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Comparative Assessment of Different Methods in Generating Design Storm Hyetographs for the Philippines

ABSTRACT

Design storm hyetographs are synthetic temporal rainfall patterns used as input for flood modeling studies, drainage design and hydrodynamic modeling. In practice, the Philippines adopts the alternating block (AB) method to derive hyetographs using PAGASA-synthesized rainfall intensity-duration-frequency (RIDF) curves. In this study, six other methods- AB from actual RIDF curve, actual normalized 24-hour storms and four different patterns derived by Huff (1967)- were tested using the tipping-bucket raingauge records of a local weather station. Nonparametric statistical tests were employed to determine the significant difference between and among distributions. Moreover, Chi-squared goodness-of-fit test was used to compare the hyetographs with data from actual storms. The PAGASA AB hyetographs, while accurate in some instances, do not always represent actual storms well. Furthermore, other methods may have better fits for other storms. This study recommends further research in establishing design hyetographs in the Philippines.

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INTRODUCTION

The apparent increase in storm intensity and frequency over the recent years has made the Philippines one of the most flood-prone countries in the world. From 2004 to 2013, there had been over 60 reported major reported floods in the country (*Badilla et al. 2014*), including those events brought about by Typhoon Ketsana (Ondoy) on September 2009 and the heavy Southwest Monsoon (Habagat) on August 2012. According to *Israel and Briones* (*2012*), the World Bank has stated that climate change may worsen the incidence of flooding in already high risk areas and may make other areas historically not flood-prone be eventually vulnerable. This has prompted the Department of Public Works and Highways (DPWH) to push for a number of flood-mitigating projects and the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) to carry out studies about impacts of climate change on floods (*Badilla et al. 2014*).

Highly essential to flood modeling studies, drainage design, hydrodynamic modeling and to engineering hydrology in general (*Palynchuk and Guo 2011*) is the development of reliable storm hyetographs. Hyetographs depict the relationship of rainfall depth over a certain duration and return period. Preference is given to the use of actual storm distributions and its derivatives for simulating flood events in existing drainage systems (*Santra and Das 2013*), while synthetic hyetographs are favored for designing stormwater facilities. Additionally, the most appropriate hyetographs are necessary flow modeling of watercourses as well as the hydrodynamic analyses of the functioning of surface water runoff systems. In the Philippines, actual hyetographs are generally unavailable and research studies about hyetograph development specific to a location and climatic type have been scarcely, if not at all, established. As a result, flood modelers and drainage designers resort to extensively using the technique called “alternating block” as recommended by *DPWH-JICA* (*2003*).

Alternating Block (AB) is a simple procedure of generating synthetic storm patterns (*Chow et al. 1988*) and is heavily dependent heavily dependent on Rainfall-Intensity-Duration-Frequency (RIDF) curves (*Ghazimezade et al. 2011*). RIDF curves are derived from statistical analysis of rainfall events, either on annual maxima series or partial duration series, over a period of time and used to capture important characteristics of point rainfall for shorter durations (*Bougadis and Adamowski 2006*). In the Philippines, PAGASA generates the RIDF curves and makes them commercially available for hydrologists and drainage designers at a certain price.

Being the country with practically one of longest and most complete rainfall records in the world, the United States has actively pioneered to produce standard methods for generating synthetic design storm profiles. To name a few, *Pochwat et al.* (*2017*) enumerated the SCS (1986) Types I, IA, II and III, Huff (1967) Types I, II, III and IV and Triangular Storms by *Yen and Chow* (*1980*). *Prodanovic and Simonovic* (*2004*) likewise mentioned the RIDF-based methods of *USACE* (*2000*) and *Keifer and Chu* (*1957*), which exhibit extreme peaking patterns similar to SCS and AB. Hyetograph research is so advanced and established in the US that their existing hyetographs are just continuously being improved.

