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Evaluation of Climate Forecast System Reanalysis and local weather station data as input for run-of-river hydropower assessment in Agusan River Basin, Philippines

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***Abstract*—Stream flow discharge determination is essential for the assessment of hydropower potential. However, obtaining representative meteorological data which is a key input parameter in hydrological modelling in the actual watershed of focus is oftentimes difficult. In this study, the stream flows for the Agusan River Basin were simulated to assess its hydropower potential. The river basin, located in Southern Philippines, has an area of about 11,700 km^2 but has no weather stations within its boundaries. Weather data from Climate Forecast System Reanalysis (CFSR) and local weather stations near the study area were used as input for the Soil and Water Assessment Tool (SWAT) to model the watershed runoff. The hydrologic modelling was conducted for the years 2000 – 2015. The potential power of streams were calculated using the resulting flows from the simulation, and the hydraulic head determined using a developed digital elevation model (DEM) based algorithm. A total of 1876 sites on 69 sub-watersheds were identified as potential location for run-of-river hydropower generation in the studied river basin using the model outputs. Power potential for each sites ranges from 100.1 kW to 18.16 MW (average: 3.69 MW) for simulations using CFSR data and 533.3 kW to 2.376 MW (average: 2.45 MW) for simulations using the local weather station data. Initial analysis shows that using CFSR data will yield higher values for the simulated stream flows as compared to the values obtained using local weather station data. Therefore, for watersheds without observed weather data, using measurements from local station near the study will give more conservative values for hydropower assessment.**

Keywords*— *hydropower assessment, hydrological modelling, weather data, Climate Forecast System Reanalysis, Soil and Water Assessment Tool

I. INTRODUCTION

Growth in human activity and development increases the demand for energy. In developing countries such as Philippines, dependable and sustainable sources of energy is essential for further economic growth and improved human conditions [1]. However, Philippines is currently having challenges to meet the energy demand, especially in the southern region of the country. As of 2014, the total electricity consumption for the country reached 77, 261 GWh with system peak demand of 11,822 MW at 4.58% average annual growth rate. Additional committed power projects are on the pipeline, however most of these projects are coal-fired which are less environmentally friendly than the renewable energy counterparts. Of the total electricity produced, 85% comes from non-renewable sources and is expected to further increase after the commissioning of the committed power projects. In addition, Philippines is also heavily reliant on imported conventional fuels like coal and petroleum. For the year 2014, 52% of the total electricity generated are from plants running on fuels sourced from outside the country [2]. This makes the country vulnerable to sudden changes in global prices and supply of such fuel which can greatly impact the electricity generation and consequently hurting the local economy.

Philippines have plenty of options for renewable energy development. One of such is hydropower which contribute to about 12% percent of total electricity generation of the country. Apart from the existing plants, there are still lots of untapped potential that needs to be identified and developed. Moreover, the developments are not only limited to the large hydropower schemes but also includes the micro and off-grid systems that can benefit rural and isolated communities [3]. One advantage of hydropower is that it does not need any fuel and only rely on the energy of falling water to drive turbines and generator to produce electricity [4]. Another important note, especially for the small run-of-river systems, is that during its relatively long operational life it only produces minimal carbon dioxide emissions mainly limited during the construction phase of the project [5]. In this aspect, it dies not only help in energy security, but also helps in mitigating environmental degradation and climate change.

Several methods were already developed for hydropower resource assessment [6][7][8][9]. One model that can be used in discharge modeling is the Soil and Water Assessment Tool (SWAT). It is a basin scale, continuous physically based model designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged basins [10]. It is computationally efficient, and capable of continuous simulation over long time periods that can model components such as weather, hydrology, soil temperature, nutrients, pesticides, and land management. The hydrologic cycle in its simulations employs the water balance given by the equation

$$SW_t = SW_o + \Sigma^n_{i=1}(R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

where SWt is the final soil water content (mmH_2O), SWo the initial soil water content (mmH_2O), t time in days, R_{day} amount of precipitation on day I (mmH_2O), Q_{sur} the amount of surface runoff on day i (mmH_2O), E_a the amount of ET on day i (mmH_2O), W_{seep} the amount of percolation and bypass exiting the soil profile bottom on day i (mmH_2O), and Q_{gw} is the amount of return flow on day i (mmH_2O). The SWAT model simulates these parameters on hydrological response units (HRUs). These are unique combinations of land use, soil type, and slope class that represent watershed area.

