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RESEARCH ARTICLE

Analysis of Rainfall Variability in the Province of Quirino

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Abstract
The temporal variability of rainfall in Quirino Province was analyzed through the use of rainfall data of seven (7) rain gauges within the neighboring provinces like Nueva Vizcaya and Aurora. The length of record analyzed from 1997 to 2016. In this study, rainfall frequency analysis and consistency of rainfall data from the different stations through the use of double mass curve analysis was performed and analyzed. The annual series was used to screen each station's annual rainfall data while the province's average Thiessen rainfall was screened using maximum period series process. It was found out that all the data of the seven (7) rainfall stations were consistent. To attain allowable error in estimation of 10%, 5% and 1% for the mean annual rainfall the number of rain gauge station needed in the province should be 18, 72 and 1799, respectively.

Keywords: Double Mass Curve; Frequency Analysis; Rainfall; Rain Gauge; Temporal Variability; Thiessen

Introduction

The Philippines has 7, 107 islands, lies on the western rim of the tropical Pacific just off the southeastern portion of the Asian continent, and is surrounded by the South China Sea and the Pacific Ocean. The high sea surface temperature rings a warm and wet climate to the Philippines (Flores and Balagot, 1969). Rainfall is the most important climatic element in the Philippines because agriculture, influenced by the annual and seasonal variation of rainfall, plays an important role in the Philippines economy (Jose, 2001; Akasaka, et. Al., 2007).
In the Province of Quirino some portuons of the province lie on the East fall under Climatic Type III, which is characterized by no pronounced seasons. Rain is evenly distributed throughout the year. Dry season is from March to the early part of October while remaining days of October to February are wet. The western portion falls under climatic Type IV which is characterized by rainfall or more or less evenly distributed throughout the year with dry season from March to August and wet from September to January (DENR-02). Rainfall variations are likely the most evident effects of the changes occurring on the earth's climate system (Ayugi et. al. 2016). An understanding to the temporal characteristics of precipitation is hence central to water resources planning and management, especially given the evidence of climate change and variability in recent years (Liu et. Al 2015). Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling and water resources assessments (Gallego et. Al. 2011). Therefore, many studies on the temporal characteristics of rainfall in different part of the world have beed conducted. As a result, this study will perform and analyze the rainfall frequency and consistency of the rainfall data from the different stations.

Methods

The rainfall data used in the study were acquired from the different weather stations located within the Province of Quirino, neighboring provinces and Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

Interpretation of Rainfall Data

Before rainfall records of each station were used, they were first checked for continuity and consistency. The continuity of a record was broken with missing data due to many reasons such as damage or fault in a rain gauge during a certain period. When the condition relevant to the recording of a rain gauge station had undergone significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time significant changed took place.
Multiple Linear regressions has the equation of the form:

$$\mathbf{P_X = a + b_A P_A + b_B P_B + \cdots + b_N P_N}$$

Where **a** is near zero and the **b**'s approximate the coefficients of equation 1 divided by the number of index stations. The advantage of the regression approach is that it adjusts, to some extent, for departures from the normal ratio assumption. In the mountainous regions, the Normal-Ratio and Multiple Linear Regression Analysis methods therefore yield more reliable estimates. Estimates for missing precipitation data are generally most reliable for general-type storm over flat terrain or over relatively smooth windward mountain slopes. Severe and spotty convective activity and rugged terrain lessen the reliability. Estimates for long intervals (months or years) are more reliable than those for short intervals such as day.

Test of Consistency of Record

The checking for inconsistency of a record was done by the Double-Mass Curve Analysis. This technique was based on the principle that when each recorded data came from the same parent population, they were consistent. The procedure of analysis for the testing of consistency of a rainfall record was described below.

