and calibrated discharge for Usman-NE monsoon event

RESULTS AND DISCUSSION

Consistently low precipitation levels were observed among 3 GCM deterministic models with a non-uniform pattern throughout the forecast period. Upon incorporating the GCM rainfall forecasts into the hydrological analysis, it became evident that the subsequent discharge forecasts consistently demonstrated underestimations, as seen in Figure 4, although the timing of the peak was reasonably accurate. The discrepancy arises from the fact that the initial precipitation forecasts did not accurately capture the magnitude of the expected rainfall. As a consequence, the discharge projections were unable to accurately reflect the actual discharge. In an effort to improve the accuracy of the GCMs, a downscaling approach was employed. This involved enhancing the original GCM forecasts, which had a grid resolution of 50 km, by downscaling them to a finer resolution of 5 km.

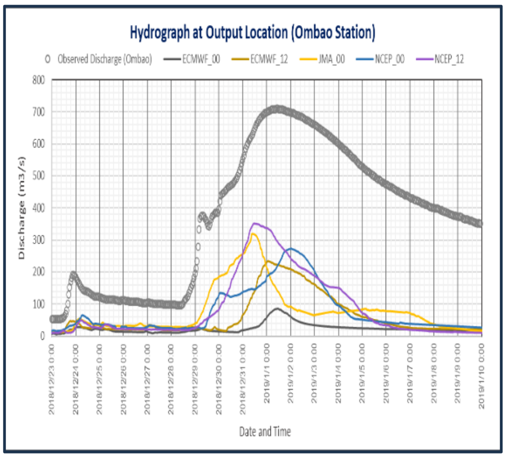

Figure 4. Simulated RRI model hydrographs using the three GCM rainfall forecasts, namely NCEP-GFS, ECMWF-IFS and JMA-GSM at 50km

Specific rainfall concentrations can be seen in some areas of the main domain indicating that the downscaling technique improved the specificity of rainfall predictions by incorporating local features, such as mountains, which have a significant impact on weather patterns at a smaller scale. However, it can be noticed that the downscaling technique was not able to predict the exact convergence zone of the interaction which is at the Bicol river basin area, where the actual rainfall occurred. Consequently, the dry rainfall forecast in the basin directly influenced the subsequent discharge forecasts as seen in Figure 5. To further explore the probability of predicting the interaction event in the BRB, the study undertook downscaling of NCEP global ensemble forecast system (GEFS) originally provided in one degree resolution. The ensemble members comprise 20 different initial conditions. Figure 7 depicts cumulative basin average rainfall (mm) forecasts in BRB area for NCEP ensemble members 1-20 with the observed basin average rainfall. The results indicated that three out of 20 ensemble members have the closest values to the observed rainfall, reasonably predicting the event. The discharge generated from these rainfall forecasts also indicated good agreement with the observed discharge, as seen in Figure 6, having ensemble member 19 as the closest curve.

Analyzing the errors in prediction despite downscaling

The downscaling technique incorporated a more specific rainfall details in some areas of the main domain in comparison to GCM original forecasts. However, most of the models struggled to accurately predict the rainfall amount in the basin resulting from the TC-Monsoon interaction. One of the primary reasons for this challenge is the model's inability to capture the convergence zone at the right location and with the correct strength. The interaction between a tropical cyclone and the monsoon is a complex atmospheric phenomenon, involving the convergence of two large-scale weather systems. The combined influence of these systems creates intricate atmospheric dynamics, making it challenging for weather models to accurately simulate their impacts on rainfall patterns. Improving the prediction of rainfall resulting from the interaction of a tropical cyclone and the monsoon requires enhancing the original GCM model resolution. It will take further studies to understand why the interaction was not predicted well at the exact location and in order to indicate the precise parameters, numerous sensitivity tests should be conducted.

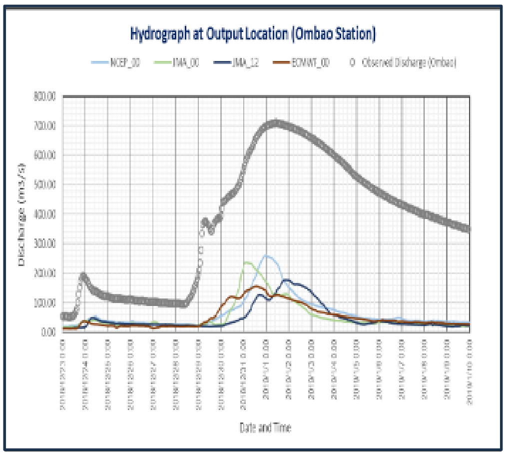

Figure 5. Simulated RRI model hydrographs using the downscaled GCM rainfall forecasts at 5km