Weather input data is very important in this model to accurately simulate the hydrologic cycle. Common sources of climatological observations are the ground observations from local stations. However, this is oftentimes difficult such as the case of the Agusan River in which there are no local weather stations within its boundaries. The closest possible station can used but as the distance increase from the basin boundaries, the reliability of such observed data may become less reliable in representing the actual weather in the watershed in focus.

Other sources climatological data that can be used for discharge modelling are the weather reanalysis based from forecast models that extrapolate non-observed variables from actual observed data from local stations [11]. In this study, The Climate Forecast System Reanalysis (CFSR) from the National Centers for Environmental Prediction (NCEP) was used and evaluated for its applicability in Agusan River Basin. The CFSR was designed and executed as a global system to provide high resolution estimates of atmosphere–ocean–land surface–sea ice coupled system. The CFSR includes variables such as maximum and minimum temperature, precipitation, wind speed, relative air humidity and solar radiation for the 32-year period between 1979 and 2010 [12].

II. Methodology

A. Study Area

The area in focus for this study, as shown in Fig. 1, is the Agusan River Basin situated in Mindanao at the southern region of the Philippines. It is located between 7°12' to 9°5'N latitude and 125°7' to 126°19'E longitude. It is the third largest river basin in the Philippines and has total approximate area of 11,700km². It encompasses most of the province of Agusan del Sur and parts of Agusan del Norte and Compostela Valley. There are 11 major tributaries within the watershed area including Agusan River, Ojot River, Adgaoan River, Simulao River, Gibong River, Kayonan Rivera, and Wawa River. There are two pronounce climate types in the river basin. The northern part is characterized by the absence of a dry season and a very pronounce maximum rainfall occurring from December to February, while the southern portion is described as no dry season with evenly distributed rainfall throughout the year [13].

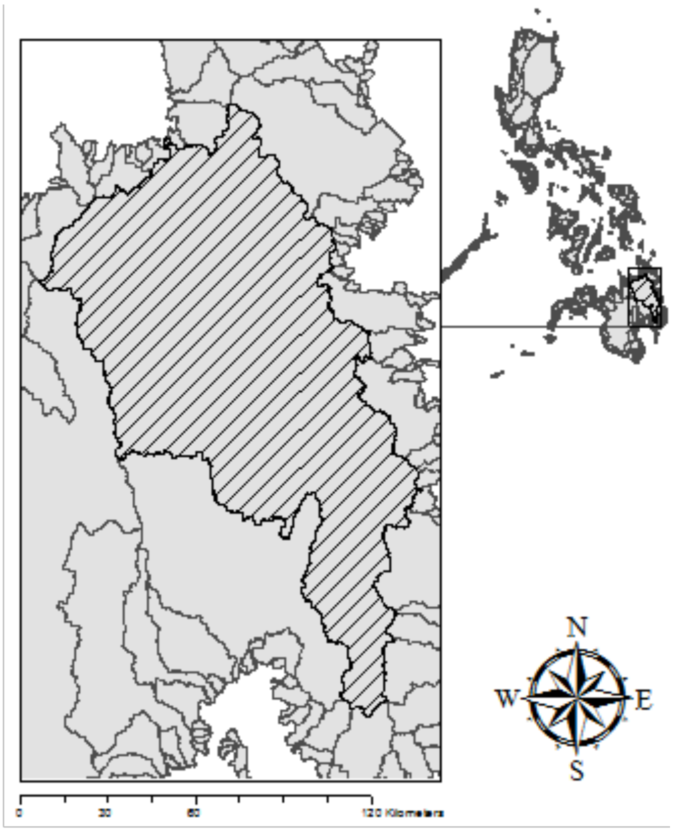

Fig. 1. Agusan River Basin

B. Input Datasets

The Digital Elevation Model (DEM) used was derived from Synthetic Aperture Radar (SAR) image with 10-meter horizontal resolution. It was the primary input for the stream delineation, slope classification, and head determination.

The land use-land cover dataset was acquired from the National Mapping and Resource Information Authority (NAMRIA). The prevalent land covers within the watershed area are annual crop, built-up areas, closed forest, fallow, fishpond, grassland, inland water, mangrove forest, marshland or swamp, open forest, open or barren, perennial crop, shrubs, and wooded grasslands. SWAT has an internal database with which the local classifications are correlated.