A group of surrounding (base) stations in the neighborhood of the problem station X was selected. The annual rainfall data of the Station X and also the average rainfall of the group of base stations covering a long period were arranged in chronological order (i.e. the oldest record as the first entry and the latest record as the last entry in the list). The accumulated precipitation of the station X (i.e. $\sum P_X$) and the accumulated values of the average of the group of base stations ($\sum P_{av}$) were calculated starting from the oldest record. Values of $\sum P_X$ were plotted against $\sum P_{av}$ for various consecutive time periods. A decided break in the slope of the resulting plot indicated a change in the precipitation regime of station X. To make the record prior to the point of break in slope comparable with that of the more recent record, it was adjusted by the ratio of the slopes of the two segments of the double-mass curve. Hence, the precipitation values at station X beyond the period of change in regime were corrected through the relation:

$$\mathbf{P_{CX} = P_x \left(\frac{b}{a}\right)}$$

When the decrease in the trend of rainfall regime occurred after the point of break in slope.

$$\mathbf{P_{CX} = P_x \left(\frac{a}{b}\right)}$$

When increase in the trend of rainfall regime occurred after the point of break in slope.

where:

$\mathbf{P_{CX}}$ = corrected precipitation at any time period at any time period t, at station X

$\mathbf{P_x}$ = original recorded precipitation at time period t, at station X

a = slope of the double-mass curve for the past record

b = slope of the double-mass curve for the latest record

Considerable caution was exercised in applying the double-mass curve technique. Lindsey (1988) emphasized that the plotted points always deviate about a mean line and changes in slope are accepted only when marked or substantiated by other evidence.

Determination of the Average Depth of Rainfall

A rain gauge represents only one sampling point of the real distribution of rainfall over an area. The average depth of precipitation over a specific area, on a storm, seasonal or annual basis, is required in many types of hydrologic problems. In this study, the Thiessen Method was considered.

The Thiessen method attempts to allow for nonuniform distribution of gages by providing a weighing factor for each gage. For this study, the weighing factor for each of the stations was obtained using the Thiessen polygon tool of GIS Software. The weighted average rainfall for the whole province was computed by multiplying the precipitation at each station by its assigned percentage of area and totaling as recommended by Linsley (1988). Thus,

$$\mathbf{P_{ave} = P_A C_A + P_B C_B + \cdots + P_N C_N}$$

where:

$\mathbf{P_{ave}}$ = weighted average rainfall for the total area

$\mathbf{P_A}$, $\mathbf{P_B}$,…, $\mathbf{P_N}$ = observed rainfall values from stations A, B,…, N, respectively

$\mathbf{C_A}$, $\mathbf{C_B}$,…, $\mathbf{C_N}$ = weighting factors for stations A, B,…, N, respectively

Adequacy of Length of Rainfall

The adequacy of the length of record for a given level of significance was tested using the formula suggested by Mockus (1960) which is,

$$\mathbf{Y = (4.30t \ \log_{10} R)^2 + 6}$$

where:

Y = minimum acceptable years of record

t = Student's statistical value at the 90 percent level of significance with (Y – 6) degrees of freedom

R = ratio of magnitude of the 100-year of event to the 2-year event

Adequacy of Rain gauge Stations

The optimal number of stations that should exist at a desired percentage of error in the estimation of mean rainfall was obtained through statistical analysis as emphasized by Subramaya (1984).

If there are m stations in the area, each recording rainfall values $P_1, P_{2,\ldots} P_M$ in a known time the optimal number of stations N was calculated as

$$\mathbf{N = \left(\frac{Cv}{\varepsilon}\right)^2}$$

where:

N = optimal number of stations

$\boldsymbol{\varepsilon}$ = allowable degree of error in the estimation of the mean rainfall, usually taken as 10%

Cv = coefficient of variation of the rainfall values of the existing m stations (in percent)

If there are "m" stations in the catchment, each recording rainfall values P_1, P2, $_{\ldots}P_M$ in a known time, the coefficient of variation Cv was calculated as

$$\mathbf{Cv} = \frac{\mathbf{100 \; x \; \sigma_{m-1}}}{\overline{\mathbf{P}}}$$

$$\boldsymbol{\sigma}_{\mathbf{m-1}} = \sqrt{\frac{\sum_1^m (\mathbf{Pi} - \overline{\mathbf{P}})^2}{\mathbf{m-1}}}$$

where:

