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Climatological analysis of the Southwest Monsoon (Habagat) in Type 1 Climate Areas in the Philippines from 1949–2018

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Abstract

The Southwest monsoon (SWM) rainfall is used in agriculture, industry, and electrical energy and fills reservoirs that supply water to households. However, it generates high levels of rainfall which can negatively affect Philippine agriculture. The historical behavior and trends of the SWM rainfall in the Philippines were identified using collected rainfall data from fourteen (14) meteorological stations situated in Type 1 climate areas of the country, where the impact of SWM is well-pronounced. The time series analysis from 1949 to 2018 for the months of June to September showed an overall increase in accumulated rainfall with a slope of +1.8047, as well as in the decadal frequencies of high precipitation event days (HPE) at the 85th, 95th, and 99th percentile with slopes of +1.0586, +0.4740, and +0.1030, respectively. The trendline for the no-rain days graph has a slope of -0.1177, indicating a decreasing trend. These findings suggest a possibility of an increase in SWM rainfall in the coming decades.

Introduction. - Heavy rainfall is considered one of the most disastrous weather extremes that greatly affect human activities and environmental systems [1]. The factors that facilitate heavy rainfall events include (i) the southward expansion of the high-pressure system to the north of the Philippines, (ii) the El Niño Southern Oscillation (ENSO), and (iii) enhanced moisture-converged cold surges [2]

The Southwest monsoon (SWM) are trade winds that bring warm and considerably humid air mass during the months of June to September every year. The Southwest monsoon (SWM) rainfall results from the passing of air over large areas of warm equatorial ocean that stimulates evaporation from its surface; as the moisture-heavy air cools, it moves north and precipitates [3]. It contributes 43% of the precipitation in the mean annual rainfall in the Philippines [4]. According to [5], the western side of the country is greatly affected by rainfall from the Southwest monsoon (SWM) during boreal summer. It also simultaneously occurs with the peak occurrence of tropical cyclones in the country which is during the months of July and August. This co-occurrence allows tropical cyclones to influence the southwesterly winds of the monsoon which contributes to an increase in the amount of precipitation during the season [4,6]. Crost et al. [7] found that an increase in rainfall during the dry season increases agricultural production, while rainfall during the wet season harms crops and produces conflict. According to the International Rice Research Institute [8], 30% of the total rice area in the country is rainfed and upland, which are heavily reliant on rainfall for crop production. However, this agricultural system is also sensitive to the variability in rainfall patterns which could bring sudden heavy rainfalls that are damaging to the crops [9]. In 2016, it was found that there is an increasing trend in economic loss and damage due to tropical cyclones [10]. Since the country is vulnerable to variations in climate and rainfall, changes in the onset and intensity of rainfall can significantly affect livelihood, food security, and economic stability, by disrupting agricultural production and damaging infrastructure [5,11].

The East Asian Monsoon and South China Sea Monsoon rainfall trends have been studied intensively over the past years [12,13,14]. However, the rainfall trends of the Southwest monsoon have received relatively little interest from the scientific community, thus the need for this research. The study of Cruz et al. [5] presented data regarding the climatological analysis of Philippine Southwest monsoon rainfall. Their examination of the rainfall extremes indicated an increasing trend in the number of days without rain and a decreasing trend in the heavy rainfall days from 1961 to 2010, which can be detected with statistical confidence. However, multiple meteorological stations have been constructed in other parts of the country since then. A shift in rainfall was also observed in different portions of the country due to the reduction of the topography of mountains, urbanization, and climate change. Hence, utilizing a wider scope of data in terms of geography and time will increase the accuracy of *Habagat* rainfall trends and patterns, thus the need for this study [15].

This observational study analyzed the trend and behavior of SWM or habagat rainfall in the

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northwestern portion of the Philippines using rainfall data from fourteen (14) synoptic stations from 1949 to 2018. It specifically aims to:

(i) identify the high precipitation event days (HPE) where the total amount of rainfall collected in each station belongs to the upper 85th, 95th, and 99th percentile;

(ii) determine the number of days with and without rain;

(iii) present a time series analysis that will show the trend of rainfall for the past seventy (70) years in the Type 1 climate areas of the Philippines where the impact of SWM is well pronounced;

(iv) identify years where the SWM rainfall deviates from the climate mean;

(v) detect years with normal, below-normal, and above-normal rainfall using the Southwest Monsoon Rainfall Anomaly Index (SWMRAI) threshold; and

(vi) analyze the graphs and investigate the trends present in the graphs.

