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Flood Frequency Analysis of Kadamaian and Wariu Rivers in Kota Belud, Sabah, Malaysia

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Abstract

Flood frequency analysis is crucial for understanding flood risks in specific regions. This study applied the Gumbel Distribution Method to analyze flood frequency using river discharge data from the Kadamaian and Wariu Rivers in Kota Belud, Sabah, Malaysia. The analysis involved data collection, parameter estimation, goodness-of-fit testing, and determination of annual recurrence intervals (ARIs). The study found that the ARIs for the Kadamaian and Wariu Rivers are 50 years and 30 years, respectively, highlighting the need for targeted flood mitigation strategies in these areas. These findings emphasize the higher flood risk in the Kadamaian River basin, necessitating more robust flood control measures compared to the Wariu River basin. The Gumbel distribution provided accurate flood frequency estimations validated by the Kolmogorov-Smirnov test and correlation coefficient (R2). The calculated ARIs offer valuable insights for flood hazard assessment and contingency planning. These findings underscore the importance of accurate flood frequency analysis in enhancing flood mitigation strategies and disaster preparedness. It is recommended that local authorities incorporate these results into flood management and urban planning initiatives.

Key Words	Annual recurrence interval (ARI); Flood hazards; Flood frequency analysis; Gumbel distribution; Magnitude; Probability distribution; Sabah; Weibull plotting position
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INTRODUCTION

Flood frequency analysis is a technique for preparing and calculating the size of floods that occur in a specific area based on recurring factors (Hamzah et al., 2021; Pankaj & Sunil, 2015; Sharir et al., 2022). It is a tool for determining the design of rainfall levels, river discharge rates, and drainage structures, focusing on the hydraulic capacity required for a drainage system to control flooding (Mohamad Hamzah et al., 2019; Sharir et al., 2022; Sharir & Roslee, 2022). In this analysis, the flood probability distribution is frequently paired with the maximum annual discharge data (Shabri, 2012). Recent studies have demonstrated the effectiveness of using advanced hydrodynamic models, such as HEC-RAS, in simulating flood events, which significantly enhances flood risk management and mitigation strategies (Garg & Ananda Babu, 2023).

Current studies on flood frequency analysis in the Kota Belud region have primarily focused on traditional methods without incorporating modern approaches or comparing different methodologies. There is a lack of comprehensive studies that validate the Gumbel Distribution Method against recent advancements in flood frequency analysis. This study aims to fill this gap by providing a detailed comparison and highlighting the significance of using the Gumbel Distribution Method in this region. The novelty of this study lies in its application of the Gumbel Distribution Method in the context of the Kadamaian and Wariu Rivers in Kota Belud, a region that has not been extensively studied using this approach. The analysis not only provides a detailed assessment of flood frequencies but also validates the method's applicability in this unique geographical area, offering valuable insights for local flood management strategies. The integration of hydrodynamic models, such as the WRF model, has shown that accurate flood simulations are crucial for assessing the impact of heavy precipitation events and improving flood management practices (Nabi & Kumar, 2022).

The Gumbel Distribution Method, also known as the Extreme Value Distribution (EV Type I), Generalized Extreme Value Distribution (GEV), Normal Log, Pearson Log III (LP3), and Pareto Distribution, are several widely used methods for analysing the best flood frequency distribution based on the goodness-of-fit test scale (Bhagat, 2017; Farooq et al., 2018; Kordrostami et al., 2020; Pankaj & Sunil, 2015; Romali et al., 2018; Romali & Yusop, 2017; Selaman et al., 2007). Depending on the range of data available in the area, the researcher may use hydrological data like rainfall intensity rate, water level, and maximum annual discharge to analyse flood frequency (Hamzah et al., 2021; Kordrostami et al., 2020; Pankaj & Sunil, 2015; Romali & Yusop, 2017).