$\boldsymbol{\sigma}_{\mathbf{m-1}}$ = standard deviation

Pi = precipitation magnitude in i^{th} station

$\overline{\mathbf{P}} = \sum_1^m \overline{P}_i$

$\overline{\mathbf{P}}$ = mean precipitation

Statistical parameters for Rainfall Frequency Analysis

The purpose of the frequency analysis of an annual series is to obtain a relation between that magnitude of the event and its probability of exceedance. The Log-Normal distribution method was used.

Events was ranked from the highest to the lowest with the largest event being given a rank, m= 1, the second largest event, m = 2, and so on. The variables were transformed in their corresponding logarithmic values and the mean was computed as follows:

$$\mathbf{M = Antilog} \; \frac{\sum \mathbf{log\,x}}{\mathbf{N}}$$

The standard deviation (S) was computed as follows:

$$\mathbf{S = Antilog} \sqrt{\frac{\left[\sum(\mathbf{log\,x})^2 - \frac{(\sum \mathbf{log\,x})^2}{\mathbf{N}}\right]}{\mathbf{N-1}}}$$

With the use of a log-probability paper, the values were plotted at their corresponding probabilities as listed below and formed a straight line.

Mean, M = 50%

M X S = 15.9%

M / S = 84.1%

A rough estimate of the goodness of fit of the distribution to the data was determined by plotting the probability of occurrence (P) of the events through the use of the equation:

$$\mathbf{P} = \left(\frac{\mathbf{m}}{\mathbf{N+1}}\right)$$

The goodness of fit was an eyeball estimate. When found satisfactory, the resulting straight line was used in predicting the frequency of occurrence of an event of a given magnitude.

Multiple Linear Regression

This technique is applied to test the combined effects of the different independent variables on the dependent variable. In this procedure, any variable suspected to affect the dependent variable Y are included in the analysis. For k independent variable, X_1, X_2,…X_k, the functional form of the multiple linear regression is

$$\mathbf{Y = A + B_1X_1 + B_2X_2 + \cdots + B_kX_k}$$

where the B_i's were the partial regression coefficients.

Results

Interpretation of Data

Before the rainfall of all stations were analyzed, the data were checked for continuitiy and consistency. Mıssing rainfall data were estimated based on the rainfall data from neighbouring stations.

Estimation of Missing Rainfall Data

To ensure a better outcome of the study it was deemed necessary to estimate this missing record. The missing rainfall data of a station was computed from observations or rainfall at some other stations as close to and as evenly spaced around the station with the missing record as possible. The station with missing data were computed through multiple linear regression method of estimation.

Rainfall Consistency

Before rainfall records were used in the study, they were tested through the use of double-mass curve technique to verify that any trend detected were due to meteorological causes and not to changes in gage location, in exposure, or in observational methods (Searcy and Hardison, n.d.). The double mass curves depicted in Fig 1, in which all of them were virtually unbroken straight lines and no significant changes in slope, an indications that the rainfall records were consistent.

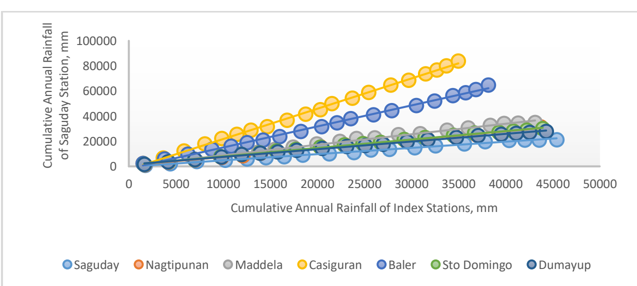

Figure 1. Double mass curve of the seven (7) stations

Mean Depth of Rainfall

To calculate the average rainfall over an area, the rainfall was calculated at a range of suitably placed raingauge stations within the province. The number of raingague stations depended on the surface area and rainfall distribution.