Other countries have likewise explored developing novel methods of hyetograph generation and in most cases, adopted and modified the existing methods to suit a particular location. These include the double triangular hyetographs (*Lee and Ho 2008*) and regionalized design storms (*Yeh et al. 2013*) in Taiwan, storm profiles for the arid mountainous and coastal regions of Jordan (*Al-Rawas and Valeo 2009*) and design storms from multi-parameter probability distribution modeling in Brazil (*Beskow et al. 2015*). Modification of the Huff curves has also been particularly popular especially for the three climatic types in Slovenia (*Dolsak et al. 2016*), for design storms and flood simulations in Guangzhou, China (*Pan et al. 2017*) and for Peninsular Malaysia (*Azli and Rao 2010*).

Research on establishing design storm hyetographs in the Philippines is still at its infancy. This is due to the fact that the pertinent data for this undertaking is either limited or inaccessible. The AB method may fill in for this gap for now but *Guo and Hargadin* (*2009*) emphasized that SCS and RIDF-based design storms like those derived from AB method, represent the "worst time distribution to form a severe storm". The imprudent use of these methods may result to overdesign of drainage facilities. Likewise, while the current practice of developing design storms may take into account the factor of climate change, it is but necessary to evaluate first how well these synthetic storm patterns represent the actual storms. This study therefore aims to provide options in generating design storm hyetographs in the context of the Philippines. This has preliminarily tested the readily available tipping bucket rainfall records from the UPLB-PAGASA-National Agrometeorological Station (NAS). Comparative assessment was done among the design storms derived using the AB method and those from six other selected methods namely, AB from actual RIDF curve, actual normalized 24-hour storms and four patterns developed by Huff (1967). Lastly, the reliability of each method to represent the actual storms was investigated.

MATERIALS AND METHODS

Data Collection and Processing

The rainfall charts from the tipping-bucket recording raingauge of the UPLB-PAGASA-NAS were used to extract the maximum rainfall intensities at 0.5, 1-, 1.5-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, 12-, and 24-hour durations. Data from 1998 to 2014 was considered, which corresponds to the same 17-year period used by PAGASA to derive its own RIDF for that station. This study particularly tested the readily available data from that weather station in Los Baños, Laguna and as such, this paper recognizes the limitation that the area only represents one of the four climatic types in the country.

While the PAGASA RIDF (*PAGASA 2014*) is available, it was imperative to create the study's own actual RIDF that is tailor-fit to the actual rainfall data. Gumbel method was used in the frequency analysis of the rainfall values, which is the same method that PAGASA uses in generating its RIDF. The actual RIDF curve typically exhibits an exponential decrease of rainfall intensity with duration (**Figure 1**). Storms with shorter duration tend to have greater intensity for a given return period. The RIDF was established only for 2-, 10-, 50- and 100-year return periods, noting that these return periods are the most commonly used in drainage evaluation and design (*DPWH-JICA 2003*).

Development of Different Hyetographs

Design storm hyetographs were generated from RIDF and actual rainfall patterns from the same rainfall charts of UPLB-PAGASA-NAS. The 24-hour rainfall distribution was highly considered as this is the typical synthetic storm temporal pattern used by PAGASA in their flood risk assessments (*Badilla et al. 2014*) and by DPWH in drainage design (*DPWH-JICA 2003*). The study in runoff modeling of *Levy and McCuen* (*1999*) likewise reinforces that 24 hours is a reasonable storm-