The frequency distribution of floods is analyzed to estimate the return of the flood recurrence time at a particular site. The predicted return is then compared to the observed value of the current data. The flood recurrence period is conceptually represented by the symbol T, which is expressed in years. A flood intensity with a probability of 1/T exceeding a specific year is referred to as a T-year flood. This is known as the exceedance probability. For instance, "100 years of floods" does not always imply that a flood happens once every 100 years. This refers to the likelihood of it occurring — 1 in 100, or 1%, within a year. This means that regardless of when the most recent incident of this nature occurred, there is a 1% probability that it will happen in any given year. In other words, it has a 10% probability and is ten times less likely to occur than a flood with a 10-year recurrence period. Calculating flood intensities for exceeding possibilities or recurrence times (from 0.1 to 0.001) is essential, especially when flood mitigation design is factored in. This is a typical source of misunderstandings and confusion over the concept of a recurrent period, which results in inaccurate evaluations of the risk or hazard of flooding.

Generalised Logistics and Gumbel Distribution (EV Type 1) is appropriate for representing the severity and frequency of floods in Malaysia (Department of Irrigation and Drainage, 2018). Although both distribution systems are suitable for Peninsular Malaysia, the Gumbel Distribution (EV Type 1) is more practicable for distribution in Sabah and Sarawak (Jefrin et al., 2017, 2018; Selaman et al., 2007). For each sample of the flood frequency distribution, the plotting position is calculated using a variety of formulas (techniques), including Weibull, Gringorten, and L-moment (Jefrin et al., 2017; Mohamad Hamzah et al., 2019; Romali & Yusop, 2017; Selaman et al., 2007). In Peninsular Malaysia, the plotting position of each frequency distribution is determined using the Weibull formula (Department of Irrigation and Drainage, 2018). For flood frequency analysis in Sarawak, the Gumbel distribution using the L-moment technique is best for plotting the flood probability distribution (Selaman et al., 2007). In contrast, the Gumbel distribution approach utilising the Weibull plotting position technique is the most appropriate since it receives good validation in Sabah (Jefrin et al., 2018).

The data are validated, and the best distribution to suit the observed data is chosen in flood frequency analysis using the model-fitting goodness score (Millington et al., 2011). Several practical tests have been suggested to evaluate the effectiveness of flood frequency distributions, including the Kolmogorov-Smirnov (KS), Chi-Squared, Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and relative mean absolute error (RMAE) tests (Bezak et al., 2014; Farooq et al., 2018; Millington et al., 2011). The level of significance was assessed using the P-value. Meanwhile, the optimal model evaluation for the flood frequency distribution is estimated based on R^2 in $0.7 < R^2 < 1$ (Department of Irrigation and Drainage, 2018).

STUDY AREA

The research area is located in a section of the Kota Belud district on Sabah's west coast and faces the South China Sea (Figure 1). Kota Belud is approximately 70 kilometres from Sabah's capital, Kota Kinabalu(Sharir et al., 2022; Sharir & Roslee, 2022). This district is estimated to be 1,385.6 square kilometres (km^2) (Pejabat Daerah Kota Belud, 2017). The section contains three major river basins. Three river basins include the Tempasuk River Basin (122 square kilometres), Kadamaian River Basin (445 square kilometres), and Wariu River Basin (343 square kilometres)(Sharir & Roslee, 2023a, 2023b).

