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REGIONAL RAINFALL FREQUENCY ANALYSIS FOR SAMARAHAN RIVER BASIN

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Abstract - In planning to mitigate flood, it is essential for engineers to determine the magnitude and frequency of rainfall. The rainfall frequency and magnitude can be determined by rainfall frequency analysis. This study analyzes the regional rainfall frequency of the Samarahan River basin. There are 12 rainfall stations over the 508km^2 of basin area, of which 11 are included in this study. The rainfall frequency analyses of each individual station in Samarahan River basin are conducted using Gumbel distribution and Weibull plotting position formulas. The curves that are close to each other are grouped into the same region. Other factors such as topography, station elevation, type of rainfall distribution and isohyet are also considered in determining the region. Subsequently, a regional rainfall frequency map of Samarahan River basin is established. The findings show that Samarahan River basin can be divided into three homogenous regions. In comparison to previous research, there are changes in grouping the rainfall stations selected into regions. These changes may be due to different years of data used and number of rainfall stations selected since the data is limited. Dissimilar outcomes may also be caused by other factors such as nature change over time. This research updates the rainfall analysis of the Samarahan River basin using more adequate data compared to previous research.

Keywords**:** Regional Rainfall Frequency Analysis, Rainfall Frequency Analysis, Samarahan River Basin, Gumbel distribution, Weibull plotting position

1.0 INTRODUCTION

Kota Samarahan is one of the divisions in Sarawak, situated about 30 kilometers from the capital Kuching, with a total area of 508 km^2. It officially become the main education centre for the state with the construction of Universiti Malaysia Sarawak (UNIMAS), Universiti Teknologi Mara (UiTM) and Tun Abdul Razak Institute of Teacher Education.

Floods are frequent in Kota Samarahan causing a lot of concern from the communities. The latest flood that hit this area was on February 2016 that involved thousands of families [2]. According to the Department of Irrigation and Drainage Sarawak, flood events in Sarawak mostly occur from February to March. Droughts have occurred regularly in Kota Samarahan for the past few years. In July 2012, a total of 203 cases of water shortage happened in Sarawak with Kota Samarahan the worst hit division, along with Betong and Miri [3]. Thus, Kota Samarahan is vulnerable to both disasters.

When preparing to mitigate drought and flood, it is crucially important to determine the magnitude and frequency of rainfall. Hydrologic data such as rainfall play the main role in designing hydrologic structures. In order to obtain the data, rainfall frequency analysis can be used. Subsequently, the analysis can be developed to form a regional rainfall frequency analysis map based on homogeneous region. The use of regionalization technique is important in order to produce the map.

For the Samarahan River basin, the regional rainfall frequency curve and map have been updated to 2007 in previous research [1]. Six rainfall stations (Kampung Semilang, Ketup, Semonggok, Paya Paloh, Kota Samarahan and Asajaya) were studied using eleven years of rainfall data from 1997 to 2007. Figure 1 shows the trendlines of daily mean rainfall/average daily mean rainfall (DMR/ADMR) versus reduced variate for six rainfall stations in Samarahan basin [1]. The curves are then interpreted into a map as presented in Figure 2. As a result, three homogeneous regions are formed. Region 1 consists of Kampung Semilang whereas Ketup, Semonggok, Paya Paloh and Kota Samarahan stations are grouped into Region 2. Asajaya station is located in Region 3.

