ISSN 2278-3091
Volume 9, No.1.2, 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse0591.22020.pdf
https://doi.org/10.30534/ijatcse/2020/0591.22020

# Tidal FloodingFrequency Analysis using Partial Duration Series Approach

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## ABSTRACT

Tides are fluctuation in sea level and are influenced by astronomical and non-astronomical factors. In Malaysia it is triggered by heavy or continuous downpour. The selected stations for the research are located along Malacca straits, which are Permatang Sedepa, Bagan Datuk and Pelabuhan Klang. This analysis optimize the occurence of tidal flooding using several distribution namely Gumbel, Fréchet, Generalized Extreme Value (GEV), Pareto, Generalized Pareto (GP), and Lognormal (3 Parameters). Based on the result obtained from the analysis, GP is the best fit distribution for Pelabuhan Klang with threshold of 5.40 m and Permatang Sedepa at a threshold of 4.90 m, while partial duration series at Bagan Datuk is best explained by Pareto distribution at threshold level of 3.20 m. High tide magnitude with a return period of 50-years are 8.54 m, 8.76 m and 3.47 m at Pelabuhan Klang, Permatang Sedepa and Bagan Datuk respectively. While the calculated magnitude at return period of 100-years are 10.84 m, 11.46 m and 3.51 m respectively at each tidal stations. This study is important particularly in an attempt to reduce the risk of extreme tidal flooding which is caused by continuous precipitation in Peninsular Malaysia.

**Key words:** High tide; extreme maximum; peak over threshold; statistical distribution.

## 1. INTRODUCTION

Tides start in the ocean and move towards the coastline. They are essentially the rise and fall of sea water. High tide occurs when the highest wave hits certain location during full moon and new moon phases. When the earth, moon and sun lie in a line, both the gravitational forces of the moon and sun exert a greater magnetic force on the water, thereby producing bigger waves.Floods may have a serious impact on human lives and the environment. In Malaysia, the government agency responsible for the acquisition, processing, archiving and dissemination of sea level data is the Department of Survey and Mapping Malaysia (DSMM). Malaysia has 21 tidal stations, of which 12 are located along the Peninsular Malaysia and nine are located along the coast of Sabah and Sarawak. Most of the tidal stations in Malaysia are established between 1981 to 1986 with the technical aid provided by the Hydrographic Department, Maritime Safety Agency, Japan and is funded by the Japan International Cooperation Agency (JICA) under the Colombo Plan.

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Floods in Malaysia are associated with the northeast and southwest monsoon and the inter-monsoon between the two monsoons[1]. Malaysia has an equatorial climate with constant high temperature and high relative humidity[2]. The monsoon season between the months of November and February may bring 600 mm of rainfall within 24 hours in the east coast of Peninsular Malaysia, Sabah and Sarawak[3]. There are three types of flood in Malaysia, namely flash flood, monsoon flood and coastal flood [4]. Flash floods occur as a result of a heavy downpour within a short time period. Monsoon floods are the result of continuous downpour during the monsoon season[5], while coastal floods are typically caused by the high tides in the coastal area. The flood event can be minimized by having a proper flood management system [6].

The majority of tidal flooding in Malaysia are the result of heavy or continuous downpour. High tides in Malaysia occur between September and December. In 2017, the occurrence of flash flood is triggered by a 2.6 m high tide event and a three-day continuous downpour in Kedah [7]. The occurrence of tidal flooding have been reported in Selangor with the extreme events occurring between October and November [8]. A high tide of more than 4.5 m, along with heavy downpour and winds, has triggered flooding in certain areas.

The objective of this study is to determine the suitable threshold level for optimizing tide analysis, and to fit the selected data set into an appropriate distribution and parameter estimates in an effort to determine the return period of high tide data.

## 2. METHODOLOGY

### 2.1 Peak over Threshold

Several methods can be employed to define extreme level events, including the r-largest method in preference to 1-largest of annual maximum, revised JP method, peak over threshold, and percentile methods. According to [9], the data for AMS and r-largest value are not suitable for extreme storm analysis due to their inefficiency. There are several advantages of using PDS series instead of annual maximum (AM). Firstly, more data can be taken into account when utilising PDS instead of AM. Selecting a higher threshold value would ensure the selection of events that are more extreme. Thus, it is important to select an optimal threshold value which maintains the tail of extreme data. This leads to proper selection of PDS for flood frequency analysis using a statistical approach.