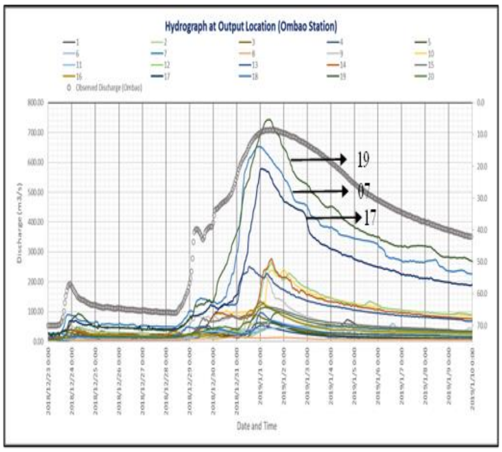

Figure 6. Simulated RRI model hydrographs using the downscaled NCEP ensemble forecast at 5km

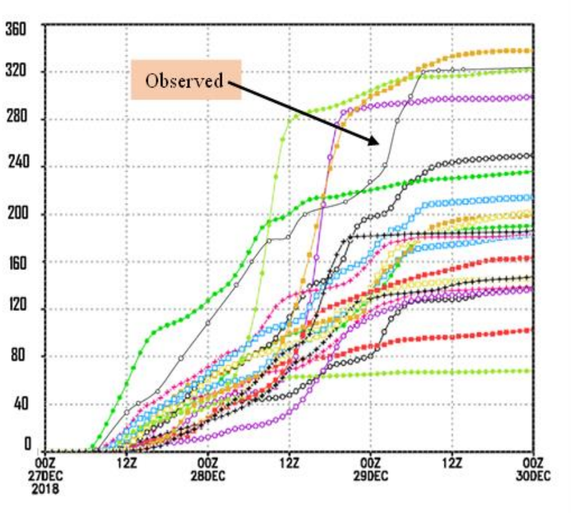

Figure 7. Cumulative basin average rainfall(mm) forecast in BRB area for ensemble members 1-20 with the observed basin average rainfall

Applications of RRI

At any given precipitation forecast values, RRI model can provide valuable information related to flood forecasting that are relevant to decision makers and community. With the use of the forecast rainfall from ensemble member 19, the closest forecast to the observed rainfall, two other datasets can be derived: the time to flood and time to peak, and flood duration as described in Figures 8-9:

The time to flooding is a parameter that represents the time at which the floodwater in each point reaches a certain level (knee deep) for the first time after the onset of the rainfall event and the time to peak represents the number of hours it will take before the peak discharge occurs at a certain point. At the local level, this information can also be useful for indicating the time at which flooding reaches warning categories such as alert, alarm, and critical levels. The flood duration parameter is used to estimate the time that water remains at the knee-deep level at a given location.

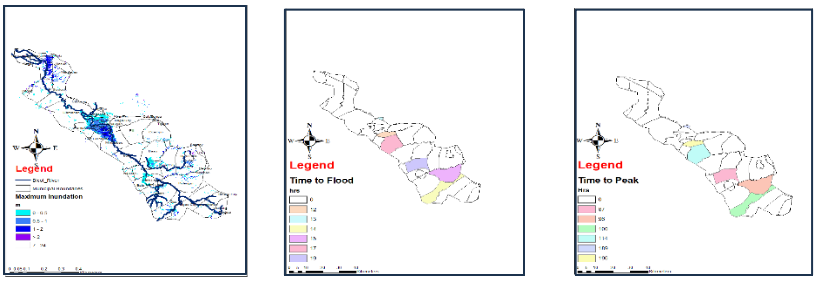

Figure 8. Simulated RRI model time to flood and peak using Ensemble member 19 forecast with reference to the maximum

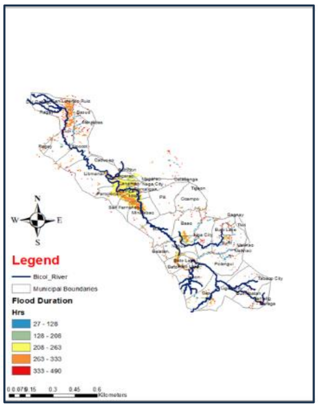

Figure 9. Simulated flood duration by RRI model using Ensemble 19 forecast

Validation of the flood modelling output

Validating hydrological models with respect to real flood events is crucial to their applicability. In this research, the datasets collected during the post-flood survey conducted two weeks after the flooding event were used to validate some of the outputs from the RRI flood simulations.