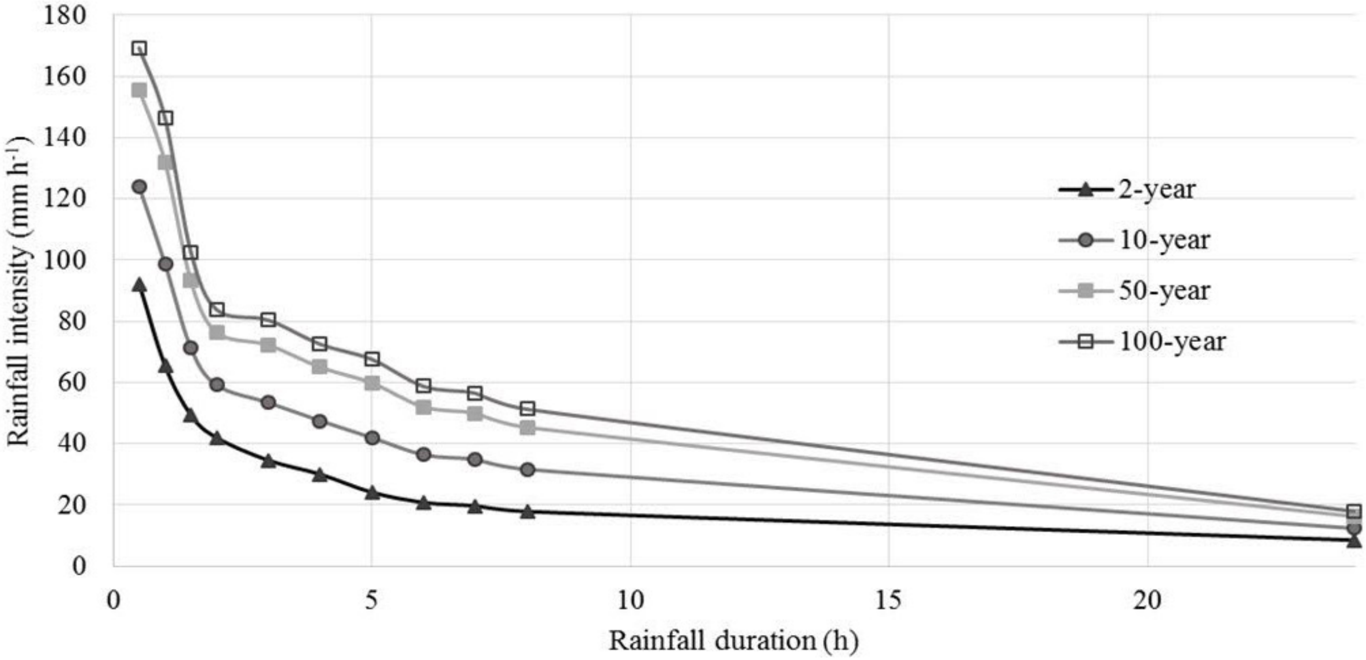

Figure 1. Actual Generated RIDF Curve from UPLB-PAGASA-NAS.

length specifically for watersheds with sizes from 3.2 to 80.5 km^2. Small catchments are sensitive to rainfall events of short duration, while large catchments should consider events longer than 30 minutes, to reasonably account for the travel time of flood. The selected storms must be sufficiently long (in common cases, 24 hours) so that the entire watershed is contributing to runoff at the concentration point (*Placer County Flood Control and Water Conservation District 1999*).

Hyetographs by Alternating Block Method

The alternating block method (*Chow et al. 1988*) is a procedure used to generate synthetic storm patterns, as recommended from the Manual on Flood Control Planning (*DPWH-JICA 2003*). The rainfall intensity at a certain return period for each of the duration is obtained from the RIDF curve. The increments, or blocks, are recorded into a time sequence with the maximum intensity occurring at the center of the required duration and the blocks are arranged in descending order alternately to the right and left of the central block to form the storm plots. The method was employed for both the PAGASA-generated RIDF and the actual RIDF.

Normalized 24-hour Hyetographs

From the same rainfall charts, the extreme 24-hour rainfall events were selected for the months of July to November for the same 17-year period. Numerous rainfall profiles were produced and the values per profile were rearranged to peak on the 12th hour using alternating block method. The values per duration were averaged and then individually divided by the maximum 24-hour rainfall magnitude to produce a single normalized 24-hour rainfall pattern. The hyetographs at specified return periods were obtained by multiplying the ordinates of the normalized 24-hour storm with the corresponding 24-hour rainfall depth obtained from Gumbel analysis.