The soil dataset classified in series type were primarily obtained from the soil survey reports of the Bureau of Soils and Water Management (BSWM). A comprehensive database was developed containing the physical and chemical properties of each soil type. Other properties not available from the soil survey reports such as the moist bulk density, available water capacity, saturated hydraulic conductivity, erodibility factor, and moist soil albedo were derived from mathematical models. Supplemental data from the Digital Soil Map of the World (DSMW) developed by the Food and Agriculture Organization of the United Nations (FAO/UNESCO) were also used.

Weather data used were obtained from two sources, first is CFSR from the National Centers for Environmental Predictions (NCEP), and the second is from three local weather stations of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) namely Butuan Station, Hinatuan Station, and Malaybalay Station. The long term records of precipitation, temperature, wind speed, solar radiation and relative humidity were required for the hydrological modeling.

Observed discharge data were gathered from the Bureau of Designs (BOD) of the Department of Public Works and Highway (DPWH). Daily discharge observations from gauging stations located in segments of Agusan River, Simulao River, and Wawa River

C. Discharge Modeling

The hydrologic model SWAT used in this study was coupled with a GIS platform. The methodology for SWAT simulations follow four major steps as shown in the process flow diagram in Fig. 2.

The process starts with the watershed delineation using the DEM of the river basin. The process includes the filling of sinks that modifies sudden changes in elevation to facilitate flow, the flow accumulation that shows the areas where water will most likely accumulate based on the terrain, and the stream delineation with a minimum catchment area of $100km^2$. The subwatersheds were delineated based on the catchment areas of the delineated streams. Afterwards, the land use-land cover, soil, and slope data were overlaid. Each unique combinations represent a single HRU. Once the HRUs are defined and delineated, the weather databases were entered into the input tables of the model. The other databases were also written including the soil database adjusted according to the local soil data.

The SWAT model was run to simulate daily discharge starting from the year 2000 up to year 2015, with three years of warm-up period. Two simulations were completed, one using the CFSR weather data as input, and another one using the local weather data as input. The daily surface runoff of the river reaches for the whole duration of the simulation were then extracted. A representative year containing the average daily

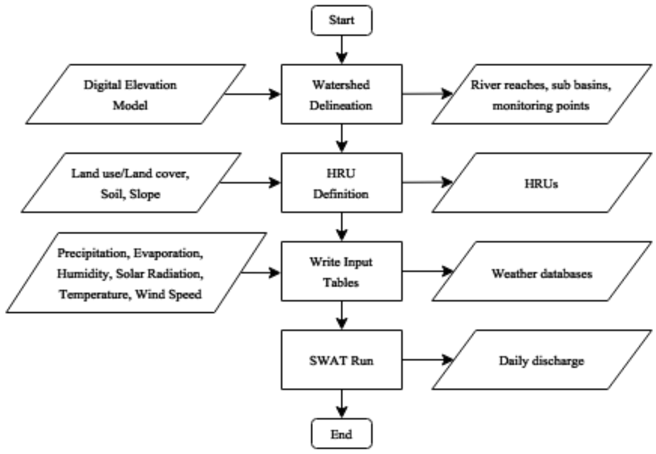

Fig. 2. SWAT process flow diagram

discharge was then calculated from the daily values. Afterwards, a flow duration curve was generated and the discharge values at 80% exceedance were used as the dependable flow of the river reaches.

D. Head Determination

A head determination algorithm was developed and implemented using Python – a programming language that can handle raster and vector GIS datasets through the use of Geospatial Data Abstraction Library (GDAL). The program prompts for the input data for the river cells, the preference for minimum head of 20m, and the preference for maximum horizontal distance between the virtual intake and virtual powerhouse of 500m.

The main input for the algorithm was the river cells which is a raster dataset containing the elevations along the rivers. This terrain data was derived from the source DEM by extracting the elevations using the delineated river reaches. The program then sorts all the river cells and stores the coordinates and the elevations to a list. It sorts the list in a descending order and proceeds to the computation beginning from the cell with the highest elevation. The computation searches the river cells for the neighboring cells that satisfy the user-defined minimum head but the search is limited to the range of distance satisfying the user-defined length between the virtual intake and virtual powerhouse. In this case, the virtual intake is the cell with the highest elevation. Once the search is done from the current virtual intake, the program iterates through the list to search for the next cell with the succeeding highest elevation. The iteration is terminated only when all the river cells have been taken into account. The result of the algorithm is the raster and vector files representing the segments connecting the virtual intakes and virtual powerhouses that satisfy the specifications.