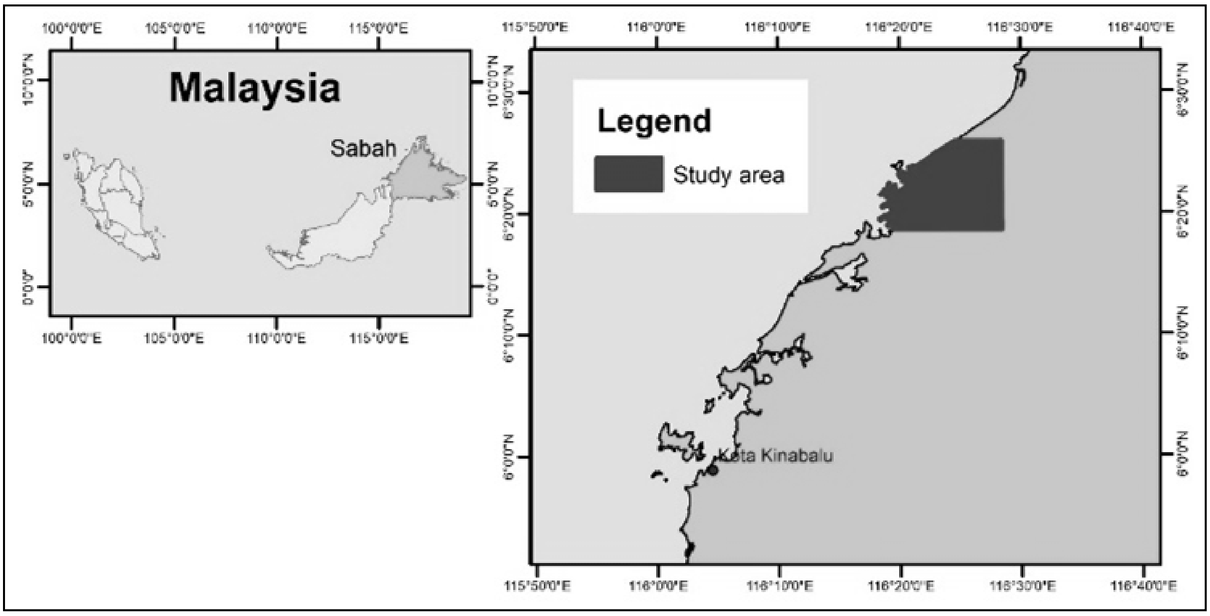

Figure 1: Location of Kota Belud area, Sabah, Malaysia.

METHODOLOGY

The flood frequency study is defined by four steps: data collection, plotting distribution and estimating parameters, good-of-fit test, and annual recurrence interval result.

Data Collection

Hourly river discharge data from the Kadamaian River and Wariu River stations provided by the Sabah Department of Irrigation and Drainage covers a period of 50 years, from 1969 to 2018. The data is measured in cubic metres per second (m^3/s) and missing or untraceable hourly discharge data will be estimated using the hours before and after.

There are two ways to determine flood frequency using hourly river discharge data: annual maximum series data and partial duration series data. Annual maximum series data is derived from the peak river discharge of each year, while partial duration series data considers all values that exceed a certain threshold during the recording period.

For this study, the annual maximum series data will be used as the primary data to create a flood frequency distribution model since it avoids selecting corresponding data from the same event period throughout the year, which could lead to larger values when using partial duration series data. The hourly discharge data was collected from two hydrological stations, the Kadamaian River (Tamu Darat) at 6.2644 latitudes and 116.4547 longitudes, and the Wariu River (Bridge No. 2) at 6.3245 latitudes and 116.483 longitudes, and consists of 50 independent data points selected from 439,000 hourly river discharge series data.

Plotting Distribution and Estimation Parameters

Once the series data for river discharge is obtained, the statistical distribution function is determined to accurately depict the results of flood frequency analysis. The Gumbel Distribution Method (EV Type I) with the Weibull plot position technique was selected for this study, but the validity of this model depends on the validation value obtained. The flood frequency distribution analysis involves two steps: determining the Weibull plot position and selecting the appropriate distribution for the Gumbel method.