Hyetographs by *Huff* (*1967*) Method

The four storm patterns by Huff method were developed by considering the observed 24-hour storms in the months of July to November. The storms, a total of 70, were classified according to the quartiles in which the rainfall is heaviest. The quartiles describe the time of peak intensity occurred in a given storm. The storms were grouped and analyzed into four distributions with the following time of peak: Type I (0 to 6 hours); Type II (6 to 12 hours); Type III (12 to 18 hours); and Type IV (18 to 24 hours).

Nomenclature

For purposes of brevity throughout the study, each distribution method has been given denotations (**Table 1**).

Statistical Analysis

Test for significant difference

To prove significant difference among the

Table 1. Nomenclature of the distributions.

Distribution	Denotation
Alternating block method using RIDF from PAGASA	AB-P
Alternating block method using RIDF from actual data	AB-A
Normalized	NORM
Type 1 of HUFF method	HUFF1
Type 2 of HUFF method	HUFF2
Type 3 of HUFF method	HUFF3
Type 4 of HUFF method	HUFF4

hyetographs, nonparametric tests were employed. Nonparametric tests are more advantageous than parametric tests when the distribution is not normal (*Chalmer 1987*). They usually involve ranking of observations and deducing similarity from the ranks. In this study, the method developed by *Kruskal and Wallis* (*1952*), henceforth referred to as Kruskal-Wallis test was employed to see if at least one of the distributions are significantly different (the alternative hypothesis). Moreover, rank-sum test– which may be used in comparing two independent datasets such as rainfall data– was employed to see how each of the distribution compare to what PAGASA is using and how the values are overestimated or underestimated.

Goodness-of-fit test for each hyetograph with actual data

To accomplish the main objective of this work, i.e. to see what distributions represent actual rainfall events well, chi-squared goodness-of-fit test was employed among the distributions and selected storms from 1998-2014. This test employs comparing observed and expected data sets. The test statistic is obtained as follows:

$$test\ statistic = \sum_{i=1}^{k} \frac{O_i - E_i}{E_i}$$

where Oi is the ith value of the observed data set and Ei is the ith value of the actual data set. Microsoft Excel has a function (syntax: =CHISQ.TEST(actual_range,expected_range)) to immediately compute the p-value for sets of expected and observed data sets. In the analysis, cumulative 24-hour rainfall hyetographs of the seven distributions were deemed as expected values and the 24-hour cumulative storm depths derived from actual data provided by PAGASA were denoted to be the observed or actual values. The cumulative hyetographs were normalized by the total value so that the range of values will be from 0 to 1. In determining the return periods of the storms, RIDF curves were used. Since it would be tedious to construct hyetographs for each return period, the closest of the 2, 10, 50, and 100-year return periods were selected. For example, if a value of 0.015 was obtained as the annual probability of non-exceedance for a storm (corresponding to a 67 year return period), the return period was rounded off to 50 years. Such assumption is not erroneous because the distributions were normalized – in fact for the HUFF distributions, the normalized distributions for each return period are the same.

In selecting the type of intervals, one can opt to select by equal probabilities or by equal intervals. The latter was followed in this paper. In selecting the number of intervals, one must avoid intervals that yield very low expected values because the test statistic may blow up (tend to infinity) when expected values are near zero.

RESULTS AND DISCUSSION

Comparison of Generated Hyetographs

There were 24-hour cumulative hyetographs generated from the different distribution methods at different return periods (**Figure 2**). It can be observed that not all curves are the same. Furthermore, AB-A generally provides the largest values of rainfall and the steepest slope. On the other hand, HUFF2 has consistently produced the smallest curves. Moreover, HUFF4 has the mildest slope.