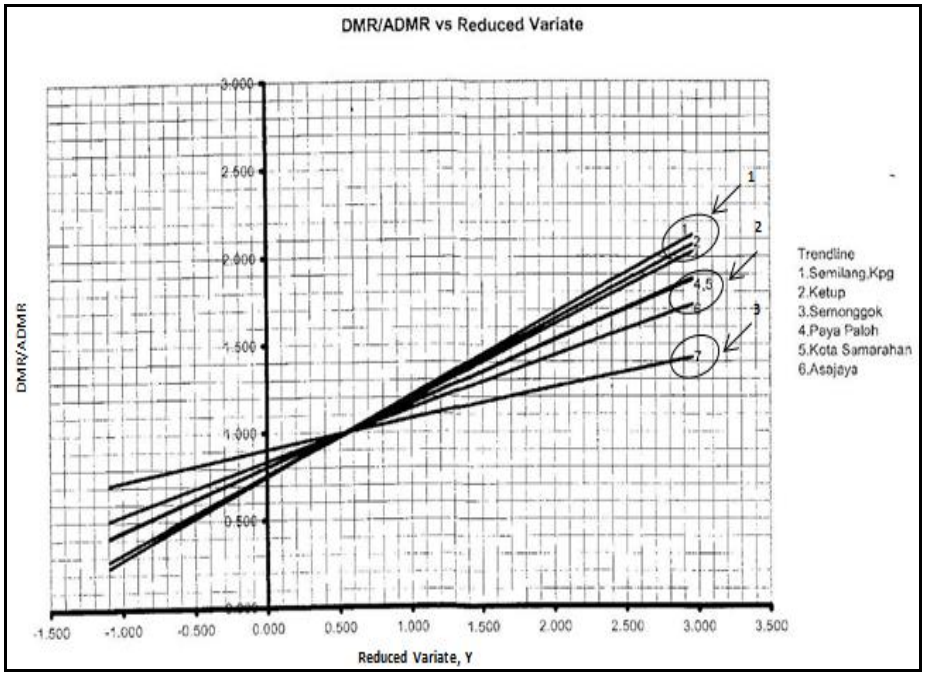

Figure 1. Trendlines of DMR/ADMR versus reduced variate for all rainfall stations in Samarahan River basin by Ahmad [1]

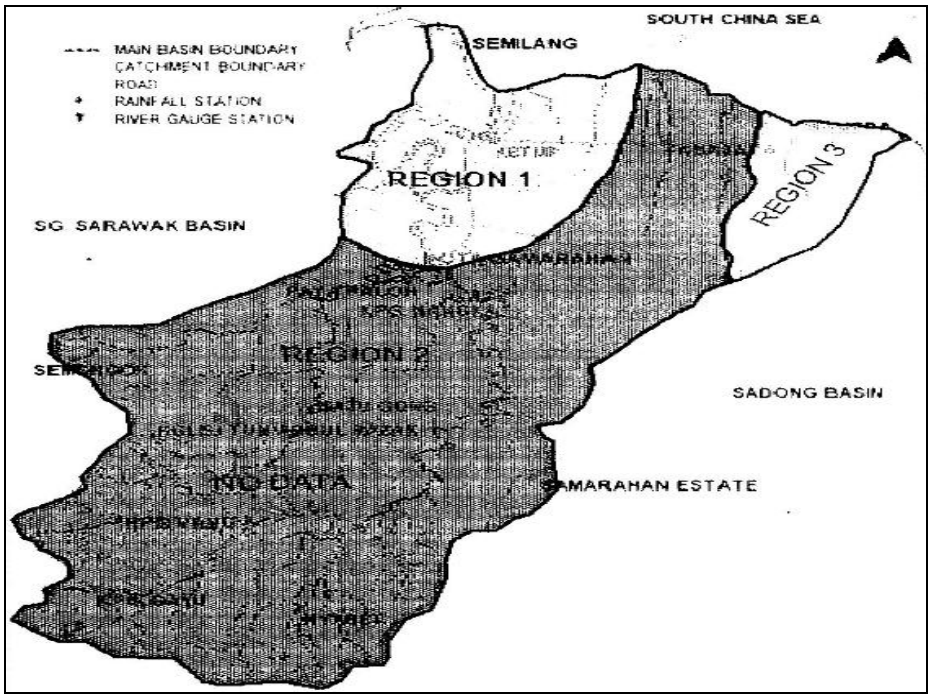

Figure 2. Rainfall region map for Samarahan River basin by Ahmad [1]

The main purposes of this study are to update the existing regional rainfall analysis for the Samarahan River basin by developing regional rainfall frequency curves and a regional rainfall frequency map then comparing the analysis obtained with previous research.

2.0 METHODOLOGY

In this research, the required hydrological data are sourced from the Department of Irrigation and Drainage (DID) Sarawak. A topographical map of Sarawak with scale 1: 1,000,000 and the Mean Isohyetal Map of Sarawak attained from Sarawak Hydrological Year Book 2014 (SHYB) are used. According to Sarawak Hydrological Station Inventory in 2014, there are a total of 12 rainfall stations within the river basin. However, JPS Samarahan is excluded in this study because it is considered a new rainfall station with the first installation in 2009. Table 1 below shows the years of data used for each rainfall station.