Methods. - The methodology used for this study was adapted from the study of Cruz et al. [5]. Total rainfall data from the years 1949–2018, collected from fourteen (14) synoptic meteorological stations—the Baguio PAGASA weather station, and thirteen (13) stations which are included in the Climate Type I of the modified Corona's climate classification—were requested from PAGASA. A time-series analysis was used to determine the historical trend and variability of the SWM rainfall. The no-rain days and high precipitation event (HPE) days were then determined and the HPE days were classified into 85th, 95th, and 99th percentiles. Using the calculated spatial average of each standardized rainfall anomaly, the Southwest monsoon Rainfall Anomaly Index (SWMRAI) for each year was obtained. Finally, using the standard deviation of the SWMRAI as the threshold, the SWM rainfall extremes were determined.

Collection of Raw Rainfall Data. The daily, monthly, and annual rainfall data that was used to determine the trends and historical behavior of the Southwest monsoon (SWM) or *Habagat* in the country are from the year 1949 to 2018. They were collected from PAGASA's fourteen (14) synoptic meteorological stations (see Table 1). In this study, the reference period for the baseline climate is from 1949 to 2018. Since the synoptic meteorological stations were not built in the same years, the months with missing data were replaced with the climatological mean of the monthly total rainfall, following the methods of Cruz et al. [5].

Table 1. Coordinates and year built of the fourteen (14) synoptic stations used to determine trends and historical behavior of the southwest monsoon in the country.

Location	Year and Month Built
Ambulong, Batangas	Jan 1951
Baguio City, Benguet	Jan 1949
Cabanatuan, Nueva Ecija	Jan 1989
Coron, Palawan	Jan 1951
Cuyo, Palawan	Jan 1951
Dagupan City, Pangasinan	Jan 1951
Iba, Zambales	Jan 1951
Laoag City, Ilocos Norte	Jan 1951
NAIA (MIA), Pasay City	Jan 1949
Port Area (MCO), Manila	Jan 1949
Puerto Princesa, Palawan	Jan 1951
San Jose, Occ. Mindoro	Jan 1981
Sangley Point, Cavite	Jan 1974
Science Garden, Quezon City	Apr 1961

Data Analysis. The time-series analysis was used to determine the historical trend and variability of the SWM rainfall. From the data provided by PAGASA, days with no rain and HPE were determined. The HPE days were then classified into 85th, 95th, and 99th percentiles, which according to Bagtasa et al. [16], are considered days with heavy rain. Using the formula adapted from Wilks [12], standardized anomalies were determined for each station per year. The Southwest monsoon Rainfall Anomaly Index (SWMRAI) for each year was then obtained using the calculated spatial average of each standardized rainfall anomaly. The standard deviation of the SWMRAI was derived and used as a threshold to determine the rainfall levels.

No-rain Days. The number of days where the rainfall collected in a station is 0 mm was determined per year and tallied per decade. A bar graph was then generated with the decadal frequencies of no-rain days for the months of June to September from 1949 to 2018 for each station.

High Precipitation Events Days. The high precipitation events (HPE) days, days with rainfall in the upper 85th, 95th, and 99th percentile, were determined using daily rainfall data from all fourteen (14) synoptic stations and were tallied per decade. They are referred to as HPE85, HPE95, and HPE99, respectively. A graph containing the decadal frequencies of HPE85 days per station was generated. The same was done for HPE95 and HPE99 days.

Standardized anomalies. A rainfall index was used to determine the annual variation of SWM rainfall per station. Rainfall data from PAGASA is expressed as a standardized anomaly so that it can be directly compared to rainfall data from different stations regardless of local conditions such as elevation and land use. Adapted from Wilks [17], the standardized anomalies are expressed as:

$$(1) \qquad Z_i = \frac{x_i - \bar{x}_i}{s_{xi}}$$

Where:

x_i = SWM rainfall value at station i for a particular year
$\bar{x_i}$ = mean SWM rainfall for station i
s_{xi} = standard deviation at station i from 1949–2018

The data that were obtained from this step are 843 Z_i values – one value for each of the fourteen stations per year. The Z_i values were grouped per year and their average was calculated to obtain 70 Z_{it} values which were needed for succeeding calculation.