Gumbel Distributions

The flood recurrence period can be defined as the average number of attempted flood events occurring in a year with an event magnitude more significant than the designated event (Benjamin & Cornell, 1970). Today's flood management policies and plans focus on 100-year flood events with a 1% chance of occurring each year. Additionally, there is a proposal to raise the flood recurrence period to 200 years (Pusat Ramalan & Amaran Banjir Negara, 2021). Extreme value distribution is also referred to as Gumbel's distribution. It is a type of probability analysis frequently used in hydrologic studies to anticipate floods for extreme values. The inflow for each return period was calculated using the Eq. (1) below:

$$Xt = \bar{X} + K.S \quad (1)$$

Where, Xt is value of variate with a return period, T, $\bar{X}$ is Mean of the variate, S is standard deviation of the sample, K is frequency factor expressed as in Eq. (2):

$$K = \frac{Yt + Yn}{Sn} \quad (2)$$

Yt is Gumbel's reduced variate, as shown in Eq. (3) below:

$$Yt = -\ln \ln \frac{T}{T-1} \quad (3)$$

Weibull plotting position

The maximum annual river discharge data is arranged according to the highest to the lowest magnitude, and the probability P for each event is equal to or greater than (plot position) calculated with the Weibull plot position formula. The formula of Weibull is, Eq. (4):

$$P = \frac{\mathrm{m}}{\mathrm{N}+1} \quad (4)$$

Where m is the order of numbers, N is the record number, and P is the probability of exceedance. The probability will be obtained using the following relationships, Eq. (5):

$$T = \frac{1}{\mathrm{P}} \quad (5)$$

(6)

$$F = 1 - \frac{1}{T}$$

Where in Eq. 6, p is the probability of exceedance (Probability that an event will exceed in a year), T is the return Period, and F is the frequency (rate of an event occurring). The river discharge will be plotted against the flood recurrence period. The flood recurrence period of 1 to 200 years is estimated through the plotted graph.

Goodness-of-Fit Test

Objective quantitative tests are employed to evaluate the goodness of fit of the model because it offers an unbiased approach to the analysis. In this study, the Kolmogorov-Smirnov statistical tests were utilized to assess the distribution's performance. The test statistics for evaluating the goodness of fit are as follows:

H_0: The data adheres to a specific distribution
H_A: The data does not adhere to a specific distribution

The calculated p-value is used to evaluate the tests. If the calculated p-value is less than 0.05 ($p<0.05$), H0 is rejected. Rejection of H0 implies that the specific distribution does not explain the data adequately. The Kolmogorov-Smirnov (KS) test is suitable for continuous data and is known to have a distribution that is independent. It is also appropriate for small sample sizes. However, to use this test, it is necessary to determine the location, shape, and scale parameters as they cannot be estimated directly from the data.

Annual Recurrence Interval (ARI)

The recurrence interval, also known as the return period, predicts the likelihood of an event occurring. The magnitude of an event at a selected return period can be mathematically calculated by taking the inverse of the cumulative distribution function, which is also called the quantile function. In this study, the Gumbel Extreme Value Distribution method is used to determine the return period. The obtained return period will then be utilized in the hydrodynamic model analysis to determine the probability of flood frequency and generate a flood inundation map of the study area.

RESULTS

Flooding is the most common geological hazard that can happen everywhere, especially in floodplain areas where people might choose to dwell along the population growth. Knowing the potential size of significant floods and how often they are likely to occur helps minimize flood damage and loss of life. The analysis revealed that the Annual Recurrence Interval (ARI) for significant flood events varies considerably between the Kadamaian and Wariu Rivers, with the former showing a higher frequency of severe events. This suggests the need for tailored flood management strategies in the region. For instance, the higher ARIs observed for the Kadamaian River indicate a greater vulnerability to extreme flood events, which necessitates the implementation of enhanced flood mitigation measures, such as the construction of additional retention basins and improved early warning systems. Conversely, the lower ARIs in the Wariu River may allow for different management strategies focused on periodic maintenance and community preparedness.