Table 1 Years of data used for each rainfall station

Rainfall Station	Years of Data
Kampung Gayu	1984-2013
Dragon School	1984-2014
Kampung Baru	1984-2014
Ketup	1984-2014
Paya Paloh	1984-2014
Plaman Nyabet	1984-2014
Samarahan Estate	1984-2014
Semera	1984-2014
Semonggok	1984-2014
Kampung Semilang	1984-2014
Asajaya	1984-2014

The rainfall frequency analyses of individual stations in this study are carried out using graphical method. Gumbel distribution is selected since it has been adopted in Hydrological Procedure No. 26. It is identified that Gumbel distribution turns out to be the best selection [5, 10]. This is followed by many researchers through checking the goodness of fit tests. The plotting position for each station is done by applying the Weibull formula. The rainfall frequency analysis is developed with the trendlines of DMR/ADMR versus reduced variate for all rainfall stations in Samarahan River Basin. To get a similar range of value with reduced variate, DMR/ADMR is used instead of ADMR.

Gumbel Type 1 represents the distribution of the largest depth of storm rainfall within a certain duration for each 12 months period [5]. The probability relationships in this distribution are:

$$P(x) = \exp(-e^{-y})$$
(1)

Where

$$y = \propto (x - u)$$
(2)

The "reduced variate" is denoted as y whereas the parameters which may be estimated from the observed largest values are signified as x and u. In order to estimate the probabilities of exceedance or non-exceedance of ranked data for Weibull formula, the following equation is suggested [8]:

$$\frac{r}{(n+1)}100$$
(3)

Researches stated that if n is the total number of values to be plotted and m is the rank of a value in a list ordered by descending magnitude, the exceedance probability of m[th] largest value, x_m, is, for large n [4]. Weibull plotting position is expressed in equation 4 for the return period:

$$P(X \geq x_m) = \frac{m}{n+1} \quad (4)$$

To develop the regional rainfall frequency curve, the first step is to overlay the frequency curves of all stations attained, followed by delineation of the curves into regions. By observing the curve from a station that lies closely to a curve from another station, delineation can be done. The stations with similar patterns or trends lie around the same area are then grouped under the same region.

Subsequently, the regional rainfall frequency curve produced by Gumbel distribution and Weibull plotting is interpreted into a map. The rainfall stations are grouped into different regions based on the trendlines and other factors such as geographical location of the site, type of rainfall distribution and isohyet.

3.0 RESULTS AND ANALYSIS

Figure 3 shows the updated regional rainfall frequency analysis curve for the Samarahan River basin. The basin can be divided into three homogenous regions as shown in Figure 4. Region 1 having the highest rainfall consists of Kampung Semilang and Asajaya. Most stations fall under Region 2 that receive moderate amounts of rainfall, which are Ketup, Plaman Nyabet, Semera, Dragon School, Kampung Baru, Paya Paloh and Semonggok. Kampung Gayu and Samarahan Estate are positioned into Region 3 and classified as experiencing the least amount of rainfall.