E. Power Calculation

The resulting line segments from the head determination algorithm were spatially joined with the river reaches containing the dependable flow values obtained from the flow duration curves. Each segment will have both the head and flow values for the specific river reach it was located. The theoretical power potential was then calculated using the following equation

$$P = \rho \times g \times Q \times h \times \eta \qquad (2)$$

where P is the theoretical power in watts, ρ is the density of water (1000kg/m^3), g is acceleration due to gravity (9.81 m/s^2), Q is the volumetric flow rate in cubic meters per second, h is the head in meters, and η is the dimensionless combined turbine and generator efficiency (0.8). All the segments that met the set preference for the head determination algorithm but have zero corresponding dependable flow will yield zero power potential and thus excluded from the final results.

Once the theoretical power potentials were obtained, the potential sites were classified into different types based from the power output ranges indicated in Table 1.

TABLE I. CLASSIFICATION OF THEORETICAL POWER POTENTIAL

Power (kW)	**Classification**
Less than 5	Pico
5 to 100	Micro
101 to 1000	Mini
1001 to 3000	Small
3001 to 10000	Medium
Greater than 10000	Large

III. RESULTS AND DISCUSSION

On the initial step of the discharge modeling, SWAT delineated 69 subwatersheds with its corresponding river reaches using the DEM of the Agusan River Basin based from 100km^2 minimum catchment area. The subwatersheds shown in Fig. 3 has an average area of 169km^2 with the largest, subwatershed 62, has an area of 555km^2. Increasing or decreasing the set catchment area during the delineation can affect the sizes and as well the numbers of delineated watersheds. Consequently, this will also affect the simulated discharge values for the river reaches. Larger subbasins areas will have higher discharge values while smaller subbasins will have lower discharge values.

Succeeding procedure required the reclassification of the input land use/land cover dataset into the classes included in the internal database that can be recognized by SWAT. The new land use/land cover classes are listed in Table 2. Large portion of the river basin are covered by forests and agricultural lands accounting for 50.00% and 30.04% of the total area respectively.

Another step that was required before the HRU definition was the derivation of slope from the input DEM. The obtained slope data for the whole river basin were classified based from the ranges in Table 3.

Once the preparation and reclassification of the land use/land cover, soil, and slope were completed, the three dataset were overlaid to create HRUs. A total of 5112 HRUs were created. Examples of HRUs are shown in Table 4 where different types present in Subbasin 8 were listed.