Annual Maximum Series

Flood frequency analysis primarily uses annual maximum flood series data observed at gauging stations (hydrologic stations) to estimate flood magnitude. A statistical distribution method and historical flood data are needed for this purpose. There is a total of 439,000 data for 50 years. Only one maximum data is taken to represent the year and make it only 50 data required in the annual maximum series. The y-axis represents river discharge data in cubic meters per second (m^3/s), and the x-axis represents years from 1969 to 2018. Hourly data descriptive statistics are shown in Table 1 for Kadamaian River Station and Wariu River Station.

The annual maximum series (AMS) consists of the highest maximum data between 1969 and 2018 (Figure 2). AMS descriptive statistics are summarized in Table 1. For Kadamaian River Station, the hydrology station recorded the highest discharge flow in 2010, which was 1,362.05 m^3/s, while the hydrology station recorded the minimum discharge flow of 248.05 m^3/s in 1982. The average maximum discharge flow for Kadamaian River Station is 759.36 m^3/s; the median of the maximum discharge flow is 736.36 m^3/s, and the standard deviation is 291.39 m^3/s. While for Wariu River Station, the hydrology station recorded the highest discharge flow in 2010, which was 891.48 m^3/s, while the hydrology station recorded the minimum discharge flow of 127.55 m^3/s in 1990. The average maximum discharge flow for Wariu River Station is 442.06 m^3/s, the median of the maximum discharge flow is 407.14 m^3/s, and the standard deviation is 166.87 m^3/s.

Table 1: Descriptive analysis of river discharge data at both hydrological stations.

	Kadamaian River		**Wariu River**	
	Hourly river discharge	**Annual maximum series**	**Hourly river discharge**	**Annual maximum series**
Min (m^3/s)	0.71	248.05	0.63	127.55
Average (m^3/s)	34.82	759.36	19.06	442.06
Max (m^3/s)	1362.05	1362.05	891.48	891.48
S.D (m^3/s)	10.05	291.39	5.45	166.87