Thiessen polygons were constructed to create initial territorial boundaries for each of the rainfall stations. The polygons obtained involved the division of the province into a number of separate territories, each of which focused on a separate or single station. The simple Thiessen polygons shown in Fig 2 indicate the territorial distribution of mean annual rainfall.

As shown in Table 1, the Nagtipunan station covered the largest area of 43.72% of the total area of the Quirino province which was about 1393 sq. km with an average depth of rainfall distribution weightage factor of 0.44 mm. The station with least coverage was the Sto Domingo with an area of 2.26 % or 72 sq. km. of the whole study area.

Table 1. Area Coverage of Each Station

Station	Area (sq km)	Area Covered (%)	Weighting Factor	Altitude at AMSL (m)
Nagtipunan	1393	43.72	0.44	206.35
Dumayup	136	4.27	0.04	320
Sto Domingo	72	2.26	0.02	370
Casiguran	159	4.99	0.05	4
Baler	70	2.20	0.02	173
Maddela	751	23.57	0.24	160.63
Saguday	605	18.99	0.19	101.8

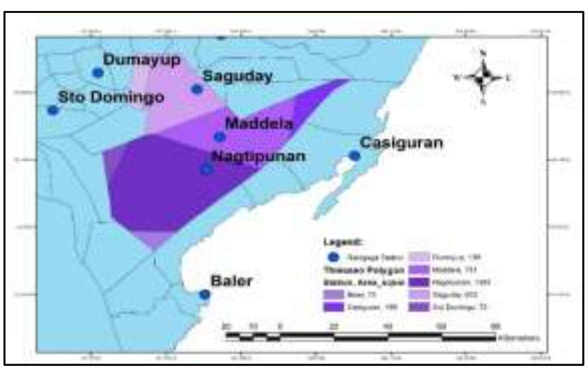

Figure 2. Thiessen Polygon

Adequacy of Rain Gauge Station in the Area

The optimal number of rain gauge stations provide more accurate rainfall estimation for Quirino province. The optimum number of stations that should exist at specified allowable errors of estimation for mean annual and monthly rainfall were listed in Table 2. Eighteen (18) stations are required to optimize rain gauge network with allowable error of about 10%. This indicated that the number of rain gauge stations of three (3) in Quirino is not adequate to estimate the mean annual rainfall of the province at 90% degree of accuracy or reliability. Additional 18 stations will be needed to attain the desired allowable error of estimate of 10%. As the allowable percentage error was reduced, a greater number of rain gauge stations will be needed.

Table2. Recommended Optimal Number of Rainfall Stations in Quirino a different Allowable Percentages of Error of Estimation.

	Percentage of Error		
	10%	5%	1%
	Number of Station		
Annual	18	72	1799
Monthly Basis			
January	103	413	10334
February	159	635	15877
March	76	303	7579
April	91	362	9052
May	58	233	5837
June	51	206	5150
July	76	304	7595
August	42	166	4162
September	42	167	4187
October	18	72	1804
November	82	328	8191
December	77	308	7706

Frequency Analysis

Rainfall events and their impact on hydrological systems and culture are important factors when planning and maintaining a large number of water management projects. Regional frequency analysis of extreme rainfall is critical in the formulation of hydrometeorological engineering procedures (Zhou, 2017).
The different annual rainfall amount of the seven stations at different probabilities of occuerence is shown in table 3 and the annual rainfall frequency curves all fitted to the log-normal distribution is shown in fig 3 to 9. The outcome indicated that extreme rainfall patterns were deteriorating (i.e., rainfall during high frequency events is declining as it increases during low frequency events). These findings support the findings of different researchers worldwide and

has been linked with climate change due to global warming (Merabtene et. al, 2016).