### 2.2 Statistical Distribution

Several extreme distributions are is taken into consideration in determining the return period for time series data. Implementation of the peak over threshold data involves the utilisation of the Generalized Pareto distribution[10]. When investigating flooding event, it is essential to choose a distribution that is able to explain the tail of the data since the tail represents extreme cases.However, the selection of smaller threshold value increases the sample size, which resulted in values deviating from the extremes. On the other hand, selecting a very high threshold value would limit the number of exceedances and therefore lead to excessive variance. In summary, a sufficient number of events should be taken into account in order to reduce the variance and ensure that the computation of flood frequency can be carried out without bias.The probability density function for each distribution is presented in Table 1.

**Table 1:** Probability density function

| Distribution | Probability Density Function (pdf) |
|---|---|
| Gumbel | $f(x) = \frac{1}{\sigma} e^{(-z-e^{-z})}$ |
| Frechet | $f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x}\right)^{\alpha+1} e^{-\left(\frac{\beta}{x}\right)^{\alpha}}$ |
| Generalized Extreme Value | $f(x) = \frac{1}{\sigma} e^{(-(1+kz)^{-\frac{1}{k}})(1+kz)^{1-\frac{1}{k}}}$ |
| Lognormal (3 Parameter) | $f(x) = \frac{1}{(x-\gamma)\sigma\sqrt{2\pi}} e^{(-\frac{1}{2}(\frac{\ln(x-\gamma)-\mu}{\sigma})^2)}$ |
| Pareto | $f(x) = \frac{\alpha\beta^{\alpha}}{x^{\alpha+1}}$ |
| Generalized Pareto | $f(x) = \frac{1}{\sigma}(1 + k(\frac{x-\mu}{\sigma})^{-1-\frac{1}{k}}$ |

L-moment is a linear combination of probability weighted moments which gives a simple interpretation of the location, shape and dispersion of the sample data. This study employs L-moment method since it is able to describe the shape of distribution and thus provides a greater degree of accuracy. Additionally, this method is particularly robust when dealing with outliers. This method is not affected by sample variability in contrast to other product moment methods. It is an unbiased method compared to other methods of parameter estimation [11][12]. L-moment method is suitable for a large sample size due to its asymptotic properties [13].

### 2.3 Goodness of Fit Testing

Hydrological parameters often involve an investigation of extreme events. Researchers investigating flood magnitudes with high return period are concerned with the upper tail of the distribution while those investigating drought focus on the lower tail of the distribution [14]. Goodness of fit testing is carried out to determine whether the selected distribution explains the data set in the earlier section. The hypotheses for the goodness of fit testing are as follow:

$H_0$: The data follows a specific distribution

$H_A$: The data does not follow a specific distribution

Anderson Darling (AD) test statistics is used to compute the probability that a sample may have a normal distribution. It has the ability to overcome the limitation of the KS test even though it can only be used for certain distributions. In contrast to the Kolmogorov Smirnov method, AD is more sensitive towards the tail of the distribution. Mathematically, the test statistics can be written as follows:

$$A = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\left(lnF(X_i) + \ln\left(1 - F(X_{n-i+1})\right)\right) \quad (1)$$

where n is sample size, *F(x)*is the cumulative distribution function for the tested distribution, and the ith sample is calculated after sorting the data in ascending order. The *p*-value is dependent on the statistical value obtained from the above equation. p-value is the probability that the data in this sample is from a random data. The formula for calculating the *p*-value of a goodness of fit technique proposed by Agostino and Stephen is presented in Table 2.

**Table 2:** *p*-value formula for AD test statistics

| A-D test statistics | $p - value$ |
|---|---|
| $A \geq 0.60$ | $p = \exp(1.2937 - 5.709(A) + 0.0186(A)^2)$ |
| $0.34 < A < 0.60$ | $p = \exp(0.9177 - 4.279(A) - 1.38(A)^2)$ |
| $0.20 < A < 0.34$ | $p = 1 - \exp(-8.318 + 42.796(A) - 59.938(A)^2)$ |
| $A \leq 0.20$ | $p = 1 - \exp(-13.436 + 101.14(A) - 223.73(A)^2)$ |