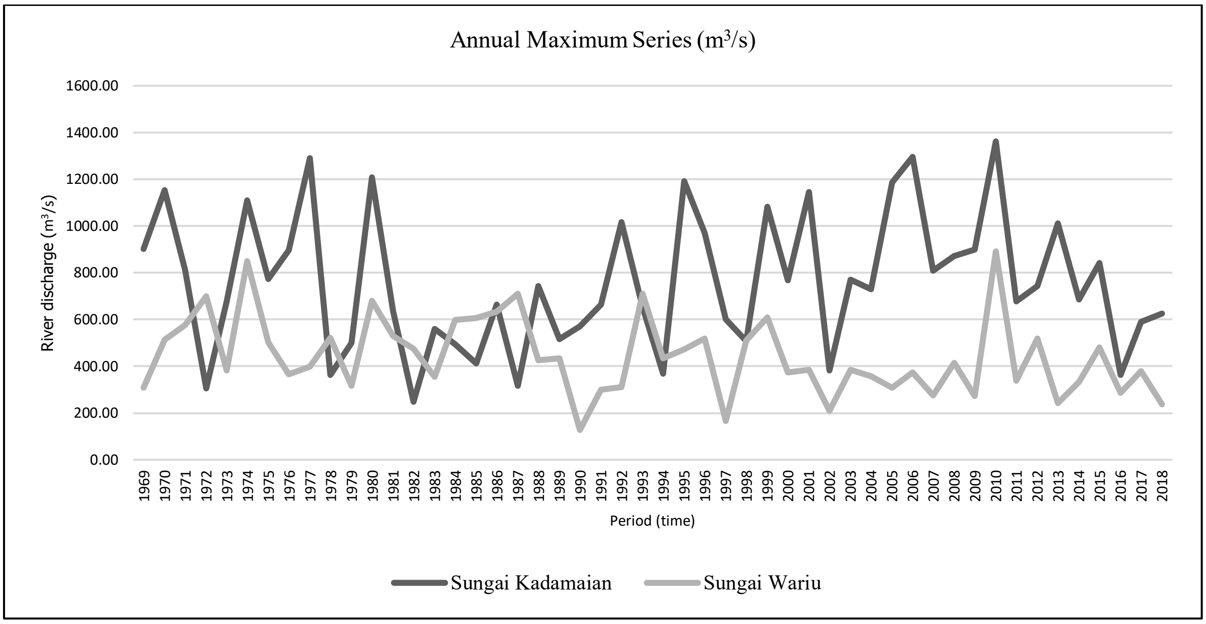

Figure 2: Maximum annual discharge series (AMS) for Kadamaian River Hydrological Station and Wariu River Hydrological Station.

Flood Frequency Distribution

This section presents the results of probability distribution analysis using the Gumbel Distribution (EV I) technique for both hydrological stations. The method of plotting this distribution uses the Weibull formula. The results of this analysis were used to produce probability plots and flood frequency curves for Kadamaian River and Wariu River Stations.

The probability of exceeding (P) means that it is possible that in a certain period, the flood will reach or exceed a certain magnitude. In contrast, the probability of not exceeding (F) means that the likelihood of flooding will not occur in a certain repetition period.

This research will use this probability in determining the flood discharge for a specific flood recurrence period (ARI) which will be discussed in the following sub-topic. The Empirical Curve (x) is the observation value obtained from the maximum annual series discharge data used to get the Gumbel value and measure the goodness of the resulting distribution. Figure 3 illustrates the Gumbel distribution's probability plot and flood frequency curve using the Weibull Formula for the Kadamaian River and Wariu River Stations.

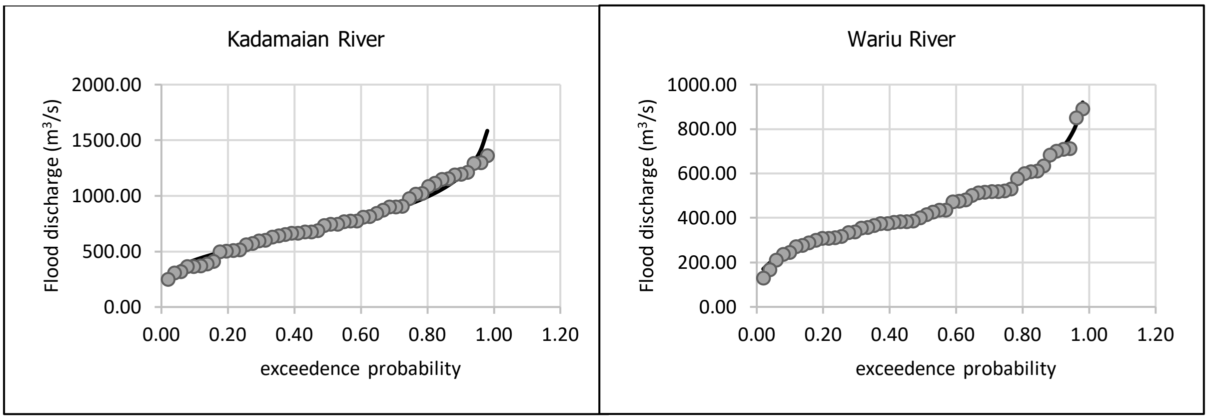

Figure 3: Gumbel Distribution using Weibull Formula for Kadamaian River Station and Wariu River Station.

Goodness-of-Fit of the Model

To assess the suitability of the probability distribution that fits the given data, a goodness-of-fit test was conducted on the maximum annual discharge data spanning 50 years. This test involves comparing the empirical distribution function (EDF) based on the data with the cumulative distribution function (CDF) to determine if they are in good agreement. The aim of this test is to identify the best probability distribution to use for the analysis (Hamzah et al., 2021).

In this study, the Kolmogorov-Smirnov (KS) test is used to evaluate the goodness of fit of the probability distribution model. Figure 4 shows a comparison graph of empirical values (obtained from observational data) and Gumbel values (theoretical values) produced from the Gumbel distribution (EV I) to get the p-value in the KS test for both hydrological stations.