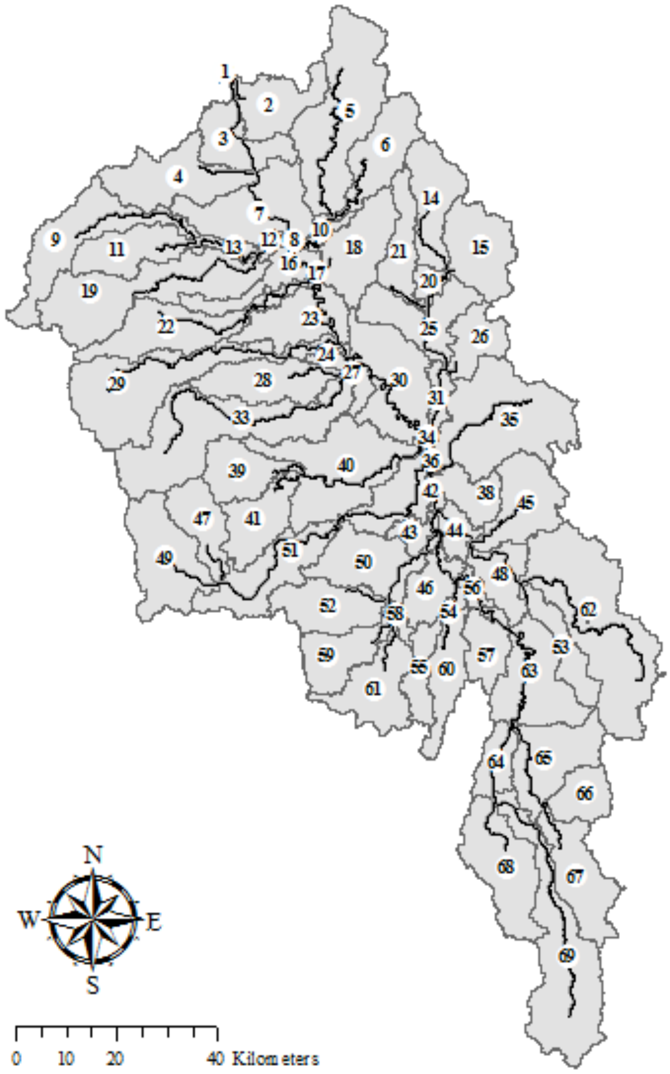

Fig. 3. Delineated watersheds and river reaches in Agusan River Basin

TABLE II. RECLASSIFIED LAND USE/LAND COVER DATA OF AGUSAN RIVER BASIN

Land use/Land cover	**Area (km^2)**	**Percent (%)**
Forest (mixed)	3502.39	29.93
Agricultural (row crops)	2102.24	17.96
Forest (deciduous)	1601.91	13.69
Agricultural (generic)	1413.99	12.08
Range (brush)	1387.57	11.86
Forest (evergreen)	750.40	6.41
Wetlands (mixed)	452.73	3.87
Range (grasses)	166.56	1.42
Water	149.56	1.28
Residential	135.12	1.15

Summer pasture	33.95	0.29
Pasture	5.94	0.05
Wetlands (forested)	0.29	0.00
Wetlands (non-forested)	0.05	0.00

TABLE III. SLOPE CLASSES WITHIN THE AGUSAN RIVER BASIN

Slope Class	Area (km^2)	Percent Area (%)
20 - 9999	4513.74	38.57
15 - 20	1125.29	9.62
10 - 15	1330.69	11.37
5 -10	1660.15	14.19
0 - 5	3072.88	26.26

TABLE IV. HYDROLOGIC RESPONSE UNITS IN SUBBASIN 8

HRU Number	Combination(LULC/Soil/Slope)	Percent Area of Subbasin (%)
1	Agricultural (generic)/San Manuel/0-5	1.68
2	Residential/San Manuel/20-9999	7.51
3	Residential/San Manuel/10-15	1.68
4	Residential/San Manuel/0-5	71.89
5	Residential/San Manuel/15-20	1.94
6	Residential/San Manuel/5-10	4.66
7	Water/San Manuel/5-10	0.65
8	Water/San Manuel/0-5	9.97

SWAT assigns simulated weather to each subbabsin based from the long term weather observations from the nearest station.In this study, two sets of weather data were used for the purpose of discharge modeling and hydropower assessment. The locations of the three local weather stations (i.e. Butuan Station, Hinatuan Station, and Malaybalay Station) and the CFSR are shown in Fig. 4. CFSR data are well distributed within the river basin as compared to the local weather station which are all outside the basin boundary.

After running SWAT for the years 2000 to 2015, simulation values for precipitation and river discharge were obtained. Results from 3 subbasins, subbasin 5 in the northern part and subbasins 62 and 63 in the southern part, were used to evaluate the effect of using the two weather datasets.

Comparison of the average monthly precipitation from the results of the simulations using the two weather datasets are shown in Fig. 5. Precipitation data in subbasin 5 using the local station derived weather input exhibits a good fit having R^2 value of 0.87 to the observed values from Butuan Station. In contrast, the result using CFSR data and Butuan station data have R^2 value of 0.01 indicating that there is no correlation.

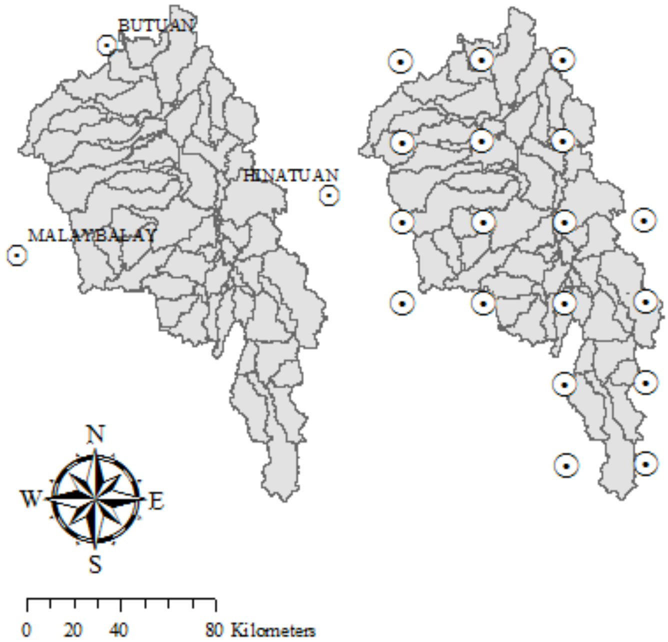

Fig. 4. Locations of local weather stations (left) and distribution of CFSR data (right)

In the case of subbasins 62 and 63. The nearest local weather station is Hinatuan station. SWAT generated the same precipitation data for both subbasin using the local station derived weather data. The calculated monthly values have R2 value of 0.84. Since the CFSR data is more distributed the simulated precipitation data for subbasins 62 and 63 have different values. Again, the simulated precipitation using CFRS data exhibits no correlation to nearest local station.