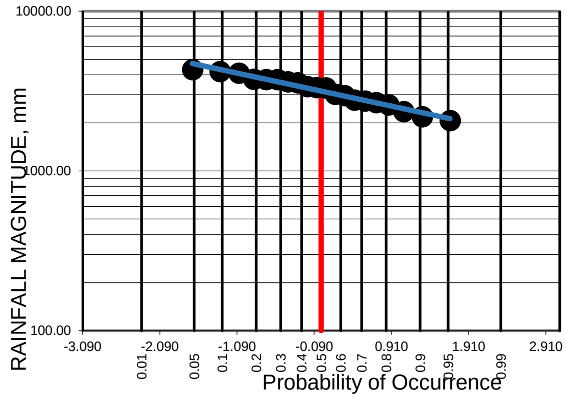

Figure 3. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Baler.

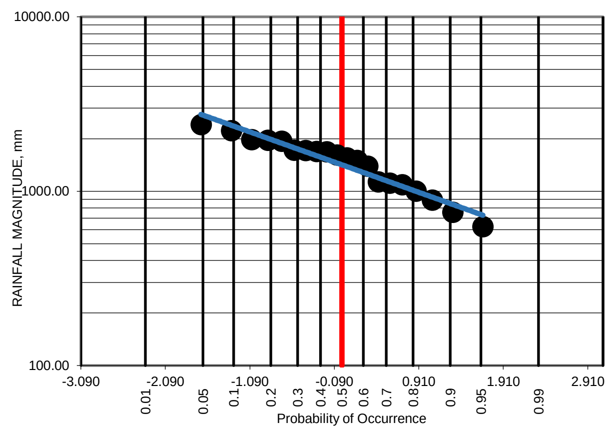

Figure 4. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Sto Domingo.

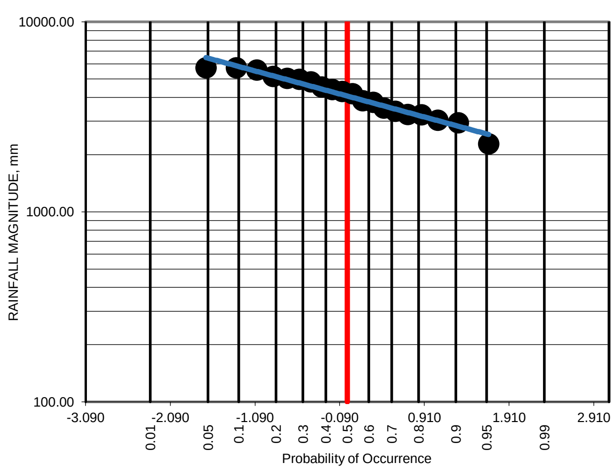

Figure 5. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Casiguran.

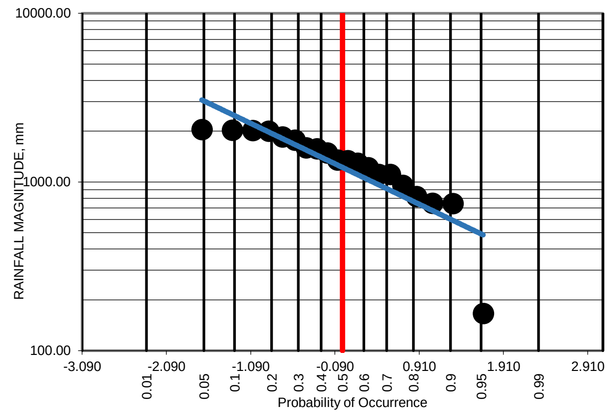

Figure 6. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Dumayup.

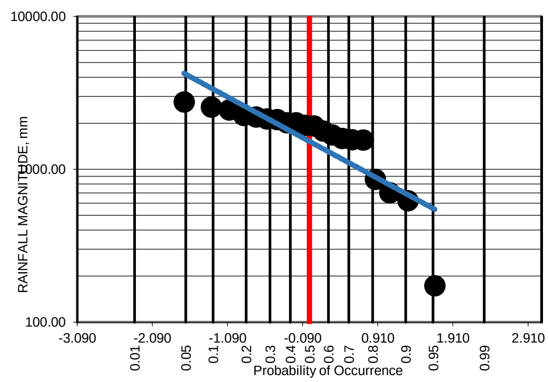

Figure 7. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Maddela.