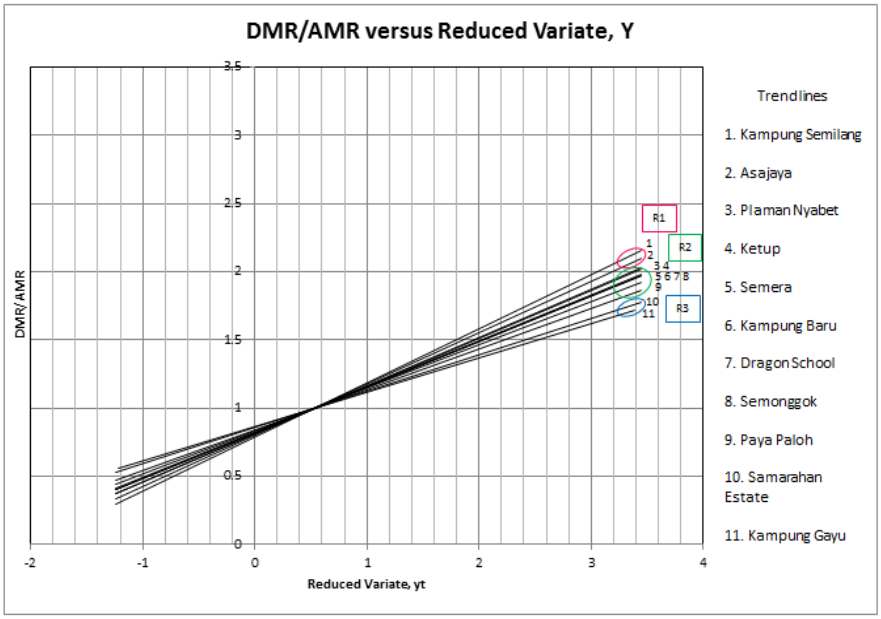

Figure 3. Trendlines of DMR/ADMR versus reduced variate for all rainfall stations in Samarahan River basin

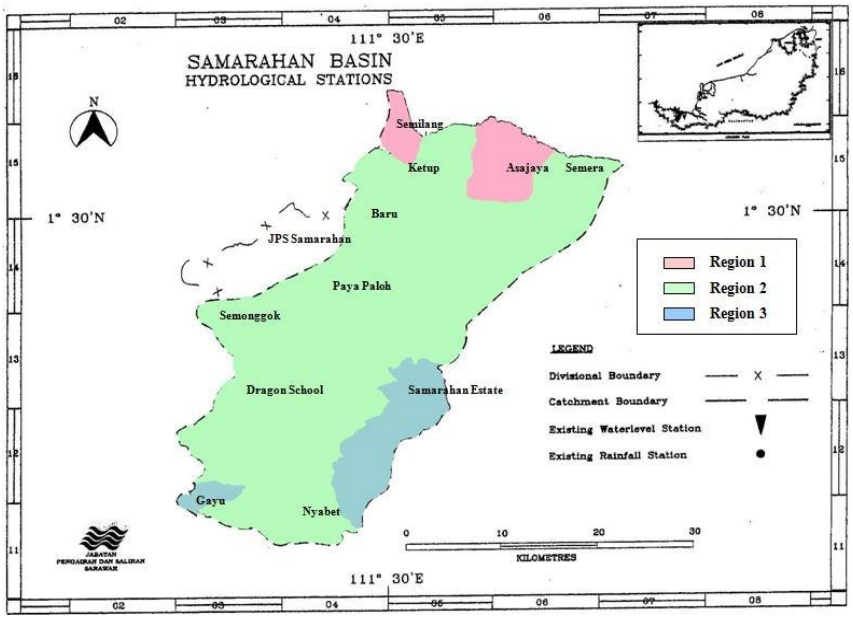

Figure 4. Regional rainfall frequency map of Samarahan River basin

Instead of considering the trendline patterns only, the result analyses are also justified according to types of rainfall, station elevation, topography and distance from sea. The contour map, isohyetal map and rainfall inventory of Samarahan River basin assist in validating the findings.

Based on the Mean Isohyetal Map 2014, it can be observed that the range of isohyet values are high around Region 1 and Region 2 of rainfall stations Kampung Baru, Paya Paloh, Semonggok, Semera, Kampung Semilang, Ketup and Asajaya. These are located within the range of 3850 to 4200 isohyets. Mean rainfall precipitations at these rainfall stations are high. Two rainfall stations from Region 2 and Region 3 of Dragon School, Plaman Nyabet, Kampung Gayu and Samarahan Estate receive low rainfall magnitude in the range of 3500 to 3850 isohyets. This verifies that the method of grouping the regions using trendlines is accurate.

When referring to Rainfall Inventory for rainfall station in Samarahan River Basin 2014, the ground elevation is 5 m in Kampung Baru, Paya Paloh, Semera, Kampung Semilang, Ketup and Asajaya. In contrast, Plaman Nyabet, Samarahan Estate and Semonggok have elevations of 30 m, 30 m and 32 m respectively, while both Dragon School and Kampung Gayu are 60 m. Results show that rainfall stations in higher elevation do not always receive higher amounts of rainfall. As stated by researches, precipitation in the storm months are probably going to lessen with distance from the sea and the reductions are similar in magnitude for both rain shadow and ocean facing gauges [6]. However, it is found that the rain shadows are less variable in the decreases per km distance compared to ocean faced gauges. In this study, Samarahan Estate and Kampung Gayu station can be considered as rain shadow gauges since they are further from the sea and in mountainous areas. Both stations are valid to be sorted into Region 3 as they have smaller amounts of rainfall, although higher in elevation. The same considerations apply to Region 2 as well.