Evaluation of the simulated discharge values were also conducted. The selected subbasins have the delineated river reaches of the three of the eleven major tributaries of Agusan River Basin. Subbasin 5 have observations from the gauging station of a segment of Wawa River in Sibagat, Agusan del Sur. Subbasin 62 have observations from the gauging station of a segment of Simulao River in Bunawan, Agusan del Sur. Lastly, subbasin 63 have observations from the gauging station of a segment of Agusan River in Sta Josefa, Agusan del Sur.

From the daily discharge values generated, a representative year containing the daily average values for the whole duration of the simulation were calculated for each of the three selected subbasins. Afterwards, flow duration curves were produced to determine the dependable flow that can be used.

In Fig. 6, the flow duration curves for subbasin 5 shows that the observed discharge have higher values at exceedance below 20%. Beyond that, discharge values from simulations using CFSR data have higher estimated values. On the other hand, the results from simulations using local weather data fits well with that of the observed values having R^2 value of 0.90. For the exceedance range of 40% and 80%, which are used for hydropower assessment, the R^2 indicates a better fit with value of 0.99.

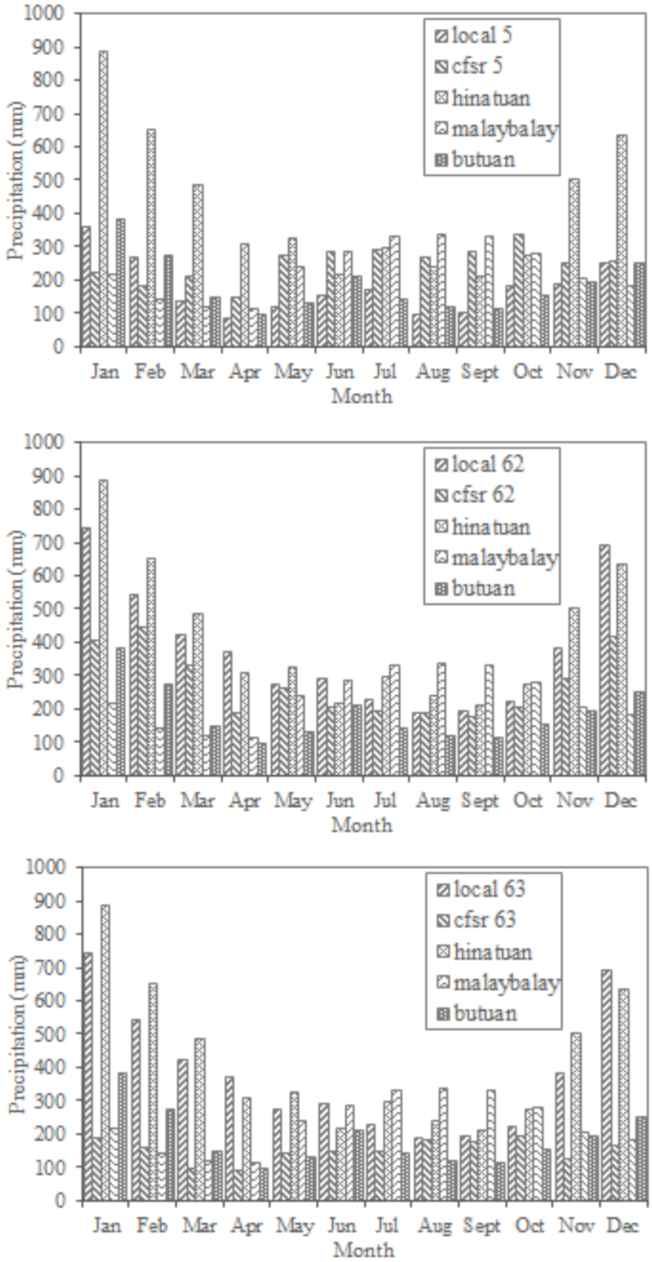

Fig. 5. Simulated average monthly precipitation for Subbasins 5, 62, and 63 compared to the observed average monhtly precipitation from local stations

The flow duration curves for subbasin 62 in Fig. 7 again shows higher observed values at lower exceedance but in this case it is up to 38%. After which, the results from simulations using local weather data exhibits again a good fit with that of the observed values having R^2 value of 0.98 for the exceedance range of 40% and 80%. In contrast, discharge values from simulations using CFSR data are underestimated and have lower correlation.