The observation that there is variety among the seven hyetographs was statistically proven using Kruskal-Wallis test (**Table 2**) as applied to the 100-year storms. At six degrees of freedom and 1% level of significance, the critical value is 16.8 while at 5% level of significance the critical value is 12.6. The value obtained is 21.45, which indicates that there is at least one distribution that is significantly different from the rest.

It can be also hypothesized if there is significant

Table 2. Summary of Kruskal-Wallis test parameters as tested for 100-year storm patterns.

Distribution	Average rank	KW
AB-P	118.146	
AB-A	153.500	
NORM	196.125	
HUFF1	188.740	21.45
HUFF2	184.740	
HUFF3	172.167	
HUFF4	166.083	

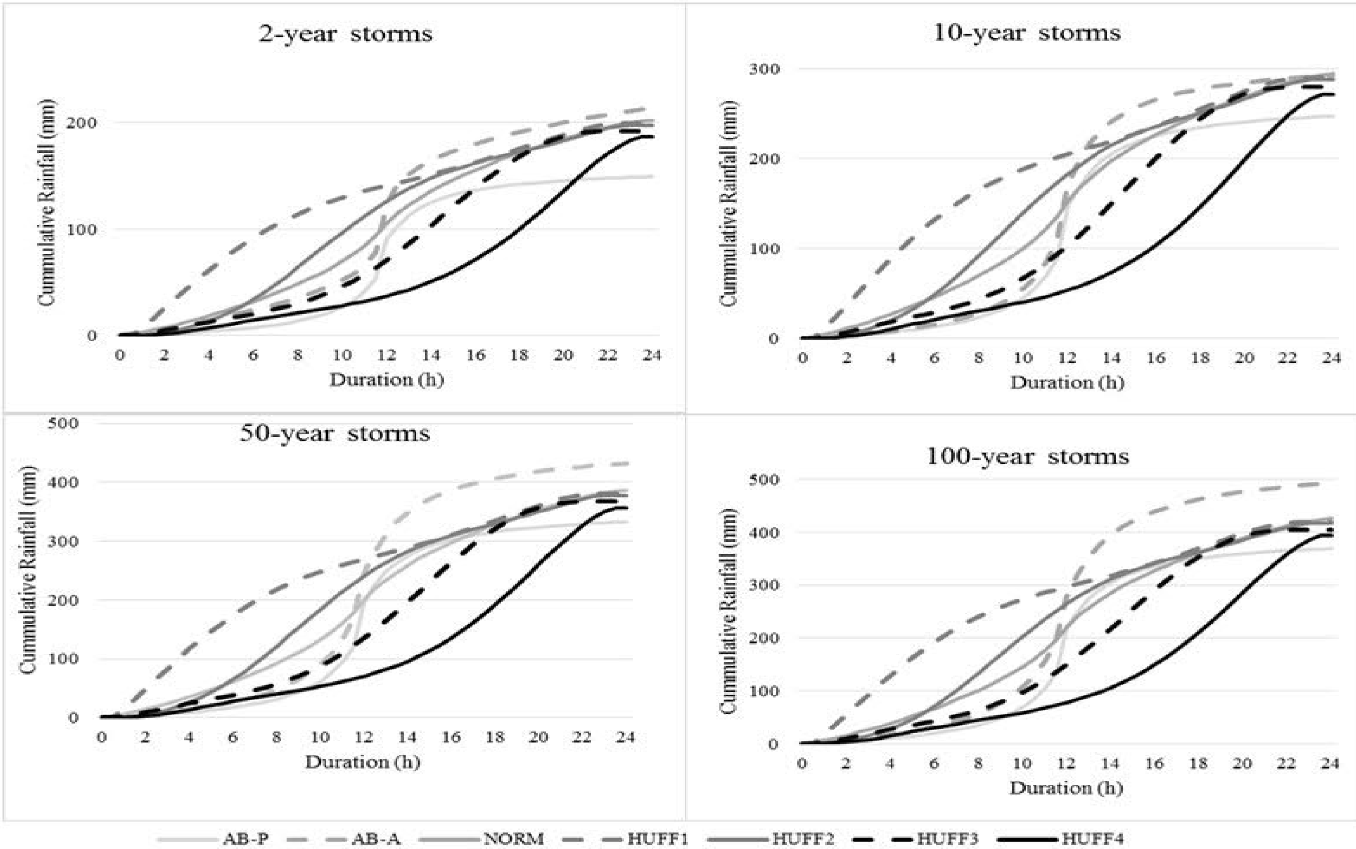

Figure 2. Cumulative 24-hour hyetographs at different return periods.

difference between AB-P and each of the six other distributions (**Figure 2**). To test this hypothesis, rank-sum test was performed. At 5% significance level, there is a significant difference between each of the six distributions and AB-P (**Table 3**) at 5% significance level; however at 1% significance level, only NORM, HUFF1, and HUFF2 are supported by statistical evidence to have dissimilar distributions with AB-P. Furthermore, the distributions are overestimating the values with respect to AB-P based from their rank sums with NORM overestimating the most at 62.83%.

Validation of Hyetographs with Actual Data

To see how well the hyetographs represent the pattern of actual data, the cumulative hyetographs normalized by the total were compared. The best distribution varies for each storm. For example, AB-P looks the best fit for the 2010 Typhoon (TY) Conson (**Figure 3**). However, for the 1999 Tropical Storm (TS) Eve, HUFF4 seems the best fit with the other distributions seem to fit poorly. Furthermore, there is not one distribution that fits the 2008 TY Fengshen well.