Southwest Monsoon Rainfall Anomaly Index. The spatial average for Z_i, the annual variation, at each station were calculated to derive a single index called the SWMRAI. For each year (t), SWMRAI is expressed as:

$$(2) \quad SWMRAI_t = \frac{1}{N}\sum_{i=1}^{N} Z_{it}$$

Where:
N = total number of stations in a particular year t
Z_{it} = standardized rainfall anomaly at year t

The data that were obtained from this step are 70 values – one SWMRAI value per year.

Standard deviation of SWMRAI. The standard deviation *s* of SWMRAI was also calculated to identify a threshold for determining the years with normal, above normal, and below-normal rainfall. The formula for standard deviation that was used is:

$$(3) \quad s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}{n-1}}$$

Where:
n = total number of stations
x_i = SWMRAI of each year
$\bar{x_i}$ = mean of x_i

The positive and negative *s* values were used as the upper and lower bounds. A year where the SWMRAI exceeds the positive *s* value means that the SWM rainfall at that year has above-normal rainfall and vice versa.

Standard deviation of annual rainfall data. The standard deviation of the total collected rainfall of year *t* in station *i* was calculated. A time-series graph of the SWM accumulated rainfall, taken as an average across all stations, was produced. Error bars were added to indicate the positive and negative standard deviation of annual rainfall data.

Safety Procedure. Protective measures were done to prevent the risk of file corruption as well as to ensure security. A copy of the files was downloaded directly from the email that PAGASA sent before any calculation was done and was stored in a virus-free flash drive. A copy of the original files was also uploaded to a Google drive folder, where files of calculated data were also stored.

Results and Discussion. - The average annual accumulated rainfall of all stations during the months of June to September, from the year 1949 to 2018 showed an inter-annual variability (see Figure 1). In the 70-year time series, a minimal increasing trend for the annual accumulated rainfall can be observed from its linear trend slope of +1.8047. The spatial variability which has a slope of -0.1065, however, indicates a decreasing trend. This implies that the degree to which rainfall amounts vary across time is decreasing. Great spatial variability can be observed in the years 1951, 1958, 1968, 1972, 1990, 2012, and 2018. It is also worth noting that the deviation between stations tends to be lower in years with lower accumulated rainfall. According to several studies [18,19], the observed interannual variability of rainfall is highly correlated to the effects of the El Niño Southern Oscillation. The shifting phenomenon of other monsoons in Southeast Asia also has an impact on rainfall variability [20]. Furthermore, The results for spatial variability are supported by the study of Cruz et al. [5] which also reported a decline in the linear trend of the spatial variability of total SWM rainfall from the year 1960 to 2010.

It can also be seen from Figure 1 that in 1972, the annual accumulated rainfall was significantly higher. This increase can be attributed to prolonged flood conditions due to the occurrences of tropical cyclones, further aggravated by the intensification of the SWM. The events that were primarily responsible for these conditions are Super Typhoon Rita and Typhoon Susan, which altered the monsoon winds over the Philippines. They were then succeeded by Typhoons Edeng, Gloring, Isang, and Huaning only weeks after. It is interesting to note that the 1972 great flood over Luzon occurred during an El Niño episode [21]. Villafuerte et al. [22] confirmed that with the development of El Niño in the north-central Philippines, wetter conditions during the months of July to September are expected.

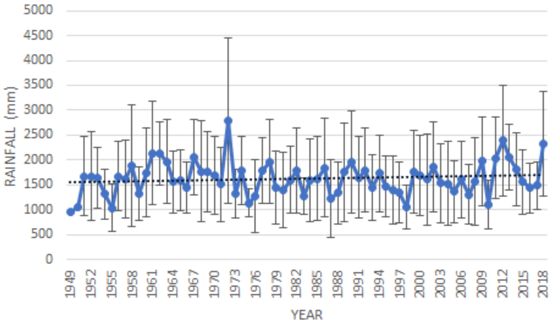

Figure 1. Time series of the annual SWM accumulated rainfall, taken as an average across all stations. Error bars indicate the standard deviation of station values. Dashed line indicates the linear trend.