Table 2. Validation of the time to flood and the duration of flood

Municipality	Time to flood in hrs (RRI)	Time to flood in hrs (Post-Flood Survey)	Time Deviation in hrs		
			Overestimate	Underestimate	Within the range
Oas	14	23		-9	
Polangui	15	13	2		
Nabua	19	12	7		
Minalabac	17	14	3		
Milaor	12	15		-3	
Bombon	13	15		-2	

Municipality	Duration of flood in days (RRI)	Duration of flood in days (Post-Flood Survey)	Time Deviation in days		
			Overestimate	Within the range	Underestimate
Oas	11-14	7	4-7		
Polangui	1-5	3		/	
Nabua	11-14	14		/	
Minalabac	11-14	14		/	
Milaor	11-14	10	1-4		
Bombon	8-11	5	3-6		

The time to flood/peak and duration of flood are crucial data in the context of operational flood forecasting because they serve as the basis for the issuance of flood warnings. The generation of these datasets will make the forecasting process simpler and easier to understand, initiating more cooperation and awareness on the part of the affected communities. However, these datasets predicted by the RRI model and the actual datasets can differ due to several model assumptions and simplifications. Firstly, the lag time can vary depending on factors such as the size of the sub-catchment, soil type, land cover, and channel characteristics. It is to be noted that the entire municipality was only represented by one grid cell in RRI model and such factors may not have been captured completely as the post-flood survey was conducted in the low lying areas of each municipality. Aside from the lag time, the actual rainfall distribution in the specific municipality may not have been corresponding to the distribution made by RRI.

CONCLUSIONS AND RECOMMENDATIONS

Firstly, it has been found that the interaction of two weather systems can lead to complex and challenging-to-predict weather events. Understanding how these two systems interact is crucial for accurate flood forecasting, as their combined impacts can result in intense and prolonged rainfall. Secondly, it was revealed in this study that downscaling through the configuration of the WRF model enhanced the rainfall occurrence but did not guarantee the prediction of the rainfall at the exact convergence zone with the right magnitude. It highlights the effectiveness of ensemble forecasting when predicting the rainfall from these events in the precise location. By having three out of 20 ensemble members that potentially predict the rainfall amount from TC-Monsoon interaction with 1-day lead time in the BRB, forecasters gain insight into the potential worst-case scenarios that may arise from the interaction of these weather systems and optimize preparedness. Thirdly, in flood modeling, both the accuracy of the rainfall forecast, and the configuration of the hydrological model are critical factors that significantly influence the reliability of flood predictions. Proper configuration is crucial to ensure that the model accurately represents the behavior of the river system during rainfall events. And lastly, when carefully employed, the RRI model can generate information that translates hydrological parameters into elements of risks understandable by local communities and decision makers. The findings indicate that additional research and adjustments to the model parameters may be necessary to address the limitations of the downscaled forecasts in capturing the true precipitation characteristics in the area of interest. Aside from ensemble forecasting, data assimilation is deemed necessary in simulating the actual rainfall with acceptable range of accuracy. It is also recommended to evaluate the rainfall forecasts from three ensemble members to assess the bias statistically. Further, while initial validation using a single event may provide some insights into the accuracy of the forecast models, it is crucial to extend the analysis to multiple events for more comprehensive validation. The study also emphasizes the importance of updating the rating curve parameters regularly to maintain the accuracy and validity of the RRI model. Validation of the flood modelling output with respect to real flood events is crucial for their fruitful application. For the RRI model to be a valuable tool for understanding and predicting flood events, calibration, validation, and continuous improvement of parameters based on observed data are essential to minimize the differences in timing and duration and improve their predictive capabilities.

ACKNOWLEDGEMENTS

I am truly grateful for the encouragement, insightful feedback, and patience during challenging times of my Supervisor, Prof. Tomoki Ushiyama. His dedication to my research growth has been instrumental in expanding my knowledge and honing my research skills. His mentorship not only enriched my understanding of the research but also inspired me to explore new perspectives and ideas. I also extend my heartfelt thanks to my co-supervisor, Assoc. Prof. Mamoru Miyamoto for providing the necessary resources, access to valuable data, and constructive criticism that helped improve the quality of this research. And most especially to ICHARM and JICA for providing me with valuable opportunity to be involved in such scholarly endeavors.

REFERENCES

Asghar, M. R. (August 2018). "Real-time Flood and Inundation Forecast in Trans-Boundary River Basin Using Multi-Model High-Resolution Precipitation Forecast."

Goswami, S., Bal, P. K., Mitra, A. (2018, September 1). “Use of Rainfall Forecast from a High-Resolution Global NWP Model in a Hydrological Stream Flow Model over Narmada River Basin During Monsoon” Modeling Earth Systems and Environment, 4. doi:10.1007/s40808-018-0436-y.

Sayama, Takahiro. Rainfall-Runoff-Inundation (RRI) Model. 2021.

Guarín, G. P. (2008). "Integrating Local Knowledge into GIS-Based Flood Risk Assessment: The Case of Triangulo and Mabolo Communities in Naga City – The Philippines." pp. 171-202

International Federation of Red Cross and Red Crescent Societies (IFRC) (2005). World Disasters Report 2005: Focus on information in disasters. IFRC, Geneva.

Skamarock, W. C., Klemp, J. B., Dudhi, J., Gill, D. O., Barker, D. M., Duda, M. G., Huang, X.-Y., Wang, W., & Powers, J. G.: A Description of the Advanced Research WRF Version 3. In Technical Report (Issue June). https://doi.org/10.5065/D6DZ069T, 2008.