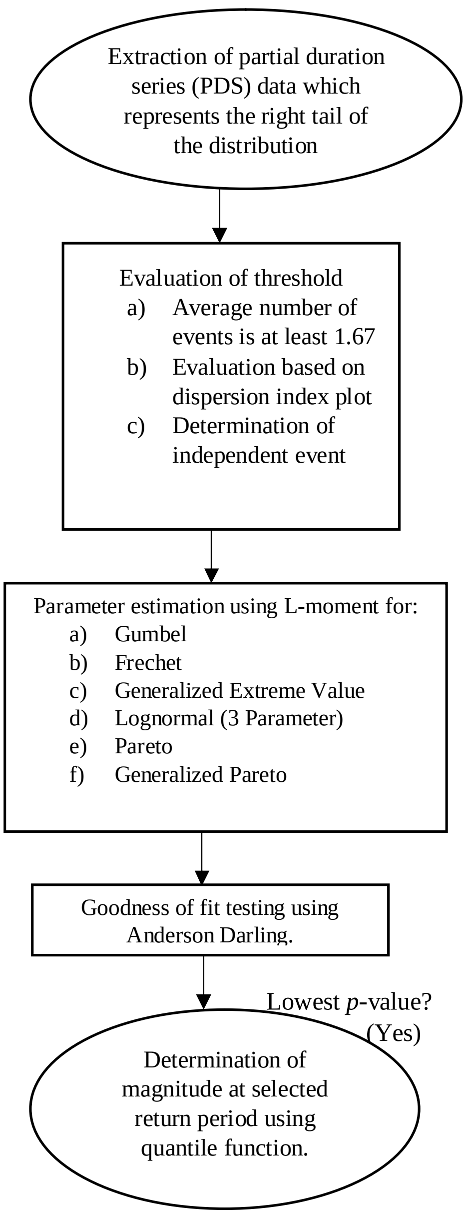
## 2.4 Return Period

The computation of magnitude at selected return period is based on the quantile function of a selected distribution. Quantile function is the inverse of cumulative distribution function shows in Table 3.

**Table 3:** Quantile function for distribution

| Distribution | Quantile function |
|---|---|
| Gumbel | $x(F) = \sigma(\ln(-\ln(F))) + \mu$ |
| Frechet | $x(F) = \dfrac{\beta}{(-\ln(F))^{\frac{1}{\alpha}}}$ |
| Generalized Extreme Value | $x(F) = \xi + \frac{\alpha}{k}\{1 - (-\log(F))^k\}$ |
| Lognormal (3 Parameter) | $x(F) = e^{\sigma\phi^{-1}(F)+\mu} + \gamma$ |
| Pareto | $x(F) = \dfrac{\beta}{(1-F)^{\frac{1}{\alpha}}}$ |
| Generalized Pareto | $x(F) = \xi + \frac{\alpha}{k}\{1 - (1-F)^k\}$ |

where $\phi^{-1}(F)$ is the inverse of probability distribution function for normal distribution. Basically, the flowchart to determine the magnitude at selected return period can be implemented as follow:



## 3.RESULTS AND DISCUSSION

### 3.1 Descriptive Analysis

The flood frequency analysis is conducted using high tide data along Malacca Straits. There are three tidal locations used in this study which are Pelabuhan Klang, Permatang Sedepa and Bagan Datuk. Figure 1 shows the plot for daily mean high tide and the descriptive analysis is shown in Table 4.

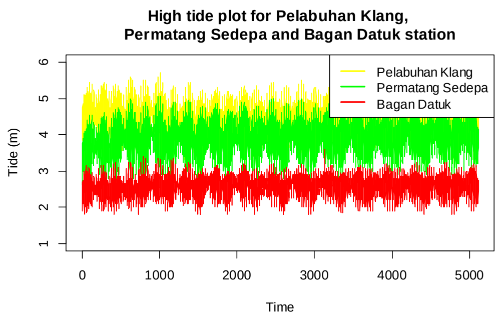



**Figure 1:** High tide plot at each station

**Table 4:** Descriptive statistics

| Station | Minimum (m) | Maximum (m) | Mean (m) |
|---|---|---|---|
| Pelabuhan Klang | 0.60 | 10.00 | 4.46 |
| Permatang Sedepa | 0.45 | 9.45 | 3.97 |
| Bagan Datuk | 0.40 | 3.55 | 2.62 |

### 3.2 Partial duration series

PDS is a set of data collected above a certain defined threshold. The tail of the extreme data will then be fitted into an appropriate distribution. Table 5 presents the descriptive statistics of the selected partial duration series.