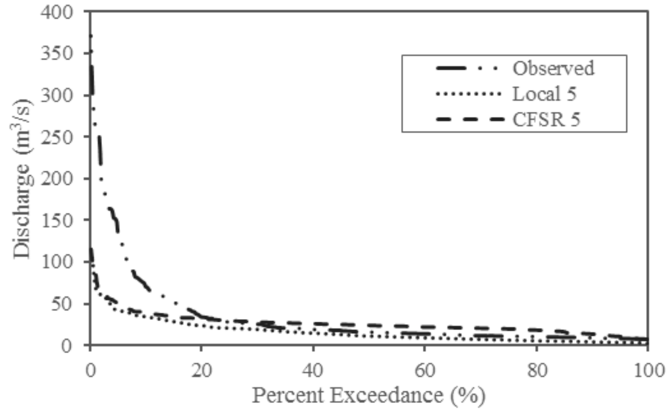

Fig. 6. Flow duration curves for Wawa River and subbasin 5

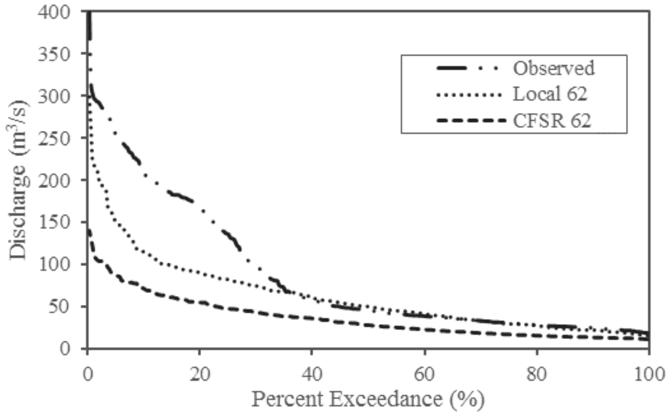

Fig. 7. Flow duration curves for Simulao River and subbasin 62

Subbasin 63 display a similar trend to that of subbasin 5. Shown in the flow duration curves in Fig. 8 that the observed values in Agusan River is higher up to 5% exceedance as compared to the CFSR-generated discharge, and up to 40% exceedance for the local-generated discharge. The 40% to 80% range is again useful for the hydropower assessment having R^2 value of 0.96.

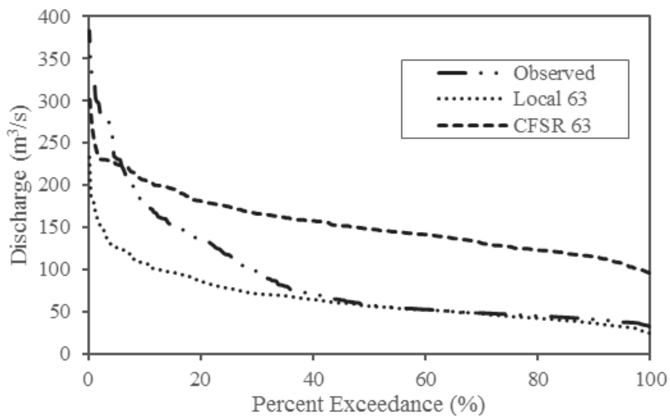

Fig. 8. Flow duration curves for Agusan River and subbasin 63

Consistent in all the flow duration curves for all the evaluated subbasins, the observed discharge values from the different gauging stations are always higher at the lower percent exceedance as compared to the simulated flow data. It can be attributed to the non-exclusion of the event-based sudden increase in river flows such as during the occurrences of typhoons and thunderstorms. This had the effect of increasing the calculated average values for the dates of the years in which such surge in flow rates occurred. The CFSR-data discharge flow duration curves display a similar behavior with the local weather data discharge, albeit have a different magnitude which either overestimate in some cases and underestimate for others. Calibrating the CFSR data for the study area in future simulations might give closer results.