To put numbers to the observations, chi-squared goodness-of-fit test was applied between each distribution and each of the selected tropical cyclones from 1998 to 2014. For a significance level of 5%, a p-value greater than 0.05 means that there is not enough evidence to reject the null hypothesis that the distribution

Table 3. Parameters of rank sum test (N=96, n = 48, m=48, μ=2328, σ= 136.47).

Parameters	Storm Hyetographs					
	AB-A	NORM	HUFF1	HUFF2	HUFF3	HUFF4
Rank sum	2640	2884.5	2771	2761	2659	2668
Rank sum (AB-P)	2016	1771.5	1885	1895	1997	1988
% difference	30.95	62.83	47.00	45.70	33.15	34.21
Z	2.28	4.07	3.24	3.17	2.42	2.49
$Z_{\alpha = 1\%}$	2.58	2.58	2.58	2.58	2.58	2.58
$Z_{\alpha = 5\%}$	1.96	1.96	1.96	1.96	1.96	1.96

of the hyetograph conforms to the distribution of the selected storm (**Table 4**). For example, in comparing AB with the 1998 TY Faith the p-value was 0.0000, which means that the hyetograph from PAGASA is not representative of the TY Faith, as are AB-A, HUFF1, and HUFF4. However, NORM, HUFF2, and HUFF3 have p-values greater than 0.05; therefore, they represent the TY Faith well. For TY Faith, HUFF3 – with the largest p-value – is the best fit.

Several observations were observed in the chi-squared test p-values (**Table 4**). First, there is not one distribution that best represents each storm– one distribution may be a better fit for a certain storm than others. Second, only TY Conson is best represented by AB-P compared to the other distributions. Third, the distributions that follow the alternating block method have storms that fit them reasonably but in some cases, there are better fits; moreover, in some storms the family of alternating block