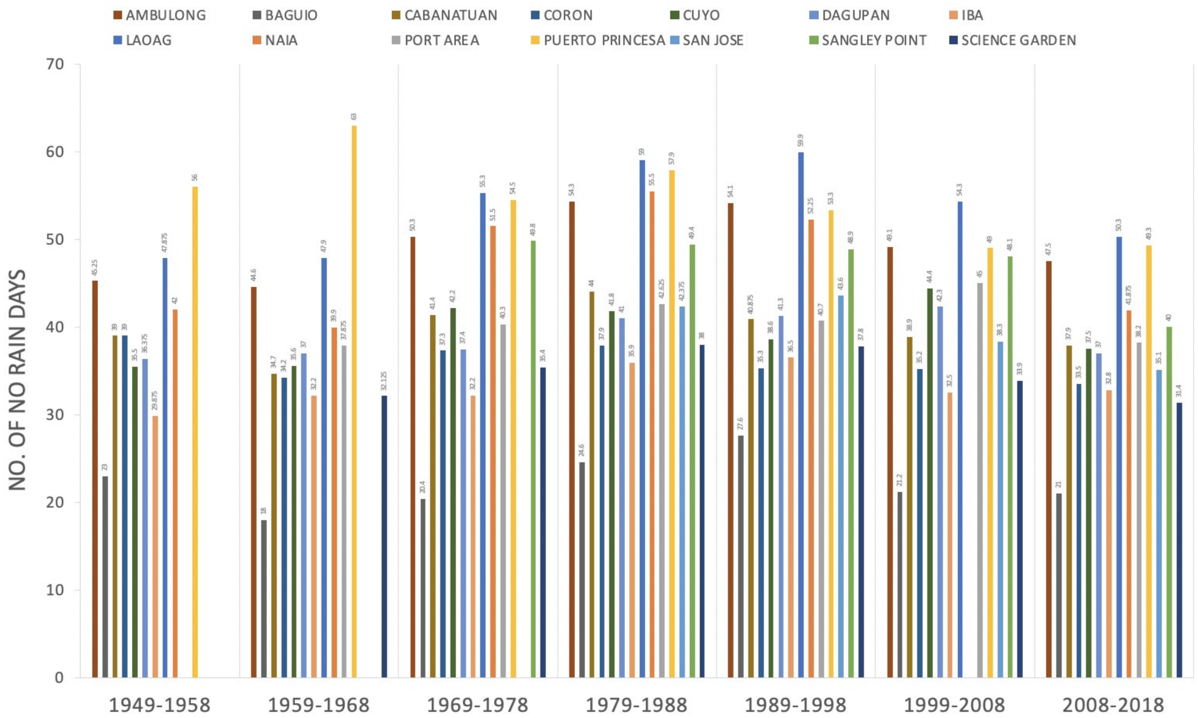

Figure 2. Decadal frequencies of no-rain days for the months of June to September from 1949 to 2018 for each station.

As seen in Figure 2, there is a decline in the frequency of no-rain days during SWM season for the past four decades (1979 to 2018), with the linear trend having a slope of -0.1177. The number of no-rain days has decreased from decades 1949–1958 and 1959–1968, increased from decades 1959–1968 to 1979–1988 and decreased from decades 1979–1988 to 2009–2018. It can be observed in the graph that in all stations, the years from 1979 to 1998 have the most number of no-rain days. Results also showed that the station in Iba received the most rain averaging 2887 mm per year, and the station in Puerto Princesa received the least rain averaging 708 mm per year for the past 70 years. Changes in the extremes are important to understand because of their climatic impact in terms of floods and droughts, which result in serious consequences especially on the agricultural and energy sectors [5].

Moreover, the decadal changes in the number of HPE days—those who are above the 85th, 95th, and 99th percentile (Figure 3)—are increasing as well. In other words, there is an overall increasing trend in the number of days belonging to the 85th, 95th, and 99th percentile rainfall throughout the decades. The slopes of their trends are +1.0586, +0.4740, and +0.1030, respectively. It can also be seen in the figures that all the trendlines have a positive slope, regardless of their percentile value. This indicates that rainfall has continually increased in terms of intensity within the 70-year period.