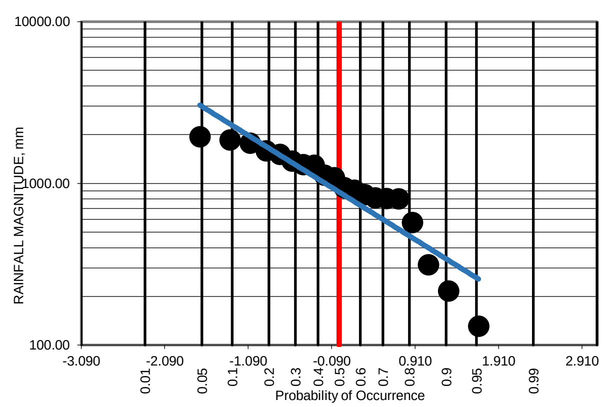

Figure 8. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Saguday.

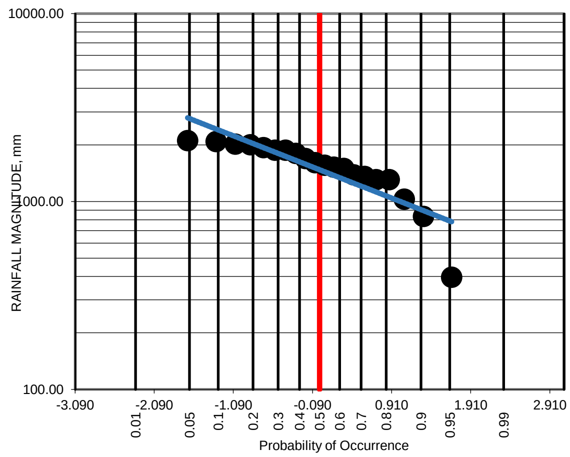

Figure 9. Annual Rainfall Frequency Curve Using Log-Normal Distribution for Nagtipunan

Table 3. Annual rainfall amounts (mm) at different probabilities of occurence for each of the seven stations.

Station	10%	20%	30%	40%	50%	60%	70%	80%	90%
Dumayup	2027.9	1976.4	1718.8	1539.8	1347.5	1248.2	1110.553	849	747.2
Sto Domingo	2250.8	1955.8	1722.2	1692.6	1586	1438.8	1121.764	1018.6	771.3
Baler	4216.76	3755.86	3708.59	3501.82	3331	2999.62	2765.27	2621.31	2211.80
Casiguran	5756.52	5138.5	4931.64	4491.124	4241.25	3808.02	3424.96	3240.92	2955.98
Maddela	2564.391	2243.651	2135.365	2019.152	1934.895	1724.469	1572.917	999.6656	631.7698
Nagtipunan	2092.542	1993.167	1880.225	1761.26	1588.452	1511.422	1371.47	1307.921	854.92
Saguday	1864.824	1573.64	1351.815	1224.777	1011.227	873.6406	806.8442	618.2302	225.2003
Quirino Province	2388.78	2164.68	2020.59	1882.30	1719.73	1573.99	1427.66	1201.67	807.93

Conclusion and Future Works

There are a total of seven (7) stations that were used in this study namely: Dumayup Station, Sto Domingo Station, Baler Station, Casiguran Station, Maddela Station, Nagtipunan Station and Saguday Station. All the missing records of stations with missing data were calculated through the application of multiple linear regression analysis.

Double-mass curve technique was used in testing the consistency of rainfall records of each station and it was found out that the rainfall records of the seven stations were consistent.

The estimated optimal number of rain gauge stations in the province of Quirino needed to estimate the annual rainfall at percentage allowable error of 10, 5, and 1 are 18, 72 and 1799, respectively.