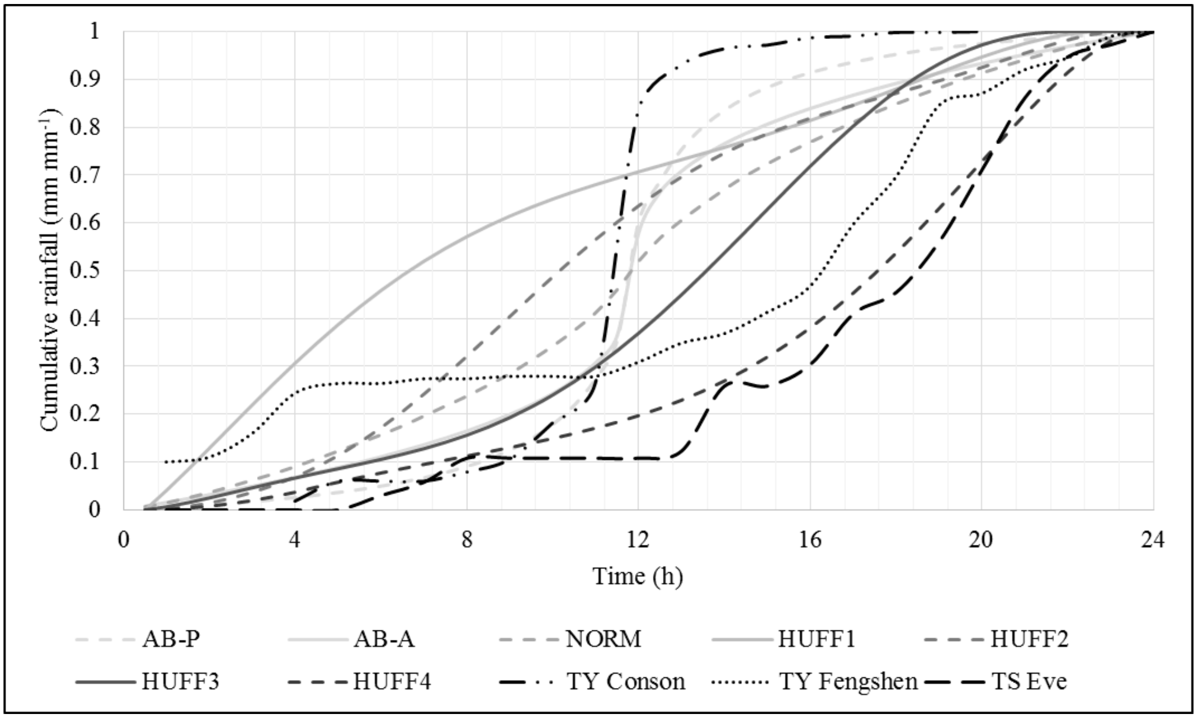

Figure 3. Cumulative hyetographs of the seven distributions and rainfall data from TY Conson, TS Eve, and TY Fengshen.

Table 4. Chi squared test p-values (four significant figures); values in bold numbers are the highest p-values for each row, corresponding to the best distribution.

Storm	Year	AB-P	AB-A	NORM	HUFF1	HUFF2	HUFF3	HUFF4
Faith	1998	0.0000	0.0019	0.2190	0.0065	0.1544	**0.2524**	0.0029
Eve	1999	0.0001	0.0044	0.0673	0.0000	0.0113	0.3027	**0.9467**
Lingling	2001	0.0000	0.0000	**0.2259**	0.0174	0.0897	0.0334	0.0258
13W	2002	0.0000	0.0001	**0.1611**	0.0000	0.0417	0.0540	0.1320
Nepartak	2003	0.1347	0.8300	0.7003	0.0002	0.5789	**0.8332**	0.0410
Xangsane	2006	0.2494	**0.3887**	0.2752	0.0193	0.3783	0.3045	0.0017
Durian	2006	0.0000	0.0001	0.4079	0.0221	0.1831	0.1279	0.0543
Mitag	2007	0.0727	0.5254	0.3680	0.0000	0.1678	**0.7368**	0.3186
Fengshen	2008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
Ketsana	2009	0.0000	0.0001	0.1472	0.0001	0.0367	**0.2407**	0.1831
Conson	2010	**0.8149**	0.6260	0.1384	0.0006	0.1880	0.2022	0.0007
Noul	2011	0.0727	0.5254	0.3680	0.0000	0.1678	**0.7368**	0.3186
Haikui	2012	0.0000	0.0003	0.0857	**0.2322**	0.1148	0.0323	0.0000
Son-Tinh	2012	0.0000	0.0010	0.4152	0.2998	**0.4247**	0.0206	0.0009
Trami	2013	0.0000	0.0017	0.1870	0.0000	0.0592	**0.4217**	0.1676
Hagupit	2014	0.0000	0.0012	**0.4636**	0.0633	0.3217	0.3067	0.0092
Rammasun	2014	0.0000	0.0026	0.0369	0.0000	0.0088	**0.0478**	0.0225