Beside the distance from sea, it is important to relate the situation with mountainous regions as well. One of the important processes taking place in mountainous areas is orographic enhancement influenced by wind speed and wind direction [7]. They also stated that on the upwind side, the amount of rainfall increases as the wind speed increases. However, only a small difference in precipitation occurs on the leeward side meaning that the rainfall amounts are less affected by the wind speed. This shows that the topography of stations is important in affecting the rainfall distribution. Further, this concept also applies to the type of rainfall distribution received by the stations.

There are three major types of rainfall; namely, convectional rainfall, orographic rainfall and frontal rainfall. For Region 1, frontal rainfall is likely to happen as it is near enough to the sea to be considered

a coastal area. During north-east monsoon, a wide region along the east coast of Peninsular Malaysia and coastal areas in Sarawak will receive continuous frontal rain due to the collision of trade winds. This rainfall happens once the different characteristics of air masses meet; for example, the meeting between warm air mass and cold air mass [9]. Frontal rainfall usually occurs in the tropics (between 23° North and South Latitude) as well as the Temperate Zone (Latitude 66° North and South of the Equator) [9]. Since Malaysia is a tropical country, Region 2 tends to get convectional rainfall. Convectional rain is produced once air within a few meters above the earth's surface is heated by the sun [9].

Region 3 is located in a mountainous area and tends to receive orographic rainfall. The researchers state that this kind of rainfall for the most part happens at the zone confronting the slope or mountain known as the windward side [9]. In contrary, the inverse side or leeward side gets the descending dry air and low or no rain, called the rain shadow area. Principally, orographic rainfall happens due to mountains that serve as an obstacle, forcing vapor to rise.

Ahmad [1] used data from 1997 to 2007. In this study, the data used are from 1984 to 2014. From the superimposed trendlines obtained in this study, it can be observed that the stations can be divided into three homogeneous regions. In comparison to Ahmad [1], the grouping of rainfall stations into regions is slightly different. This is because the year of rainfall data used and the number of rainfall stations selected are not the same for both analyses. Previous research included only six stations which are Kampung Semilang, Ketup, Semonggok, Paya Paloh, Kota Samarahan and Asajaya. In this study, eleven rainfall stations are considered. Table 2 shows the comparison of rainfall stations selected with its regions for both research.

Table 2 Comparison of previous and current research

Region	Ahmad [1]	Current Research
1	Kampung Semilang Ketup Semonggok	Kampung Semilang Asajaya
2	Paya Paloh Kota Samarahan	Ketup Plaman Nyabet Semera Dragon School Kampung Baru Paya Paloh Semonggok
3	Asajaya	Kampung Gayu Samarahan Estate
Number of Rainfall Station	6	11

When looking at the regional rainfall frequency map of the Samarahan River basin by Ahmad [1], Region 1 and Region 2 are located at the North West and North East of Samarahan basin, with Region 3 situated at the rest of the basin area. A different location of regions is attained for this study. Region 1 is identified at the North West of Samarahan River Basin whereas Region 3 is found at the South West as well as South East area. Region 2 lies in between both regions.

4.0 CONCLUSION

The regional rainfall frequency curves in this research are produced based on Gumbel distribution and Weibull plotting position. The resulting regional rainfall frequency map shows that the Samarahan River basin can be divided into three homogenous regions. Region 1 consists of Kampung Semilang

and Asajaya, Region 2 consists of Ketup, Plaman Nyabet, Semera, Dragon School, Kampung Baru, Paya Paloh and Semonggok stations, and Region 3 consists of Kampung Gayu and Samarahan Estate. Topography, station elevation, isohyet and type of rainfall distribution are all taken into account. Updated results differ from Ahmad [1] due to the range of data used and the number of rainfall stations selected. Although previous research concludes the basin to have three regions as well, the classification of rainfall stations into these regions are not the same. Dissimilarity in outcomes may also be due to natural change over time. Limitations include the exclusion of the new JPS Samarahan station installed in 2009 and the lack of data for one year at one station. It is recommended to make sure all the data required are available in future studies. With adequate data, the pattern of rainfall frequency regions for this analysis would be expected to have slight change. Further research should also check the goodness of fit by using other distributions and different plotting positions for comparison.

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