**Table 5:** Descriptive analysis of each series

| Station | Pelabuhan Klang | Permatang Sedepa | Bagan Datuk |
|---|---|---|---|
| **Threshold** | 5.40 | 4.90 | 3.20 |
| **Sample size** | 23 | 19 | 15 |
| **Rejected Peaks** | 18 | 14 | 15 |
| **λ** | 1.643 | 1.357 | 1.071 |
| **Minimum ($m^3/s$)** | 5.45 | 4.95 | 3.25 |
| **Maximum ($m^3/s$)** | 10.00 | 9.45 | 3.55 |
| **Mean ($m^3/s$)** | 5.946 | 5.526 | 3.307 |
| **Standard Deviation ($m^3/s$)** | 1.196 | 1.267 | 0.084 |
| **Skewness** | 2.501 | 2.106 | 1.563 |
| **Kurtosis** | 5.014 | 3.184 | 1.867 |
| **CoV** | 0.201 | 0.229 | 0.026 |

**Note:** λ= Average number of peaks per year

### 3.3 Statistical distribution

Figure 2 to 4 shows probability density function plot at each stations.

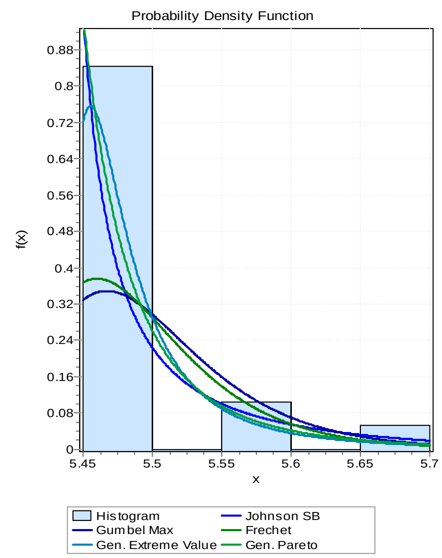



**Figure 2:** Probability density function plot at Pelabuhan Klang

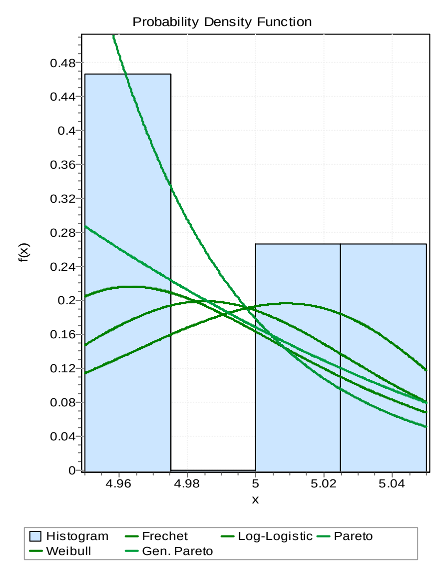



**Figure 3:** Probability density function plot at Permatang Sedepa

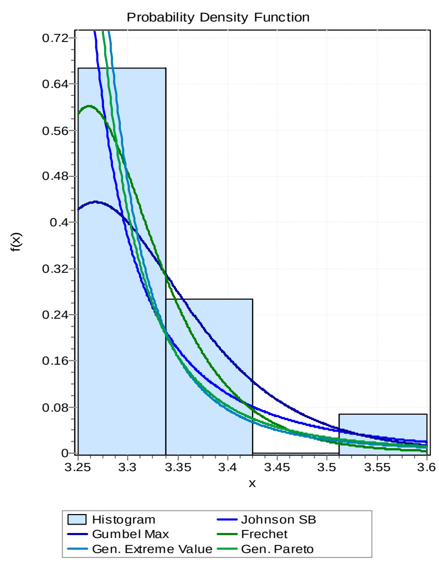



**Figure 4:** Probability density function plot at Bagan Datuk

### 3.4 Return Period

**Table 6:** Magnitude at selected return period

| Return Period | Pelabuhan Klang | Permatang Sedepa | Bagan Datuk |
|---|---|---|---|
| **Threshold** | **5.40** | **4.90** | **3.20** |
| **5** | 5.81 | 5.42 | 3.34 |
| **10** | 6.21 | 5.92 | 3.38 |
| **20** | 6.88 | 6.76 | 3.42 |
| **50** | 8.54 | 8.76 | 3.47 |
| **100** | 10.84 | 11.46 | 3.51 |

Statistical approaches concerning return period particularly involving 100-years was widely implemented to represent critical event in hydrology [15]. Conventional implementation basically involves assumptions that the occurrence of extreme events follows stationary distribution and independent from one event to another. Return period concept is inversely related to exceedance probability of specific value. As an example, the partial duration series flood flow which exceeds 0.02% probability in any year is representing 50 year flood. In other words, the probability of 50-year flood being exceeded is written mathematically 1/50 for every year. In engineering practice, particularly in hydrological infrastructure, failure probability of a structure over its lifetime is the most crucial aspect to be explained to the planners and public. It is also important to optimize the cost and reliability of the hydrological infrastructure[16]. The ability to reduce the impact of flooding is crucial especially for this analysis which considers the population who lives near the coastal area. There are many research conducted on determination of hydrological frequency, however, none is considered to be suitable for all site at once[17]. Hence, it is important to conduct the analysis of flood frequency from time to time to ensure that the impact of flooding the area can be minimized.