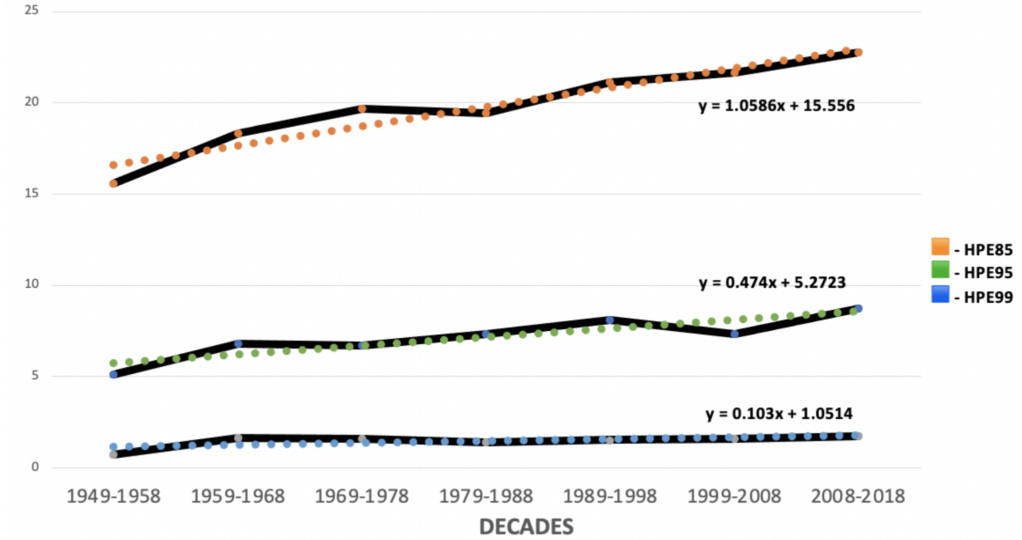

Figure 3. Overall trends of HPE85 (orange), HPE95 (green), and HPE99 (blue) days, defined as exceeding the 85th, 95th, and 99th percentile from 1949 to 2018, for the months of June to September for each station.

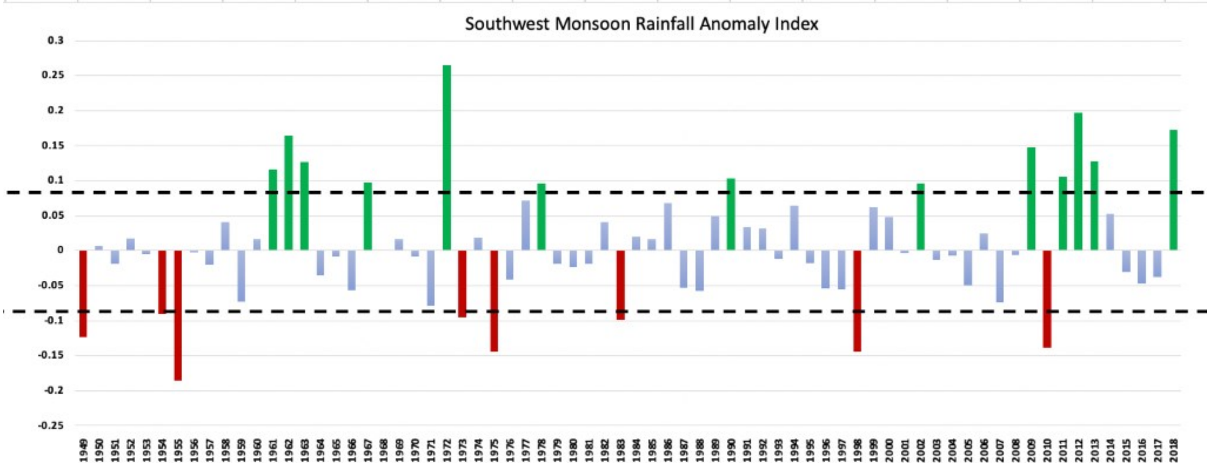

Figure 4. Time-series of the annual Southwest Monsoon Rainfall Anomaly Index (SWMRAI), taken as an average across all stations. The standard deviation of these indices (dashed line) sets the thresholds for normal rainfall. Years are classified as follows: above-normal (green), normal (blue), and below-normal (red).