method fails miserably. Fourth, TY Fengshen has a distribution that does not fit any of the seven methods. These observations can be summed up in one statement: that the storms have varied distribution in time. Such observation is not surprising. According to *Wright et al.* (*2013*), extreme rainfall can vary greatly temporally and spatially. Such variation has far-reaching implications in the reliability of the current method used by PAGASA and DPWH.

One implication based from these observations is to avoid using exclusively one hyetograph to model all the storms. In the Philippine context, where PAGASA and DPWH use alternating block method, Table 2 revealed that while in some cases the method can best represent a storm, in other cases it does poorly. Moreover, even if the method is reasonable in some storm events, there are better methods. Furthermore, while HUFF3 seems to represent storms better than alternating block method in this analysis, the study does not intend to suggest that the former should be adopted rather than the latter. In fact, Koutsoyiannis (1994) has pointed out the advantages of the alternating block method over the Huff methods and while he also discussed the limitations of the latter, he stated that alternating block method "remains a powerful engineering tool that results in reliable design values". However, if in the case that the two agencies' method misrepresents a storm, the method being an underestimation (**Table 3**) of the other methods will produce underestimated design flood values, which will lead to the construction of flood-weak infrastructures. The warning, therefore, is not to rely on only one encompassing hyetograph for all the storms, rather to be open-minded to pursue research on other methods of generating rainfall hyetographs.

CONCLUSIONS AND RECOMMENDATIONS

In this study, design storm hyetographs using alternating block and other methods were generated and the reliability of each method to the represent the actual storms was investigated with validation from the tipping bucket rainfall records from 1998-2014 for the weather station in Los Baños, Laguna. The design hyetographs for 2-, 10-, 50- and 100-year return periods were established using alternating block method based on PAGASA's RIDF, actual generated RIDF and normalized 24-hour storm, and four distributions of Huff. Nonparametric statistical methods were employed to see how the current method of PAGASA compares with other methods. Goodness-of-fit test was applied in each of the methods tested to see if PAGASA represents each storm well and which method best represents each storm. From the results of the analysis, the following are concluded:

1. There are many ways of representing storms by generating hyetographs and these methods are significantly different. Thus, if some methods represent a storm well, other methods may perform poorly.
2. There is not one hyetograph that best represents every storm. As a corollary, the alternating block method, which is the method used by PAGASA and DPWH, is not the best representation of any storm.
3. One distribution may be better than others in some instances but worse in other instances. Therefore, even though HUFF3 best represented most storms in this paper, it still cannot be concluded that it is the best method of generating hyetographs and while alternating block only performed the best in one storm, it does not follow that it is the worst method of generating hyetographs.
4. In some storms, and considering the methods of generating hyetographs discussed, all the available methods may not be sufficient, such as in TY Fengshen. Thus, having several models of representing rainfall patterns is not a guarantee of the accuracy of the representation.

There is not one best representation of storm and that one distribution may be better than others in some instances but worse in other instances. In conclusion, variability of the performance of alternating block method- the method used by PAGASA and DPWH in designing hyetographs- should prompt the government and the hydrologic community in the Philippines to put more effort in storm hyetograph research in the country. This study likewise recommends to test data from other weather stations representing other climatic types.

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