The p-value is the observed value, while the significant alpha value is the tabulated value. If the p-value is smaller than the significant alpha value, $\alpha = 0.05$, the null hypothesis, H0, will be accepted. Thus, the tested data are consistent with the defined distribution (Farooq et al., 2018; Suhaimi et al., 2020). If the value of p is greater than the significant alpha value, then the alternative hypothesis, Ha, will be accepted.

In other words, the data does not follow a specific distribution. The KS test on the results of the Gumbel distribution analysis (EV I) shows that both hydrological stations have a p-value that is smaller than the significant alpha value ($p<0.05$). Consequently, this distribution is consistent with the null hypothesis, which claims that the data provided would follow a specific distribution.

In addition to the KS test, the accuracy measurement method using the correlation coefficient (R^2) is also used to evaluate the extent to which the flood frequency distribution produced matches the observation data. The results of the calculations show that the coefficient correlation value, R^2 is equal to 0.9681 for the Kadamaian River Station data and 0.9906 for the Wariu River Station data. If the value of r approaches one (1), this graph shows a good correlation. The r values shown for Kadamaian River Station (r = 0.9839) and Wariu River Station (r = 0.9953) show that the distribution pattern is narrow, and the Gumbel distribution method is seen as ideal for predicting river discharge flow.

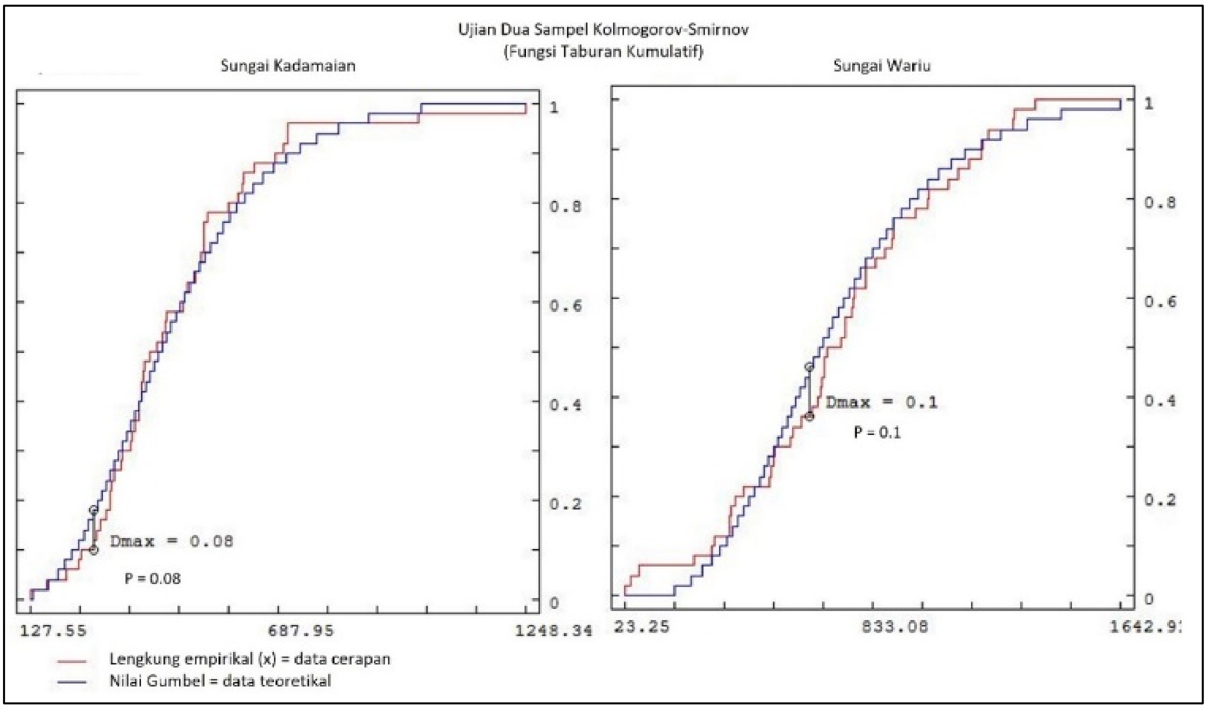

Figure 4: Kolmogorov-Smirnov Test Graph to obtain p-values for both hydrological stations.