The frequency distribution of annual rainfall was fitted to the Log-Normal Distribution. At 50% probability of occurrence, Casiguran station had the highest amount of rainfall of about 4241.25 mm while the lowest rainfall amount of about 1011.227 mm was observed at Saguday station.

In order to avoid the occurence of missing rainfall data, it is recommended that raingauges be regularly monitored. Rainfall frequency analysis on daily and weekly basis must be also analyzed. Develope rainfall distribution and rainfall maps can be utilized in any water resources development planning purposes for the province.

References

Akasaka, I., Morishima, W. & Mikami, T. (2007) Seasonal March And Its Spatial Difference Of Rainfall In The Philippines. International Journal of Climatology. 27:715-725(2007). DOI: 10.1002/joc.1428

Amiri, M. A. & Mesgari, M.S. (2017) Modeling The Spatial And Temporal Variability Of Precipitation In Northwest Iran. Atmosphere 2017, 8, 254; doi:10.3390/atmos8120254

Ayugi, B.O., Wen, W. & Chepkemoi, D. (2016) Analysis Of Spatial And Temporal Patterns Of Rainfall Variations Over Kenya. Journal of Environment and Earth Science. ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online). Vol. 6, No. 11, 2016

Cho, J., Bosch,D.D. , Lowrance, R. et. al. (2009). Effect of spatial distribution of rainfall on temporal and spatial uncertainty od swat output. Transactions of the ASAABE. 52. 10. 13031/2013.29143

Flores JF, Balagot VF (1969) Climate Of The Philippines. Climates Of Northern And Eastern Asia. In: Arakawa H (ed) World survey of climatology, vol 8. Elsevier, Amsterdam, pp 159–213

Gallego, M., Trigo, R., Vaquero, J., et. Al. (2011). Trends in Frequency Indices of Daily Precipitation Over the Iberian Peninsula During the Last Century. J. Geophys. Res.: Atmosphere, 116 (2011)

Hu, Ling. (2014) Research On The Application Of Regression Analysis Method In Data Classification. Journals of Networks, Vol. 9, No. 11, November 2014

Liu, Y., Yang, R., Long, H. et al.(2015) Spatio-temporal characteristics of rural settlements and land use in the Bohai Rim of China. J. Geogr. Sci. 25, 559–572. https://doi.org/10.1007/s11442-015-1187-6

Loo, Y.Y., Billa, L. & Singh, A. (2015) Effcect Of Climate Change On Seasonal Monsoon In Asia And Its Impact On The Variability On Monsoon Rainfall In Southeast Asia. Geoscience Frontiers 6 (2015) 817-823

Merabtene, T., Siddique, M and Shanableh, A. (2016). Assessment Of Seasonal And Annual Rainfall Trends And Variability In Sharjah City, UAE. Vol. 2016. Advances in Meteorology. https://doi.org/10.1155/2016/6206238

Onyutha, C., Rutkowska, A., Nyeko-Ogiramoi, P., et. al. (2018) How Well Do Climate Models Reproduce Variability In Observed Rainfall? A Case Study Of The Lake Victoria Basin Considering Cmip3, Cmip5 And Cordex Simulations. Stochastic Environment Research and Risk Assessment (2019) 33:687-707

Prabakaran, S. Naveen Kumar, P. and Sai Mani Tarun, P.(2017) Rainfall Prediction Using Modified Linear Regression. APRN Journal of Engineering and Apllied Sciences. Vol 12, No. 12, June 2017.

Subramaya, K., (1984), "Engineering Hydrology", Tata McGraw-Hill Publishing Company Limited.

University of Delaware. Double-Mass Curves. https://udspace.udel.edu/handle/19716/1592

Zhou, Z., Smith, J.A. Yang, L. et.al. (2017) Regional frequency analysis of extreme rainfall for the Baltimore metropolitan region based on stochastic storm transposition NASA astrophysics data system (ads).