Unlike the no-rain days graph, no station has consistently experienced the greatest or least HPE days. According to Cruz et al. [5], the 95th percentile of daily rainfall from the baseline climate is already considered as heavy rainfall. A negative trend in the 85th, 95th, and 99th percentiles of HPE days can be observed in their study, which is in contrast with our findings. However, this may be due to the difference in the number of stations and years analyzed. The study of Cruz et al. [5] utilized data from only 9 stations over a 50-year period, whereas this paper utilized data from 14 stations in a 70-year span.

As shown in Figure 4, the years with above-normal rainfall are 1961, 1962, 1963, 1967, 1978, 1990, 2002, 2009, 2011, 2012, 2013, and 2018, while the years with below-normal rainfall are 1949, 1954, 1955, 1973, 1975, 1983, 1998, 2010. The rest of the years are categorized under normal rainfall.

The standard deviation of SWMRAI, ±0.08460741, was used as the threshold in determining the years with above-normal and below-normal SWM rainfall. Within the 70-year period of study, 49 years were normal, 13 years were above-normal, and 8 years were below-normal. In the study of Cruz et al. [5], the majority of the years from 1961 to 2010 also fell in the normal rainfall category. Data from PAGASA was used in determining El Niño and La Niña years. Two (2) out of twelve (12) years when the Type 1 climate areas of the Philippines received above-normal rainfall, were La Niña years (1962, 1972). It is worth noting that one El Niño year (2002) belonged to the same category. One (1) out of eight (8) occurrences of below-normal rainfall were El Niño years (1983). Moreover, all except one below-normal rainfall years are La Niña years (1949, 1954, 1955, 1973, 1975, 1998, 2010). These findings show that El Niño years are not necessarily associated with below-normal rainfall, and the same idea can be applied to La Niña years as well.

Limitations. Not all stations had available rainfall data from 1949–2018 since they were constructed at different years, and some had to stop operations due to maintenance problems. This resulted in missing data in some years.

Conclusion. - During the Southwest monsoon season, there is an overall increase in the amount of rainfall and a decrease in drier days in Type 1 climate areas of the Philippines as compared to the past years. The frequency of no rain days has decreased, the trend lines observed in the frequency of high precipitation days at the 85th, 95th and 99th percentile are increasing, and the average accumulated Southwest monsoon rainfall has increased as well. The extremes in the number of no-rain days are the years from 1979 to 1998, and there are no extreme years for the number of HPE days in all three percentiles. This shows that during this period, a lot of days had zero precipitation, and for the years during this period that had above-normal rainfall, it can be inferred that precipitation was heavy during the rainy days. For the SWMRAI, 1955 is the year with the lowest recorded below-normal rainfall, while 1972 is the highest recorded above-normal rainfall value. The decrease in the frequency of no-rain days, and the increasing trend lines observed in the frequency of high precipitation days at the 85th, 95th, and 99th percentile, as well as the average accumulated Southwest monsoon rainfall shows that there is an overall increase in the amount of rainfall in the northwest portion of the Philippines during this season. It was found that whether a year falls in the below-normal, normal, or above-normal rainfall categorization is not dependent on its classification as an El Niño or La Niña event. In summary, based on the results of the data analysis, it can be concluded that there is a possibility of increased rainfall and shorter dry periods during the SWM season in future years. If the rainfall trend continues to increase in the future, heavy rainfall-related risks such as flooding and landslide occurrence are likely to escalate.

Recommendations. - Other factors such as passages of landfalling and non-landfalling tropical cyclones, wind, urbanization, and heat flux were not included in this study. An in-depth analysis on the correlation between other factors could provide better predictions for SWM rainfall. Lastly, it is recommended that sectors that are highly vulnerable to heavy rainfall, such as the agricultural sector, to regularly monitor the trend and prepare a risk management plan and risk reduction plan to help them mitigate the negative effects of SWM in the future, since it is expected that rainfall will be heavier than previous years.

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