Annual Recurrence Interval (ARI)

Estimating the value of flood recurrence for a certain recurrence period is essential and needs to be done after looking at the probability distribution. This is because the frequency and size of floods in a region can be influenced by the flood recurrence period. This information is crucial for lowering the risk of future flooding. Using Gumbel distribution analysis, floods with different recurrence periods of 5, 10-, 20-, 50- and 100 years were calculated. The magnitude value for each ARI is given in Table 2. This demonstrates how the following techniques can be used to extrapolate or calculate additional values that aren't depicted in the chart.

Table 2: Flood recurrence interval (ARI) for both hydrological stations.

ARI (Year)	**Exceedence probability**	**Flood peak discharge (m^3/s)**	
		Kadamaian River	**Wariu River**
2	0.500	714.85	416.28
5	0.200	992.01	576.84
10	0.100	1175.50	683.14
20	0.050	1351.52	785.11
30	0.033	1452.78	843.77
50	0.020	1579.35	917.10
100	0.010	1750.08	1016.01
150	0.007	1849.64	1073.69
200	0.005	1920.19	1114.56

According to Hydrological Procedure 11, it is assumed that the design recurrence interval (ARI) of floods is the same as the design recurrence interval (ARI) of storms (Department of Irrigation and Drainage, 2018). The observational data obtained only show ARI up to 50 years. As mentioned before, ARI values for 100-, 150- and 200 years can be estimated through the Gumbel distribution method. This fits with how the stormwater system in Malaysia is made, which is meant to handle storms, especially those that happen only once every 100 years (Daniel, 2020; Zakaria et al., 2017). The result of the Annual Recurrence Interval will be used to create a 2D flood model using a hydrodynamic model. The flood simulation produced through this analysis can then serve as a baseline for flood contingency planning in assessing flood hazards in the future.

Flood Pattern

The findings from the Kadamaian and Wariu Rivers show similarities with flood patterns observed in other tropical regions, such as the flood frequency studies conducted in the Kelantan River basin. However, the unique topography and land use patterns in Kota Belud present additional challenges that are not observed in those regions. For example, the higher frequency of extreme events in the Kadamaian River may be attributed to the steep terrain and rapid runoff characteristics, which differ significantly from the relatively flatter regions studied elsewhere. These differences underscore the need for localized flood management strategies that consider the specific geographical and environmental conditions of each basin.

CONCLUSION

Flood frequency analysis using the Gumbel Distribution Method in conjunction with the Weibull plot position technique has proven effective in estimating flood magnitudes and recurrence intervals for the Kadamaian River and Wariu River hydrological stations in Sabah, Malaysia. The goodness-of-fit tests, including the Kolmogorov-Smirnov test and correlation coefficient evaluation, indicated a strong agreement between the distribution model and observed data. The analysis provides a comprehensive understanding of flood hazards by estimating annual recurrence intervals for various return periods.

This study is limited by the availability of long-term hydrological data, which could affect the robustness of the frequency analysis. The data used, while extensive, may not fully capture the variability of flood events due to possible gaps in record-keeping or changes in land use over time. Future research should focus on improving data collection methods, possibly incorporating remote sensing and satellite data to enhance the accuracy of flood frequency predictions. Additionally, exploring the impact of climate change on flood frequency in this region could provide valuable insights for adapting flood management strategies in the future.

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