Using the discharge values at 80% exceedance as the dependable flow rate and the resulting elevation data from the head determination algorithm, the theoretical hydropower potential were calculated and a total of 1876 sites were identified. Listed in Table 5 are number of potential sites based from the set capacity ranges. In agreement with the observations, from the flow duration curves, the ranges of the power potentials using CFRS is larger with a minimum of 100.1 kW and maximum of 18.16 MW. The number of potential sites are also skewed more towards to the Medium and Large classifications. In comparison, simulations using the local weather station data resulted power potential within the range of 533.3 kW to 2.376 MW and more sites classified under Mini and Small.

TABLE V. CLASSIFICATION OF POTENTIAL HYDROPOWER SITES IN AGUSAN RIVER BASIN

	Number of Potential Sites				**Average Capacity (MW)**
	Mini	***Small***	***Medium***	***Large***	
Local	431	869	576	0	2.45
CFSR	403	509	903	61	3.69

IV. CONCLUSION

Hydropower resource assessment is highly reliant on quality weather data, especially for the hydrologic modeling aspect of the process. Therefore, the use of reanalysis data such as CFSR and long term observation data from local weather stations for discharge modeling in data-sparse areas, such as the Ahusan River Basin, was evaluated in this study. Based from the initial comparisons of the generated flow duration curves from the observed and simulated data, model results using the local station weather observations demonstrates a good correlation with the observations from the gauging stations. The dependable flow within the range of 40% to 80% have R^2 values of 0.98, 0.99, and 0.96 for the river reaches in Wawa River, Simalo River, and Agusan River respectively. On the other hand, the use of CFSR does not give results that fits well with the actual flow measurements and have overestimated values for hydropower potential.

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REFERENCES

[1] H. Liming "Financing rural renewable energy: A comparison between China and India," Renewable Sustainable Energy Rev., vol. 13 no. 5, pp. 1096–1103, 2009

[2] Department of Energy, Philippines, "2014 Power Statisctics," Available at: http://www.doe.gov.ph/electric-power-statistics/philippine-power-statistics [Accessed 20 Apr. 2016]

[3] D. Hayes "Asian Renewables: Southeast Asia renewable overview," Refocus, vol. 5 issue 3, pp. 48-51, 2004

[4] M. Jacobson "Review of solutions to global warming, air pollution, and energy security," Energy Environ. Sci., vol. 2, pp. 148-173, 2009

[5] O. Paish "Small hydro power: Technology and current status," Renewable and Sustainable Energy Reviews, vol. 6, pp. 537-556, 2002

[6] P. Rojanamon,T. Chaisomphob and T. Bureekul "Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact," Renewable and Sustainable Energy Reviews vol. 13, pp. 2336-2348, 2009

[7] A. Pandey, D. Lalrempuia and S.K. Jain, "Assessment of hydropower potential using spatial technology and SWAT modeling in the Mat River of Southern Mizoram, India." Hydrological Sciences Journal , pp. 1–25, 2014

[8] N.S. Patil, I.T. Shirkol and S.G. Joshi. "Geospatial technology for mapping suitable sites for hydro power plant." International Journal of Innovative Technology and Exploring Engineering, vol. 3 issue 3, pp. 156-160, 2013

[9] R. K. Ramachandra, "Spatial Decision Support System for Assessing Micro, Mini and Small Hydel Potential." Asian Network for Scientific Information, pp. 596-603, 2004

[10] J. Arnold, R. Srinivasan, R. Muttiah, and J. Williams "Large area hydrologic modeling and assessment. I: Model development," J. Am. Water Resour. Assoc., vol. 34, pp. 73–89, 1998

[11] J. Monteiro, M. Strauch, R. Srinivisan, K. Abbaspour, and G. Gucker, "Accuracy of grid precipitation data for Brazil: application in river discharge modelling of Tocantins catchment," Hydrol. Processes, vol. 30, pp. 1419-1430, 2016

[12] S. Saha, et al, "The NCEP Climate Forecast System Reanalysis," Bulletin of Amreican Meteoroligical Society, vol. 91 no.8, pp. 1015-1057, 2010

[13] Asian Developnet Bank, "Philippines: Master Plan for the Agusan River Basin," Available at: http://www.adb.org/sites/default/files/project-document/68233/36540-phi-tacr.pdf [Accessed 20 Apr. 2016]