Selangor has the highest mean tide of about 4.5 m. The occurence of high tides at Pelabuhan Klang takes place twice a year between April-May and October-November. These events may cause tidal flooding and is known as Keling tidal. These flooding events have an impact the communities living close to the ocean. The government has to take measures to continuously improve the existing flood mitigation plan. The waves in Bagan Datuk are about 3.2 m high and typically hit the coastal area in October 2018 [18].

Wide variety of activities taking place in the areas surrounding Pelabuhan Klang, which is one of the major ports in the country. Transfer of goods from one ship to another takes place in Pelabuhan Klang area[19]. [20] ranked Pelabuhan Klang to be among the top 100 port city in the world due to the functionality of the port in several categories, including logistics activity, port throughput and infrastructure. A higher level of activity the the areas surrounding Pelabuhan Klang could cause land subsidence and coastal erosion which may be the reason for the decreasing trend observed at Pelabuhan Klang [21].

The flood event could also be triggered by other factors, for instance a rise in sea level due to various reasons and climate change[22]. These factors could cause erosion of shoreline, floods, inundation of land, etc. [23]. Klang may be faced with problems such as an increase in sea depth. Port Klang is located at the estuary of the Klang river. A wide variety of human activities take place in this area since Pelabuhan Klang is the biggest port in Malaysia[24].

Considering only the annual maximum (AM) data means that, for the period between 2004 to 2017, only 13 data would be used in the computation for determining the return period of tidal flood. This is one of major disadvantages of using the AM method, since the elimination of moderate and small tidal flooding will not be considered throughout the analysis[25]. In order to achieve a more optimum result for the present study, not less than 30 data have to be taken into account.

The Anderson Darling test result shows Generalized Pareto is the best fit distribution for Pelabuhan Klang with threshold of 5.40 m and

Permatang Sedepa with threshold of 4.90. The PDS for Bagan Datuk station with a threshold of 3.20 m indicates that Pareto is best fit for the series. The anticipated 100-year high tide for Pelabuhan Klang and Permatang Sedepa is approximately 10 to 11 m while that for Bagan Datuk is approximately 3.5 m. Data for the period between 2004 and 2017 shows that there is an event with a magnitude of 10 m in August 2013. Documents in news archive show that there was a heavy downpour at that time of the year which caused flooding in early September [26]. The high tide reading during that period is likely to be caused by the heavy rainfall. It is known that rainfall affects hydrological cycles [27][14]. The research carried out by [15]has shown that there was a daily occurrence of heavy downpour between 29 August to 5 September. In Permatang Sedepa an event with a magnitude of 9.45 m was recorded in September 2017 while the highest tide of 3.55 m was recorded in Bagan Datuk in April 2008. Tidal flooding in Malaysia are frequently caused by continuous or heavy downpour[29]. The return period concept is crucial in the design of water resources as it represents risk of experiencing an exceedance event for the allocated duration [16]. It is important to minimize flood impact with an appropriate flood management [6].

## 4.CONCLUSION

An appropriate statistical distribution has to be identified in an effort to minimize the impact of tidal flooding, particularly around the Pelabuhan Klang, Permatang Sedepa and Bagan Datuk tidal stations.The usefulness of the location as shipping routes and vessels make this study important especially to reduce flooding impact specifically to those who stays in the nearby area. Based on the frequency analysis computed using univariate distribution, the magnitude at higher return period is estimated. The most fitted distribution are Generalized Pareto and Pareto, respectively. Tidal data has low variance, without distinct outlier, hence, only small increase in the level depth can cause changes along the straits. Mitigation plans have to be implemented to prevent tidal flooding events in the study area.In order to improve the study, multivariate distribution can be implemented to capture the data structure more accurately.

## ACKNOWLEDGMENT

The authors would like to thank the Earth Observation Centre, Universiti Kebangsaan Malaysia and the Department of Survey and Mapping Malaysia (JUPEM) for providing the data for this research. The authors wish to express their gratitude to Yayasan Sime Darby (YSD) for supporting this research via research grant ZF-2017-008.

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